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Abstract

Residential single family 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 needed to reheat water that was already heated once before. Average losses of water are estimated to be 6.35 gallons (24.0 L) per day. (This is water that is run down the drain without being used while waiting for hot water.) The amount of wasted hot water has been calculated to be 10.9 gallons (41.3 L) per day. (This is water that was heated, but either is not used or is used after it has cooled off.) A check on the reasonableness of this estimate is made by showing that total residential hot water use averages about 52.6 gallons (199 L) per day. This indicates about 20 percent of average daily hot water is wasted.

Estimating Energy and Water Losses in Residential Hot Water Distribution Systems

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ABSTRACT

Residential single family 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 needed to reheat water that was already heated once before.

Average losses of water are estimated to be 6.35 gallons (24.0 L) per day. (This is water that is run down the drain without being used while waiting for hot water.) The amount of wasted hot water has been calculated to be 10.9 gallons (41.3 L) per day. (This is water that was heated, but either is not used or is used after it has cooled off.) A check on the reasonableness of this estimate is made by showing that total residential hot water use averages about 52.6 gallons (199 L) per day. This indicates about 20% of average daily hot water is wasted.

EXISTING STUDIES

Several studies have identified end uses of hot water draws in single family residences (Weihl and Kempton 1985; Kempton 1986; DeOreo et al. 1996; Lowenstein and Hiller 1996; Lowenstein and Hiller 1998; Mayer et al. 1999; Henze et al. 2002). Two different techniques have been used, flow trace analysis and temperature-based event inference analysis. The flow trace analysis method analyzes the flow patterns of water into the water heater to identify individual draws based on the amount and patterns of flow. The other method identifies the end-use by tracking the temperature rise of hot water at each fixture or appliance. The second method is more accurate at identifying end-uses, but requires a more intensive monitoring process.

There are several shortcomings with this research. This type of study has been done for only a small number of houses, less than 50 in total. There has been no attempt to take a statistically representative sample of houses in any of these studies. Furthermore, these studies have not identified how much of the hot water has been wasted. Only one study has attempted to characterize the efficiency of the delivery of hot water to uses, and that study was of only 7 houses and is 2 decades old (Kempton 1986; Kempton 1987).

To get an estimate of the amount of hot water that is wasted, an independent method was developed to calculate lost hot water from information about total water draws for residential end uses.

The best description of residential end uses of water in North America at this time is the Residential End Uses of Water Study (REUWS) report (Mayer et al. 1999). This study represents a time-and-place snapshot of water use in 1200 single-family homes in 12 North American locations in 1996 to 1998. Water consumption was measured using compact data loggers on the main water meter to each house. Flow trace analysis software was used to allocate individual draws to end uses. The flow was through a residential water meter recorded in 10 second intervals, which provided sufficient resolution of the flow to identify the patterns of specific fixtures within the household. The draws were entered in a database, and were analyzed and summarized for the entire group. 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 mode (most commonly recorded) flow rates during the draw.

Several other studies have examined hot water distribution system losses (Schultz and Goldschmidt 1978; Schultz and Goldschmidt. 1983; Stewart Jr. et al. 1999a; Stewart Jr. et al. 1999b). These studies are important but did not characterize losses in actual residential buildings.

Losses

There are three types of loss in hot water distribution systems; 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 used to reheat water that was already heated once before. These three types of losses can be exemplified by showers, faucets, and dishwashers. (Actual leaks of hot water from pipes and fittings are not considered here.)

The first type may be the easiest to identify. After a shower the hot water left in the pipes cools off. To get hot water for the next shower, this cooled off water must be discarded, before hot water gets to the shower. Not only has the energy used to heat this water been wasted, but the water itself is thrown away. This is water that must be treated twice, once at the water treatment plant and again as wastewater, but it does not provide the consumer with any useful service.

Although draws for sinks and dishwashers may not waste water, from an energy perspective, these uses must be considered in addition to the shower losses.

The sink loss is from uses at a single lever sink, where the consumer 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 cooled off hot water in the piping system to be replenished with hot, so that it can cool off once again. This wastes the energy that was used to heat the water.

For dishwashers, not only is energy wasted as the hot water remaining in the pipes cools off before the next use, but this energy must be replenished by the dishwasher heating the cooled off water it receives from the hot water pipe to a hot enough temperature for safe and sanitary dish washing.

Estimates of Shower Losses

A method was developed to estimate shower losses using the REUWS event database (Mayer et.al. 1999). The REUWS database contains records of 1.96 million events, which are all classified by type. Nearly 49,000 events were classified as showers.

Conceptually, the total water used by a shower event can be split into two distinct 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 event. When both the person and the flowing water are ready, the hot water flow is reduced and some cold water is mixed in to achieve the desired showering temperature. 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 1, which shows a sample of the flow trace data from the REUWS report. In the figure, the shower draw is shown as overlapping with the rinse cycle of the clothes washer.

From these assumptions, an ideal simplified model can be created. 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 at one time. 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 part of the draw may consist of hot water that the consumer inadvertently is wasting after the cooled off water has already been discarded.

Figure 2 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. 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 after the user adjusted flows to get the desired shower water temperature.

From these parameters, the volume of part A, the wasted hot water, can be calculated from the total water flow parameters of the draw using Equation 1.

$$A = PEAK \times \frac{(VOLUME - MODE \times DURATION)}{PEAK - MODE} \tag{1}$$

where

PEAK is the maximum flow rate recorded during the event,
VOLUME is the total amount of water used by the event,
MODE is the most commonly recorded flow rate during the event, and
DURATION is the time duration of the event.

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 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 (13.2 L).

A histogram of the distribution of shower waste is shown in Figure 3. There is a very long tail on this distribution, indicating that for some showers, the loss can be a very significant amount of water.

According to the REUWS report, the average shower uses 17.2 gallons (65.1 L). 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 (3.48 gallons (13.2 L)), 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 (14.6 L).

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 (6.55 L) per house per day. The total amount of shower waste is thus estimated at 5.21 gallons (19.7 L) per day

Estimates of Sink Losses

An estimate of losses for faucet end use events can be made with some reasonable assumptions. Theoretically there are two different types of losses. There are those draws where the consumer discards cooled off heated water until the arriving water is sufficiently hot. This is similar to the waste for showers 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. This is an energy loss, but not a water loss.

An estimate of the water losses when consumers waited for hot water was done by applying the same algorithm to faucet draws that lasted at least one minute. The same criteria of 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 (2.91 L). 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 (4.31 L).

The other type of faucet waste is the case of short draws that never have a chance to provide hot water to the user. The simplifying assumption here is 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. Applying these assumptions, that works out to 4.0 gallons (15.1 L) of water per day 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 electric resistance heating elements in the dishwasher. If the water heater is gas fired, the lost heat is made up for by electricity, which has much higher source-to-site losses than gas.

Dishwashers have three to eight hot water draws per load. The typical flow rate during each draw is 1.5 gallons per minute (0.09 L/s). If the same assumption that was made for short faucet draws holds, the first 20 seconds of each draw would have cooled down to room temperature and does not provide hot enough water. This means about 2 gallons (8 L) of water per load that was heated by the water heater does not arrive at the dishwasher hot enough to provide a useful service. From the REUWS report, there are 0.10 loads per capita per day and the average household was 2.8 people. The average daily wasted hot water for dishwashers is about 0.56 gallons (2.1 L).

Total estimates of lost hot water

The average daily water loss from showers and long draws at faucets totals to 6.35 gallons (24.0 L) per day per house. This is 3.7% of the average household's indoor daily water use of 173 gallons (655 L) and 12.1% of the daily hot water use.

The average amount of wasted hot water is 10.9 gallons (41.3 L) per day. This happens when the heat in the water is not used, either because the cooled off hot water is discarded or the cooled off hot water is used as is, even though it's no longer hot. This means 20% of the daily hot water use is wasted.

PLAUSIBILITY

Because there as so many estimates and assumptions in these calculations it is prudent to confirm this value by independent methods. Unfortunately, the author is not aware of any other studies that would allow this. However, as a check on the plausibility of this value, it is possible to compare the volume of wasted hot water to an independent estimate of total hot water use. A recent residential appliance saturation survey done by investor owned utilities in California provides a value of the total gas use by water heaters in average single family homes.(KEMA-XENERGY et al. 2004) In California nearly 90% of single-family homes have gas water heaters. This study surveyed nearly 22,000 residential houses and did a conditional demand analysis on their energy bills. The average annual energy consumption for gas water heaters in single-family homes in California is 206 therms (21.7 GJ).

A simplified energy consumption algorithm has been developed which allows calculation of average daily energy use for water heaters.(Lutz et al. 1999) Reasonable assumptions about typical California water heaters and the conditions under which they operate are shown in Table 1.

Table 1 – Assumed Parameters for Average Gas Water Heater

Parameter	Value
Energy Factor	0.58
Recovery Efficiency	0.78
rated input power	40,000 Btu/h (11.7 kW)
Tank temperature	130ºF (54.4ºC)
Inlet water temperature	58ºF (14.4ºC)
Ambient temperature	67.5ºF (19.7ºC)

Applying these parameters to the simplified energy consumption algorithm gives an estimate of water heater energy consumption. Adjusting the average daily hot water consumption to 52.6 gallons (199 L), causes the annual energy consumption to match the 206 therms (21.7 GJ) per year from the conditional demand analysis reported in the residential appliance saturation survey study discussed above. 52.6 gallons (199 L) per day is comfortably larger than the 10.9 gallons (41.3 L) per day of wasted hot water estimated earlier.

CONCLUSIONS

From these calculations, about 20% of total hot water use in single-family residences seems to be wasted. Although these calculations are based on many assumptions and simplifications the results do seem reasonable to this author and point to a significant opportunity for increasing residential energy efficiency. Further studies should be done to improve the reliability of these results.

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FIGURE CAPTION SHEET

Figure 1 Sample Flow Trace of Shower and Other Draws source: (Mayer et al. 1999)

Figure 2 Idealized Flow to a Combination Shower/Tub

Figure 3 Distribution of Waste Hot Water per Shower (from analysis of REUWS data)