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The Potential for Energy Savings With Water Conservation Devices

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ABSTRACT

With the use of residential water saving devices, substantial decreases in water consumption may be realized. Perhaps of even greater significance, however, are the resultant reductions in water-related energy requirements -- for water supply, wastewater treatment, and water heating.

Through a survey of water-related energy use, a relationship between water usage and energy consumption is developed. Results obtained indicate that energy requirements for water heating far exceed those for water supply and wastewater treatment. Based on estimates of residential water consumption with and without water conserving products, the potential for energy savings is assessed. Reduction in household water heating energy consumption of about 35 percent are predicted with the use of "conventional" water saving products. Also considered in this study are the energy saving potentials of grey water recycling and grey water heat recovery systems.

Key Words

Energy; energy consumption; grey water; heat recovery; recycling; residential; wastewater treatment; water; water conservation; water heating; water usage

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Recently, many domestic water conservation and water-related energy conservation systems and devices have been proposed or have become commercially available. These include products ranging from simple toilet flush mechanisms to domestic water recycling and waste-heat recovery systems. Potential benefits of using such devices are twofold -- reduced water consumption, and decreased water-related energy requirements (for water supply, wastewater treatment and domestic water heating). Unfortunately, while some devices require no additional energy for operation, and may in fact save energy, others require operating energy far in excess of any expected water-related energy savings. Accurate determination of overall energy savings is difficult however, because little information about the relation between water usage and energy consumption is available.

In order to more accurately assess the energy saving potential of water/energy saving devices, an analysis of water-related energy consumption was performed by the Product Performance Engineering Division of the Center for Consumer Product Technology, National Engineering Laboratory, National Bureau of Standards. This work was funded by the Office of Energy Related Inventions at the National Bureau of Standards, to provide a basis for acceptance or rejection of products in this class under their Energy-Related Invention Evaluation program.

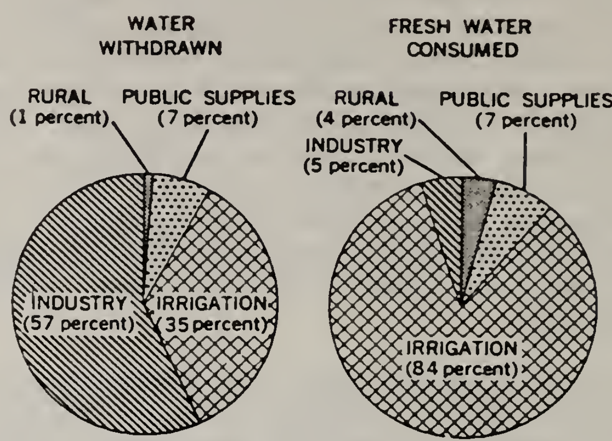
This analysis included a study of energy use in water supply, wastewater treatment, and residential water heating, as well as a survey of state-of-the-art water saving and water-associated energy saving devices. The results of the energy use study provided a means of translating water consumption into energy consumption. Water-energy conversion factors developed in the study were then combined with water usage values for conventional and water-conserving plumbing fixtures and appliances, to yield estimates of energy savings attainable through water conservation. The effects of grey water recycling and grey water heat recovery on energy usage were also determined.

The purpose of this report is to present the relationship between water usage and energy consumption, but more importantly to show some of the impacts of various water and water-associated energy saving devices on energy consumption, for the impacts of these devices can be quite significant.

2. DOMESTIC WATER USE IN PERSPECTIVE

Estimates of water use in the United States in 1970 indicate that an average of 1400 billion liters per day were withdrawn for all purposes other than for hydroelectric power [1]. Most water withdrawn is returned to a natural water course with only a minor change in quality, such as a temperature rise for power plant cooling water, but 24% of withdrawals are classified as consumption, that is, water not directly returned to a surface or ground water supply. The breakdown of water withdrawals and consumption by category is shown in Figure 1.

Figure 1 - Water Withdrawals and Fresh Water Consumption in the United States in 1970 [1]



Much of water consumption is associated with irrigation, and returns to the natural water cycle through evaporation and transpiration. Water supplies for irrigation require only minimal treatment and, of course, do not add to the load on waste treatment plants. Accordingly, the cost and energy required to supply water for irrigation is considerably less than for potable water. Excluding irrigation and considering only potable water, residential water usage accounts for approximately 40% of all fresh water consumption [1]. In short, although water for domestic purposes amounts to only a small fraction of all water uses, in terms of cost and energy consumption it represents one of the highest use levels. Domestic water usage is therefore extremely important when considering the energy aspects of water consumption.

3. WATER-RELATED ENERGY USE

Energy is consumed in nearly every phase of water use -- from obtaining water (from a natural source) to disposing of wastewater and sludge. Considerable amounts of energy are also required for domestic water heating. In order to determine the significance of water-related energy requirements and the potential for savings, energy consumption for each process in the water use cycle must be evaluated. Energy requirements for three major processes were considered in this study. These included energy for

- o Water Supply
- o Wastewater Treatment
- o Domestic Water Heating

Based on the results obtained through energy analyses of each of these areas, the effects of reduced water consumption, water recycling, and other factors on energy consumption were then estimated.

3.1 ENERGY REQUIREMENTS FOR WATER SUPPLY

By water supply we mean the process of obtaining water, treating (purifying) this water, and then distributing the water to points of use. Energy is consumed in each of these steps, both directly and indirectly. Direct energy requirements are easily determined, from fuel bills for instance, whereas indirect energy requirements, such as the energy expended in constructing and maintaining a water project, are much more difficult to evaluate. Indirect energy requirements represent less than 10% of the total energy required for a typical surface water storage and conveyance system however, so first order estimates may be obtained by considering only direct energy requirements [2].

3.1.1 Obtaining Water

In many parts of the country, water is obtained as surface water from nearby rivers and lakes; other areas utilize ground water or obtain water by other means. In 1970, surface water withdrawals comprised about 60% of all water withdrawn for public and rural - domestic uses [1]. Surface water is transported either by gravity flow or pumping, with minimal energy requirements. Ground water, however, requires pumping from greater depths than surface water and, therefore, significantly greater energy expenditures. Additional pumping energy may also be required to deliver the water to treatment plants and points of use at higher elevations.

Based on a combined motor and pump efficiency of 79 percent, the electric energy required to pump and transport municipal water supplies by use of large pumps in good condition is estimated to be 3.5×10^{-3} watt-hours per liter (Wh/L) per meter of lift [2]. Pumping plants tend to be more efficient in large sizes and energy requirements per meter of lift may range from 2.5×10^{-3} to 4.5×10^{-3} Wh/L. Unfortunately, actual pumping heights, which vary significantly with geographic location, are not well documented. Energy estimates may be obtained however, by considering "typical" conditions. Assuming, for example, an average ground water depth of 60 meters, pumping energy requirements of 4.5×10^{-3} Wh/L per meter of lift, and negligible energy requirements for surface water, the energy requirements for obtaining water are estimated at about 0.10 Wh/L.

3.1.2 Treating Water

Energy requirements for water treatment are dependent on the size and type of treatment plant, and the treatment processes required. Water treatment usually consists of the following processes: aeration, flocculation - sedimentation, filtration, chlorination, and sometimes fluoridation [3]. Energy is used directly to drive chemical transfer equipment, chemical-feed equipment, flash mixers, flocculators, sludge collectors, backwash pumps, and metering pumps [4]. Additional energy is required for sludge disposal, lighting, heating and air conditioning of buildings, transport of chemicals to treatment plants, and production of lime, soda ash, alum, chlorine, and other chemicals used [2].

Because plant design and equipment used varies among treatment plants, operating energy requirements range considerably. For example, energy requirements for treatment processes used in Kansas City, Missouri were 40 x 10^{-3} watt-hours per liter of water treated (Wh/L) in 1972 [4], while the average energy consumption for the East Bay Municipal Utility District (EBMUD) system in California was about 7 x 10^{-3} Wh/L [2]. Energy requirements for water treatment, on a nationwide basis, are expected to be within this range.

Based on information from Hertzberg [3], Roberts and Hagan [2] have estimated the average chemical requirements per liter of water treated at: chlorine, 1.3 mg; alum, 3.9 mg; and lime, 5.7 mg. Chemical requirements may vary depending on initial and finished water quality, but these estimates will be considered typical for our purposes. Chemical production is reported to require about 3.3 Wh/g for chlorine [5], 3.0 Wh/g for alum [6], and 0.95 Wh/g for lime (from calcium carbonate) [7]. The energy requirements for chemical production per liter of water are therefore: chlorine, 4.3 x 10^{-3} Wh; alum, 12.0 x 10^{-3} Wh; and lime, 5.4 x 10^{-3} Wh. The energy required to transport the necessary chemicals has been estimated to be equivalent to 2.0 x 10^{-3} Wh for each liter treated [2]. Total energy requirements for water treatment are summarized in Table 1.

Table 1 - Energy Requirements for Water Treatment

Function	Energy Requirements Per Liter (10^{-3} Wh)
Treatment Processes	7 - 40
Chemicals	
Chlorine	4
Alum	12
Lime	5
Chemical Transporation	2
Total Energy for Water Treatment	30 - 63

3.1.3 Distributing Water

After water treatment, most municipal systems require additional pumping -- to deliver water to elevations higher than the treatment plant, to overcome friction losses in pipes, and to maintain service pressure. Energy requirements for pumping are a function of distance and elevation pumped, and can vary substantially. Kanasas City, Missouri, for example, uses an average of about 0.5 Wh/L for distribution [4], while the EBMUD system uses only 0.2 Wh/L [3]. A national average has not been reported, but typical pumping energy requirements are expected to be in the same range. As an example, total on-site energy use for Washington Suburban Sanitary Commission (WSSC) water plants for 1977 was reported to be 0.43 Wh/L [8] (not including chemical-related energy use) -- within the range of the estimates. The breakdown of energy requirements for water supply are summarized in Table 2. Note that energy use for water treatment represents only about 10% of the total energy requirements for water supply.

Table 2 - Energy Requirements for Water Supply

Function	Energy Requirements Per Liter (Wh)
Obtaining Water	0.10
Treating Water	0.03 - 0.06
Distributing Water	0.2 - 0.5
Total Energy for Water Supply	0.33 - 0.66

On the basis of these reported values for energy consumption it appears that energy requirements for water supply may be estimated at about 0.5 Wh/L. If all energy is supplied by electricity which is generated and distributed at a typical efficiency of 33 percent, total primary energy requirements (energy supplied to the generating station) for water supply are approximately 1.5 Wh/L.

3.2 ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT

Wastewater treatment is generally divided into three stages. These are commonly referred to as primary, secondary, and tertiary treatment processes and are characterized as follows:

- o Primary treatment -- mechanical process in which large solids and smaller suspended or dissolved solids are extracted generally by settling and filtration.
- o Secondary treatment -- biological process in which bacteria consume and decompose organic matter remaining after primary treatment.
- o Tertiary treatment -- chemical process which is designed to remove inorganic chemical pollutants, and other materials.

Each of these treatment processes are composed of a series of unit processes and operations, the order and types of which may vary from one plant to another. As individual processes and operations vary greatly in energy consumption, "similar" treatment plants may have substantially different energy requirements.

In 1969, the average per capita consumption of electrical energy for sewage treatment in the United States was 0.0573 kWh/day, whereas the average overall residential consumption of electrical energy was 5.09 kWh/day [9]. Thus the total energy consumed in sewage treatment was about one percent of the total residential consumption of electrical energy. Nearly 1/3 of all wastewater treated in 1968, however, received only primary treatment [10] -- which requires considerably less energy than more advanced treatment. The Federal Water Pollution Control Act of 1972 requires that by 1977 all publicly-owned treatment plants provide secondary treatment. Because of funding limitations the act has not been completely successful. Nevertheless, most waste facilities now provide treatment up to the secondary level. Current energy consumption for wastewater treatment might well be twice the 1968 rate!

Operation of facilities is the major component of energy consumption in wastewater treatment. Because unit processes and operations have widely varying energy consumptions and because there are innumerable combinations of process flow sheets, the energy consumption of each process and operation is generally estimated separately, then summed for the entire system. Smith [9] has estimated the on-site electrical power consumption for most of the conventional and advanced processes used to treat municipal wastewater, and summed these estimates for various combinations of processes. Energy requirements for three levels of treatment commonly used are presented in Table 3. These energy requirements are based on a 40 million liter per day plant size. For smaller plants the energy consumption is slightly higher, while larger facilities would have a somewhat smaller demand.

Table 3 - Estimated Energy Requirements for Wastewater Treatment [9]

Level of Treatment	On-site Energy Consumption Per Liter Treated (Wh)
Primary treatment	0.06
Secondary treatment	
Primary plus trickling filters	0.13
Primary plus activated sludge	0.23
Tertiary treatment	
Secondary treatment plus lime clarification, filtration, carbon adsorption	0.43
Secondary treatment plus filtration and reverse osmosis	0.79

Roberts and Hagan [2] note that the preceding estimates may not be representative for some conditions and should be adjusted upwards. But later work by Roberts and Hagan [11], which is based in part on the work of Smith [9], and includes indirect as well as direct energy requirements, indicates that new, well-designed treatment plants (not necessarily representative of existing plants) may have total primary energy requirements of about the same magnitude as those predicted by Smith. Based also on the work of Smith, Mills and Tchobanoglous [12] have estimated the on-site operating energy requirements for a 40 million liter per day activated sludge plant at 1.2 watt-hours per liter treated. The variation in estimates is principally due to differences in assumed values for aeration and heating energy consumption during the activated sludge process.

A 1976 survey of municipal wastewater treatment needs [13] indicates that more than 90 percent of all treatment plants have a capacity of less than 20 million liters per day, with tertiary plants comprising less than one percent of all plants. Also, more than 50 percent of all secondary treatment facilities utilize the activated sludge process [14]. On-site energy requirements might therefore be approximated as those for an activated sludge plant. In view of the previously cited figures, a reasonable estimate for these energy requirements would be about 1.0 Wh/L. Assuming all energy is supplied by electricity which is generated and distributed at an efficiency of 33 percent, primary energy requirements for operation are estimated at 3.0 Wh/L. This estimate is conservative, as in practice many of the operational energy requirements are satisfied by energy sources other than electricity, at a higher overall conversion efficiency.

While the operation of facilities is the major component of energy requirements for wastewater treatment, significant quantitites of energy consumption are involved in the construction and maintenance of the treatment facilities and equipment. Recent work by Smith [15] indicates that energy used for construction of the treatment plant and the sewage system might represent as much as 55 percent of the total energy consumed over the life of the plant. For a typical treatment plant, Mills and Tchobanoglous [12] estimate these requirements, in terms of primary energy, to be about 0.6 Wh/L. The total primary energy requirements for wastewater treatment, on a per unit basis, are therefore approximately 3.6 Wh/L.

3.3 ENERGY REQUIREMENTS FOR RESIDENTIAL WATER HEATING

In most of America's 70 million occupied housing units, water is heated in a central water heater. Energy generally is supplied to the heater as gas, oil, or electricity. Census data revealed the following fuel-type breakdown in 1970 [16]:

Table 4 - Water Heaters In Service -- Breakdown By Fuel Type

Fuel Type	Percent of Occupied Households
Electricity	25.4
Natural Gas	55.1
Liquified Petroleum Gas (LPG)	5.0
Fuel Oil	9.8
Other and None	4.7
	100.0

Several investigators [17,18] have analyzed heat flows in typical residential water heating systems. These studies indicate that electric water heaters operate at an efficiency of about 0.77 at point of use. Gas and oil-fired units are estimated to have an overall efficiency of about 0.51. For an electricity generation and distribution efficiency of 33 percent, census and service efficiency data can be combined to yield a weighted water heating efficiency (in terms of primary energy) of 44 percent.

For actual water heater operation, the cold water inlet temperature has been geographically, demographically, and seasonally averaged to a value of 12.8°C [19]. Using this temperature, and the weighted water heating efficiency, the energy required to heat water can then be given as a function of delivered water temperature. Water heating energy requirements are presented in Table 5 for various water delivery temperatures.

Table 5 - Energy Requirements for Water Heating

Delivery Temperature (°C)	Water Heating Energy Requirements Per Liter (Wh)
12.8[A]	0.0
21.1	22.0
37.8	65.9
40.6	73.3
54.4	110
60.0	125
62.8[B]	132

A - corresponds to unheated water use

B - average water heater thermostat setting on new water heaters

3.4 WATER-RELATED ENERGY REQUIREMENTS -- SUMMARY

In terms of primary energy, the estimated energy consumption that is associated with each liter of water used in a household is broken down as follows:

- o Water Supply — 1.5 Wh
- o Wastewater Treatment — 3.6 Wh
- o Water Heating — 0-130 Wh depending on delivery temperature

Comparison of these values indicates that energy requirements for water heating are an order of magnitude larger than for water supply and wastewater treatment. Energy requirements for water supply are less than half those for wastewater treatment, which in turn comprise only about 0.2 percent of national energy utilization [14]. Water heating energy requirements, however, are significant on a national scale. They accounted for 3 percent of total energy consumption in the United States in 1974 [16].

4. DOMESTIC WATER USE AND CORRESPONDING ENERGY REQUIREMENTS

Daily household water use for a family of four is frequently estimated to be 965 liters [20]. Of this amount 243 liters passes through the water heater [19]. The remainder is either used at cold water delivery temperatures or mixed with hot water at points of use. Domestic water usage patterns and delivery temperatures have been estimated by Bailey et al. [20] and Muller [16] and are presented in Table 6 along with water-related energy requirements.

It can be seen from Table 6 that water heating energy requirements comprise more than 90 percent of all water-related energy consumption, with bathing and clothes washing making major contributions. Also noted is the fact that a substantial amount of energy is consumed in heating the cold water used in toilets. This energy transfer is at the expense of the space heating system, which has a weighted service efficiency near that for water heating. Assuming a six month heating season, "cold water heating" (for toilet, cooking, and drinking) accounts for nearly 9 percent of total water-related energy requirements. While energy requirements for water supply and wastewater treatment appear relatively insignificant, water heating energy requirements are quite substantial. They should be of primary concern when evaluating the energy saving potential of water/energy saving devices.

5. POTENTIAL FOR ENERGY SAVINGS

Water-related energy consumption may be reduced in many ways. These range from developing more energy efficient methods of producing and heating potable water and treating wastewater, to using water more wisely in the home. Of interest in this study are the energy savings which may be realized through use of water/energy saving devices or systems installed at the residential level -- in particular, water saving devices and plumbing fixtures, and water recycling and grey water heat recovery systems.

5.1 ENERGY SAVINGS THROUGH WATER CONSERVATION

5.1.1 Effects of Reduced Flow

Water conservation will result in a reduction in the volume of water processed at water and wastewater facilities, and the energy required for

Table 6 - Current Residential Water Usage and Corresponding Energy Consumption

Function	Daily Water Usage [20]	Approximate Delivery Temperature [16]	Energy Requirements Per Household[A] Water Supply	Water Heating	Wastewater Treatment	Total
	(liters)	(^{o}C)	(kWh/day)			
Toilet	379	21.1[B]	0.57	4.17	1.36	6.10
Bathing	303	40.6	0.45	22.2	1.09	23.7
Clothes Washing	132	40.6[C]	0.20	9.68	0.48	10.36
Dishwashing	57	60.0	0.09	7.13	0.21	7.43
Kitchen Sink	45	21.1[B]	0.07	0.50	0.16	0.73
Lavatory	30	40.6	0.05	2.20	0.11	2.36
Utility Sink	19	40.6	0.03	1.39	0.07	1.49
Total	965		1.46	47.3	3.48	52.2

A - based on estimates obtained in Section 3

B - assumed to leave house at 21.1^{o}C

C - based on the following data from Reference [16]

Type Wash	Water Temperature - ^{o}C	Percent of Wash Loads
Hot	60.0	30
Warm	37.8	50
Cold	12.8	20

water distribution, chemicals, and other purposes. However, when one considers the portion of wastes treated at sewage treatment plants attributable to household waste flows, in relation to (1) the ground water infiltration into sewer lines (often 30 percent of waste flow [21]), and (2) industrial waste flow, the maximum theoretical potential reductions in sewage flow reaching the plant are only about 7 percent [22]. In addition, because many energy-consumptive treatment processes and operations are flow-independent, large volume flow reductions might result in only small decreases in energy requirements for facility operation. A sudden, substantial reduction in flow volume may even tend to increase plant energy consumption for an existing facility. For example, a 53 percent decrease in wastewater flow experienced by Las Gallinas Valley Sanitary District, Marin County, California during the drought of 1977 was accompanied by a slight increase in operating energy consumption, due supposedly to greater energy requirements for recirculation pumping within the plant [23].

Although the reduction in flow volume resulting from use of water saving devices or methods may not reduce energy consumption directly, the flow reduction is in effect an increase in plant capacity. This "increased" capacity would enable existing water facilities to serve a greater population with no increase in energy consumption. It might even eliminate or postpone the need for expansion or new construction of facilities, and corresponding energy expenditures. In this respect there is a direct relation between flow reduction and energy savings. Hence, for each reduction in water consumption, all corresponding water-related energy requirements may be considered saved.

Further benefits may be realized through flow reduction. Cole [24] indicates that a substantial increase in the life of a sewage treatment plant can be obtained if water saving toilets are required in all new housing following that plant's construction. In addition, the flow reduction effect of water saving devices on sewage treatment processes will result in small increases in detention times and waste concentrations. These increases are beneficial in that they tend to increase treatment efficiency [28]. Ground water infiltration, however, may overshadow any benefit of household waste water flow reduction and must be corrected before flow reductions will have impact [24]. Another benefit of water saving devices is that if flow reducing devices are installed throughout the home as original equipment, it should allow the water distribution system to be scaled down, easing installation and saving money and energy [25].

On the effect of water saving toilets on sewer systems, calculations by Cole [24] show that the depth and velocity of flow in the sewer and in the pipe connecting the house to the sewer are not reduced substantially below those that exist in a sewer with standard 20 liters per flush toilets unless the flush amount is reduced to 7.5 liters or less. On sewers that serve a population of at least 500 persons the velocities and depths are not substantially reduced for any of the predicted flush volumes. Sharpe [22] notes that problems could develop in collection lines that service a population of fewer than 500 persons. In such cases conventional design velocities may not be adequate for solids removal; and blockages, odor problems, and excessive pipe corrosion will result.

5.1.2 Water Saving Devices

Water usage and thus water-related energy consumption can be significantly decreased through use of domestic water saving devices and methods. Water saving devices are fixtures attachments, inserts, or new systems which modify or replace standard plumbing fixtures and fittings; and result in water consumption less than with the standard fixtures. These products fall into three categories: retrofit or add-on type items, replacement fixtures with "built-in" devices, and specialty items or systems.

Retrofit devices are items which are added to existing fixtures or replace corresponding parts on the fixture or fitting. For faucets, these devices include flow restrictors, aerators, and spray taps. Retrofit items are generally inexpensive and easily installed -- usually by the homeowner. For toilets, water savings comparable to those for replacement "water saver" units may be achieved with these devices, although the resulting toilet performance in some cases may be inferior.

Water saving replacement fixtures appear and operate the same as standard units, but have integral water saving features. They are generally more expensive than conventional fixtures and may be used as direct substitutes for standard fixtures in new and replacement installations. Recent Environmental Protection Agency studies [26,27] indicate that various water saving devices are cost effective. Specifically mentioned for retrofit applications are shower flow restrictors, toilet inserts and dual-flush modifications for toilets. In addition broad based programs involving the free distribution of inexpensive water-saving devices are thought to be economically justified [26]. Water saving products are, in some locales, required by code. In areas where water saving devices are not required by code, a severe constraint to widespread adoption of various water-saving devices has been their general lack of availability. These devices are not usually carried as stock items in most hardware and plumbing supply stores. Apparently the demand for the items has not warranted their being routinely stocked, and many of the newer devices are as yet little known in the plumbing trade [22].

Specialty devices do not operate in the same manner as conventional fixtures. They are generally more expensive than conventional water saving fixtures, and their installation is more complex than fixture replacement. Specialty devices offer greater water savings than conventional water saving fixtures, but many require additional energy for operation. Use of specialty items may be restricted due to cost and public acceptance problems as well as local plumbing and health codes. Typical specialty items include vacuum toilets, incinerating toilets, air-assisted showerheads, and self-closing fixtures.

Milne [25] and Nelson [28] have compiled very complete directories of currently available water-saving devices. Included by Milne are discussions of such topics as the operational characteristics, estimated water savings, cost considerations and public acceptance, for each type of water saving device. More specific product information, such as flow rates and design features of various devices on the market, is given by Nelson by model for each manufacturer. The reader is referred to these works for a summary of state-of-the-art water saving products.

5.1.3 Potential Savings

In surveying currently available water saving products it becomes apparent that two different levels of savings may be realized -- one representing use of "conventional" type water saving products (retrofit devices and water saving replacement products) and the second representing the use of specialty devices or systems. Estimates of water consumption for standard products, and for currently available conventional and specialty water saving devices or systems are shown in Table 7. As indicated in Table 7, sizeable reductions in water consumption may be realized through use of conventional water saving devices. Greatest savings are obtained, however, with specialty devices, which reduce water use to a minimum.

Table 7 - Water Consumption of Standard and Water Saving Products

Device	Water Consumption		
	Standard Products[29]	Current Water Saving Products Conventional[29]	Current Water Saving Products Specialty
	(liters)		
Toilets (liters/flush)	19-27	13	2[D]
Showerheads [A] (liters/min)	up to 45	11	2[E]
Clothes Washers (liters/load)	100-200	60-72[B]	-
Dishwashers (liters/load)	28-60	28[C]	-
Faucets [A] (liters/min)	up to 19	6	2[F]

A - flow rate is selected by user

B - front-loading model

C - short-cycle setting

D - vacuum toilet (requires energy for operation)

E - air-assisted showerhead (requires energy for operation)

F - spray taps

It has been estimated that a complete replacement of plumbing fixtures and appliances by their currently available water saving counterparts would result in a 34 percent saving in residential water consumption [21]. Reduced water requirements and corresponding energy usage with conventional water-saving products are shown in Table 8.

Comparison of these figures with those in Table 6 reveals that through the use of water-saving devices and fixtures, water-related energy requirements may be reduced by 35 percent. Over 90 percent of these savings are in water heating energy. Residential water heating accounts for 3 percent of total national energy usage, hence, this reduction in energy requirements is roughly equivalent to a 1 percent decrease in national energy use.

Specialty devices offer even greater reductions in water-related energy consumption. They must be selected judiciously, however, as some types of devices consume far more energy in operation than they save. In the case of air-assisted showerheads, operating energy (used to run an air compressor) is small compared to the energy saved in hot water heating. Incinerating toilets, on the other hand, require input energy far in excess of any water-related energy savings. Operating energy requirements for each water saving device under consideration should be weighed against expected water-related energy savings.

5.1.4 Actual Versus Predicted Savings

The volume of water expended in a water consuming activity is a result of the interaction between user and plumbing fixture. The user has specific needs or desires -- ranging from clean hands to clean toilet bowls -- and operates the fixture until these requirements are met. The water consumed in doing so is a function of user habits and plumbing fixture characteristics. While fixture flow characteristics may be improved through use of water saving devices, projected flow reductions might not be realized with some devices because fixture performance may degrade or because actual water usage patterns may differ from those assumed. For example, shower flow restrictions which reduce maximum water flow rates from 20 to 10 liter/min will save little or no water if flow rates of around 10 liter/min are already being used. There is a serious lack of reliable data pertaining to the rates and durations of water flow commonly used in the home. Until this gap is filled, there will remain no firm basis on which to predict water/energy savings.

Actual water savings realized through large scale water conservation programs may fall short of predicted reductions for another reason -- many homes are already equipped with water saving devices. A 1979 survey of plumbing codes reveals that an increasing percentage of jurisdictions now regulate the volume of water used in plumbing fixtures, at least in new plumbing installations [30]. Table 9 illustrates the increasing awareness of the need for water and energy conservation in plumbing codes. Figures given in Table 9 represent percentages of jurisdictions regulating the various items listed.

Table 8 - Residential Water Usage and Corresponding Energy Consumption With Conventional Water Savings Devices

Function	Daily Water Usage [21]	Approximate Delivery Temperature [16]	Energy Requirements Per Household[A] Water Supply	Water Heating	Wastewater Treatment	Total
	(liters)	(^{o}C)	(kWh/day)			
Toilet	242	21.1	0.36	2.66	0.87	3.89
Bathing	190	40.6	0.29	13.9	0.68	14.9
Clothes Washing	91	40.6	0.14	6.67	0.33	7.14
Dishwashing	41	60.0	0.06	5.13	0.15	5.34
Kitchen Sink	45	21.1	0.07	0.50	0.15	0.73
Lavatory	15	40.6	0.02	1.10	0.05	1.17
Utility Sink	10	40.6	0.02	0.73	0.04	0.79
Total	634		0.96	30.7	2.28	34.0

A - Based on estimates obtained in Section 3

Table 9 - Percent of Jurisdictions Regulating the Water Consumption of Plumbing Fixtures [30]

Device	Percent of Jurisdictions Regulating Water Consumption		
	1977	1978	1979
Toilets	9	23	32
Showerhead flow rates	7	20	51
Faucet flow rates	6	17	35

(Note: these figures do not represent percent of residences).

5.2 ENERGY SAVINGS THROUGH WATER RECYCLING

Water recycling is considered, by some, to be the ultimate means of water conservation. Through recycling, household water consumption may be significantly reduced and with some systems nearly eliminated. Bailey et al. [20] have considered the reuse potential of household wastewater in terms of treatment required before reuse, and reasons for treatment. As shown in Figure 2, a whole realm of reuse possibilities for household waterwaste systems exist. Some schemes require only minor wastewater treatment before reuse, while others call for complete renovation of wastewater.

Figure 2 - The Reuse Potential of Household Wastewater [20]

Potential Household Water Sources

		Potable Supply	Sink (Kitchen)	Sink (Bathroom)	Dishwasher	Laundry	Shower or Bath	Toilet	Point of Water Use
		✓	X_{HA}	X_{HA}	X_{HA}	X_{HA}	X_{HA}	X_{HA}	Sink (Kitchen)
		✓	X_{HA}	X_{HA}	X_{HA}	X_{HA}	X_{HA}	X_{HA}	Sink (Bathroom)
		✓	X_{HA}	X_{HA}	X_{HA}	X_{EA}	X_{HA}	X_{HA}	Water Heater
		✓	X_{HA}	X_{HA}	S_{HA}	X_{HA}	X_{HA}	X_{HA}	Dishwasher
		✓	SD_{HA}	SD_{HA}	SD_{HA}	SD_{HA}	SD_{HA}	X_{HA}	Shower or Bath
		✓	S_A	S_A	S_A	S_A	S_A	X_{HA}	Laundry
		✓	SD_{HA}	SD_{HA}	SD_{HA}	SD_{HA}	SD_{HA}	X_{HA}	Outdoor Faucet
		✓	SD_E	SD_E	SD_E	SD_E	SD_E	X_E	House Heating Sys.
		✓	S_A	S_A	S_A	S_A	S_A	X_{EA}	Toilet

Treatment Required Before Use:
- ✓ No treatment required
- D Disinfection
- S Minor chemical and physical treatment
- X Complete renovation

Reasons for Treatment:
- H Health
- E Engineering
- A Aesthetic

Although the reuse of wastewater from any appliance or drain is technically possible if given suitable treatment and a suitable piping system, it may not be economically or aesthetically feasible. Through an analysis of various reuse schemes and techniques for treating the wastes produced, Bailey et al. [20] have concluded that "Advanced waste treatment schemes other than simple filtration and disinfection are generally not practical for a normal household. Most households could not meet the operating expenses or provide the operating attention required by the majority of the advanced treatment systems. Even when an extensively treated water is reused for all purposes but drinking the costs are prohibitive. The only economical and practical reuse is the filtration and reuse of wash waters for toilet flushing, and in areas where aerobic treatment is economical, the filtration and reuse of the aerobic effluent for toilet flushing."

A system which has received a great deal of development efforts involves the recycling of bathing and laundry wastewaters (both referred to as grey water) for toilet flushing and possibly outside irrigation. A typical recycling system provides for the collection of grey water through conventional plumbing, and transport into a settling tank. The settled wastewater is generally processed through some type of filter (paper cartridge, diatomaceous earth, or sand) and then disinfected prior to storage and reuse. Siegrist et al. [31] report that at least one such recycle system is commercially available at a cost of $2500 plus shipping. The annual operating costs, as estimated by the manufacturer, are $45 per year. This cost includes the filter cartridges, disinfectant and energy for operation.

Separate grey water and toilet water drainlines are required with the recycle system. Installations in existing homes would, in most cases, require replumbing toilets on a new, separate drain line -- an expensive proposition which would likely offset any system savings. In new construction homes, however, separate grey water drain lines could be installed with minimal effort and expense, making recycling systems more economically attractive.

Cohen and Wallman [31] report that, two prototype grey water recycling systems were installed at three homes and were monitored for a period of one year. One recycling system included storage, cartridge filtration, liquid chlorine disinfection, and reuse, while the other included storage, diatomaceous earth filtration, chlorine tablet disinfection, and reuse. The waste flow reduction achieved by the units averaged about 40 liters per capita per day or 24 percent of the total daily wastewater flow. The recycle systems were found to be manageable, simple to use, and capable of reliable and safe operation. The operation of conventional flush toilets was not impaired by the recycled grey water and the performance of the systems was found to be aesthetically acceptable to the users. Maintenance of the units - replacement of filter cartridges and disinfiction chemicals - was typically required at one to three month intervals. The costs for the "homebuilt" systems were about $500-$600 installed, and yearly operating costs were $21 to $45. Another limited field study of a similar prototype system by McLaughlin [33] generated results which were basically similar to those found by Cohen and Wallman.

In addition to the grey water recycling studies cited, efforts have been directed toward evaluating the feasibility of recycling a portion of the total household wastewater flow for toilet flushing. As part of the Boyd County Demonstration Project, four recycle systems were installed to serve five homes [34]. These recycle systems included an aerobic treatment unit to which all wastewater generated in the home was transported. The effluent from the aerobic unit flowed into a settling chamber from which the effluent was either processed further for recycling or directed to a disposal system. The performance of the recycle system was monitored closely for a period of one year. Based on analyses of six samples of the recycled water, the recycle systems were found to produce a generally clear and odorless water, low in biological oxygen demand (BOD) and suspended solids, with zero fecal coliform counts. Also noted was a high degree of consumer satisfaction with the day-to-day use of recycled water [31].

If all toilet flushing requirements were met by a recycle system, a flow reduction similar to that for a non-water toilet would be achieved -- 379 liters per day or 39 percent of the total daily flow. From Table 6, however, it is seen that water-related energy requirements would be reduced by only 6.1 kWh/day or 12 percent. This reduction includes a 9 percent savings in water heating. Depending on the length of heating and cooling seasons, thermal energy lost from grey water during recycling will result in additional energy savings or added cooling load. Recovery of this waste heat is considered in the following section.

5.3 ENERGY SAVINGS THROUGH GREY WATER HEAT RECOVERY

All water which enters a conventionally plumbed household passes directly to the sewer or septic tank after use (except water which is used for purposes such as drinking and car washing). Grey water comprises more than half this volume and carries significant amounts of thermal energy. With a grey water heat recovery system a portion of this heat may be transferred to incoming cold water (or ambient air during the heating season), resulting in decreased energy requirements for water and space heating, respectively.

At present, systems for recovering waste energy from domestic drain water are not commercially available. However, several demonstration-type installations have been made in the United States and Europe. Descriptions and analyses of some of these systems are given by the literature [35,36,37].

From estimates of water usage and delivery temperatures given in Table 6, the thermal energy delivered to the points of water use is found to be 18.5 kWh/day (relative to a 12.8°C inlet water temperature). Maximum possible heat recovered would be significantly less than this due to (1) thermal losses from grey water (before entering the drain), piping, and storage vessels, and (2) the inability to utilize all waste heat. Some waste heat is not utilized because long retention time would be required to remove most of the available heat from wastewater. During this time hotter wastewater would become available and would displace the cooler wastewater.

Energy which is transferred from pipes and other equipment to ambient surroundings represents an energy gain during winter (heating) months, but a thermal load during summer (cooling) months. These losses may be of the same magnitude as the energy recovered. As a result, the energy saving potential of the grey water heat recovery system is highly dependent on the duration of heating and cooling seasons.

The temperature of grey water, as it enters the drainage system is of prime importance in determining the thermal losses from grey water. Little research has been performed in evaluating this parameter, and reliable temperature estimates are not available. For purposes of calculating the thermal losses from grey water, which occur before entering the drain, a temperature drop of 5.5 $^{\circ}$C (10 $^{\circ}$F) from delivery temperature was used.

The thermal losses from grey water while enroute to the heat exchanger are dependent on several factors including (1) pipe diameter, material, and length, and (2) water usage patterns. The use of thermal insulation on drain pipes would reduce thermal losses somewhat, but in many retrofit installations insulating the drain pipes may not be practical. Drain pipe heat loss may be estimated by considering a 9 meter section of 50 mm diameter copper drain pipe. To raise the pipe temperature, approximately 2.5 watt-hours are required per celsius degree increase, whereas to maintain an elevated temperature, about 8.5 watts are required (lost) per degree above ambient air temperature. For each function shown in Table 6, the drain pipe temperature will be raised approximately from ambient temperature (21.1 $^{\circ}$C) to the delivery temperature for that function. In addition, convective pipe losses will occur for the duration of the event. Estimates obtained in this fashion represent the minimum energy available for recovery, since the pipe may be warm for a previous water draw when a second draw is made.

The thermal losses from grey water can be estimated by assuming a 5.5 $^{\circ}$C decrease in grey water temperature before entering the drain, and calculating pipe heat loss based on water delivery temperatures and durations, and the preceding heat loss rates. Calculated values for heat loss and available energy are presented in Table 10.

Table 10 - Thermal Energy Flows for Grey Water

Function	Energy Delivered to Point of Use[A]	Losses Before Entering Drain	Losses From Pipes	Energy Available at Heat Recovery Tan
	(kWh/day)			
Bathing	9.78	1.93	0.04	7.81
Clothes Washing	4.26	0.84	0.07	3.35
Dishwashing	3.12	0.36	0.06	2.70
Lavatory	0.97	0.19	0.03	0.75
Utility	0.61	0.12	0.01	0.48
Total	18.7	3.44	0.21	15.1

A - referenced to a cold water inlet temperature of 12.8°C

B - based on a 5.5°C temperature drop

The energy content of the grey water entering the heat recovery tank (15 kWh/day) is simply the energy delivered to point of use less the thermal losses from grey water. If grey water from all sources is utilized, the volume of grey water passing through the heat exchanger is, from Table 6, 541 liters/day. The average thermal energy of the grey water entering the heat exchanger is therefore 28 Wh/L (relative to a 12.8°C incoming cold water temperature). This corresponds to an average grey water inlet temperature of 37°C.

The energy recovered from delivered grey water is dependent on the type of heat removal device used. Heat recovered using a grey water/potable water heat exchanger is expected to be about 4.4 kWh/day or roughly 20 percent of all primary water heating energy requirements. Wastewater exit temperatures would be approximately 30°C with such a device. A more sophisticated system, which uses a heat pump to transfer the thermal energy, would produce lower wastewater exit temperatures and would save considerably more than this amount. Water heating energy savings of nearly 55 percent were achieved with the heat pump equipped system described by Ebersbach [36].

Depending on local costs of water and power, grey-water systems may be cost effective on a residential scale. Unfortunately, they are not readily available. Careful attention to health codes will, of course, be necessary.

6. CONCLUSIONS

Through use of commercially available water saving devices, household water use could be reduced by 34 percent. Water-related energy requirements would be decreased by 35 percent, with over 90 percent of all savings in the form of reduced energy requirements for water heating. These water-related energy savings are equivalent to nearly a 5 percent reduction in total residential energy consumption. Specialty water conserving devices or systems offer even greater saving, but the operating energy requirements of these devices should be carefully considered as they may negate water-related energy savings.

Residential water recycling is an effective means of reducing water consumption. However, advanced waste treatment schemes other than simple filtration and disinfection are generally not practical for a normal household. By reuse of grey water for toilet flushing, savings similar to that for a non-water toilet would be achieved -- 379 liters per day. Energy savings equivalent to 9 percent of residential water heating energy might also be realized. Residential water recycling systems do not yet appear cost effective, and would violate local plumbing and health codes in most areas.

Grey water heat recovery systems have the potential to cut water heating energy consumption by half. The concept has been successfully demonstrated in several pilot system installations but such systems are not currently commercially available or cost effective for single family installations. Compliance with local codes may present a problem.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

With the use of residential water saving devices, substantial decreases in water consumption may be realized. Perhaps of even greater significance, however, are the resultant reductions in water-related energy requirements - for water supply, wastewater treatment, and water heating.

Through a survey of water-related energy use, a relationship between water usage and energy consumption is developed. Results obtained indicate that energy requirements for water heating far exceed those for water supply and wastewater treatment. Based on estimates of residential water consumption with and without water conserving products, the potential for energy savings is assessed. Reduction in household water heating energy consumption of about 35 percent are predicted with the use of "conventional" water saving products. Also considered in this study are the energy saving potentials of grey water recycling and grey water heat recovery systems.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Energy; energy consumption; grey water; heat recovery; recycling; residential; wastewater treatment; water; water conservation; water heating; water usage

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