Residential Hot Water Distribution Systems: Roundtable Session

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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: combustion and standby losses from water heaters, the waste of water (and energy) 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; heat losses from recirculation systems and the discarded warmth of waste water as it runs down the drain.

Several technologies are available that save energy (and water) by reducing these losses or by passively recovering heat from wastewater streams and other sources. Energy savings from some individual technologies are reported to be as much as 30% (Acker and Klein, 1996; Wardell, 2000). Savings calculations of prototype systems including "bundles" of technologies have been reported above 50% (Howard, 2000).

This roundtable session will describe the current practices, summarize the results of past and ongoing studies, discuss ways to think about hot water system efficiency, and point to areas of future study. We will also recommend further steps to reduce unnecessary losses from hot water distribution systems.

Introduction

Trends over the last 30 years have prevented water heating system efficiencies from keeping pace with appliance and heating/cooling system efficiencies. While energy regulations have decreased the flow of hot water through fixtures such as showerheads and faucets, standard plumbing practice has increased the diameter of the pipes, resulting in a degradation of distribution system efficiency. Electric and gas water heater efficiencies have improved as a result of federal regulation, but gas water heater efficiency standards still lag behind.

The distribution problem is compounded by the tendency in new homes to spread the bathrooms and kitchen over a wide area, often locating them in different wings. Also, most new home construction has been in the south and west, where basements are very rare. This means that water heaters are generally located in the garage, pipes are often run under the slab and, regardless of where they run, they are rarely insulated.

All of these factors contribute to our observation that pipes in new homes contain more water than in older home designs, waiting times are longer and hot water distribution systems are generally less efficient. The resulting water that is wasted requires energy to heat, pumping energy to deliver, chemicals to treat; and increases the burden on both water and wastewater treatment facilities.

Determining how to improve the efficiency of residential hot water use is both challenging and important. It is challenging because the boundaries are difficult to define, and hot water use is influenced by behavior and difficult to predict. It is important because about 19% of residential energy is consumed to heat water (EIA, 1999; EIA, 2000).

Water utilities and wastewater treatment facilities are subject to ever-increasing needs to expand capacity. Because many of the ways to increase the efficiency of hot water use will reduce the use of water, this is an additional reason to improve the efficiency of residential hot water systems.

What we do and don't know about the use of hot water in residences indicates that this problem needs a lot more work. One reason this will be challenging is the fact that the variability of hot water use is quite large, both between households and between people in one household. For example the range of average hot water use per person for bathing can vary by as much as five times (Kempton, 1987). The variation from day to day is also large; peak days can be over three times the average (Hiller, 1998).

Compounding this variability is the scarcity of reliable data. Because of the difficulty of measuring hot water consumption by end use, only a handful of studies with a small number of households each have been done in the past couple decades. And only two of those have attempted to measure water temperatures at the end use (Kempton 1987; Henze 2002).

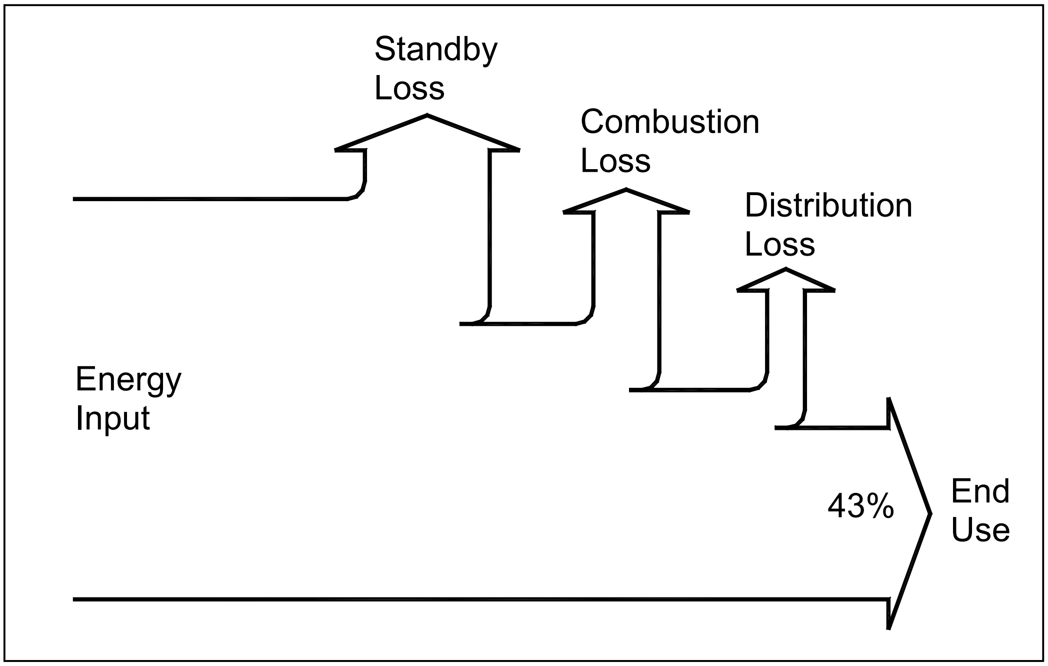
New technologies and practices the authors are aware of indicate significant reductions in energy consumption are possible. We will be reporting on some of these in this paper and suggesting research agendas and possible policy changes to address these problems.

Bounding the Problem: Defining Hot Water System Efficiency

Where the Energy Goes

Figure 1 is a geometric illustration of where the energy that enters a water heater goes. In this example for a standard gas water heater in a typical small house (~ 1400 square feet), about 31% is lost from the pilot light and water heater tank and 17% is lost up the flue. About 18% of the heat that leaves the water heater is lost on its way to the hot water fixtures. The overall efficiency in this example is 43%. For large homes and multifamily buildings the picture is much worse.

Figure 1. Typical Small-House Gas Water Heating System Efficiency Losses



Measuring Distribution System Efficiency

The problem of water heater efficiency is relatively easy to quantify. Federal appliance regulations define minimum efficiency levels and provide a test standard by which water heaters can be fairly compared. The consumer has a wide variety of water heater types and efficiencies to chose from. By comparison, the problem of distribution system efficiency is more difficult to conquer.

This section discusses basic theory on how distribution system efficiency can be measured. For reference, Figure 2 presents a schematic of a typical residential water distribution system.

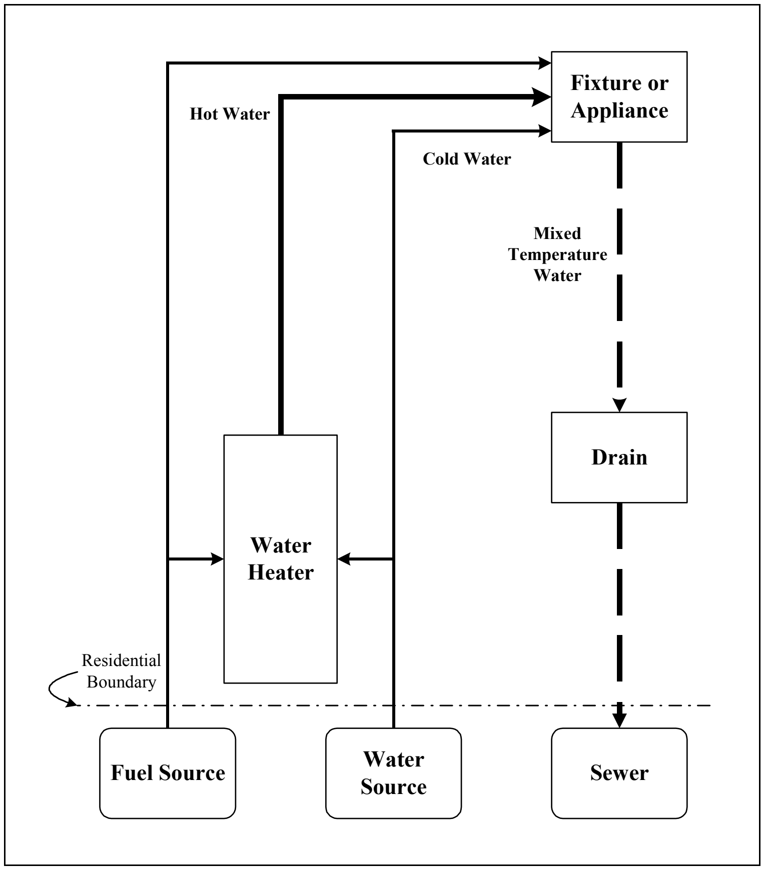
How to measure hot water distribution system efficiency is an intriguing question. Is it the efficiency of the piping system?

$$\eta = \frac{\sum HW_{out\ of\ tap}}{\sum HW_{into\ pipes}}$$

Does it account for the loss of energy in warm wastewater? No one would ever consider using a furnace to heat a house without a return air system, but this is the accepted practice for hot water. Looked at this way the efficiency can be written as:

$$\eta = \frac{\sum \left(HW_{out\ of\ tap} - HW_{down\ the\ drain}\right)}{\sum HW_{into\ pipes}}$$

Figure 2. Typical Residential Hot Water System



If we include the efficiency of the water heating system, then efficiency becomes:

$$\eta = \frac{\sum \left(HW_{out\ of\ tap} - HW_{down\ the\ drain} \right)}{\sum WH_{energy\ consumption}}$$

But even this doesn’t fully account for all the considerations. It won’t capture, for instance, the energy benefits of shifting to washing clothes in cold water. It also doesn’t account for differences in behavior patterns, or the “desired” temperature of hot water by different occupants. Because hot water use varies so much over time, efficiency should be evaluated over long periods of time to average out variations in use patterns.

A Day in the Life of a Hot Water System

To help understand the range of hot water use, we present two scenarios that contrast hot water use over a typical day for two different households representing opposite ends of the hot water use spectrum.

Household A represents a family with four children and two working adults (Table 1). The house is a large 1990’s slab-on-grade ranch house with the features described in the introduction. Effective pipe length is over 100 feet on the longest pipe run. Total average daily use is approximately 200 gallons of hot water per day.

Table 1. Typical Day Heavy Hot Water Use (Household A)

Event	Number (per day)	Duration (minutes)	Flow (gpm)	Total (gallons)
Shower (adult)	2	15	1	30
Shower (teenager)	2	30	1	60
Wash (face & hands)	12	1	0.5	6
Dish rinse	3	0.5	1	1.5
Clothes washer	2	5	2	20
Dinner prep	1	5	1	5
Dinner cleanup	1	10	1	10
Dishwasher	3	5	2	30
Bath	1	4	5	20
Pre-draws (to get hot water)	5	2	2	20
Total Daily Use				202.5

Household B represents an "empty nester", a retired single adult occupying a small home. The owner lived through the Depression, so is frugal by nature. In addition for the past four decades she has lived in a small town that faced repeated water shortages. She goes swimming a few times a week and showers at the pool.

The house is laid out well with the kitchen, bathroom, and laundry room right next to each other. It has a new tankless, pilotless instantaneous gas water heater and a GFX heat recovery on the drain. And once a week she does a load of laundry in cold water (and dries the clothes on the line in the backyard.) Her average daily hot water use is not even 10 gallons a day. The hot water draws on a typical day in her house are shown in Table 2.

Table 2. Typical Day Heavy Hot Water Use (Household B)

Event	Number (per day)	Duration (minutes)	Flow (gpm)	Total (gallons)
Wash (face & hands)	4	1	0.5	2
Dish rinse	3	0.5	1	1.5
Dinner cleanup	1	5	1	5
Total Daily Use				8.5

As these two examples show, hot water use can vary dramatically between households. Any solution to the problem of inefficient hot water distribution systems must successfully address this problem for the variety of hot water use patterns in residential buildings.

Issues and Challenges for Residential Hot Water Distribution Systems

One and Two Family Dwellings

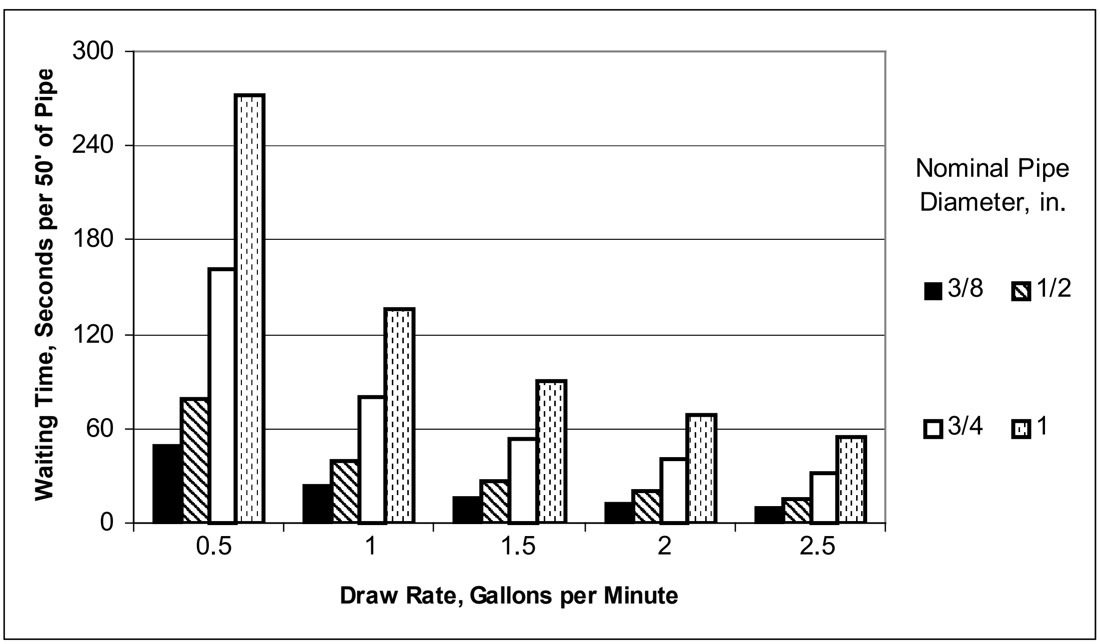
One of the challenges to improving hot water use efficiency is that most people do not even know how their hot water is actually produced and supplied in their homes, much less how much it costs.

People largely ignore "energy vampires" like water heaters consuming fuel and losing heat through inefficiency since they often reside out of sight, out of mind. When informed there are devices in their garage or basement costing $250 that may consume over $2,200 (natural gas) or $4,000 (electric) in utility billings over their useful life (assume ~ 9 yr) most people are shocked, and are willing to discuss energy efficient solutions. If a basic 30% savings level can reliably be obtained, then over the same life span between $660 (natural gas) and $1,200 (electric) are "put on the table" when just looking at simple payback – more if life-cycle costing is applied to improvements as "investments."

However, there is usually a first-cost barrier to adoption of new technology, since the builder does not live there after they deliver a "product" to someone else. The builder accrues no benefit and the market has yet to accurately inform consumers of the price benefits of efficient hot water.

In addition, there is a reluctance of consumers – hence designers, builders, code officials, utility companies – to try new products. This is due to: a) insufficient experience in the marketplace, b) overshadowing memory of past failures and problems, or c) lack of long term warranty and support infrastructure for the product.

Figure 3. Wait Times for Delivery of Hot Water



One consumer discomfort is helping increase awareness of these problems. Many people wait a long time to get hot water at one or more fixtures in their home. Figure 3 compares the wait time for four fixture flow rates in 50 feet of pipe for different pipe diameters. It shows that wait times are more than 5 times as long for 1" pipes as compared to 3/8" pipes. It also shows that wait times are proportional to fixture flow rate.

Multifamily Dwellings

In addition to these problems, multifamily dwellings have other unique considerations. Economic disconnects can exist between rent payers and energy billings to property owners.

There are many inefficiencies in the design and control of large-building hot water service. A trade off exists between large volumes of wasted water until taps run hot, versus energy wasted in re-circulation systems that provide near-instantaneous hot water at taps.

Tenants in multi-unit buildings who have hot water included in net monthly rent have little incentive to reduce hot water use since they tend to perceive the good as being "free."

If an apartment or condo/coop has a central hot water generator, the first cost of replacement or "early retirement" is significant and is usually resisted unless the device suffers a complete failure. In some cases the Architectural Reserve Studies commonly performed for these building owners take a very low-ball approach to future costs of replacement, and often fail to take into account escalation of energy costs at the same time inflation is monetized.

Stakeholders

This section identifies the different stakeholders, and sheds light on their role in or reaction to the market.

- Water heater manufacturers: Storage water heater manufacturers focus on low cost production and avoiding liability. Manufacturers of tankless and condensing water heaters are trying to break into the market. Both are subject to Federal appliance regulations, neither can control the quality of the water supply and both consider the hot water distribution system outside their purview. Neither have an EPA nor DOE ***EnergyStar***^{TM} program imprimatur.
- New homebuyers are not informed of the options, or of the consequences of different hot water system choices.
- Existing homeowners are acquainted with the problems of poor hot water systems, but are generally unaware of potential solutions, or not able to exercise them.
- Owners of multifamily dwellings look at the issue differently depending on whether the units are supplied by a central water heater or have individually metered water heaters. When the efficiency of the hot water system affects their pocketbook they care, but often don't know how to evaluate the alternatives.
- Tenants don't have control over the systems, but they do care about long waits and running out of hot water.
- Federal standards institutions only regulate the water heaters and the appliances. Building codes rarely address the energy aspects of the hot water distribution system, although they do set standards for the equipment being specified.
- Code officials care primarily about safety and ease of checking compliance.

- Testing laboratories like to test pieces of equipment, not systems.
- Electric utilities generally don't want summer afternoon peak. Natural gas utilities don't want either the summer afternoon peak or the winter evening peak. Electric utilities do however benefit from the advantageous base-load characteristics of tank-type water heaters that "always" provide some connected demand from many customers.
- Water system operators are supply constrained. Water and wastewater treatment districts are capacity constrained. Both want to cut down usage as it is often much cheaper than paying for new facilities.
- Cities and counties around the country are instituting regulations that require recirculation systems to save water.
- Pipe manufacturers, both copper and PEX (cross-linked polyethylene) want to see more total product being sold. PEX manufacturers see a booming new market. In areas where the soils and the water are corrosive to copper, plastic makes sense, particularly from a cost standpoint. Long-term durability of pipe and fittings remains to be seen, while early market results are favorable.
- Manufacturers of "home run" piping system components such as manifolds and plastic pipe fittings are trying to change the status quo and increase their market share. To work correctly, the manifold needs to be installed very close to the water heater and plumbers may not realize this.
- Recirculating pump and control manufacturers are concerned primarily about providing convenience, not about overall efficiency. To work properly, the recirculation loop needs to run close to the fixtures and the takeoffs to the fixtures need to be small diameter.
- Plumbers and builders want to maintain the status quo and are generally averse to trying new technology because of learning time and increased risk. Plumbers are trained for copper and PVC and builders don't fully know the cost tradeoffs and long-term performance.

Potential Solutions to these Issues and Challenges

Water Heaters

Considering the improvements to other appliance efficiencies over the last decade, residential and commercial gas storage water heaters are still dismally inefficient. In residential buildings over 50% of the systems installed operate on natural gas (EIA, 1993). The current federal minimum energy factor for a 40-gallon gas storage heater of 54% will only increase to 59% in 2004, compared to the current 78% minimum AFUE for furnaces. While standing pilots have been eliminated from furnaces, boilers, and gas stoves, they continue to be dominant in water heaters; standards that would eliminate them are held at bay by commodity pricing and pressure from manufacturers and the building industry. Technology improvements are not likely to improve energy factors by more than 20% because of the standing pilot. Conservation measures such as applying heat traps and adding external insulation can only gain minor efficiency improvements.

There are two alternatives to standing pilot gas storage heaters. Closed combustion condensing water heaters offer very high-efficiency at a correspondingly high cost that can often be cost-effective. Using long-life stainless steel tanks, they have energy factors in the mid-80's and recovery efficiencies in the mid-90's, and lend themselves well to combined heating systems and multifamily applications. Pilot-less instantaneous gas ("tankless") water heaters are another alternative that is lower in cost than condensing water heaters and is in widespread use in Japan and Europe. Because of their very low standby losses they can achieve energy factors in the low 80's. Fluctuations in water temperature with varying demand (in addition to higher cost) have made them less marketable in the U.S., though with recent improvements in controls this is no longer an issue. Periodic maintenance that is required for the "tankless" systems, particularly in areas with water impurities, may impose a market barrier.

The high input capacities of both condensing gas storage, and gas tankless heaters, mean they can generally eliminate the experience of running out of hot water when applied to single-family residences. Demand for energy efficiency and higher capacity hot water systems, and the increasing popularity of "combined hydronic" systems that use the same heat source to deliver space conditioning and domestic water heating, may drive the antiquated standing pilot water heaters from the market before federal standards can rise to the occasion.

Boilers connected to storage tanks or "indirect water heaters" offer another potentially cost-effective alternative since they do not suffer the heat losses attendant to the uninsulated center flue of the gas storage water heater, and do not have standing pilots. Best applications are multifamily buildings and homes with hydronic heating that already use a boiler for space conditioning; the boiler is used to heat water in a domestic hot water storage tank either directly, or via a heat exchanger.

On the electric water heater front, little can be done to improve upon electric storage water heaters other than increasing insulation. However, since electric water heaters provide 38% of U.S. residential water heating needs (EIA 1993), this is an important market for improved efficiency. A strong exception is the heat pump water heater, which has had a surprisingly difficult time in the market, perhaps due to oversights in design that have lead to early failures. Heat pump water heaters generally have more than twice the efficiency of electric resistance units. An advanced heat pump water heater is entering the market this year that may prove to be a strong competitor (Energy Design Update, 2000). One example is called the "Hot Shot", and has been promoted by several electric utility companies in the Northeast

Distributed "point of use" instantaneous resistance water heaters may also be a cost-effective alternative to storage type heaters because they substantially reduce distribution-piping losses, and provide rapid delivery, reducing water wastage.

Rising gas and electric utility rates are making solar water heating more economically attractive. Solar Rating and Certification Commission (SRCC) ratings assure that the failures of the 70's and 80's are not repeated. The SRCC is the only independent agency now rating solar energy *systems* as well as their components, like collectors. The National Renewable Energy Laboratory is supporting the development of two integrated collector storage systems constructed mostly of polymer materials that could break the current price barriers. Of course these systems must integrate electric or gas backup heating.

Distribution Systems

Based on a small sample (less than 10) a hot water distribution system in a single-family residence may lose 10% of the heat supplied from the water heater before the water finds its way to the tap (Kempton, 1987). Multifamily systems employing recirculating hot water loops often lose more than 30%. Added to the inconvenience of having to wait, sometimes for several minutes, for water to reach the tap, there is much room for improvements to hot water distribution systems.

There are several technologies for improving efficiency and performance in single-family units and apartments with individual water heaters. By adding a recirculation loop and pump, hot water can be delivered almost instantaneously to the tap while reducing wasted water. Recirculation systems can also save energy. Of course if the circulation is not controlled, pipe heat loss will be much greater for recirculation systems. Recirculation pumps may be provided with timers to limit operation to occupied periods. A better strategy is to control the recirculation pump on demand, using either a pushbutton or a motion sensor at each primary point of hot water use. These systems can be retrofitted to existing residences by using a cold water line as the return pipe.

Insulating hot water pipes may seem to be an obvious solution to reducing loss. However, when hot water draws are widely spaced, water standing in the pipes will eventually cool whether the pipes are insulated or not. Insulation benefits therefore vary with hot water use patterns, but insulation is always worth the investment with hot water recirculation systems where pipes carry hot water over extended periods of time. Insulation should also be added to the first six- to eight feet of piping connected to a storage tank water heater, since the close-in lengths of pipe can serve as energy-losing “fins” increasing the water heater’s standby losses.

With the introduction of plastic piping such as PEX, an approach to plumbing a house has been adopted that is similar to methods used for installing wiring. Instead of extending a large diameter hot water main from the water heater with branches to fixtures, small (3/8" and 1/2") diameter pipes are run from a central manifold at the water heater to each individual fixture. Because the smaller pipes hold less water volume and run directly from the water heater to the fixture, the waiting time is reduced and less heat is lost between uses. Application of these "home run" or "parallel" piping systems are still somewhat restricted by the acceptance of PEX by local building codes. PEX has become the norm in some locations that experience problems with copper corrosion.

In multifamily buildings the diversity of tenant schedules requires that hot water be available 24 hours per day, so it must be continuously recirculated. Particularly when multiple buildings are served by a single central hot water system, piping losses can constitute more than half of the total hot water load, even with well-insulated piping. Supplying each building with one or more water heaters to reduce the length of distribution piping therefore is well advised.

Multifamily dwellings that employ gas water heating present an interesting quandary. Because standby losses are substantially smaller when buildings use central water heating instead of one storage gas water heater per unit, operating efficiencies for central systems can be much higher. However, one study (Thrasher, DeWerth & Becker 1990) has shown that tenants use much less hot water if they are individually metered. The use of Btu meters to sub-meter central hot water systems is discouraged by the cost of installing the meters, regularly billing the tenants, and in some cases by state utility regulations. More study is required to determine the best hot water system design approach for multifamily buildings from both a performance and behavioral perspective.

Heat Recovery

At least one manufacturer produces a device to recover waste heat from warm drain water, operating on the principle that water adheres to the walls of a vertical pipe (Wardell 2000). The device consists of a section of copper drainpipe that is wrapped on the outside with another coil of smaller diameter copper tube. Inlet water is circulated through the tube heat exchanger, extracting heat from the drain water that is used to preheat water entering the water heater. The best application of this technology is may be places like Laundromats, large apartment buildings or exercise centers, where large volumes of hot water are concentrated in a small number of drainpipes, and where the demand for hot water occurs at the same time the warm water is running down the drain.

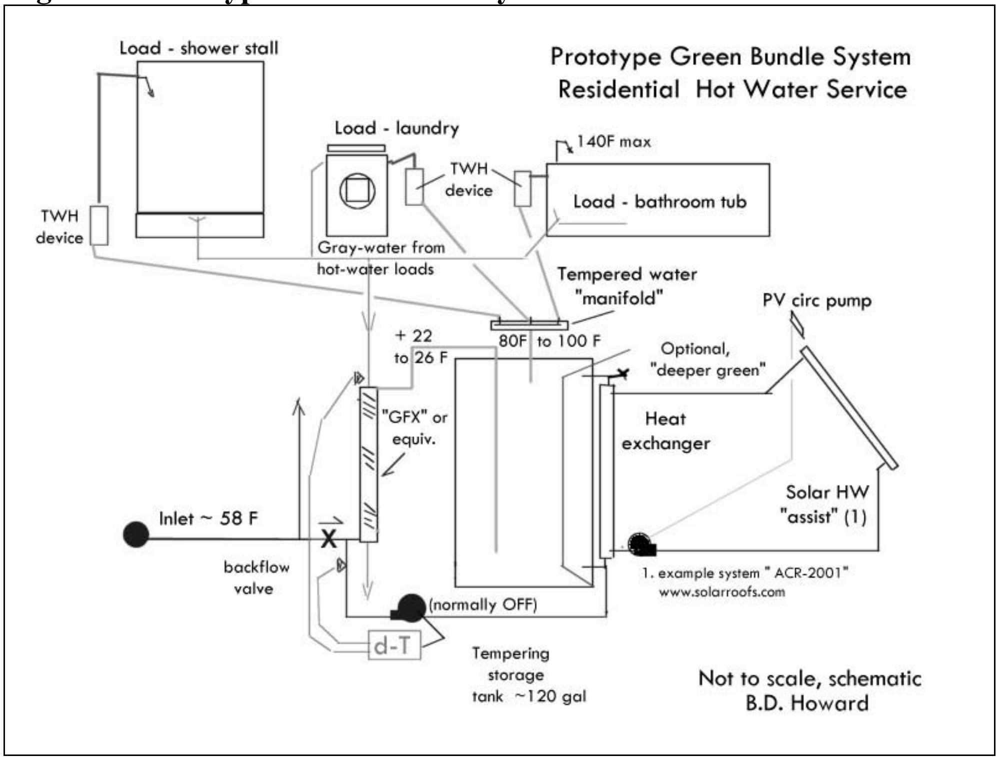
Desuperheaters, or heat exchangers that capture waste heat from air conditioner and heat pump condensers, were once available from several manufacturers but are now limited primarily to water source heat pump equipment. They can utilize electric water heaters for storage, eliminating the need for a separate storage tank. Best applications are those with high air conditioning and water heating loads, such as laundry facilities.

Researchers are also currently investigating the feasibility of recovering waste heat from refrigerator condensers for use in heating water (California Energy Commission Contract #400-00-038, in progress). Though refrigerator waste heat can be an asset in winter, in summer the heat contributes to cooling load. Applying this heat to augment domestic water heating would effectively reduce both water heating and air conditioning loads. Reducing condensing temperatures may also result in better refrigerator performance.

Green Building Applications

Another novel approach is the “bundling” of efficient water heating technologies into high performance green building applications (Figure 4). An example of such a system combines tankless water heaters at/near demand points, with waste heat recovery plumbed to a larger than normal “tempering” tank where inlet water is boosted by 20 to 30 ^{o}F (12.5 to 18.75 ^{o}C). This tempered water is fed to loads in the building via manifolds and PEX tubular piping. A low cost downsized solar collection and heat exchange system can be fitted (or) not to the tempering tank. No auxiliary energy is supplied to the tempering tank, and the tankless units are only energized to “finish” the heated water at the points of use (Howard, 2000).

Figure 4. Prototype Green Bundle System



Recommendations and Next Steps

1. Conduct a statistically valid study of residential hot water use and plumbing practice to thoroughly understand hot water systems and identify energy and water savings opportunities.
2. Engage in a *National Hot Water Service* debate or series of workshops, to target the biggest opportunities to reduce the most waste. Treat energy waste and water waste on equal footing since the two are often co-mingled in poor performing systems.
3. Develop a standardized method for evaluating residential hot water distribution systems in conjunction with DOE, ASHRAE, ASPE and AWWA and IAPMO.
4. Create a complete and effective EnergyStar™ Water Heating System program. DOE, US EPA, National Labs and manufacturers (piping, recirculation systems, heat reclamation, insulation, fixture and water heater) need to work together to do this. Note the use of the term “water heating system” since the end result should be achieving a ~ 30% improvement in the overall delivery efficiency of the service of hot water to a consumer. The 30% benchmark is in line with other EnergyStar™ programs, such as for new home design and construction. The hot water demand has been a rated portion of the overall performance levels required when meeting the EnergyStar™ Homes Memorandum of Understanding.

5. Conduct additional study of the in-situ effectiveness of drain water heat recovery strategies, since in the limited field studies of such devices results have been widely variable and the role of a building occupants and their hot water demand profiles has a profound effect on the results. Both film-heat exchange and coil-in-tank storage heat recovery device should be studied.
6. Develop some additional parameters that level the playing field for standardized testing of water heaters. There needs to be clear understanding of the performance differences between tank-type, heat pump, and tankless strategies so that their energy efficiency can be rated on a consistent basis.
7. Encourage further cost-reductions and performance testing for solar water heating technology.
8. Conduct additional studies of hot water utilization in larger multi-family buildings to better grasp potential control strategies that could reach a compromise between "instantaneous" hot water at taps, versus elevated energy costs (electric pumping, heat loss in the loop) due to recirculation systems.
9. Include hot water systems performance, reliability, cost reductions, and energy savings in more builder, architectural and engineering conference programs.

References

Acker, L. and G. Klein. 1996. *Identifying the Parameters for Understanding the Costs and Benefits of Hot Water Demand Pumping System, a Flue Gas Baffle and a Flue Damper,* ACT/ Metlund Systems and California Energy Commission.

_____. 2002. Work currently being completed under California Energy Commission Contract #400-00-038 by Davis Energy Group and Oak Ridge National Laboratory. Project status can be viewed at www.davisenergy.com (SWHDT).

_____. 2000. "*Are HPWHs Finally, Actually Going to Arrive?"* Energy Design Update, May 2000; Vol. 20, No. 5.

Henze,G., D. Tiller, M. Fischer, and M. Rieger. 2002. *Comparison of Event Inference and Flow Trace Signature Methods for Hot Water End Use Analysis*. ASHRAE Transactions, Honolulu (in print).

Hiller, C. 1998. New Hot Water Consumption Analysis and Water-Heating System Sizing Methodology. ASHRAE Transactions. V. 104. _Pt 1. Atlanta, Georgia.

Howard, B. D. 2001. *"Designing a 'Green Bundle' Water Heating System"* Energy Design Update, March 2001, Aspen Publishers, Inc.

Howard, B. D. 2001. *"Hot Water - Cool Concepts"* V. 1 N. 1 Smart Homeowner Magazine. Sept. 2001.

Kempton, W. 1987. *Residential Hot Water: A Behaviorally-Driven System*. Princeton, American Council for an Energy-Efficient Economy.

Lutz, J. and G. Klein. 1998. *A Conceptual Framwork for Understanding Residential Hot Water Systems, Poster*. ACEEE 1998 Summer Study on Energy Efficiency in Buildings, Asilomar, CA, August 23-28, American Council for an Energy-Efficient Economy.

Pacific Northwest National Laboratory. 1995. *Federal Technology Alert, Residential Heat Pump Water Heaters*. http://www.eren.doe.gov/femp/prodtech/pdfs/FTA_res_heat_pump.pdf.

Thrasher, W.H., D.W. DeWerth, and B.R. Becker. 1990 *"Residential Buildings: Single and Multi-Family."* Comparison of Collected and Complied Existing Data on Service Hot Water Use Patterns in Residential and Commercial Establishments: Phase I Final Report. Prepared for ASHRAE. Research Project No. 600. Atlanta, Georgia, August. p. 41-70.

U.S. Department of Energy - Energy Information Administration (EIA). 1993. *Household Energy Consumption and Expenditures 1990*. COE/EIA-0321(90), Washington, D.C.

U.S. Department of Energy - Energy Information Administration (EIA) 1997. *Household Energy Consumption and Expenditures 2000*. COE/EIA-0321(97), Washington, D.C. http://www.eia.doe.gov/emeu/recs/contents.html.

U.S. Department of Energy - Energy Information Administration (EIA). 1999, "*A Look at Residential Energy Consumption in 1997*." Washington, D.C. ftp://ftp.eia.doe.gov/pub/consumption/residential/ce_tables/waterheat_consump.pdf.

U.S. Department of Energy - Energy Information Administration (EIA) 2000. *Residential Energy Consumption Survey, Trends from 1978 to 1997*, Percent of Total U.S. Residential Site Energy Consumption by End Use, Washington, D.C. http://www.eia.doe.gov/emeu/recs/recs97/decade.html.

Wardell, Charles (ed.). 2000. *GFX Shines in Measured Triplex Application*. Energy Design Update 20 (10) pg. 10-11.