BENEFITS OF DEMAND-CONTROLLED PUMPING

An electronically demand-controlled pumping system sends cold water back to the water heater until hot water arrives at the sink, shower, or other fixture where it is needed.

by LARRY ACKER AND GARY KLEIN

Much water and energy is wasted in residential buildings, due to poorly designed, poorly installed—and therefore poorly functioning—hot water delivery systems. Homes built in the United States today are typically larger than ever before and include a number of hot water fixtures not seen a generation ago, such as second and third bathrooms and spa-style showers. And water heaters are typically far away from many of the hot water fixtures. All this adds up to long waits for hot water at fixtures and water and energy down the drain to no purpose (see "Hot Water Runs Cold," *HE* Mar/Apr '05, p. 28).

One solution to water and energy waste is to deliver hot water quickly to where it is needed. By bringing water quickly to fixtures that are far from the water heater, a demand-controlled pumping system minimizes the waste of water and energy running down the drain while someone waits for the hot water to arrive. When signaled to do so by a hot water user using a push-button control, an electronically demand-controlled pumping system sends cold water back to the water heater until hot water arrives at the sink, shower, or other fixture where it is needed.

LARRY ACKER

When signaled to do so by a hot water user using a push-button control, or using a remote-controlled device as in the photo, an electronically demand-controlled pumping system sends cold water back to the water heater until hot water arrives at the sink, shower, or other fixture where it is needed.

Demand-controlled pumping devices include sensors and electronics that automatically adjust to standing ambient temperatures in the hot and cold water lines. When the pump is operating, it measures a change of temperature; it turns the pumping system off when the desired temperature change is met. This keeps warm water from the cold water side of the pump. The pumps adjust to ambient temperatures automatically, anywhere in North America.

Demand-controlled pumping systems can be installed on trunk and branch systems both in new construction and in retrofits and on structured plumbing systems installed in new construction or during a major rehab.

In retrofit and in typical new-construction applications, the primary benefit of demand-controlled pumping comes in the delivery phase: It reduces the waste of water and energy while users wait for hot water to arrive. The energy savings due to the reduction in water waste are attributable to three factors:

• The water in the circulation loop that is returned to the water heater is generally warmer than the water coming into the house. Less energy is needed to keep the water in the tank hot.

• Hot water that is sent at a high flow rate to fixtures loses significantly less heat through the walls of pipes than slow-moving hot water.

• Since the on-demand pump moves water at a higher flow rate than is typical, the hot water gets to the fixture faster, and less hot water is needed to prime the loop.

Savings Potential

In order to quantify the effects of demand-controlled pumping, a number of researchers have studied the characteristics, and estimated the hot water efficiency, of demand-controlled pumping systems in both trunk and branch and structured plumbing layouts in typical residential water-heating installations. Structured plumbing saves energy and water by optimizing the plumbing layout to minimize insulated hot water pipe runs. Combining structured plumbing with demand-controlled pumping should yield even greater water and energy savings.

Proponents and investigators of structured plumbing and demand-controlled pumping systems have developed robust estimates of the percentage of hot water savings that can be achieved with those innovations. If the savings estimates are judged reasonable, they can be plugged into an algorithm that allows this percentage of savings to be translated to an input form that can be entered into HERS residential energy simulation software. The algorithm, developed by EPA, allows percentage hot water savings estimates from any hot water conservation measure (the technologies described above, as well as low-flow showerheads, horizontal-axis clothes washers, and so on) to be translated into an energy factor enhancement coefficient. This is multiplied by the DOE energy factor (EF) for a water heater to calculate an enhanced effective water heater energy factor. This enhanced energy factor is then entered into HERS residential energy software simulations, which determine corresponding HERS scoring credit as well as energy and utility bill savings.

In 1999, on behalf of the American Water Works Association Research Foundation (AWWARF), Aquacraft conducted research in many parts of the country as part of the Residential End Uses of Water Study (REUWS). In 2002, Oak Ridge National Laboratory (ORNL) conducted a study in conjunction with the city of Palo Alto that examined the use of demand pumping systems in retrofit applications. In 2003, the Davis Energy Group (DEG) conducted a study as part of its work for the Building America program on new construction that showed that using a demand pumping system saves more energy than using standard recirculation techniques.

The ORNL study of five existing homes showed that a demand pumping system saves both water and energy in retrofit applications (see Table 1). Following typical practice in retrofit, researchers installed a demand pumping system under a sink in the hot water use location furthest from the water heater. This was typically the master bathroom or the kitchen. The group measured the savings from the one hot water use location that was served by the demand pumping system and projected those savings onto a house with four hot water use locations. It determined that the waste of water and energy were due to both technical and behavioral factors. One very interesting result was that when the on-demand circulation pump was used, since less hot water was needed to prime the loop, less water was circulated back to the water heater than normally was wasted before the water was hot enough to use. The ORNL group determined empirically that the ratio of water wasted at slow flow to the water recirculated by the circulation pump was 1.3:1.

Table 1. Water and Energy Savings in Existing Homes

Number of Hot Water Use Points	Daily Water Savings (Gal)	Annual Water Savings (Gal)	Annual Energy Savings (kWh)
1	2.5–8.2	900–3,000	200–400
4	10–32.8	3,600–12,000	800–1,600

The DEG conducted a study as part of their work for the Building America program on new construction that showed that using a demand pumping system saves more energy than using standard recirculation techniques. In a 3,080 ft² single-story house with a very large recirculation system, DEG tested six combinations of pump and controls to determine which one performed best. The demand pumping system ran less than one minute per gallon of hot water used. The next best option was a timer control system, which was on 16 hours per day, and which ran for close to 40 minutes for each gallon of hot water used. A continually pumping recirculation system ran for close to one hour for every gallon of hot water used.

All of the other circulation pump control strategies DEG tested used significantly more energy than was used by the demand-controlled system. It took less energy to operate the house with the demand-controlled pump than it would have to run it without any recirculation system at all.

According to the DEG report, run time of the demand-controlled pump could have been significantly reduced by eliminating false signals. Due to the location of the motion sensors chosen for the experiment, 70% of the total number of signals sent to the pump were false. False signals occurred when the motion sensor saw motion and sent a signal to the controls, which allowed the pump to run until the main circulation trunk line was primed with hot water. If these extra signals had been eliminated, pump run times would have been around 0.24 minutes per gallon of hot water used, and the energy required to run the properly configured system would have been 25 therms per year.

The measured energy and water savings were realized in a house where the branch piping was not intentionally configured to minimize the volume of water between the fixtures and the circulation loop. In a structured plumbing system, it would be possible to reduce the waste and wait by an additional 50%. Combining the structured plumbing with significantly reduced unintentional activation would reduce energy consumption still further. This optimized configuration would use less than the energy used by the traditional recirculation system to keep the main circulation trunk line hot, and less than the energy normally associated with running water down the drain.

Energy Benefits

Demand-controlled pumping systems can be installed on trunk and branch systems both in new construction and in retrofits, and on structured plumbing systems installed in new construction or during a major rehab.

Trunk and Branch Plumbing

Trunk and branch plumbing is the most common type of hot water distribution system found in both new and existing single-family homes. It is characterized by one main trunk line coming from the water heater that runs toward the furthest fixture. No particular effort is made to optimize the length or volume of the branch lines serving individual fixtures. The pipes are seldom insulated. Sometimes there are two main lines coming from the water heater to serve fixtures in different parts of the house. In this case, there are really two separate hot water distribution systems, each with its own waste of water, energy, and time.

The reduction in water waste will depend greatly on the configuration of the plumbing in the house. In particular it will depend on the volume of water between the water heater and the fixtures, on how many and which fixtures are on the same trunk line or lines, and on the volume of water in the branch lines off the trunk line. These are the structural variables. There are also behavioral variables, such as whether the occupants turn on the water and then leave, returning when they think that hot water has arrived at the fixture, and on whether hot water events are clustered together or spread out intermittently throughout the day. The savings described here only accrue from improving the structural waste; changing behavioral patterns would generate additional savings.

According to the Aquacraft report, the average daily hot water use per household ranges from 60 to 80 gallons per day. According to the ORNL study, the water savings potential ranges from 10 to 30 gallons per day. Drawing on these two ranges, the average household could save between 12.5% and 50% of its daily hot water consumption by using a demand-controlled pumping system. It is useful to note that the waste is greater than the potential savings; you can't save more than you waste.

In retrofit applications, it is unlikely that any effort will be made to reconfigure the piping to reroute the trunk lines to minimize the volume in the branch lines. In new construction, the typical installations of trunk and branch plumbing do not consider this either. In both cases, the potential savings are less than would be possible with structured plumbing, which is discussed below. A conservative assumption is that the savings from using a demand-controlled pumping system on trunk and branch plumbing systems are 15% of daily water use.

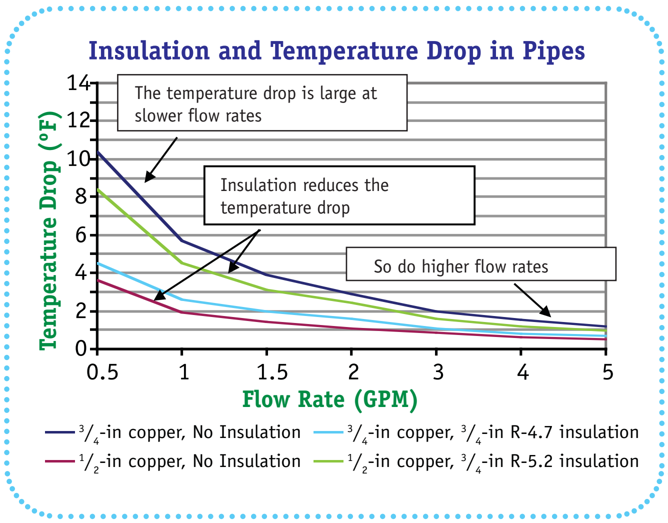

Figure 1. Based on tests of 1/2- and 3/4-inch piping for a given flow rate, R-4 insulation will reduce the temperature drop by half. The graph is for 100 ft of pipe. The hot water begins at 135°F and the ambient air temperature surrounding the pipes is 67°F.

Structured Plumbing

Additional energy savings are possible when demand-controlled pumping systems are used with structured plumbing. Structured plumbing includes

- a circulation loop that is as short as is practical and that has as few hard elbows as possible;
- fixtures or appliances that are located within 10 plumbing feet of the circulation loop on branch lines that are no larger than 1/2 inch diameter;
- insulation (R-3 minimum) on all of the hot water pipes; and
- an on-demand pumping system with electronic controls and activation mechanisms placed in key locations throughout the house, generally one per hot water-using location.

The circulation loop is intentionally located so that it is both as short as possible and within 10 plumbing feet of every fixture. Except for the friction losses due to its length, it offers few other restrictions to flow. Ideally, the only fittings in the circulation loop are the tees for the branch lines feeding each fixture. An on-demand pump—sized to overcome the now-reduced losses in the main circulation line—will be able to preheat the circulation loop relatively quickly. The pump is activated shortly before the desired use to prime the insulated line, after which the electronic controls automatically shut off the pump when they recognize that the water in the circulation loop is hot. The insulation on the pipes keeps the water hot for about an hour between uses. The small volume of cold water in each branch line will be replaced with hot water in just a few seconds. Water waste will be minimized, ideally to less than 2 cups per hot water event. Hot water will arrive at each fixture in less than five seconds, depending on the flow rate at the fixture. Assuming that the average waste is 0.5–1 gallon per hot water event in houses without a circulation system, this represents a 75%–90% reduction in water waste. There is a small additional cost of $1–$2 per year to operate the demand-controlled pump and associated controls.

When demand-controlled pumping is used in conjunction with structured plumbing systems, the energy savings come primarily from four factors—the three mentioned near the beginning of this article and a more efficient hot water distribution system. The more efficient hot water distribution system comes from reducing the restrictions to flow (by eliminating unnecessary fittings and sharp elbows) and from insulating the pipes. With more efficient distribution, the water heater need not be set as high to overcome losses caused by heat loss through the pipes. It is very common to find a 5°F–10°F temperature drop from the water heater to the furthest fixtures in a house. According to a study sponsored by the California Energy Commission (CEC), for a given flow rate, R-4 insulation will reduce the temperature drop by half (see Figure 1).

Therefore, for a given water heater setpoint, consumers will be able to reduce the amount of hot water needed for a desired mixed temperature. This will save some energy. It will also increase the effective capacity of a tank-type water heater. Also, consumers could choose to reduce the setpoint of the water heater. This will save even more energy, particularly for houses with tank-type water heaters. For tank-type water heaters, a reduction of 5ºF translates into a reduction of 10% in standby losses. For tankless water heaters, the reduction in temperature drop translates into both a smaller temperature rise and an effective increase in available hot water capacity.

LARRY ACKER

A user will activate a demand-controlled pumping system using controls, such as those shown above, shortly before hot water is needed.

Installing structured plumbing in new construction or a major rehab makes it possible to configure the circulation loop to take advantage of the lessons learned from the research. The result will be increased water savings due to the small residual volume of water in the branch lines serving individual fixtures. There will be additional savings due to the insulation on the hot water piping. A conservative assumption is that the water savings from using a demand-controlled pumping system on structured plumbing systems are 20% of daily water use.

Performance Analysis

EPA performed an analysis to quantify the potential enhancement of water heater EF due to the use of a demand-controlled pumping system under a range of conditions encountered in typical residential settings. A set of linked steady-state energy balance equations was solved in a spreadsheet-based simulation to predict the energy factor enhancement of a 40-gallon gas tank water heater, a 52-gallon electric tank water heater (the most commonly encountered sizes for storage water heaters), and for gas and electric tankless water heaters. The enhancement factor does not depend on the size of the water heater, since the effect of that parameter is already encapsulated in the value of the Gas Appliance Manufacturers Association (GAMA)/DOE energy factor. The coefficient is smaller for less-efficient water heaters. It is smaller for gas water heaters than for electric water heaters. The coefficient is higher for larger water savings. It is higher for tankless water heaters than for tank-type water heaters.

The enhancement coefficient is multiplied by the water heater's EF to determine the enhanced energy factor. The results of this calculation for the water heaters evaluated are shown in Table 2. The most notable observation is that, in many cases, the enhanced energy factor is greater than 1. While this may seem a bit counterintuitive, a large enough reduction in use due to the elimination of waste has the same effect as having a much more efficient water heater.

The impact of the energy factor enhancement ($EF_{Enhanced}$) on a HERS rating for a specific house needs to be evaluated in light of the daily volume of hot water, and of the incoming water temperature (which is determined by the climate). The $EF_{Enhanced}$ number needs to be plugged into REM:*Rate* or other HERS simulation software in place of the normal EF.

Table 2. Enhanced Energy Factor

	Gas			Electric		
Type	**NAECA***	**High Efficiency**	**Tankless**	**NAECA**	**High Efficiency**	**Tankless**
Volume (gallons)	40	40	-	52	52	-
Energy factor	0.54	0.63	0.82	0.86	0.93	0.98
Recovery efficiency	0.76	0.80	0.84	0.98	0.98	0.99
Water Savings	**Enhanced Energy Factor**					
0%	**0.54**	**0.63**	**0.82**	**0.86**	**0.93**	**0.98**
10%	0.59	0.68	0.91	0.94	1.03	1.09
20%	0.63	0.75	1.02	1.04	1.15	1.22
30%	0.69	0.82	1.16	1.17	1.30	1.39
40%	0.76	0.92	1.35	1.33	1.50	1.62
50%	0.85	1.04	1.60	1.53	1.77	1.94

* National Appliance Energy Conservation Act standards

Retrofitting Circulation Systems

The previous section examined the impact on energy factor of using demand-controlled pumping systems on trunk and branch and structured plumbing systems. Another application of the technology is to retrofit a demand pumping system on a dedicated recirculation system.

In this application, there is a large reduction in energy consumption based on dramatically reduced run times of the pump. According to DEG, a demand circulation system will use more than 90% less energy than is used by an uncontrolled recirculation pump running 24 hours a day. The savings are attributable to two factors. The first of these factors is a reduction in the electrical energy used to run the pump. The second, and much more important, factor is a reduction in the heat loss in the loop. The waste of water and the time it takes to get hot water will probably remain the same after the retrofit, since nothing is likely to be done to change the volume of water in the branch lines serving each fixture. Tables 3 and 4 provide a means for estimating the savings. In these tables, the steady-state heat transfer efficiency is assumed to be 75% for natural gas and 100% for electricity. For most single-family circulation systems it is reasonable to assume that the temperature drop is 5°F and that the pump flow rate is 1 gpm.

The standard circulation pump that is being used in over 90% of the homes with this type of hot water distribution is a 3 gpm with 6 feet of head. The average speed of the water is 1 gpm. Anything much faster will damage the walls of the pipe very quickly. The pumps are chosen to have low flow rates, in large part so that face velocity in the smallest-diameter and most turbulent sections of pipe stays below about 8 feet per second.

Using Figure 1 (p. 20), it is possible to estimate the flow rate based on the temperature drop, and vice versa. Assuming that the loop is roughly 200 feet long (not a bad length, given the size of the houses with recirculation systems), the temperature drop at a given flow rate will be roughly twice as much as that shown in the graph, which was calculated for 100 ft. At 1 gpm, this will mean a temperature drop of more than 5°F. If the flow rate is lower, the temperature drop is higher. If the flow rate is faster, the temperature drop is lower. Since the water heater sees flow rate times temperature drop, it balances out. This means that annual energy associated with a circulation system running 24 hours a day is 292 therms, or 6,388 kWh. If the flow rate is faster, say 2 gpm, or the temperature drop is larger, say 10ºF, or if both are true, select the appropriate energy use from the Tables 3 and 4. If the system has a timer set for fewer hours, proportion these amounts accordingly.

Savings due to the retrofit of a demand controlled pumping system are roughly proportional to the reduction in hours of operation. The demand-controlled pump will move the water faster at closer to 5 gpm, but due to the higher flow rate, the temperature drop will be closer to 1ºF.

LARRY ACKER

Once the line is hot, the insulation will keep it hot for 30–60 minutes. The remote controller that activates the demand pumping system can stay on the shelf for the second shower of the morning.

Table 3. Energy Use for a Circulation System and Gas Water Heater (Therms)

Continuous Pumping at 1 gpm				
	Temperature Drop			
Days	**1°F**	**5°F**	**10°F**	**20°F**
1	0.16	0.8	1.6	3.2
30	5	24	48	96
365	58	292	584	1,168
Pump Flow Rate (gpm)				
1	58	292	584	1,168
5	292	1,460	2,920	5,840
10	584	2,920	5,840	1,680

Table 4. Energy Use for a Circulation System and Electric Water Heater (kWh)

Continuous Pumping at 1 gpm				
	Temperature Drop			
Days	**1°F**	**5°F**	**10°F**	**20°F**
1	3.5	17.5	35	70
30	105	525	1,050	2,100
365	1,278	6,388	12,775	25,550
Pump Flow Rate (gpm)				
1	1,278	6,388	12,775	25,550
5	6,388	31,938	63,875	27,750
10	12,775	63,875	127,750	255,500

Assuming that the pump operates a relatively long time of 30 minutes as needed over the day, the savings will be 98%, or 286 therms, or 6,260 kWh per year.

The demand pumping system trades off cool down with the need to continuously reheat the water in the loop. However, if the recirculation system is insulated (as it should be), the pump will need to prime the line only a few times a day. Once the line is hot, the insulation will keep it hot for 30–60 minutes. This is long enough to cover many of the grouped uses in a typical daily hot water use pattern. Each use of hot water during this period brings hot water to the relevant fixture, keeping the water in the line to that point hot for the next hot water event. At some point the pipes will cool down below a useful hot water temperature and the next user will need to prime the line again. So while some energy is lost when the pipe cools down, it is much less than the energy needed to keep the line hot all day. Note that most demand pumping systems run much less than 30 minutes a day, so the savings are likely to be larger.

Significant Savings

Based on this analysis, the savings on trunk and branch hot water distribution systems due to a conservative 15% reduction in water consumption result in energy factor enhancement coefficients ranging from 1.12 to 1.17 for the range of water heaters that we evaluated.

The savings in structured plumbing hot water distribution systems due to a conservative 20% reduction in water consumption—the latter due to the demand-controlled pump and the smaller volume branch lines—plus an additional savings equivalent to another 10% reduction in water use due to insulation, result in energy factor enhancement coefficients ranging from 1.27 to 1.42 for the range of water heaters that were evaluated.

The on-demand pump primes the line just before hot water is desired. The small-volume branch lines minimize water waste. The insulation keeps the circulation loop hot for the next use, so that the next user sees hot water very quickly as it comes through the branch line.

The savings for retrofitting existing recirculation systems are energy, not water, related, as they are in the first two applications. Retrofitting a demand-controlled pump will reduce the energy needed to operate the pump and keep the circulation loop hot by up to 98% (a savings of 286 therms or 6,260 kWh per year). This reduction is roughly proportional to the reductions in the pump run time of the existing system.

Hot Water

Larry Acker is CEO of ACT Incorporated, Metlund Systems in Costa Mesa, California. Gary Klein is an energy specialist with the California Energy Commission.

Glenn Chinery of EPA developed the algorithm used in this study to convert percentage hot water savings into enhanced energy factors for water heaters.

FOR MORE INFORMATION:

The following companies offer demand-controlled pumping products:

ACT Incorporated, Metlund Systems (www.gothotwater.com)

TACO (TACO-hvac.com)

Uponor Wirsbo (www.wirsbo.com/index.php?id=122&pid=24)

All of these products comply with the applicable plumbing and electrical codes.

Mayer, P.W., W.B. DeOreo, et. al. *Residential End Uses of Water Study (REUWS)*. Denver: American Water Works Association Research Foundation, 1999.

Progress Report on Building America Residential Water Heating Research. Davis Energy Group, Nov 14, 2003. Used with permission of David Springer.

M. R. Ally, J. J. Tomlinson, and B. T. Ward. *Water and Energy Savings using Demand Hot Water Recirculating Systems in Residential Homes: A Case Study of Five Homes in Palo Alto, California*. Oak Ridge National Laboratory, Oak Ridge, Tennessee ORNL/TM-2002/245, October 21, 2002.

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