Title
Feasibility study and roadmap to improve residential hot water distribution systems

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Publication Date
2004-03-31

Feasibility Study and Roadmap to Improve Residential Hot Water Distribution Systems

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Abstract

Residential building practice currently ignores the losses of energy and water caused by the poor design of hot water systems. These losses include: the waste of water while waiting for hot water to get to the point of use; the wasted heat as water cools down in the distribution system after a draw; and the energy to reheat water that was already heated once before.

A feasibility study and an action plan for a proposed research project involving residential hot water distribution systems is being developed. The feasibility study will use past work to estimate of hot water and energy loses caused by current hot water distribution systems in residences. Proposed research project, or roadmap, will develop recommendations for improvements to residential hot water distribution systems. The roadmap addresses the technical obstacles and gaps in our knowledge that prevent water and energy reductions and market adoption of water- and energy-efficient technologies. The initial results of the feasibility study are presented here along with a discussion of a roadmap to improve the efficiency of residential hot water distribution systems.

Feasibility Study

To get an estimate of the amount of hot water that is wasted, one can develop methods of calculating lost hot water from information on the residential end uses of total water.

The best description of residential end uses of water in North America at this time is a report of a study sponsored by American Water Works Association Research Foundation (AWWARF). The Residential End Uses of Water Study (REUWS) report represents a time-and-place snapshot of water use in single-family homes in 12 North American locations. End uses were tabulated for each location, and were analyzed and summarized for the entire group. The main findings include per capita usage for each identified end use; savings available from indoor conservation measures. Water consumption for various end uses was measured using compact data loggers and flow trace analysis software. A flow trace is a record of flow through a residential water meter recorded in 10-second intervals that provides sufficient resolution to identify the patterns of specific fixtures within the household.[1]

Intuitively there are three types of hot water loss; the waste of water while waiting for hot water to get to the point of use; the wasted heat as water cools down in the distribution system after a draw; and the energy to reheat water that was already heated once before.

These three types of losses can be exemplified by showers, faucets, and dish washers. (Actual leaks of hot water from pipes and fittings are not considered here.)

From a water and wastewater utility perspective, this first type is considered the most important. The energy in the hot water left in the pipes is lost as the pipes cool off. The water is lost as that cold water is run down the drain to get to the freshly heated water from the water heater before the customers can use it. This is water that must be treated twice, but does not provide the customer with any useful service.

From an energy perspective, the sink and dishwashers must be considered in addition to the shower loss. The sink loss is from uses at a single lever sink, where the customer raises the lever straight up, as if wanting warm water, but the complete use is accomplished in less time than it takes to get hot water to the sink. All that is accomplished is for the hot water in the piping system to be replenished, so that it can cool off once again.

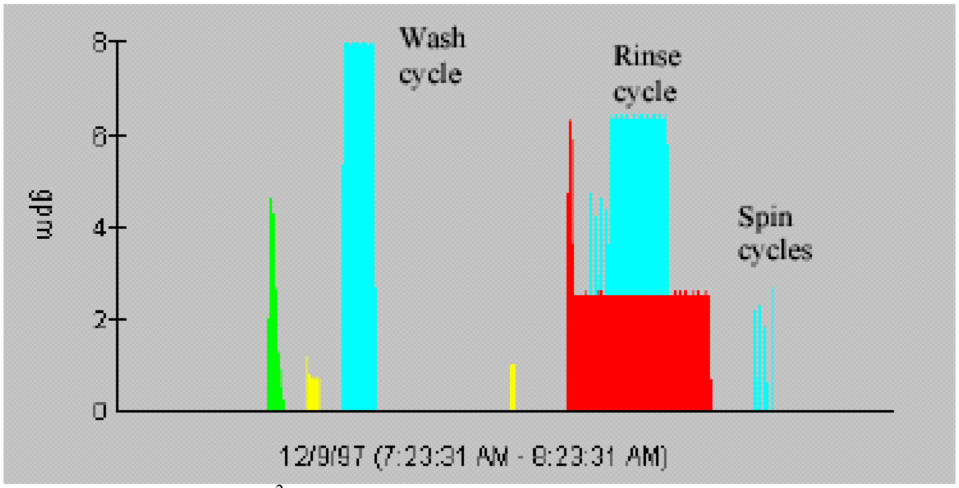
For dishwashers, not only is the energy wasted by the hot water remaining in the pipes cooling off before the next use. But it must be made up by the dishwasher heating the cool water that it receives from the hot water pipes to a hot enough temperature for safe and sanitary dish washing.

Estimates of Shower Losses

The estimates of shower loss are from a method that was developed to estimate the shower losses using the REUWS event database.[1] The REUWS database contains records of 1.96 million events, which are all classified by type.

The assumption for this estimate is that total water used by a shower can be split into two different types of flow. The first type of flow during a shower event is at the beginning when the consumer turns the shower (or bath spigot in a combined shower/bath) to full hot. This is how consumers get hot water to the showerhead quickly. All this flow is wasted hot water and occurs at the peak flow during the shower. When both the person and water are ready, the hot water flow is reduced and some cold water is mixed in. This second portion of the event is the useful part of the shower. The flow rate is constant during the rest of the shower. See the figure below which shows a sample of the flow trace data from the REUWS report. The shower is shown as overlapping with the rinse cycle of the clothes washer.

Figure 1 Sample Flow Trace of Shower and Other Draws

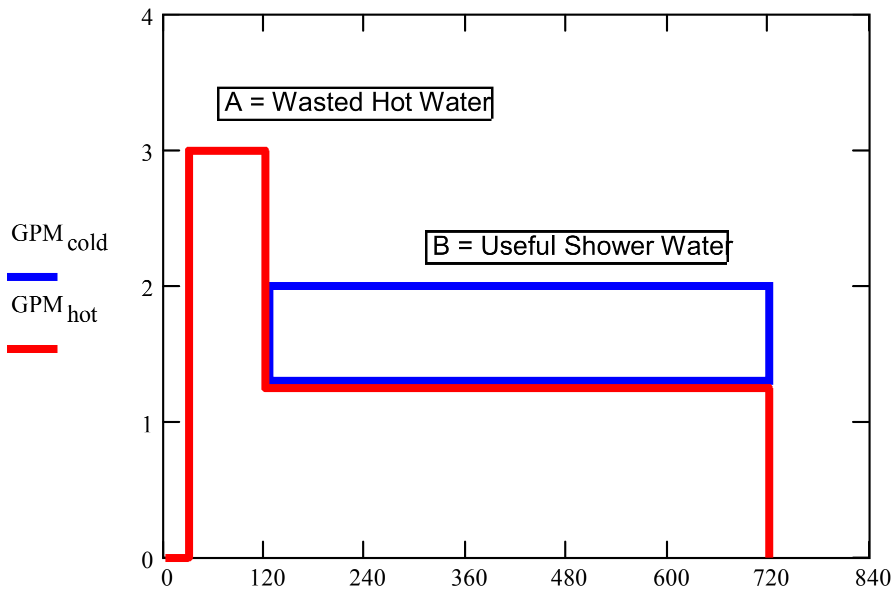


source: Mayer et al. 2003[2]

From these assumptions, an ideal simplified model can be assumed. The flows during both portions of the shower event are assumed to be constant. The first part, which is wasted, is assumed to consist completely of water that had been heated. Some portion of this is hot water that remained in the pipes since the previous draw and has cooled off. This cooled off water is what the consumer is trying to get rid of. Some of this water may consist of hot water that the consumer inadvertently is wasting after the cooled off water has already been discarded.

The following figure shows this idealized case. This is representative of the case where a combination tub/shower is used and the cooled off hot water is discarded using the tub spigot.

Figure 2 Idealized Flow to a CombinationShower/Tub



In this case, part A is the wasted hot water, and the useful shower is part B. The useful shower, is a balance of hot and cold water that the user adjusted get the desired shower water temperature.

For each event, the REUWS database records contain the total volume of water drawn, the total duration of the water draw, along with the peak and the mode flow rates during the water draw.

From these parameters, the volume of part A, the wasted hot water, can be calculated as:

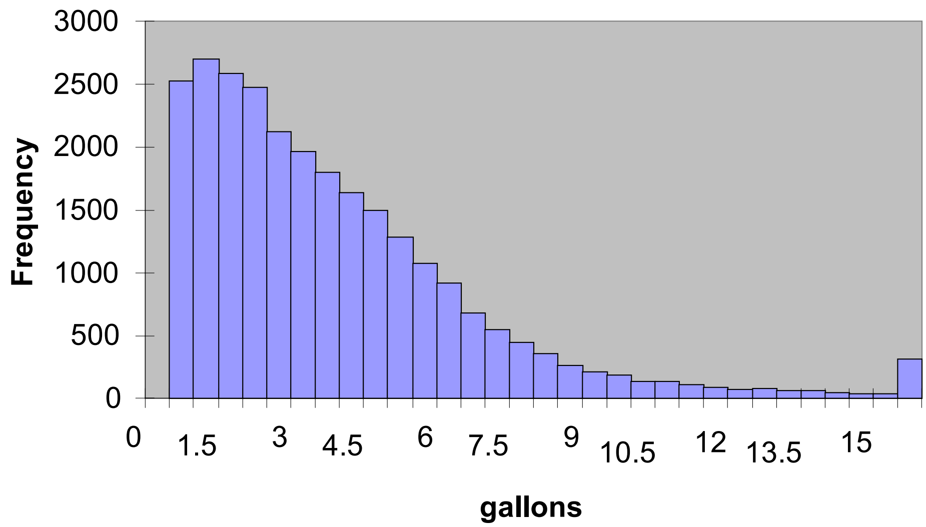
$$A = PEAK \times \frac{(VOLUME - MODE \times DURATION)}{PEAK - MODE}$$

To apply this estimation properly, those showers that can be reasonably approximated by these simplifying assumptions need to be identified. This equation will only work when the peak flow rate is above the average flow rate and the average flow rate is greater than the mode flow rate. These criteria are met for more than 26,000 of the shower events in the REUWS database. This is about one half of the shower events reported in REUWS.

Using this equation, the average waste volume for these showers is 3.48 gallons.

A histogram of the distribution of shower waste is shown below. There is a very long tail on this distribution, indicating that for some showers, the loss can be a very significant amount of water.

Figure 3 Distribution of Waste per Shower



According to the REUWS report, the average shower uses 17.2 gallons. For these showers, waste is 20% of the average shower volume. Using averages from the REUWS database the fraction of the total indoor water that is wasted in showers can be estimated. By multiplying the average number of showers per capita per day (0.75), the mean number of persons per household (2.8), the average loss per shower (3.84 gallons), and the fraction of showers with this type of loss (52.7%), the average lost water per household per day is calculated as 3.85 gallons per household per day.

Some of the remaining showers will also have this same type of loss, but will not be detected by these criteria. This is because the wasted hot water does not happen at a higher flow rate that the useful shower flow rate. Although the consumer discards the cooled off heated water, the same as in the showers for which waste can be calculated, this algorithm will not work on those shower events. This would be the case where someone is showering in a shower stall that is not a combination tub/shower. It could also happen in the case where someone does not use the tub spigot to discard cooled off hot water. An estimate is that this happens in half of the cases that the shower waste algorithm does not work on. Applying the same calculations as before, this type of waste on additional shower events comes to 1.73 gallons per house per day. The total amount of shower waste is thus estimated at 5.21 gallons per day

This is a rough approximation of shower waste. More work can be done using the REUWS database. There are indications that this type of waste is worse in new houses.[3] It may also be possible to determine if this waste is lower if there are other hot water draws directly preceding the first shower use each day.

Estimates of Sink Losses

An estimate of losses for faucet end use events can be made with some reasonable assumptions. Conceptually there are two different types of losses. There are those draws where the consumer discards cooled off heated water until water arrives that is sufficiently hot. This is similar to the shower waste discussed previously.

Another common occurrence is that consumers will just use the cold water coming from the faucet, even if it's not at the temperature they desired. While for this paper this is counted as an energy loss and not a water loss, it should be considered as not meeting consumer desires. .

An estimate of the water losses when consumers waited for hot water was done by applying the same algorithm to faucet draws in the REUWS database that lasted at least one minute. The same criteria of the peak flow rate being above the average flow rate and the average flow rate being greater than the mode flow rate were applied to all the long faucet events. There were 41,000 faucet draws in the database that met these criteria. The average wasted hot water per long faucet draw was 0.77 gallons. The average number of long faucet draws per day per house in the study was determined to be 1.48. Multiplying these values gives an average amount of hot water wasted per day in long faucet draws as 1.14 gallons.

The other case of faucet waste is the case of short draws that never have a chance to provide hot water to the user. Simplifying assumptions here are that hot water will not make it from the water heater to the faucet in less than 20 seconds and that half of the water for every sink draw is coming from the hot water pipe. The REUWS shows that 60% of all faucet draws are of 20 seconds or less. This works out to be 4.0 gallons of water that is heated but never provides any useful warmth.

Estimates of dishwasher losses

The hot water losses for dishwashers do not involve any loss of water. However the energy losses from cooled water in the hot water pipes must be compensated for by the heating elements in the dishwasher. If the water heater is gas fired, as most water heaters are in California, the lost heat is made up for by electricity, which has much higher source-to-site losses than gas.

Total estimates of lost hot water

Adding the average daily hot water loss from showers and faucets totals to 6.35 gallons per day per house. . This is 3.7% of the average household's indoor daily water use of 173 gallons.

Roadmap

To address the problem of these losses the California Energy Commission has started a project to develop a roadmap to water-and energy-efficient and cost-effective residential hot water distribution systems.

One of the first steps in the roadmap is to determine the extent of this problem. The problem needs to be bounded. The water, energy, sewer, other environmental issues need to be considered. The hot water distribution system extends from the water heater, through the piping system, up to and including the fixtures. Because of the nature of the system, health and safety need to be considered as well. If the hot water is delivered at too high a temperature scalding risk increases. If the water temperature is not high enough, legionella may become a problem. The simple feasibility study included in this paper looked at single family homes. Multifamily and manufactured homes may have similar problems as well.

Given the changing nature of house construction in the U.S. this is likely to more of a problem in new construction than in the older existing stock of housing. If a solution is found for this problem, it can be implemented much more easily in new construction.

The feasibility study at the beginning of this paper starts to address the size of the problem, but much work needs to be done to determine if the problem is worse in some places or styles of construction. This initial work indicates the problem is serious. The next step is to determine what can be changed to solve the problem.

Surveys will need to be done to find out what's being built and how well it works. To find out what current construction practices and trends are will require talking to builders, plumbers, architects, engineers, and building inspectors. Not only can they say what the plumbing systems that are being installed, but they can also tell what these systems cost. To find out how well different systems work will require surveying existing homeowners and renters. These are the best people to ask to find out what customers think of the systems that they have.

Another crucial data need is to determine how hot water is used and wasted. Most existing studies have been either of total water use, such as the REUWS study, or of the energy consumption of water heaters. A few studies have looked at hot water use at the output of the water heater. The author is only aware of two very small studies that have measured hot water temperatures at the customer end of the hot water distribution system. Neither of these studies tried to determine how much of the delivered heated water was wasted.

The roadmap proposes to make field measurements in existing homes throughout the country to see how hot water is currently being used. This will build on the work already done by Aquacraft, ASHRAE and others. Care must be taken to make sure that measurements support the agreed to boundaries and that what's counted is what's worth counting.

Another problem the roadmap must address is developing a hot water distribution simulation model. This will allow designers and code developers to optimize hot water distribution systems. One task is to compare the existing flow and temperature simulation models to analyze the performance of distribution systems. The existing models were developed for different uses and all have known shortcomings, but they do provide a good starting point. Work has already done by Davis Energy Group[4], Oak Ridge National Laboratory[5] and the National Association of Home Builders Research Center (NAHBRC)[6]. A model should be developed that draws upon the strengths of all the existing models.

To develop an understanding of how distribution systems work and to test the models controlled laboratory experiments will have to be conducted. This will determine the essential parameters of hot water distribution systems for use in simulation models, building standards and incentive programs. To bound the testing to limit the time and cost of this exercise testing should be limited to the smallest amount of data necessary. The earlier this is done in the roadmapping project the better. Phase the research, starting with the simple cases and progressively increasing the complexity, including actual piping networks. If it's possible, the project will leverage the work already done by the NAHBRC for tree and parallel configurations for two-story layouts.

Take temperature, flow, time, water, and energy data to validate and calibrate the hot water distribution system simulation model.

Once field data and laboratory tests have been completed, the validated computer simulation models can be used to explore different configurations and layouts of hot water distribution systems. Use the model to predict energy and water savings for a wide range of piping layouts, distances, water consumption patterns, etc. to determine the best configurations and also ones to avoid. The best theoretical configurations in will need to be tested in actual homes to assess actual performance and customer satisfaction. The results of these field tests can be used to recalibrate the simulation model if necessary.

One of the goals of the roadmap is to provide installation guidelines. Many builders have problems today that they are trying to solve. They are looking for reasonable, if not necessarily optimal solutions. Manufacturers of alternatives are trying to get their solutions implemented. There is a fair amount of confusion in the marketplace. Some solutions save water, but at the expense of energy. Others may save energy, at the expense of water. The roadmap is project to find solutions that save both.

At the beginning of the roadmap, installation guidelines based on the best currently available information can be provided. This will something builders and plumbers can start doing tomorrow. It may not be the optimum, but it's a clear statement of today's current best practices. At the end of the project, installation guidelines based on the results of the research will be disseminated.

Research results without any connection to practice are not very useful. The project will develop and implement market useful tools. Some of this will be based on demonstrations of the best configurations in various markets around the country. The information from the model studies must be packaged in a way that can be used by water, wastewater, and energy utilities and industry to speed hot water delivery to end-uses while at the same time reducing energy and water consumption.

One way to encourage the adoption of the best practices found by the roadmap is to develop voluntary incentive programs. This will mean working with utilities, government agencies and other organizations to encourage voluntary implementation of high performing hot water distribution systems. Options include Energy Star, Green Buildings, home energy rating systems, and maybe Water Star.

Once there has been enough research and experience, then it will be necessary to update the building and plumbing codes. This will mean working with ASME, ASPE, IAPMO, ASHRAE, ICC, CEC and others to assure that plumbing and energy codes reflect the new knowledge that is developed in this project.

As the reader can easily understand, this is a roadmap for a large project. Who needs to be involved? And at what stages? Clearly the water and wastewater utilities will need to be part of this project as funders, researchers, and finally as implementers.

Acknowledgements
The author would like to acknowledge Gary Klein of the Californian Energy Commission.

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