Evaluation of Residential Hot Water Distribution Systems by Numeric Simulation

Final Report – March 2004

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Synergistic Water Heating Technologies Program
Element 3 - Efficient Hot Water Distribution

Final Deliverable for:
Project 3.1 - Evaluation of Alternative Hot Water Distribution Systems
Task 3.1.2 "Simulate Potential Energy Savings, Perform Cost-Benefit Analyses, and Identify Market Barriers of Alternative New Systems",
Task 3.1.3 "Conduct Analysis of Existing Domestic Hot Water Distribution Systems", and
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1. Executive Summary

The goal of this project was to simulate and compare the energy and water performance, economics, and barriers to use of various domestic hot water distribution systems in new and existing California residences, and to evaluate the potential statewide impact of the use of more efficient hot water distribution systems.

Methodology

A new numerical model, developed using LabVIEW, was used to estimate the heat loss or gain from insulated and non-insulated hot water pipes. Heat loss from distribution piping affects overall energy use, water consumption, and homeowner waiting time at the end use points. This model permitted the evaluation of a wide range of options and alternatives (>250 scenarios were studied).

Two draw cycles (use patterns) were investigated. The first assumed that each individual draw was a "cold start", i.e. the water had reached the ambient temperature surrounding the pipe before each use. This pattern represents a "worst case" for potential water and energy waste. The second was a "clustered use" which had individual draws clustered in the early morning and late afternoon/evening, thereby retaining some hot water between draws. This pattern represents the likely "best case" regarding water and energy waste. Actual residential water use patterns vary between these extremes.

The economic implications of the various distribution systems and options were based on an analysis of expected utility cost savings. The average utility cost of ten California cities was used in the analysis (Gas: $.638/therm, Electric: $.116/kWh, and Water: $.85/HCF or 100 cu ft). The construction costs of the various distribution systems and options were developed from cost data provided by a major plumbing contractor based in southern California. The results shown in all tables in this report that reflect costs are based on the utility costs shown above. While these costs change over time, the relative ranking of the distribution system options to each other will not change unless the rate of escalation for utilities varies significantly from the rate of construction cost escalation.

New construction and existing housing were studied. The housing characteristics used for new construction included five examples that ranged from a four bedroom, 2½ bath, 3080 ft^2 single family detached home down to a one bedroom, one bath, 580 ft^2 apartment. The existing residences evaluated included a three bedroom, two bath, 1100 ft^2 single family home and a four bedroom, 2½ bath, 1960 ft^2 single family home. The characteristics used for new and existing hot water systems were typical of standard California practice

The following changes to conventional trunk and branch distribution systems were evaluated:

- Compare alternative piping materials used in conventional trunk and branch systems.
- Relocate water heater to a more central location.
- Add insulation to the various piping materials in standard system configurations.

The following alternative new home distribution systems were evaluated:

- Demand-actuated recirculating pump and controls in a conventional trunk and branch

system using the cold-water line for the return.
- Continuous recirculating system with a dedicated return line for larger residences.
- A parallel-pipe system with a manifold located near the water heater and ½" piping from the manifold to each individual fixture.

The following scenarios were evaluated for existing housing:
- Retrofit existing conventional system with a demand recirculation system and controls, using the cold water line for the return.
- Replace existing conventional system in kind and evaluate the impact of pipe materials and insulation.
- Replace existing conventional system with a parallel-pipe system with a manifold located near the water heater and ½" piping from the manifold to the individual fixtures.

Results

According to the model results, the pattern of energy and water waste performance among the scenarios for new construction was fairly consistent for all the single family detached houses studied. However, the results varied significantly with the water use pattern (cold start or clustered) that was assumed.

Table 1.1 shows the simulated results for the hot water distribution systems and parameters evaluated for a three-bedroom, two bath home, using a clustered (least wasteful) hot water use pattern. Demand and continuous recirculation systems waste the least water, while demand recirculation and a central water heater location waste the least energy for this set of assumptions. Changing the use pattern to cold start (most wasteful) significantly improved the performance of the parallel pipe/manifold system relative to the other systems, placing it just behind the demand recirculation systems. Continuous recirculation systems waste the most energy of all the systems. This consistently occurred among all houses and use patterns studied. Results for existing housing also showed the benefit of the demand recirculation system as a retrofit option.

The waiting time for hot water (105^{o}F) to arrive at the faucet or shower is a primary factor in the evaluation of system performance by homeowners. The waiting times associated with the various scenarios studied for one of the houses are reflected in Table 1.1. All systems had "reasonable" typical waits (<30 seconds), but demand and continuous recirculation systems and the parallel pipe systems had shorter maximum waiting times. If a cold start use pattern is assumed, the typical waiting time for the various conventional systems increase significantly while the other systems remain about the same.

The construction costs of the various distribution systems for one of the houses studied are also reflected in Table 1.1. The use of CPVC piping, parallel pipe systems (PEX), and a centrally-located water heater all resulted in lower construction costs than the typical copper trunk and branch system. The continuous recirculation systems had the highest construction cost.

Table 1.1 Hot Water Distribution Systems and Parameters Evaluated for New Construction Home, Three Bedrooms, Two Baths, 2010 ft^2, Using a Clustered (*Least Wasteful*) Hot Water Use Pattern. Note: Using a cold start (*Most Wasteful*) use pattern increases (depending on the system/option evaluated) water waste by 25% to >600% and energy consumption by 60% to >600% above that shown in the table. The "better" options in each category are highlighted in **red** below. Results for the other houses studied are in Appendix A.

System/Option Evaluated	Construction Cost[a]	Wait Time for HW (Sec.)		Annual Water Waste (Gallons)	Annual Energy Waste ($)	
		Typical	Maximum		Electric @$0.116/kWh	Gas @$0.683/therm
Conventional, Attic, Copper - Central Water Heater	$1,450	5	40	1404	35.16	11.04
Conventional, Attic, CPVC - Central Water Heater	**$1,087**	5	39	1428	**34.08**	**10.68**
Conventional, Attic, Copper	$1,271	5	99	2352	58.80	18.36
Conventional, Attic, Copper – Insulated	$1,552	5	99	2340	58.32	18.24
Conventional, Attic, CPVC	**$866**	5	95	2292	55.08	17.16
Conventional, Attic, CPVC – Insulated	**$1,147**	5	95	2292	55.08	17.16
Conventional, Slab, Copper	$1,556	54	109	10140	273.00	85.20
Conventional, Slab, Copper – Insulated	$1,838	4	102	2304	60.12	18.72
Conventional, Slab, CPVC	**$1,086**	50	98	9204	224.04	69.96
Conventional, Slab, CPVC - Insulated	$1,368	5	98	2304	55.80	17.40
Demand Recirculation, Attic, Copper	$1,880	5	**9**	**924**	**26.52**	**8.28**
Demand Recirculation, Slab, Copper	$2,447	4	**8**	**792**	**26.40**	**8.28**
Demand Recirculation, Attic, CPVC	$1,475	5	**9**	**936**	**24.36**	**7.68**
Demand Recirculation, Slab, CPVC	$1,978	4	**8**	**840**	**22.80**	**7.08**
Parallel Pipe, Attic, PEX	**$1,226**	11	36	2352	60.48	18.84
Parallel Pipe, Slab, PEX	$1,443	19	38	3432	89.16	27.84
Continuous Recirculation, Attic, Copper – Insulated [b]	$2,559	5	**9**	**924**	146.16	45.60
Continuous Recirculation, Slab, Copper – Insulated [b]	$2,861	4	**8**	**792**	426.60	133.20
Continuous Recirculation, Attic, CPVC – Insulated [b]	$1,965	5	**9**	**936**	157.80	49.32
Continuous Recirculation, Slab, CPVC – Insulated [b]	$2,185	4	**8**	**840**	389.40	121.56

a. Construction Costs are for the distribution system only as paid by the homeowner (see Section 4.2)
b. The total annual pumping power cost for these systems will add $87.60/yr. to both gas and electric totals shown above.

Projected Impact on California

The impact of applying more efficient alternative hot water distribution systems on California's overall residential energy and water consumption was estimated for the period beginning 3 to 5 years after initiation of the recommended Implementation Plan, (see Section 6.2). The more efficient systems selected for the new construction projection had both lower or equal initial cost and superior water and energy performance than the conventional systems as currently installed. For this reason a penetration rate of 100% was assumed for new construction in the state (150,000 units/year). For systems in existing California housing with excessive waiting periods (3 million units), a 10% per year penetration rate for retrofit demand recirculation systems was assumed until the market was saturated. The penetration rate for all replacement systems in existing housing (11 million units) was assumed to be an on-going 0.1% per year.

The projected annual savings in water and energy for both new and existing California homes are shown below. Projected savings in each case are given as a range reflecting the difference between the cold start and clustered water use assumptions, but actual savings are likely to be between these extremes. The projected annual savings assumes that the program to facilitate and encourage the use of more efficient systems outlined in Section 6.2 has been underway for 3 to 5 years and has reached its maximum impact level.

Projected Annual Savings	Water, 10^6 gallons	Natural Gas, 10^9 Btu	Electric, MWh
Each year	850 to 2,670	470 to 1,450	24,200 to 74,800
Total after 10 yrs	8,500 to 26,700	4,700 to 14,500	242,000 to 748,000

Using data from the California Urban Water Conservation Council on per person water consumption in the San Francisco Bay Area (www.nrdc.org/greengate/water/residentialf.asp), the potential annual savings from using alternative hot water distribution systems would equal the total annual water consumption of between 8,000 and 27,000 California homes. Using water consumption rates from areas with significant irrigation demands could lower the impact measured in homes by 50%. DOE's Energy Information Agency, Residential Energy Consumption Survey [DOE/EIA-0314(90)] data for typical household energy consumption shows a potential annual saving due to use of improved distribution systems comparable to the total annual energy consumption of between 7,000 and 22,000 California homes.

Conclusions

The simulation results from this study provided the following conclusions:

Continuous recirculation systems add substantial construction cost as well as operating cost and energy waste when compared to any other system. Although they minimize wait times for hot water and water waste, continuous recirculation systems should not be installed due to their high cost and energy waste.

Adding a demand recirculation pump and controls increases conventional system costs by about $600 but reduces operating cost, waste and wait times. Wait times can be similar to continuous recirculation systems, with the added benefit that water and energy wastes are significantly reduced compared to conventional systems. Demand recirculation systems can be installed in both new construction and retrofit housing.

For the segment of the new construction market that is sensitive to first cost (i.e. most production homes), centrally locating the hot water heater cuts wait times and waste for a modest cost increment.

Parallel pipe distribution systems may also offer an attractive alternative for some house designs and distribution system layouts. These systems are less costly to install than conventional systems and can reduce wait times to acceptable levels, however, the energy and water savings of parallel pipe systems are sensitive to hot water use patterns. When modeled assuming clustered hot water draws, parallel pipe systems use similar amounts of water and energy as conventional systems and offer no advantage with regard to waste. When the cold start use pattern is modeled, parallel pipe systems perform better than conventional systems.

Recommendations

While detailed recommendations will vary with the specific house some general recommendations can be made.

For Policymakers:

- Gather field data to better understand what hot water distribution systems have been and are being installed in the state and how these systems perform. Specific issues of interest include: actual system performance, impact of insulation on under-slab systems, and hot water use patterns of a broad sample of homeowners.
- Remove barriers to the use of CPVC and PEX piping when appropriate quality and durability can be demonstrated.
- Utilize field data to validate the results of the model used in this report and other hot water distributions system simulation models.
- Incorporate the validated results into the next round of Title 24 building standards revisions (2008); publish best practices recommendations to builders and plumbers in the interim.
- Consider ways to encourage the use of centrally located hot water heaters.
- Consider ways to encourage installation of demand recirculation and parallel pipe systems, when warranted.
- Educate builders and the public about the consequences of locating distribution systems below floor slabs and the benefits of alternative locations.
- Consider banning continuous (uncontrolled) recirculation systems.

For Residential Designers, Builders, and Plumbers:

- Consolidate bathrooms and other hot water consuming activities in the same areas to take advantage of clustered uses of hot water.
- Consider centralizing the location of water heaters to minimize the length of piping between the fixtures and the water heater(s).
- Consider locating hot water distribution piping in the attic for single story homes without basements and interstitial space between floors for multistory homes.
- Do not oversize hot water piping. Use code permitted minimums. Bigger isn't better.
- Layout systems with all hot water pipe runs as short as possible to reduce energy and water waste, and the wait for hot water.
- Consider installing a demand recirculation system in lieu of a continuous recirculation system if waiting time and water waste are an issue.
- Consider installing CPVC or PEX plastic piping in lieu of copper when appropriate quality and durability can be demonstrated.

For New and Existing Homebuyers:

- Time how long it takes for hot water to arrive at the "most important" fixtures, such as the master bath's shower. This should be done several hours after any previous uses. Is this waiting time acceptable?
- Note the distance between the water heater and the furthest hot water consuming fixture. Note or ask about the pipe material used, pipe insulation provided, and where the system is located.

2. Project Purpose

This project was an element of the Synergistic Water Heating Technologies Program of the California Energy Commission's (Energy Commission's) Public Interest Energy Research (PIER) Program. The Oak Ridge National Laboratory (ORNL), under a contract with Davis Energy Group, accomplished the work.

Objective

The objective of this project was to evaluate the performance and economics of various domestic hot water distribution systems in representative California residences. While the greatest opportunities for improved efficiency occur in new construction, significant improvements can also be made in some existing distribution systems.

Specific objectives of the project tasks were:

- Simulate potential energy savings of, perform cost-benefit analyses of, and identify market barriers to alternative new systems.
- Simulate potential energy savings of, perform cost-benefit analyses of, and identify market barriers to maintenance, repair, and retrofit modifications of existing systems.
- Evaluate potential impact of adopting alternative hot water distribution systems and report project findings.

Project Outcome

The outcome of this project is to provide homeowners, homebuilders, systems suppliers, municipal code officials and utility providers (both electric and water/sewer) with a neutral, independent, third party, cost-benefit analysis of alternative hot water distribution systems for use in California. The results will enable these stakeholders to make informed decisions regarding which system is most appropriate for use.

Performance Metrics

The information from this project is intended to be used by the target audience to increase the utilization of technologies that have significant energy reduction, cost or other benefits. The performance metric used in evaluating the project's ability to meet its impact goals will ultimately be the number of alternative systems installed in new and/or existing housing in California. This metric can be measured by surveying residential plumbers to assess how their hot water distribution system practices have changed over time as a result of this information. Impact on existing homes can also be determined by surveying both plumbers and homeowners. The impact of improved hot water distribution systems can also be measured through "before and after" monitoring of existing residences, and by "side-by-side" monitoring of similar new residences with and without distribution system improvements. These follow-on performance evaluations are not within the scope of this project.

3. Methodology

3.1 Simulation Model for Hot Water Distribution Systems

A numerical model for residential hot water distribution systems was developed that allows analysis of various types of pipe, with and without insulation. The pipe segments may be exposed to a convective environment with known conditions (either forced or natural convection), buried in attic insulation, or buried beneath a floor slab in the soil. The distribution system model is Windows-based and versatile. The model used in this project was developed by Keith A. Woodbury, PhD., University of Alabama, and Evelyn Baskin, PhD., ORNL in conjunction with other related hot water distribution systems studies sponsored by the U.S. Department of Energy at ORNL.

The model simulates one-dimensional energy transport in the axial direction of the piping system with lateral heat losses to the pipe wall. The temperature distribution in the pipe wall and insulation is computed using two-dimensional calculations, coupled to the one-dimensional pipe solution through a heat transfer coefficient. Mathematically the problem can be described as follows (see Table 3.1 for definition of symbols). In the pipe, the (axial) temperature distribution of the fluid will be governed by

$$\dot{m}c_p \frac{\partial T}{\partial x} + \rho c_p A_{cs} \frac{\partial T}{\partial t} + p q''_{loss} = k A_{cs} \frac{\partial^2 T}{\partial x^2} \qquad (1)$$

Here p is the perimeter and A_{cs} is the cross sectional area of the inner surface of the pipe, and k, c_p, and ρ are properties of the fluid. The heat loss from the fluid to the pipe wall will be modeled via a heat transfer coefficient as

$$q''_{loss} = h(x,t)\big(T(x,t) - T_s(x,t)\big) \qquad (2)$$

where $T_s(x,t)$ is the temperature of the inner surface of the pipe. The temperature distribution in the pipe and insulation can be computed from the solution of the two-dimensional heat conduction equation in radial coordinates:

$$\rho c_p \frac{\partial T_p}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T_p}{\partial r}\right) + k\frac{\partial^2 T_p}{\partial x^2} \qquad (3)$$

where the radial variation in k must be retained (to allow for insulation over the pipe) but the axial variation in k is being ignored. $T_p(r,x,t)$ is the solution for the temperature in the pipe and/or insulation, and the temperature $T_s(x,t)$ in equation 2 is simply the value of T_p at the pipe inner radius:

$$T_s(x,t) = T_p(r_0, x, t) \qquad (4)$$

The boundary condition on equation 3 is convection to a known reference temperature, where r_2 is at the outside boundary of the pipe:

$$-k\frac{\partial T}{\partial r}\bigg|_{r_2} = h(T_p(r_2,x,t)-T_\infty) \qquad (5)$$

Equation 2 is used to couple the solution for $T_p(r,x,t)$ to that for $T(x,t)$.

Table 3.1 Symbol Definitions for Equations in Section 3.1 (listed in order of use)

$\dot{m}$	Mass flow rate
C_p	Heat capacity at constant pressure
T	Temperature of fluid
x	Linear distance in axial direction of pipe
ρ	Density
A_{cs}	Cross sectional area of pipe
t	Time
p	Perimeter of pipe
q''_{loss}	Heat flux (energy per unit time per unit area)
k	Thermal conductivity
h	Convective heat transfer coefficient (heat flux per unit temperature)
r	Radial dimension normal to pipe's axial dimension

Piping systems surrounded by a large layer of attic insulation, or soil, are treated in the model as a finite radial thickness of the external material. This is basically the same as if the pipe (with or without pipe insulation) is further insulated with a thickness of attic insulation (piping buried beneath attic insulation), or soil (piping buried in soil underneath the slab).

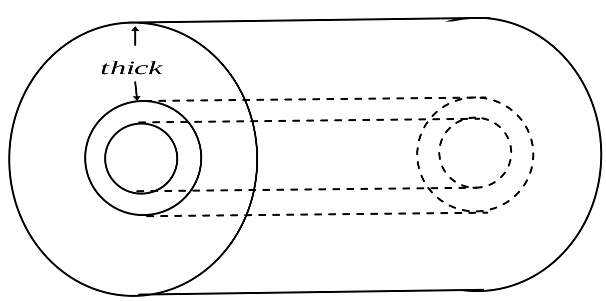

Figure 3.1 Soil or attic insulation material of thickness *thick* surrounding pipe/insulation

In Figure 3.1, the layer of surrounding material is characterized by a thickness parameter, *thick*, and this thickness of material is assumed to surround the pipe. The outer surface of the composite cylinder is assumed to be subjected to a convective/radiative boundary condition. It is assumed that the simulation time is much shorter than the time it would take the temperature on the outside of this large cylinder of added material to be change substantially during the simulation. Therefore, the solution will not be affected if one surface of the large cylinder is modeled by convective heat transfer and the others are semi-infinite (as in the case of a buried pipe) or if one surface has convection/radiation to a lower temperature than the other (as for attic insulation). The outer radius boundary of the composite cylinder is assumed to be at a constant temperature during the operation of the hot water system. Both the constant temperature that is assumed and the radius of the material are user inputs. There are two options used to determine when no water is flowing in the piping. The value input for the flow rate determines which of the following options is selected:

- If the flow rate is specified as zero, then a simulation of the system will be performed with pure conduction. The initial fluid temperature is taken as that of the environment. This approach treats the pipe as a fin on the water heater and heat from the water heater flows down the pipe to determine the total heat loss by the water heater through the pipe system when it is not in use.
- If the flow rate is specified as any value less than zero, this signals the program to perform a special computation in which the initial fluid temperature is set equal to the supply temperature and the heat loss during the cool-down is computed also as pure conduction simulation.

When there is no flow in the pipe, a new heat transfer coefficient accounting for the heat conduction from the fluid to the pipe was developed by using a correlation based on an analytical solution for heat conduction in a solid cylinder that is subjected to a step increase in temperature at its surface. This heat transfer coefficient is applied to all piping configurations and heat loss is computed using the conduction equation (#3) above plus the new heat transfer coefficient.

During flow conditions all of the above equations are used. For time periods between clustered draws (hot water uses), calculations are performed as a no flow cool down of water in the piping. The no flow cool down temperature is used as the pipe and/or insulation temperature in the subsequent draw in the cluster. During hot water use, the soil surrounding the pipe or the attic insulation surrounding the pipe is penetrated by heat to a small depth and this same depth is affected during cool down. Since the depth is not large, it is not used when the cool down piping temperature is calculated for the subsequent cluster draw.

The model solves for the temperature distribution in the water, pipe, and insulation along the length of the pipe as a function of time using a finite element technique capable of modeling various piping configurations, the entire piping layout, and hot water use events. Flow conditions can be specified for comparatively short time periods; therefore many draw patterns can be modeled. The simulation can be used to do comparative studies, such as establishing the heat loss differences between insulated and non-insulated piping and calculating the effect of various pipe diameters on the outlet water temperature.

The simulation requires the following data to compute the heat loss and outlet water temperature: the pipe parameters (length, inside diameter, and wall thickness); the pipe and insulation properties (thermal conductivity, specific heat, and density); the water flow rate; the insulation thickness; and the distribution system location (soil & attic—indicate "thick" cylinder condition and crawl space—still air). The program accepts input as Excel files.

Table 3.2 is an example of an input file showing several events of two pipe sections each, in no particular order of event. Actual files have events for a complete day of water usage. Pipe and insulation property data are automatically selected based on pipe and insulation type as specified in Table 3.2. For each additional section, five additional columns on the right of the Table are required. If the pipe section is not insulated, the insulation thickness ($S1_{ins-th}$, $S2_{ins-th}$) is set to zero. There is a limit of 50 sections per event - the evaluated houses varied between 2 and 3 sections. There is no limit on the number of events. It is assumed that all the sections in one event have the same pipe material and/or piping insulation type (this is independent of surrounding insulation.).

The computer time needed for the calculation for each event depends on the number of sections, the diameter and length of the pipe section and the specified time step (~1 second) and maximum simulation time (specified by the user, usually less than 3 minutes--time taken for the water to reach 105^{o}F). At the end of the simulation, the results are tabulated in a tab-delimited ASCII file. Figures 3.2 through 3.4 show a series of screens from input through the completion of a computational run. Note that the piping diagram shown for each type of system is just a sample representing a particular type of system (e.g., trunk and branch). The program does not draw a diagram whose dimensions match those of the particular system that is being modeled. Table 3.3 shows an example of an output file.

Table 3.2 Sample input File (S1 = pipe section 1, d = diameter, L = length, T amb = Ambient temperature, Ins-th = insulation thickness, Sur-th = surface thickness)

Event	Flowrate (gpm)	Sections	$Pipe_{material}$	$Pipe_{Type}$	$Material_{sur}$	$Location_{sur}$	$Pipe_{Insulation}$	$S1_d$	$S1_L$	$S1_{Tamb}$	$S1_{Ins-th}$	$S1_{Sur-th}$	$S2_d$	$S2_L$	$S2_{Tamb}$	$S2_{ins-th}$	$S2_{Sur-th}$
MBR shower	2.25	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	64.5	76	0	6	1/2	14	70	0	0
MBR sink-1	1.25	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	64.5	76	0	6	1/2	8	70	0	0
MBR sink-2	1.25	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	64.5	76	0	6	1/2	10	70	0	0
BR2 shower	2.25	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	37	76	0	6	1/2	13	70	0	0
BR2 shower	2.25	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	37	76	0	6	1/2	13	70	0	0
BR2 sink	1.25	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	37	76	0	6	1/2	6	70	0	0
BR2 sink	1.25	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	37	76	0	6	1/2	6	70	0	0
K sink	2.5	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	45.5	76	0	6	1/2	9	70	0	0
K sink	2.5	2	Copper	M	Mineral Fiber (loose fill)	Attic	Cellular Polyethylene	3/4	45.5	76	0	6	1/2	9	70	0	0

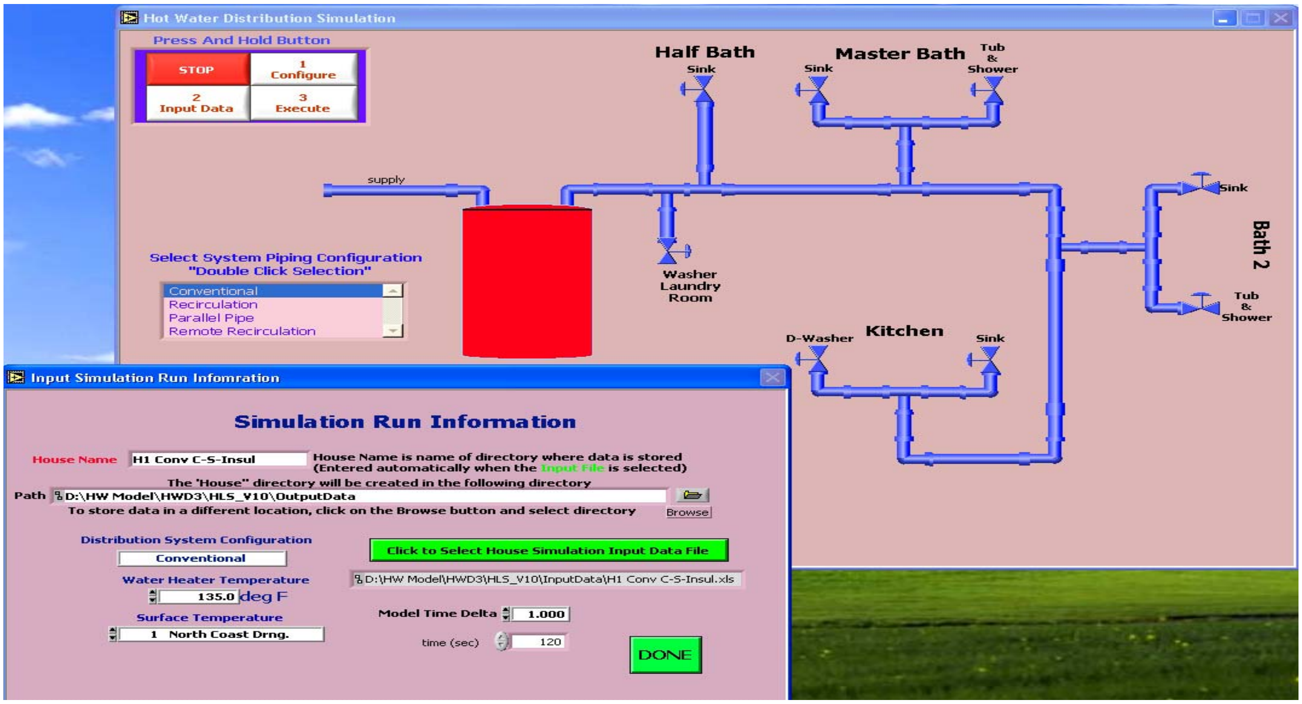

Figure 3.2 Main menu screen, popup menu one—configuration selection, popup menu two—data input/file selection

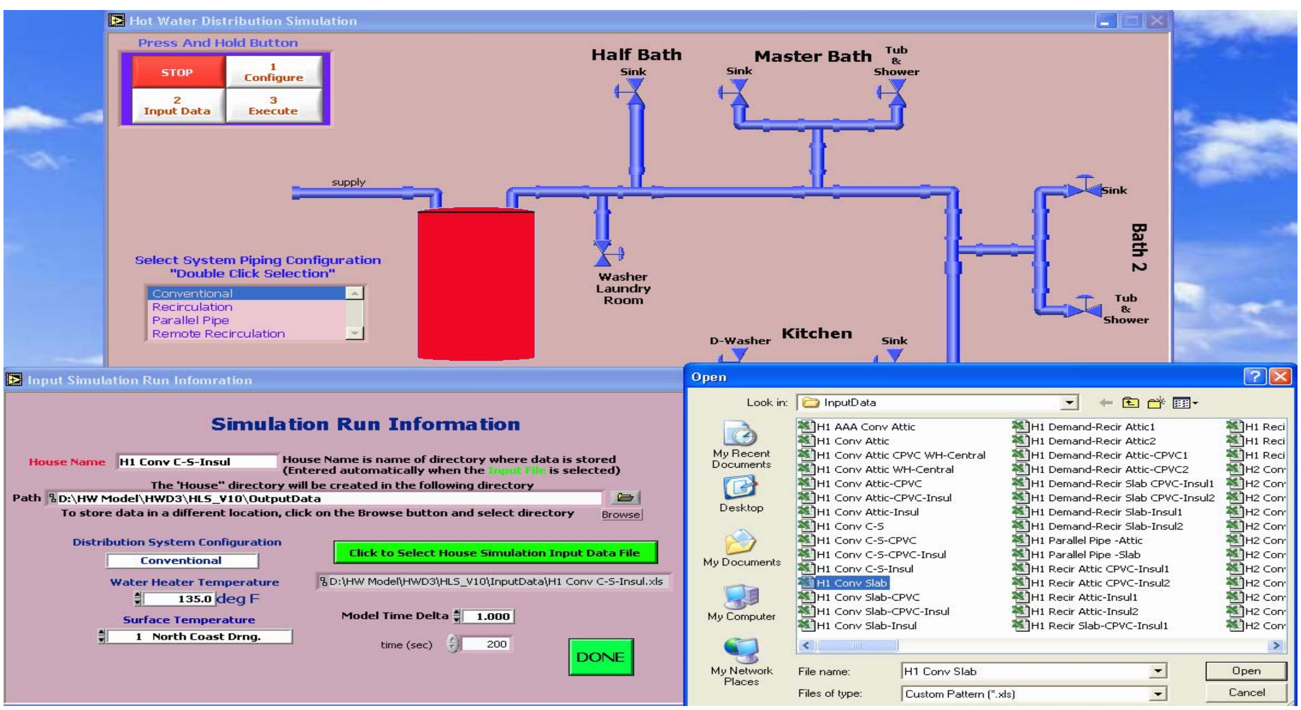

Figure 3.3 Popup open/select data file initiated by clicking green bar on simulation run information menu

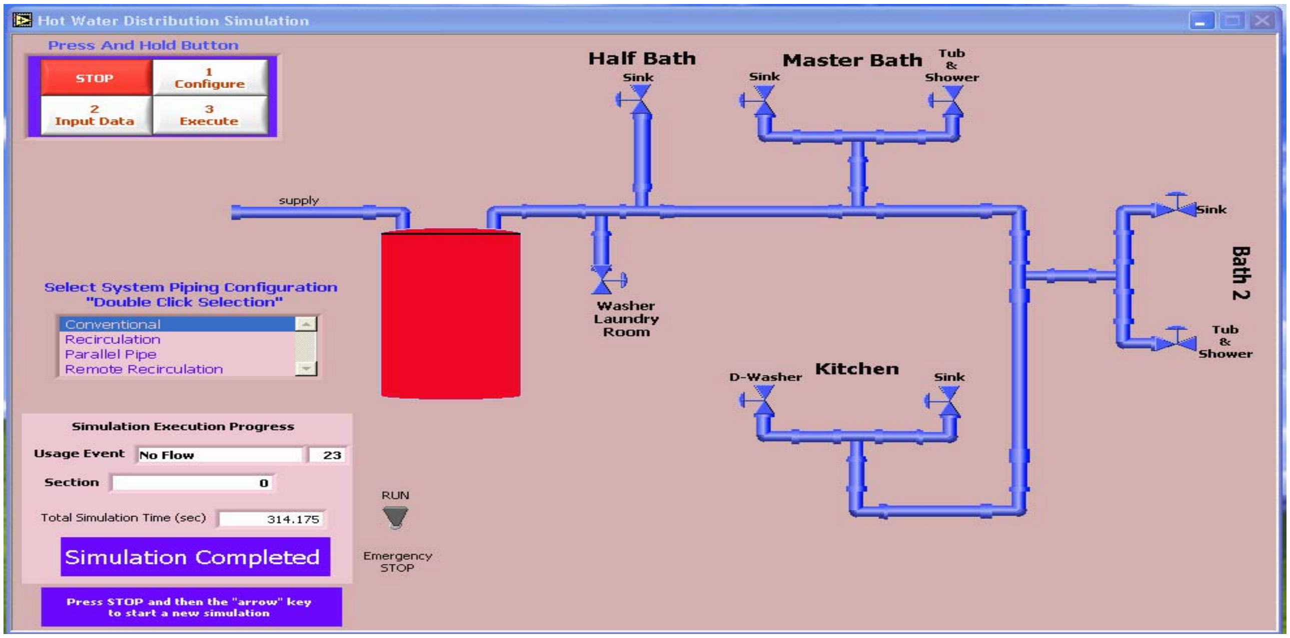

Figure 3.4 Main screen completion menu

Table 3.3 Sample Output Table

Event	Flow rate (GPM)	Time (sec) to reach 105°F	Total Heat Loss (Btu) to reach 105°F	Max Temp (°F)
MBR shower	2.25	70	328	131
MBR sink-1	1.25	109	314	127
MBR sink-2	1.25	111	317	127
MBR sink-1	1.25	109	314	127
MBR sink-2	1.25	111	317	127
BR2 shower	2.25	38	153	133
BR2 shower	2.25	38	153	133
BR2 sink	1.25	63	158	131
BR2 sink	1.25	63	158	131
BR2 sink	1.25	63	158	131
BR2 sink	1.25	63	158	131
BR2 sink	1.25	63	158	131
BR2 sink	1.25	63	158	131
K sink	2.5	39	183	133
K sink	2.5	39	183	133
K sink	2.5	39	183	133
K sink	2.5	39	183	133
K sink	2.5	39	183	133

Assumptions Used for the Numeric Simulations

Based on input from the Project Advisory Committee (PAC), ORNL used the follow assumptions in its analysis of the various hot water distribution systems and options.

- **Average Attic Temperature – 76^{o}F.** This was calculated using the ASHRAE methodology for determining attic temperature related to duct design. We averaged Los Angles and Sacramento to get a statewide average. We believe this temperature is low, but do not have any empirical data from California to suggest another temperature.
- **Average Crawl Space Temperature – 68^{o}F.** This was calculated the same way as the attic temperature.
- **Average Under Slab Temperature – 64^{o}F.** This was calculated the same way as the attic temperature. This is based on average ground water temperatures in California.
- **Shower Flow Rate - 2.25 GPM.** This is based on a review of the Aquacraft hot water studies based on a sample of 10 houses in Washington State over a 14-day period.
- **Bath Faucet Flow Rate - 1.25 GPM.** This is based on a review of the Aquacraft studies.
- **Kitchen and Laundry Faucet Flow Rate - 2.5 GPM.** This is based on recommendations from the Iowa Energy Office for the typical flow of kitchen faucets (2-4 gpm) when filling the sink is desired.

There is little data available on actual hot water usage patterns in California or elsewhere. The project initially computed all houses and system configurations with the assumption that each draw was a "cold start" – meaning that the water had cooled down to the ambient temperature surrounding the pipe before each subsequent use. This approach provided an unambiguous, standard reference point that could be used to compare one system against another.

However, this approach has two significant drawbacks. First, the cold start assumption would only be valid for the first draw of the day, and for other draws during the day when a long enough time elapsed between draws for the water in the piping to go cold. Using such an approach for closely spaced draws would largely negate the effect of insulation around the piping. Second, one of the systems being evaluated is a continuous recirculation system, and there is no such thing (except when the system is first installed and turned on) as a "cold start" for that system.

The cold start approach may overstate the total energy and water waste and tends to discount the value of insulation. An all-cold start use pattern probably represents the "worst case" for potential water and energy waste.

A subsequent decision was made to modify the model to allow approximate calculations of scenarios where draws occurred near each other in time ("clustered"). In these calculations, the extent to which water in the piping cooled down between draws was calculated, rather than assumed. In these cases, a set of draws was assumed in the morning, and then a second set in the evening, with a nine-hour gap between them. This pattern might be typical of a family that spends the middle of the day away from the house. The clustered use represents the likely "best case" regarding water and energy waste.

In the clustered approach, for the first draw of the day (early morning) water in the pipe was assumed to be at ambient temperature. All subsequent draws were based on the calculated temperature of the water remaining in the pipe for each of the segments between the water heater and the end-use fixture. These cool down temperatures were calculated based on the number of minutes between draws, as shown in Table 3.4. The second cluster of uses occurred nine hours after the first cluster and the water in the pipes had reached ambient temperatures. A similar set of cool down temperatures was calculated for the second cluster of draws and is shown in Table 3.4. After the second cluster, the delay before use the next day was assumed to be sufficient for the water temperatures to reach ambient.

Certain approximations had to be made in calculating the cool down for the clustered draw cases. The most rigorous approach would have been to take the entire profile of temperatures through the water, pipe, insulation and surrounding material (soil or attic insulation) and use these as initial conditions for the calculation of the cooling that occurs between the draws. Time and cost did not permit this much rigor.

The initial set of calculations for clustered draw scenarios produced results that indicated that insulation around the pipe, particularly for under-slab configurations, did not have as large an effect as we would have expected and other studies have suggested. Upon investigation, it was determined that the program had used the average water temperature at the end of a cool down calculation as the initial temperature of the modeled 6 inches of soil. An independent calculation by Dr. Keith Woodbury was made of a particular pipe in soil ("thick") configuration with and without insulation. This calculation showed that, for a 5 minute draw of hot water, the temperature would be elevated from ambient for only a short distance into the soil (less than an inch), and that temperature decays rapidly after the draw ends. Thus, the initial calculations overstated the heat storage in the material surrounding the pipe.

The program was changed so that the initial temperatures for the soil or attic insulation for subsequent draws in a cluster scenario are set to ambient, while the initial temperatures for the water, pipe and, if applicable, insulation, are set equal to the average temperature at the end of the cool down calculation for the time lapse since the previous draw. Ignoring the stored heat in the material around the pipe will somewhat over state the effect of insulation, but because only a small amount of heat is stored and dissipates rapidly, the overstatement should be slight. All of the calculations for cluster draw scenarios contained in this report incorporate this second, more realistic assumption.

The continuous recirculation systems were run at steady state conditions where some of the energy loss was reflected in higher surrounding temperatures. Since the continuous recirculation systems do not revert to ambient temperatures, they should not be compared with the performance of systems under the all cold start assumption. These systems are included in the cluster use tables because comparison between the continuous recirculation systems at steady state and other systems based on clustered use patterns is reasonable. The results of the simulation for both usage assumptions are also provided in Sections 4.1 and 5.1, and Appendix A.

Table 3.4 Description of Clustered Use Events

Event Description	Flowrate (gpm)	Time Before Event (min)	Number of Sections	Section 1 Length (ft)	Starting Temp	Section 2 Length (ft)	Starting Temp
MBR shower	2.25	0	2	64.5	**Tamb**	14	**Tamb**
MBR sink-1	1.25	15	2	64.5	Tnew	8	**Tamb**
MBR sink-2	1.25	15	2	64.5	Tnew	10	**Tamb**
BR2 shower	2.25	20	2	37	Tnew	13	**Tamb**
BR2 shower	2.25	15	2	37	Tnew	13	Tnew
BR2 sink	1.25	15	2	37	Tnew	6	**Tamb**
BR2 sink	1.25	15	2	37	Tnew	6	Tnew
BR2 sink	1.25	15	2	37	Tnew	6	Tnew
K sink	2.5	25	2	45.5	Tnew	9	**Tamb**
MBR sink-1	1.25	540	2	64.5	Tnew	8	**Tamb**
K sink	2.5	15	2	45.5	Tnew	9	**Tamb**
K sink	2.5	15	2	45.5	Tnew	9	Tnew
K sink	2.5	20	2	45.5	Tnew	9	Tnew
K sink	2.5	30	2	45.5	Tnew	9	Tnew
MBR sink-2	1.25	60	2	64.5	Tnew	10	**Tamb**
BR2 sink	1.25	20	2	37	Tnew	6	**Tamb**
BR2 sink	1.25	25	2	37	Tnew	6	Tnew
BR2 sink	1.25	15	2	37	Tnew	6	Tnew

Notes: *Tamb* is when the water temperature equals ambient. *Tnew* reflects the water temperature in the pipe as impacted by the previous draw.

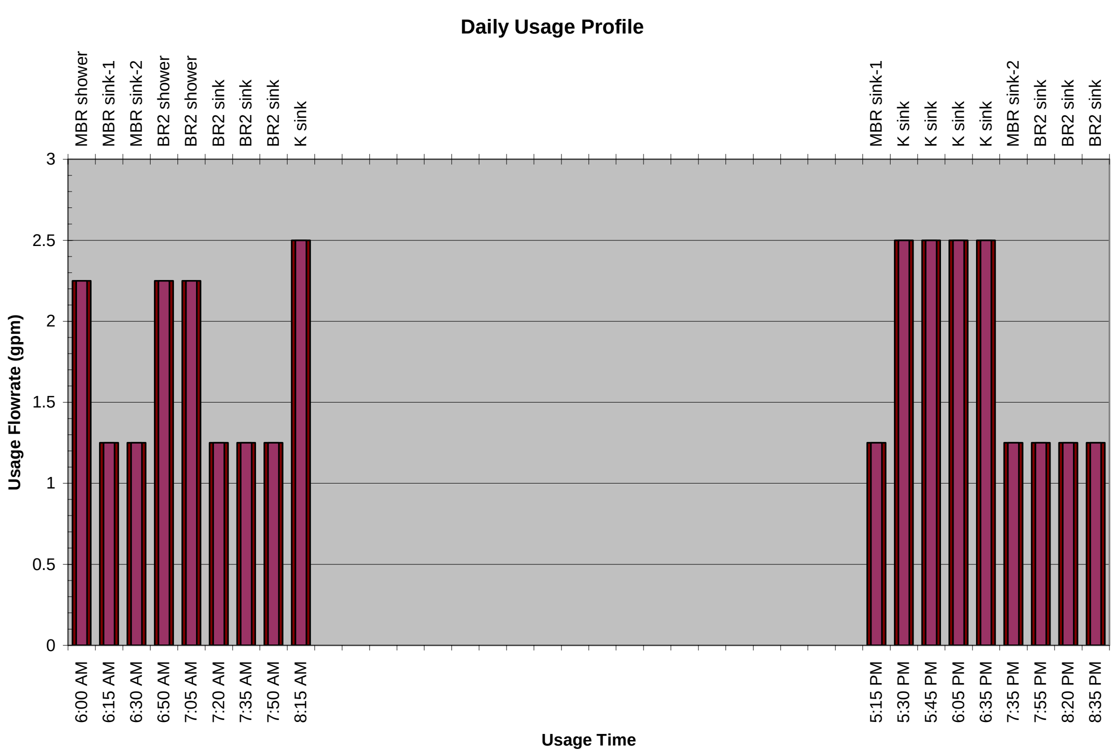

Figure 3.5 Usage profile assumption for test cases (Clustered Draw Cycle)

3.2 Cost-Benefit Analysis Parameters

The benefit of the various alternative systems and options is based on an analysis of utility (electricity, gas, water and sewer) cost savings. Ten California cities were identified to reflect the range of utility costs. These included: Davis, Fairfield, Fresno, Gilroy, Sacramento, San Bernardino, San Diego, San Jose, Stockton, and Tracy. These cities were chosen to represent the climatic and utility costs variations within the most populated portions of the state. Sewage treatment costs in these cities were a fixed monthly charge and therefore not impacted by changes in the amount of wastewater generated. Tracy, CA, which happened to have the average utility costs (water, sewer, electricity, and natural gas) of these cities were selected for use in the analysis. The costs were: electricity $0.11589/kWh, gas $0.68263/therm, water $0.85/HCF (100 cu ft or ~748 gallons).

The costs of the various systems and options for each of the houses analyzed were developed from actual cost data provided by a major plumbing contractor based in California. While these costs may vary in other parts of the state and for other sized contractors, the costs are consistent among the various systems and options, permitting an appropriate comparison to be drawn. The detailed costs for each home are reported in Section 4 (New Construction), and Section 5 (Existing Homes), and Appendix A of this report.

The costs reflected in this study are for the distribution system alone and do not include such items as the water heater, water main connection, fixtures (lavatories, sinks, showers, etc.) and valves. These costs would be the same for all systems. Thus these costs differ from the costs of the complete hot water system that spans from water main to end-use fixtures. By keeping the costs focused on the distribution system alone, one is able to directly determine whether the energy and water savings associated with a particular system adequately offsets any additional cost for the installation of that system.

3.3 Representative Housing for Analysis

3.3.1 New Construction

The following five houses are used as representative of California housing in this study. These houses were being used in the 2005 Title 24 update evaluations and the PAC recommended their use in these simulations.

- House #1 - Single Family, Three Bedroom, Two Bath, One Story, 2010 ft^2
- House #2 - Single Family, Four Bedroom, 2½ Bath, One Story, 3080 ft^2
- House #3 - Single Family, Four Bedroom, Three Bath, Two Story, 2810 ft^2
- House #4 - Apartment, One Bedroom, One Bath, One Story, 580 ft^2
- House #5 - Apartment or Condominium, Two Bedroom, Two Bath, One Story, 960 ft^2

Representative new hot water system characteristics included:

- Gas water heater is located in the garage or an exterior access closet on house perimeter.
- Electric water heater is located in the garage or an interior access closet within the house.
- No particular attention has been paid to the house layout regarding the proximity of hot water consuming devices to each other or the water heater.

- Laundry is located within the house proper.
- Pipe locations are per standard California practice based on type of residence being evaluated, including under the floor slab, or in the attic.

Floor plans and expanded descriptions of the representative new houses (#1 - #5) are found in Appendix A. The floor plans for House #1 also include plumbing layouts for: a conventional distribution system; a continuous recirculation system; a demand actuated recirculation system; and, a parallel pipe manifold system.

3.3.2 Existing Housing (1960/70s Construction Practices)

Representative existing residences evaluated included:
- House #6 - Single Family, Three Bedroom, Two Bath, One Story, 1100 ft^2
- House #7 - Single Family, Four Bedroom, 2½ Bath, Two Story, 1960 ft^2

Representative existing hot water systems evaluated included:
- Same characteristics as “new” except the laundry is located in the garage, and the crawl space is an additional pipe location..

Expanded descriptions and floor plans of the representative existing houses (#6 - #7) are found in Appendix A.

3.4 Hot Water Distribution Systems Evaluated

3.4.1 New Construction

Conventional Trunk and Branch Distribution Systems

The impact on energy and water use/cost and initial installation cost of each of the following cases was determined:
- Change piping materials in the trunk and branch distribution system for all representative residence types, holding everything else constant.
- Relocate the water heater to a more central location thereby shortening the length of the conventional distribution system. Analyze for each of the piping materials.
- Add insulation to each of the piping materials in the trunk and branch distribution systems.

Alternative Distribution Systems

The impact on energy and water use/cost and initial installation cost of each of the following cases was determined:
- Install a demand actuated recirculation pump and controls in an otherwise representative conventional system for single-family detached residences (Houses #1 - #3).
- Replace the representative conventional system with a continuously recirculating system for single-family detached residences (Houses #1 - #3).
- Replace the representative conventional system with a parallel pipe manifold system for all representative residences (Houses #1 - #5).

The results from the use of differing materials and alternative systems in new construction are reported in Section 4 and Appendix A of this report.

3.4.2 Existing Housing

The impact on energy and water use/cost and initial installation cost of each of the following cases was determined:

- Assume an existing, functioning, conventional trunk and branch system. The retrofit involved upgrading this system with the installation of a demand actuated recirculation pump and controls, using the existing cold water line as the return.
- Assume an existing, non-functioning (due to calcification or corrosion failures), conventional trunk and branch system. Replace with the various alternative pipe materials with and without and the addition of insulation.
- Assume an existing, non-functioning, conventional system. Replace with a parallel-pipe manifold system.

The detailed results from the use of the upgrade and replacement options in existing homes are reported in Section 5 and Appendix A of this report.

3.5 Method of Identifying Barriers

A questionnaire (Appendix B) was developed and distributed to a number of plumbing contractors in California. It was also used to guide telephone interviews between ORNL and California plumbing contractors. The questionnaire was designed to identify potential barriers to the use of alternative hot water distribution systems from the viewpoint of the primary party responsible (the plumbing contractor) for their installation and modification. Queries included:

- What are the most important issues to the plumbing contractor?
- What issues does the plumbing contractor believe are the most important to the homeowner?
- How familiar is the plumbing contractor with alternative systems?
- In the contractor's view, what are the barriers (cost, complexity, customer interest, codes, training, reliability, ease of repair) to increased use?

The scope of this project did not permit a statistically significant sampling of the plumbing contractors in California. However, the responses received are believed to give an indication of the barriers to more efficient systems and identify areas worthy of further evaluation by the Energy Commission.

The specific barriers to the use of alternative systems in new and existing applications are reported in Section 4 (New Construction), and Section 5 (Existing Homes) in this report.

4. Alternative New Domestic Hot Water Distribution Systems *(Task 3.1.2)*

4.1 Simulation of Potential Energy and Water Savings

Four hot water distribution system configurations were simulated for each house (#1 - #5). They included: conventional trunk and branch system, parallel pipe manifold system, demand recirculation system, and continuous recirculation system. Variations in distribution system materials, layout and environmental conditions for these simulations included: different pipe materials; with and without pipe insulation; centrally locating the water heater; and locating pipe in the attic, in the crawlspace, and under the concrete floor slab. These are reflected in Tables 4.2 and 4.3 and tables in Appendix A.

Two draw cycles (use patterns) were investigated. The first assumed that each individual draw was a “cold start”, i.e. the water had reached the ambient temperature surrounding the pipe before each use. This cold start approach overstates the total energy and water waste and tends to discount the value of insulation in most situations.

In order to bound the effect of actual hot water use patterns on system performance, a second assumption know as “clustered use” was also simulated. This approach had individual draws clustered in the early morning and late afternoon/evening hours as might be expected from a family that spent the middle of the day away from their home. The first draw of the day (during early morning) assumed water in the pipe had reached ambient temperature. The clustered use approach more closely predicts real world energy and water waste.

In addition to these two draw patterns, continuous recirculation systems were modeled at steady-state conditions where some of the energy loss was reflected in higher surrounding temperatures. Comparing simulations of continuous recirculation systems at steady state with simulations of all other systems based on clustered use patterns represents the most realistic approach for the modeling performed.

Simulation results generated for the various systems and options were ranked in order of relative energy use and cost savings. Since the cost savings associated with the various alternatives are based on a specific set of modeling assumptions regarding hot water use (see Table 4.1), system layout, and the environmental conditions around the distribution systems, they should not be viewed as either absolute or directly transferable to another house. However, the trends identified by these simulations are useful in identifying those systems and options that are relatively more efficient and therefore likely to produce actual savings under “real world” conditions.

House #1 simulation results for the cold start draw cycle are shown in Table 4.2 and Figure 4.1; results for the ‘clustered am & pm draw cycle’ are in Table 4.3 and Figure 4.2. Complete results for Houses #1 - #5 along with hot water distribution system layouts for House #1 and floor plans for Houses #1 - #5 are included in Appendix A. A discussion of the cost-benefit analysis for House #1 follows Table 4.4.

Table 4.1 Sample of Daily Hot Water Use Events with Corresponding Distribution Systems Material & Parameters

Event #	Event	Flowrate (gpm)	# Sections	Pipe Material	Pipe Type	Insul Material	Insul Type	S1 Dia (in)	S1 Length (ft)	S1 amb temp (°F)	S1 insul Thick (in)	S2 Dia (in)	S2 length (ft)	S2 amb temp (°F)	S2 insul Thick (in)
1	MBR shower	2.5	2	Copper	K	Cellular Polyethylene		3/4	64.5	50	0	1/2	14	70	0
2	MBR sink-1	2	2	Copper	K	Cellular Polyethylene		3/4	64.5	50	0	1/2	8	70	0
3	MBR whirlpool	4	2	Copper	K	Cellular Polyethylene		3/4	64.5	50	0	1/2	14	70	0
4	MBR sink-2	2	2	Copper	K	Cellular Polyethylene		3/4	64.5	50	0	1/2	10	70	0
5	MBR sink-1	2	2	Copper	K	Cellular Polyethylene		3/4	64.5	50	0	1/2	8	70	0
6	MBR sink-2	2	2	Copper	K	Cellular Polyethylene		3/4	64.5	50	0	1/2	20	70	0
7	BR2 shower	2.5	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	13	70	0
8	BR2 shower	2.5	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	13	70	0
9	BR2 sink	2	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	6	70	0
10	BR2 sink	2	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	6	70	0
11	BR2 sink	2	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	6	70	0
12	BR2 sink	2	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	6	70	0
13	BR2 sink	2	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	6	70	0
14	BR2 sink	2	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	6	70	0
15	BR2 bath tub	4	2	Copper	K	Cellular Polyethylene		3/4	37	50	0	1/2	13	70	0
16	K sink	4	2	Copper	K	Cellular Polyethylene		3/4	45.5	50	0	1/2	9	70	0
17	K sink	4	2	Copper	K	Cellular Polyethylene		3/4	45.5	50	0	1/2	9	70	0
18	K sink	4	2	Copper	K	Cellular Polyethylene		3/4	45.5	50	0	1/2	9	70	0
19	K sink	4	2	Copper	K	Cellular Polyethylene		3/4	45.5	50	0	1/2	9	70	0
21	K sink	4	2	Copper	K	Cellular Polyethylene		3/4	45.5	50	0	1/2	9	70	0
22	Dishwasher	4	2	Copper	K	Cellular Polyethylene		3/4	45.5	50	0	1/2	9	70	0
23	Washer	4	2	Copper	K	Cellular Polyethylene		3/4	21	50	0	1/2	6	70	0
24	No Flow	0	2	Copper	K	Cellular Polyethylene		3/4	64.5	50	0	1/2	14	70	0

Table 4.2 Monthly Water and Energy Waste for House #1 (Cold Start Draw Cycle)

House-1	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	11	42	43	435	256,948	23,606	0.49	10.80	3.37
Conv Attic CPVC - Central	11	41	42	426	251,851	10,119	0.48	10.08	3.15
Conv Attic Cu	37	60	103	882	521,391	50,105	1.00	22.00	6.87
Conv Attic Cu-Ins	37	60	104	883	522,140	51,092	1.00	22.07	6.89
Conv Attic CPVC	35	57	99	839	496,431	26,163	0.95	20.11	6.28
Conv Attic CPVC-Ins	35	57	99	839	496,431	26,433	0.95	20.12	6.28
Conv CS Cu	37	60	104	892	527,612	58,810	1.01	22.58	7.05
Conv CS Cu-Ins	37	60	104	892	527,612	57,115	1.01	22.52	7.03
Conv CS CPVC	35	57	100	849	501,902	29,741	0.96	20.46	6.39
Conv CS CPVC-Ins	35	57	100	849	501,902	29,494	0.96	20.45	6.39
Conv Slab Cu	38	63	111	932	551,223	114,335	1.06	25.66	8.01
Conv Slab Cu-Ins	37	60	104	884	522,890	79,804	1.00	23.22	7.25
Conv Slab CPVC	36	58	100	862	509,998	35,439	0.98	20.99	6.56
Conv Slab CPVC-Ins	36	58	100	862	509,998	30,818	0.98	20.81	6.50
Demand Recir Attic Cu *	5	6	9	99	58,390	67,669	0.11	4.89	1.53
Demand Recir Slab Cu *	4	5	8	83	48,871	157,283	0.09	8.02	2.50
Demand Recir Attic CPVC *	5	6	9	100	59,140	26,594	0.11	3.31	1.03
Demand Recir Slab CPVC *	4	5	8	85	50,295	38,218	0.10	3.43	1.07
Parallel Attic PEX	12	23	36	314	185,440	20,911	0.36	7.95	2.48
Parallel Slab PEX	12	24	38	324	191,362	26,747	0.37	8.40	2.62

* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

Table 4.3 Monthly Water and Energy Waste for House #1 (Clustered AM & PM Draw Cycle)

House-1	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	2	5	40	117	69,334	6,847	0.13	2.93	0.92
Conv Attic CPVC - Central	2	5	39	119	70,458	3,342	0.14	2.84	0.89
Conv Attic Cu	2	5	99	196	115,881	11,435	0.22	4.90	1.53
Conv Attic Cu-Ins	1	5	99	195	115,207	11,145	0.22	4.86	1.52
Conv Attic CPVC	2	5	95	191	113,108	6,200	0.22	4.59	1.43
Conv Attic CPVC-Ins	2	5	95	191	113,108	6,151	0.22	4.59	1.43
Conv CS Cu	3	9	103	410	242,631	22,360	0.47	10.20	3.19
Conv CS Cu-Ins	2	5	102	203	119,854	12,837	0.23	5.11	1.60
Conv CS CPVC	2	8	98	359	212,499	12,196	0.41	8.65	2.70
Conv CS CPVC-Ins	2	5	98	200	118,205	7,305	0.23	4.83	1.51
Conv Slab Cu	32	54	109	845	499,878	90,351	0.96	22.75	7.10
Conv Slab Cu-Ins	2	4	102	192	113,708	16,245	0.22	5.01	1.56
Conv Slab CPVC	28	50	98	767	453,631	31,538	0.87	18.67	5.83
Conv Slab CPVC-Ins	2	5	98	192	113,783	7,076	0.22	4.65	1.45
Demand Recir Attic Cu *	2	5	9	77	45,273	12,030	0.09	2.21	0.69
Demand Recir Slab Cu *	2	4	8	66	39,052	17,997	0.08	2.20	0.69
Demand Recir Attic CPVC *	2	5	9	78	46,397	6,418	0.09	2.03	0.64
Demand Recir Slab CPVC *	2	4	8	70	41,600	7,826	0.08	1.90	0.59
Parallel Attic PEX	2	11	36	196	115,881	15,042	0.22	5.04	1.57
Parallel Slab PEX	9	19	38	286	168,875	24,098	0.32	7.43	2.32
Recir Attic Cu-Ins **	2	5	9	77	45,273	267,509	0.09	12.18	3.80
Recir Slab Cu-Ins **	2	4	8	66	39,052	872,443	0.08	35.55	11.10
Recir Attic CPVC-Ins **	2	5	9	78	46,397	291,240	0.09	13.15	4.11
Recir Slab CPVC-Ins **	2	4	8	70	41,600	790,345	0.08	32.45	10.13

NOTES:

* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

** Energy supplied to the continuous recirculation system pump is calculated as 755.55 kWh/year or 62.9 kWh/month, which equals approximately $7.30/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

Definitions for Table 4.2 and 4.3:

"Wait Time for Hot Water" is the length of wait in seconds for 105°F water to reach the fixture. Three values are shown: Min. – the shortest wait, Typical – the median wait, and Max. – the longest wait.

"Water Wasted" is the sum of all water wasted down the drain in gallons before temperature at fixture reaches 105°F for all non-batch-load uses and applied only to showers and sinks (i.e., excludes bathtub, dishwasher and clothes washer).

"Energy Loss" includes two terms. As water that has been previously heated by the water heater stands in the pipe between draws, it cools off and looses some energy through the pipe wall. If it cools below a useful temperature, this water is wasted down the drain while the user waits for the water to get hot enough to use. The water down the drain carries with it whatever remains of the energy added to it by the water heater. The first term under this heading, "previously heated water wasted" give the energy lost due to the water sitting in the pipe between draws. The second term, labeled "pipe", is the energy loss during the draw due to heat transfer through the pipe walls to the surrounding environment.

"Water Costs" is the total cost of the water wasted down the drain based on the utility's lowest use rate.

"Energy Costs" for electric water heating is the sum of the BTUs lost in the pipes and the BTUs lost in the water wasted down the drain converted to kWh and multiplied by the utility rate in kWh. It assumes a DOE energy factor (EF) of 0.87 for the electric water heater. For gas water heating, the total BTUs lost are converted to therms and multiplied by the utility rate in therms. It assumes an EF of 0.56 for the gas water heater. The pumping costs for the various recirculation systems are included in the table notes and should be added to the water heating costs to obtain the total cost of operating these systems.

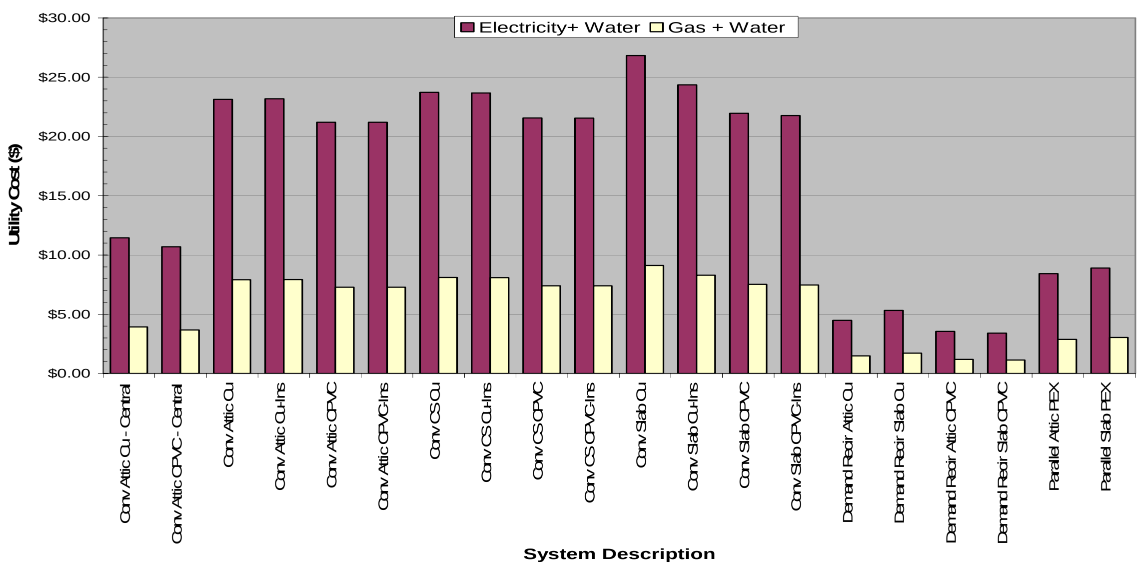

Figure 4.1 – Combined Monthly Water and Energy Waste for House #1 (Cold Start Draw Cycle)

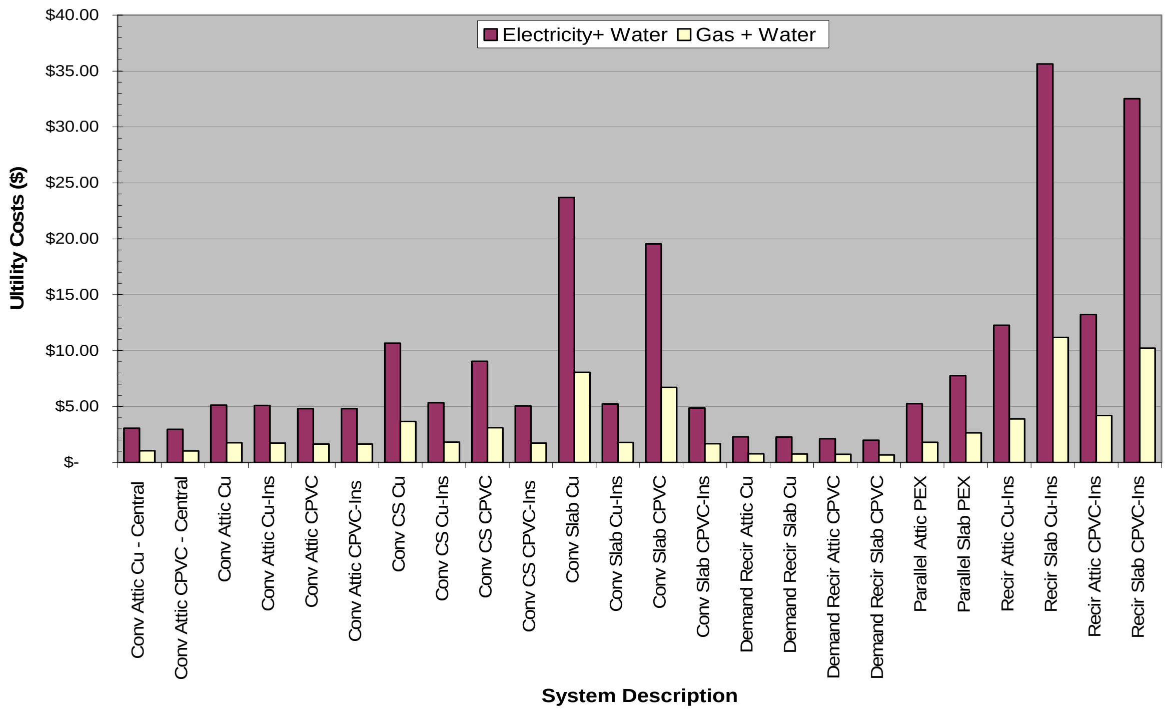

Figure 4.2 – Combined Monthly Water and Energy Waste for House #1 (Clustered AM & PM Draw Cycle)

4.2 Analysis of Cost-Benefit

The potential cost savings (benefits) of the various alternative systems and options for House #1 are shown in Tables 4.2 and 4.3. The potential construction costs, the cost to the homeowner for the various alternative systems and options for House #1 are shown in Table 4.4. The cost-benefit analysis following Table 4.4 compares the estimated construction cost for each of the alternative systems and option with the projected utility cost savings associated with each. Cost-benefit observations and conclusions follow Table 4.4.

Table 4.4 New Hot Water Distribution Systems – Homeowner's Costs

Scenario	New House Type #1
Conventional, Central WH Location, Copper, attic, uninsulated	$1150
Conventional, Central WH Location, CPVC, attic, uninsulated	$787
Conventional, Copper, attic or crawl space, uninsulated	$1271
Conventional, Copper, attic or crawl space, insulated	$1552
Conventional, Copper, under-slab, uninsulated	$1556
Conventional, Copper, under-slab, insulated	$1838
Conventional, CPVC, attic or crawl space, uninsulated	$866
Conventional, CPVC, attic or crawl space, insulated	$1147
Conventional, CPVC, under-slab, uninsulated	$1086
Conventional, CPVC, under-slab, insulated	$1368
Conventional w/ Demand Recirculation, Copper, attic or crawl space, uninsulated	$1880
Conventional w/ Demand Recirculation, Copper, under-slab, insulated	$2447
Conventional w/ Demand Recirculation, CPVC, attic or crawl space, uninsulated	$1475
Conventional w/ Demand Recirculation, CPVC, under-slab, insulated	$1978
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$1226
Parallel Pipe/Manifold System, PEX tubing, under-slab, uninsulated	$1443
Conventional w/ Continuous Recirculation, Copper, attic or crawl space, insulated	$2559
Conventional w/ Continuous Recirculation, Copper, under-slab, insulated	$2861
Conventional w/ Continuous Recirculation, CPVC, attic or crawl space, insulated	$1965
Conventional w/ Continuous Recirculation, CPVC, under-slab, insulated	$2185

Notes on Table 4.4:

1. Costs shown include Plumbing and General Contractors' OH&P for new construction.
2. Costs for materials and new construction labor provided by Dynamic Plumbing.
3. Costs for under-slab installation are considered to be comparable to attic installation by some plumbers.
4. Costs for Conventional, Central Water Heater Location are for the distribution system alone. They do not include the potentially offsetting additional costs of running additional natural gas distribution lines and providing combustion air and exhaust venting for gas water heaters. For electric water heaters, these costs does not reflect the additional cost (if any) of running 220 V power to the central location.

Cost-Benefit Observations

Based on the data shown in Tables 4.2, 4.3 and 4.4 the following observations can be made about each scenario for House #1. A conventional, copper, uninsulated, system in the attic (common practice in California) is used as the reference point for the cost/benefit analysis.

Scenario	Observation
Conventional, Central WH Location, Copper, attic, uninsulated	Total initial cost higher for gas and less for electric, saves some energy
Conventional, Central WH Location, CPVC, attic, uninsulated	Total initial cost somewhat less for both gas and electric, saves some energy
Conventional, Copper, attic or crawl space, uninsulated	**REFERENCE POINT**
Conventional, Copper, attic or crawl space, insulated	Costs more and saves no additional energy (buried in attic insulation)
Conventional, CPVC, attic or crawl space, uninsulated	Lower initial cost and saves some energy
Conventional, CPVC, attic or crawl space, insulated	Costs less but saves no additional energy compared to uninsulated CPVC (buried in attic insulation)
Conventional, Copper, under-slab, uninsulated	Costs more initially and consumes a lot more energy
Conventional, Copper, under-slab, insulated	Costs more initially and consumes about the same energy
Conventional, CPVC, under-slab, uninsulated	Lower initial cost but consumes more energy
Conventional, CPVC, under-slab, insulated	Costs more initially, saves a little energy
Conventional w/ Demand Recirculation, Copper, attic or crawl space, uninsulated	Costs more initially, saves energy and water, moderate to long payback
Conventional w/ Demand Recirculation, Copper, under-slab, uninsulated	Costs more initially, saves energy and water, moderate to long payback
Conventional w/ Demand Recirculation, CPVC, attic or crawl space, uninsulated	Costs more initially, saves energy and water, reasonable payback (electric)
Conventional w/ Demand Recirculation, CPVC, under-slab, uninsulated	Costs more initially, saves energy and water, reasonable payback (electric)
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	Costs about the same, saves energy and water for “cold start” only
Parallel Pipe/Manifold System, PEX tubing, under-slab, uninsulated	Costs more initially, saves energy and water for “cold start” only
Conventional w/ Continuous Recirculation, Copper, attic or crawl space, insulated	Costs much more initially, consumes more energy, but saves water

Conventional w/ Continuous Recirculation, Copper, under-slab, insulated — Costs much more initially, consumes more energy, but saves water

Conventional w/ Continuous Recirculation, CPVC, attic or crawl space, insulated — Costs much more initially, consumes more energy, but saves water

Conventional w/ Continuous Recirculation, CPVC, under-slab, insulated — Costs much more initially, consumes more energy, but saves water

Cost and Benefit Conclusions

For California (New) House #1 from a *cost/benefit viewpoint*, simulation results showed that distribution systems superior to a conventional system are as follows (in order of greater to lesser benefit):

Assuming a "cold start" use pattern:
1. Conventional w/ Demand Recirculation, CPVC, attic, uninsulated
2. Parallel Pipe/Manifold System, PEX tubing, attic, uninsulated
3. Conventional w/ Centrally Located Water Heater, CPVC, attic, uninsulated

Assuming a "clustered" use pattern:
1. Conventional w/ Centrally Located Water Heater, CPVC, attic, uninsulated
2. Conventional w/ Demand Recirculation, CPVC, attic, uninsulated

The overall ranking of alternative distribution systems compared with the conventional (reference point) systems vary slightly from a cost/benefit viewpoint for the other four new California houses. Generally, however, the rankings for Houses #2 and #3 in this study are similar to that for House #1. The "Conventional w/ Demand Recirculation" and "Continuous Recirculation" distribution systems were not evaluated for Houses #4 and #5 due to their small size (580 ft^2 and 960 ft^2, respectively).

For California (New) House #1 from a *homeowner satisfaction viewpoint* - waiting time for hot water to arrive - simulation results showed that the distribution systems superior to a conventional system are as follows (in order of higher to lesser satisfaction):

Assuming a "cold start" use pattern:
1. Conventional w/ Demand Recirculation, CPVC, attic, uninsulated
2. Parallel Pipe/Manifold System, PEX tubing, attic, uninsulated
3. Conventional w/ Centrally Located Water Heater, CPVC, attic, uninsulated

Assuming a "clustered" use pattern: (1. & 2. are virtually equal)
1. Conventional w/ Continuous Recirculation, CPVC, attic, insulated
2. Conventional w/ Demand Recirculation, CPVC, attic, uninsulated
3. Parallel Pipe/Manifold System, PEX tubing, attic, uninsulated

Note: Tables 4.2 & 4.3 and tables in Appendix A provide the calculated waiting period for hot water to arrive for Houses #1 - #5.

For California House #1 from an *energy and water conservation viewpoint*, simulation results showed that distribution systems superior to the conventional system are as follows (in order of greater to lesser amount of conservation):

Assuming a “cold start” use pattern:
1. Conventional w/ Demand Recirculation, CPVC, attic, uninsulated
2. Parallel Pipe/Manifold System, PEX tubing, attic, uninsulated
3. Conventional w/ Central Water Heater Location, CPVC, attic, uninsulated

Assuming a “clustered” use pattern:
1. Conventional w/ Demand Recirculation, CPVC, attic, uninsulated
2. Conventional w/ Central Water Heater Location, CPVC, attic, uninsulated

Another method of cost evaluation is to annualize the costs of the construction and add them to the annual utility costs to develop a total annualized cost of the system. This methodology permits the direct comparison of systems with differing first costs and differing annual costs. A fifty-year service life was assumed for the distribution systems. The annualized construction costs were therefore $1/50^{th}$ of the total construction costs. Table 4.5 shows the annualized costs of alternative systems in House #1.

The five lowest cost systems when a clustered use pattern is assumed are highlighted in red. The five lowest costs systems when a cold start use pattern is assumed are highlighted in blue. The impact of the two different use patterns (or draw cycles) is apparent from the fact that only two systems are among the five lowest annualized cost systems under both patterns:

- The conventional CPVC trunk and branch system located buried in the attic insulation and connected to a centrally located water heater is among the better systems under both use patterns.
- The CPVC demand recirculation system located buried in the attic insulation is among the better systems under both use patterns.

Table 4.5 Annualized Costs of Alternative Hot Water Distribution Systems in House #1 Assuming Gas Water Heating

Red highlights - five lowest cost systems for clustered use draws
Blue highlights - five lowest cost systems for cold start draws

System/Option	Water Waste		Energy Waste		Construction Cost		Total Annualized Cost	
	Clustered	Cold Start	Clustered	Cold Start	Total	Per Yr for 50 Yr	Clustered Use	Cold Start Use
Conv Attic Cu - Central	$1.56	$5.88	$11.04	$40.44	$1,450.00	$29.00	**$41.60**	$75.32
Conv Attic CPVC - Central	$1.68	$5.76	$10.68	$37.80	$1,087.00	$21.74	**$34.10**	$65.30
Conv Attic Cu	$2.64	$12.00	$18.36	$82.44	$1,271.00	$25.42	$46.42	$119.86
Conv Attic Cu-Ins	$2.64	$12.00	$18.24	$82.68	$1,552.00	$31.04	$51.92	$125.72
Conv Attic CPVC	$2.64	$11.40	$17.16	$75.36	$866.00	$17.32	**$37.12**	$104.08
Conv Attic CPVC-Ins	$2.64	$11.40	$17.16	$75.36	$1,147.00	$22.94	**$42.74**	$109.70
Conv CS Cu	$5.64	$12.12	$38.28	$84.60	$1,271.00	$25.42	$69.34	$122.14
Conv CS Cu-Ins	$2.76	$12.12	$19.20	$84.36	$1,552.00	$31.04	$53.00	$127.52
Conv CS CPVC	$4.92	$11.52	$32.40	$76.68	$866.00	$17.32	$54.64	$105.52
Conv CS CPVC-Ins	$2.76	$11.52	$18.12	$76.68	$1,147.00	$22.94	$43.82	$111.14
Conv Slab Cu	$11.52	$12.72	$85.20	$96.12	$1,556.00	$31.12	$127.84	$139.96
Conv Slab Cu-Ins	$2.64	$12.00	$18.72	$87.00	$1,838.00	$36.76	$58.12	$135.76
Conv Slab CPVC	$10.44	$11.76	$69.96	$78.72	$1,086.00	$21.72	$102.12	$112.20
Conv Slab CPVC-Ins	$2.64	$11.76	$17.40	$78.00	$1,368.00	$27.36	$47.40	$117.12
Demand Recir Attic Cu	$1.08	$1.32	$8.28	$18.36	$1,880.00	$37.60	$46.96	**$57.28**
Demand Recir Slab Cu	$0.96	$1.08	$8.28	$30.00	$2,447.00	$48.94	$58.18	$80.02
Demand Recir Attic CPVC	$1.08	$1.32	$7.68	$12.36	$1,475.00	$29.50	**$38.26**	**$43.18**
Demand Recir Slab CPVC	$0.96	$1.20	$7.08	$12.84	$1,978.00	$39.56	$47.60	**$53.60**
Parallel Attic PEX	$2.64	$4.32	$18.84	$29.76	$1,226.00	$24.52	$46.00	**$58.60**
Parallel Slab PEX	$3.84	$4.44	$27.84	$31.44	$1,443.00	$28.86	$60.54	**$64.74**
Recir Attic Cu-Ins	$1.08	N.A.	$45.60	N.A.	$2,559.00	$51.18	$97.86	N.A.
Recir Slab Cu-Ins	$0.96	N.A.	$133.20	N.A.	$2,861.00	$57.22	$191.38	N.A.
Recir Attic CPVC-Ins	$1.08	N.A.	$49.32	N.A.	$1,965.00	$39.30	$89.70	N.A.
Recir Slab CPVC-Ins	$0.96	N.A.	$121.56	N.A.	$2,185.00	$43.70	$166.22	N.A.

Costs for Central WH include $300 added for flue, combustion air, and added gas line

4.3 Identification of Market Barriers

Market barriers to the use of alternative hot water distribution systems and options include such factors as cost, code acceptance, reliability/durability, performance, customer's awareness of the alternative, and customer's perception of the alternative. "Customers" - persons involved in choosing the hot water distribution system in a particular residence - include the homeowner, the general contractor, and the plumbing contractor. This study uses input from the plumbing contractor to determine potential market barriers.

Input from Plumbing Contractors

The follow is a summary of the responses received from seven California-based plumbing contractors who are involved in the installation of water distribution systems in new and existing housing. Each was interviewed using the questionnaire in Appendix B. An attempt was made to contact 50+ plumbing contractors in the state, but work schedules, inaccurate contact information, or other reasons precluded additional input. While the number of respondents clearly does not provide a "statistically significant sampling", it does in the opinion of the authors provide useful insight into the contractors' perceptions related to hot water distribution systems.

Questions Asked

Rank the importance of each of the following <u>to you</u> as a Plumbing Contractor (1 = very low to 10 = very high)

Reliability and Durability:	**9**
Low Cost:	**5**
Energy and Water Savings:	**5**

Rank your view of the importance of the following <u>to your customers</u> (1 = very low to 10 = very high)

Length of time before hot water is available at fixture:	**10**
Reliability and Durability:	**9.5**
Initial cost of system affecting the overall home cost:	**9.5**
Adequacy of flow/water pressure:	**6**
Energy and Water Savings:	**5**

Your familiarity with, and use of, Alternative Hot Water Systems

Continuous Recirculation Systems – 80% of the respondents were familiar with and install the systems. These systems are typically not time or temperature controlled. Some time-controlled systems are beginning to be installed, but the temperature controllers are "too new" and are very rarely used. These systems are installed in a very high percentage of new homes over 3000 sq ft (75%-85%) in size. This percentage drops as the square footage of the home decreases, because distribution distances become less and the waiting time for the hot water to get to the fixture is considered acceptable.

On-Demand Recirculation Systems - 80% of the respondents were familiar with the systems, but those interviewed seldom install them in new homes.

Parallel pipe manifold systems (single dead-end hot water lines to fixture from water heater) – 15% (one) of the respondents was familiar with these systems. That firm has not installed them in the past few years.

Point of use heating (for individual fixtures) – The respondents who were familiar with the product observed that they were mainly used in commercial applications. None of the respondents had installed them in residential construction.

Wastewater heat recovery (e.g. GFX) – The respondents were not familiar with the technology and none have installed them.

Observations Based on Response

1) The main drivers in the hot water distribution system selection to the homeowners are, in priority order: time for hot water to arrive at the fixtures, reliability, and cost. The homeowners are very concerned about the waiting time and appear to be willing to pay more to minimize it.

2) Based on comments from new construction plumbing contractors, they are driven mainly by the general contractors' requests, and have little participation in the decision as to what type system is installed. The plumbing contractors are mainly concerned with the reliability and durability to avoid potential callbacks.

3) All of plumbing contractors contacted were familiar with and installed both conventional and continuous recirculation systems. They are not familiar with and do not install parallel pipe/manifold systems, point-of-use water heaters, or waste water heat recovery systems.

4) Continuous recirculation systems are in very high demand for homes of 3000 sq ft and larger, with the demand dropping as the size of the home gets smaller.

5) Conserving water and energy are not considered essential, but are of interest to the homeowner and plumbing contractor.

Barriers to the use of Alternative Systems and Options

Cost – Initial cost is an important factor in entry-level (low-cost) housing, but declines in importance as the size and cost of the home increases. From the questionnaire results, it is apparent that upscale housing owners are willing to pay significantly more for the creature comfort of having hot water immediately available.

Building Code acceptance – This factor is viewed as a "given" by the plumbing contractors. If a system of material is not code approved in their locality, they do not consider it for use. Building code acceptance of plastic (CPVC and PEX) piping in California is mixed. Therefore the use of this lower cost, more energy efficient option is limited. Continuous recirculation systems are mandated in some California communities even though the simulations and cost estimates show that they have higher initial and energy costs than all other alternatives studied in this project.

Reliability/durability – This factor is very important to plumbing contractors. Failures cost the contractor in callback visits and impact their reputation. In general, a material or system has to have demonstrated reliability and durability before it will be considered for use.

Performance – This factor is very important to the homeowner. The distribution system must provide reasonable flow of water, short waiting period for hot water to arrive, and reasonable water and energy costs. Unfortunately, the homeowner will evaluate a systems performance primarily on flow and wait since they will make the direct connection with these factors as they use the system. Energy and water costs are disguised by other uses and are delayed until the utility bill is received by the homeowner, usually well after the actual use of the hot water.

Customer's awareness of alternative distribution systems – This factor impacts the homeowner, general contractor, and plumbing contractor. The general contractor is viewed as the person primarily "calling the shots" when it comes to the decision as to what type of distribution system to install. However, both the plumbing contractor and the homeowner have the potential to impact that decision if they make their input known.

Customer's perception of alternative distribution systems – Again, this factor impacts the homeowner, general contractor, and plumbing contractor. However, the impact of this factor is likely to be shared equally among the three parties. Past experience with similar systems (e.g. plastic piping failure, law suits, publicity, union resistance to use, etc.) can taint the perception held by these decision makers causing them to avoid potentially viable options.

5. Existing Domestic Hot Water Distribution Systems

(Task 3.1.3)

5.1 Simulation of Potential Energy and Water Savings

Viable replacement hot water distribution system configurations and options were simulated for existing houses #6 and #7. When the existing distribution system had failed and needed to be replaced the following options were evaluated: conventional system replacement in-kind, and replacement with a parallel pipe/manifold system. Some of the parameters and conditions were varied including using: different pipe materials, and insulated and non-insulated pipe. In addition, the installation of demand recirculation pump and controls on an existing system was evaluated for when an unacceptable waiting time was the sole issue to be addressed.

Both the “cold start” and “clustered” draw cycles (use patterns) were investigated.

Simulation results generated for the various systems and options were ranked in order of relative energy use and cost savings. Since the cost savings associated with the various alternatives are based on a specific set of modeling assumptions regarding hot water use (see Table 4.1), system layout, and the environmental conditions around the distribution systems, they should not be viewed as either absolute or directly transferable to another house. However, the trends identified by these simulations are useful in identifying those systems and options that are relatively more efficient and therefore likely to produce actual savings under “real world” conditions.

The results of the simulations for House #6 are shown in Tables 5.1 and 5.2. The results for Houses #6 and #7 are also included in Appendix A. A discussion of the simulation results for House #6 follows Table 5.3.

Table 5.1 Monthly Water and Energy Waste for House #6 (Cold Start Draw Cycle)

House-6	Wait Time for HW (Sec)			Water Wasted	Energy Loss From (Btu)		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	22	59	78	594	351467	33458	0.68	14.82	4.63
Conv Attic Cu Ins	22	59	78	594	351467	34139	0.68	14.85	4.64
	21	56	76	570	337000	16855	0.65	13.62	4.25
Conv Attic CPVC Ins	21	56	76	570	337000	16987	0.65	13.62	4.25
Conv CS Cu	22	60	80	603	356713	38644	0.69	15.22	4.75
Conv CS CPVC	21	57	77	577	341423	18590	0.66	13.85	4.33
Conv CS Cu Ins	22	60	80	603	356713	37939	0.69	15.2	4.75
Conv CS CPVC Ins	21	57	77	577	341423	18564	0.66	13.85	4.33
Demand Recir Attic Cu *	2	3	5	47	27734	55293	0.05	3.22	1.01
Demand Recir CS Cu *	2	3	5	47	27734	62107	0.05	3.49	1.09
Parallel Attic PEX	11	25	33	250	147962	17181	0.28	6.36	1.99
Parallel CS PEX	11	25	34	251	148337	17459	0.28	6.38	1.99

Table 5.2 Monthly Water and Energy Waste for House #6 (Clustered AM & PM Draw Cycle)

House-6	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	2	4	76	150	88,522	8,856	0.17	3.75	1.17
Conv Attic Cu Ins	2	4	75	149	88,148	8,678	0.17	3.73	1.16
Conv Attic CPVC	2	4	74	149	88,223	4,722	0.17	3.58	1.12
Conv Attic CPVC Ins	2	4	74	148	87,548	4,678	0.17	3.55	1.11
Conv CS Cu	2	18	79	296	175,171	15,121	0.34	7.33	2.29
Conv CS Cu Ins	2	4	79	155	91,446	9,642	0.18	3.89	1.22
Conv CS CPVC	2	12	77	259	153,284	8,112	0.29	6.21	1.94
Conv CS CPVC Ins	2	4	77	157	92,570	5,211	0.18	3.76	1.18
Demand Recir Attic Cu *	2	2	5	37	21,962	6,155	0.04	1.08	0.34
Demand Recir CS Cu *	2	2	5	37	21,962	11,590	0.04	1.30	0.41
Parallel Attic PEX	2	9	30	151	89,197	11,814	0.17	3.89	1.22
Parallel CS PEX	7	18	30	213	126,075	14,570	0.24	5.42	1.69

NOTES: * Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

5.2 Analysis of Cost-Benefit

Tables 5.1 and 5.2 show the potential cost savings (benefits) of the various alternative systems and options for existing California House #6, described in Section 3.3.2 and Appendix A. The potential construction costs to the homeowner for the various alternative systems and options for Houses #6 are shown in Table 5.3. The cost-benefit analysis compares the estimated construction cost for each of the alternative systems and option with the projected utility cost savings associated with each. Cost-benefit observations and conclusions follow Table 5.3.

Table 5.3 Existing Hot Water Distribution Systems – Costs to Homeowner

Scenario	Existing House Type #6
Conventional, Copper, attic or crawl space, uninsulated	$1023
Conventional, Copper, attic or crawl space, insulated	$1217
Conventional, CPVC, attic or crawl space, uninsulated	$702
Conventional, CPVC, attic or crawl space, insulated	$896
Conventional with Demand Recirculation, Copper, attic or crawl space, uninsulated	$694*
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$944

* Demand recirculation system reuses existing piping system and includes pump and controls only

Notes on Table 5.3:

1. Costs shown include Plumbing Contractors' OH&P only for existing homes.
2. Existing Housing Labor is based on 125% (per R.S. Means) of new construction labor. Costs for materials and new construction labor provided by Dynamic Plumbing.
3. Actual existing housing costs will vary upwards from those shown because of differing field circumstances, the plumbing contractors' view of potential uncertainties, and the need to involve other crafts to open and restore walls to provide access for the plumbers to work. The costs shown above are best viewed a probable minimum costs

Cost-Benefit Observations

Based on the data shown in Tables 5.1, 5.2 and 5.3 the following observations can be made about each scenario for House #6. A conventional, copper, uninsulated, system in the attic (common practice in California) is used as the reference point for the cost/benefit analysis.

Scenario	Observation
Conventional,	**REFERENCE POINT**

Copper, attic or crawl space, uninsulated	
Conventional, Copper, attic or crawl space, insulated	Costs more initially, no energy savings in crawl space
Conventional, CPVC, attic or crawl space, uninsulated	Lower initial cost, saves some energy
Conventional, CPVC, attic or crawl space, insulated	Lower initial cost, no energy savings in crawl space
Conventional with Demand Recirculation, Copper, attic or crawl space, uninsulated	*Not Comparable*, used primarily as retrofit to existing system to reduce waiting, saves energy and water, long payback with gas WH
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	Lower initial cost, lower energy and water (cold start), slightly higher energy and water (clustered start)

Cost and Benefit Conclusions

For California (Existing) House #6 from a *cost/benefit viewpoint*, simulation results showed that the distribution systems superior to a conventional system are as follows (in order of greater to lesser benefit):

Assuming a “cold start” use pattern:
1. Conventional, CPVC, attic, uninsulated
2. Parallel Pipe/Manifold System, PEX, attic or crawl space, uninsulated

Assuming a “clustered” use pattern:
1. Conventional, CPVC, attic, uninsulated

Actual existing housing costs will vary upwards from those shown in Table 5.3 because of differing field circumstances, the plumbing contractors’ view of potential uncertainties, and the need to involve other crafts to open and restore walls to provide access for the plumbers to work. It is likely that the installation of a rigid pipe conventional system would require more restoration than the flexible tubing used in the parallel pipe system. This situation could easily reverse the order shown above.

For California (Existing) House #6 from a *homeowner satisfaction viewpoint* - waiting time for hot water to arrive - simulation results showed that the distribution systems superior to a conventional system are as follows (in order of higher to lesser satisfaction):

Assuming a “cold start” use pattern:
1. Replace Existing Conventional w/ Parallel Pipe/Manifold System, PEX, attic, uninsulated

Assuming a “clustered” use pattern:
1. Replace Existing Conventional w/ Parallel Pipe/Manifold System, PEX, attic, uninsulated

The ranking of options to the conventional systems from a cost/benefit viewpoint vary slightly with the specifics of the particular house being evaluated. However, similar results also occurred in House #7.

For California (Existing) House #6 from an *energy and water conservation viewpoint* simulation results showed that distribution systems superior to the conventional system are as follows:

Assuming a “cold start” use pattern:
1. Replace Existing Conventional w/ Parallel Pipe/Manifold System, PEX, attic, uninsulated

Assuming a "clustered" use pattern:
1. Conventional, CPVC, attic, uninsulated

For California (Existing) House #6 from a *reducing the waiting time alone viewpoint* the simulation results showed that the addition of a demand recirculation pump and controls to an existing system is the "best" in all cost and benefit evaluations for both cold start and clustered use patterns.

5.3 Identification of Market Barriers

Refer to Section 4.3 for the identification and discussion of market barriers to the use of alternative hot water distribution systems for new homes. These barriers are by-and-large common to both new construction and existing homes. The exceptions for existing homes include the absence of a general contractor in most of the decisions and the fact that plumbing work is typically done in an occupied residence where disruption of the occupants add another dimension to the decision making process. Another potential barrier to use of some distribution systems is that the unique physical characteristics of the existing house that may preclude the use certain alternative systems and options. These physical characteristics should be viewed as "givens" and not subject to potential mitigation.

6. Evaluate Potential Impact

(*Task 3.1.4)*

6.1 Analysis of Statewide Impact of Successful Implementation

This section evaluates the impact of the application of more efficient alternative distribution systems on overall energy and water consumption at the state level. The evaluation is based on the efficiency of alternatives, their cost effectiveness, and the type and magnitude of barriers to their use that are described earlier in this document. It addresses the impact of alternative domestic hot water distribution systems for new housing and existing housing separately. The impact is projected at the point of maximum potential application (penetration) of the technologies, which is projected to be 3 to 5 years after the initiation of the activities described in Section 6.2 (Implementation Plan).

6.1.1 Alternative New Domestic Hot Water Distribution Systems

Assumptions used in this analysis of the potential impact of applying more efficient hot water distribution systems in California's new construction market:

- An average of ~150,000 homes are built per year in California (source: http://www.californiabuildermagazine.com/admin/files/ca_metrotab.pdf)
- The analysis will use the "best" alternative systems for Houses 1-5 from this report
- The analysis assumes a 100% penetration rate since the "best" alternative systems have both a lower or equal initial construction cost and lower ongoing operating costs. This penetration rate would require the support of an aggressive informational campaign to educate builders, plumber, homeowners, and code officials in the first several years (see Section 6.2).
- Houses 1-5 from this report will be used to represent various types of new housing being built in California (see section 3.3.1, New Construction for house descriptions). The ratio of results will be divided between the five types as follows: #1-30%, 45,000 units; #2-10%, 15,000 units; #3-20%, 30,000 units; #4-10%, 15,000 units; and, #5-30%, 45,000 units.
- Alternative systems are compared with a conventional uninsulated copper distribution system buried in the attic insulation (a current practice) in order to determine potential energy and water savings. Using an under-slab location with uninsulated copper pipe (another current practice) as a reference point would increase the projected energy and water savings by about 300-400%.

Analysis of potential impact:

See Tables 6.1 and 6.2 for the summary of the impacts. The "cold start" use pattern yields the highest impact in terms of water and energy savings while the "clustered" use pattern yields the probable minimum impact. The actual annual water and energy savings is between these extremes, though most likely closer to the savings shown in the clustered use pattern analysis.

Opportunity – House #1. From the assumptions listed above for the new construction market, there are approximately 45,000 units built per year of this type that would benefit from alternative hot water distribution systems. The two most efficient systems identified included: a conventional CPVC piping system with demand recirculation located in the attic, and a parallel pipe/manifold system with PEX tubing located in the attic. Both systems have acceptable typical waiting periods for hot water to arrive. Using the performance of these alternative systems in 45,000 units of the House #1 type, there is an annual water savings of between 60 and 358 million gallons and an energy savings of between 38,340 and 226,130 MBTUs compared with the current norm.

Opportunity – House #2. From the assumptions listed above, there are approximately 15,000 units per year of this type that would benefit from alternative hot water distribution systems. The two most efficient systems identified included: a conventional CPVC piping system with demand recirculation located in the attic, and a parallel pipe/manifold system with PEX tubing located in the attic. Both systems have acceptable typical waiting periods for hot water to arrive. Using the performance of these alternative systems in 15,000 units of the House #2 type, there is an annual water savings of between 49 and 148 million gallons and an energy savings of between 31,660 and 91,735 MBTUs compared with the current norm.

Opportunity – House #3. From the assumptions listed above, there are approximately 30,000 units per year of this type that would benefit from alternative hot water distribution systems. The three most efficient systems identified included: a conventional CPVC piping system with demand recirculation located in the attic, a parallel pipe/manifold system with PEX tubing located in the attic and a conventional CPVC piping system located in the attic. The first two systems have acceptable typical waiting periods for hot water to arrive. The waiting time for third system is probably marginally acceptable. Using the performance of these alternative systems in 30,000 units of the House #3 type, there is an annual water savings of between 21 and 222 million gallons and an energy savings of between 13,470 and 139,905 MBTUs compared with the current norm.

Opportunity – House #4. From the assumptions listed above, there are approximately 15,000 units per year of this type that would benefit from alternative hot water distribution systems. The most efficient system identified was a parallel pipe/manifold system with PEX tubing located in the attic. This system has an acceptable waiting period for hot water to arrive. Using the performance of this alternative system in 15,000 units of the House #4 type, there is an annual water savings of between 2 and 47 million gallons and an energy savings of between 1,965 and 30,090 MBTUs compared with the current norm.

Opportunity – House #5. From the assumptions listed above, there are approximately 45,000 units per year of this type that would benefit from alternative hot water distribution systems. The two most efficient systems identified included: a conventional CPVC piping system located in the attic, and a parallel pipe/manifold system with PEX tubing located in the attic. The first system has a marginally acceptable waiting period for hot water to arrive while the second system is fully acceptable. Using the performance of these alternative systems in 45,000 units of the House #5 type, there is an annual water savings of between 4 and 73 million gallons and an energy savings of between 1,710 and 50,575 MBTUs compared with the current norm.

Total Potential Impact in New Construction. Combining the impacts of opportunities (Houses #1 - #5) yields a potential total water savings of between 136 and 848 million gallon per year and a potential energy savings of between 87,145 and 538,435 MBTUs per year.

6.1.2 Existing Domestic Hot Water Distribution Systems

Assumptions used in this analysis of the potential impact of applying more efficient hot water distribution systems in existing California homes:

- The total number of existing homes in California is ~11million.
- 25-50% of existing homes have an unacceptable waiting time (>30 seconds) for hot water (source: Larry Acker, Metlund); this translates to 2.75 to 5.5 million existing homes. Assuming 3.0M homes and a market penetration rate of 10% per year yields 300,000 homes per year for ten years. At the tenth year the existing home market will become saturated.
- 0.1% per year of existing homes has a deteriorated distribution system that requires major repair or replacement, or ~11,000 existing homes per year. This percentage is assumed to continue indefinitely.
- Houses 6-7 from this report will be used to represent the existing housing stock in California. The ratio of results will be evenly divided between the two types.
- Alternative systems are compared with a conventional uninsulated copper distribution system located below the crawl space (common in existing homes) in order to determine potential energy and water savings.

Analysis of potential impact:

See Table 6.1 for the summary of the impacts.

Opportunity – Shorten Waiting Time. From the assumptions listed above for existing homes, there are between 2.75 and 5.5 million existing homes that would significantly benefit from the installation of a demand recirculation system to reduce the waiting time for hot water and water waste. With a simple payback at over eight years for gas water heating, this suggests that the dominant factor in installing this option would be the reduced waiting period. This is likely to reduce the implementation by most residents with modest income, therefore, a 1.5 to 3.0 million homes total market for this approach may be more realistic. Using 1.5 million homes and a market penetration rate of 10% per year yields 150,000 homes per year. Using the performance of this technology from houses #6-7 combined, we have an annual water and energy savings of between 695 and 1,780 million gallons and between 451,350 and 1,128,300 MBTU per year over the existing systems. Once market saturation was reached in ten years there would be no further annual savings to be achieved from this opportunity.

Opportunity – Replace Failed Systems. From the assumptions listed above, there are approximately 11,000 existing homes per year that would require the replacement of the existing hot water distribution system. The most likely system to be used for replacement is a parallel pipe manifold system with PEX tubing. It is assumed that the PEX system, which is easier to install in an existing home, would be selected due to its lower total costs (plumbing system and house restoration after installation). Using the performance of this technology from houses #6-7 combined, we have an annual water savings between 12 and 46 million gallons and energy savings between 8,454 and 34,656 MBTU over a replacement in kind of the existing system.

Total Potential Impact in Existing Housing. Combining the impacts of opportunities (Houses #6-#7) yields a total average water savings between 707 and 1826 million gallons per year and an average energy saving between 459,804 and 1,162,956 MBTUs per year during the first ten years until market saturation of the "shortened waiting time" opportunity was reached. In subsequent years the "replace failed systems" opportunity would continue to increase the total savings with an annual water savings between 12 and 46 million gallons and energy savings between 8,454 and 34,656 MBTU.

Combined New and Existing Housing Impact

Using data from the California Urban Water Conservation Council on per person water consumption in the San Francisco Bay Area, (www.nrdc.org/greengate/water/residentialf.asp) the potential annual savings from using alternative hot water distribution systems would equal the total annual water consumption of between 8,000 and 27,000 California homes. Using water consumption rates from areas with significant irrigation demands could lower the impact measured in homes by 50%. *DOE's Energy Information Agency, Residential Energy Consumption Survey [DOE/EIA-0314(90)]* data for typical household energy consumption shows a potential annual saving due to use of improved distribution systems comparable to the total annual energy consumption of between 8,000 and 24,000 California homes.

The total annual water savings after ten years would equal the total annual water consumption of between 80,000 and 270,000 California homes. The total annual energy savings after ten years would be comparable to the total annual energy consumption of between 80,000 and 240,000 California homes.

Table 6.1 Statewide Impact Assuming Cold Start Water Use Pattern (For New Housing)

House #1 Reference Point: Conventional, CU, In Attic , Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Parallel Pipe, PEX, In Attic, Uninsulated	25,000	4.382	109,550	6,816	170
Substitute: Demand Recirc., CPVC, In Attic, Uninsulated	20,000	5.829	116,580	9,384	188
Total MBTU Savings/Year (This House Type)			**226,130**		**358**

House #2 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Parallel Pipe, PEX, In Attic, Uninsulated	5,000	5.591	27,955	8,748	44
Substitute: Demand Recirc., CPVC, In Attic, Uninsulated	10,000	6.378	63,780	10,392	104
Total MBTU Savings/Year (This House Type)			**91,735**		**148**

House #3 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Parallel Pipe, PEX, In Attic, Uninsulated	15,000	4.143	62,145	6,432	96
Substitute: Demand Recirc., CPVC, In Attic, Uninsulated	15,000	5.184	77,760	8,340	125
Total MBTU Savings/Year (This House Type)			**139,905**		**222**

House #4 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Parallel Pipe, PEX, In Attic, Uninsulated	15,000	2.006	30,090	3,132	47
Total MBTU Savings/Year (This House Type)			**30,090**		**47**

House #5 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Parallel Pipe, PEX, In Attic, Uninsulated	20,000	2.145	42,900	3,312	66
Substitute: Conventional, CPVC, In Attic, Uninsulated	25,000	0.307	7,675	264	7
Total MBTU Savings/Year (This House Type)			**50,575**		**73**

Table 6.1 Statewide Impact Assuming Cold Start Water Use Pattern - Continued (Existing Housing)

House #6 Reference Point: Conventional, CU, Crawl Space, Uninsulated					
Strategy	Housing Units/Year	MBTU Savings Unit/Year	Total MBTU Savings/Year	Gals Saved/ Unit/Year	Mgals Water Saved/Year
Add: Demand Recirc.to Existing CU Conventional System	150,000	3.666	549,900	6,672	1,001
Substitute: Parallel Pipe, PEX, Attic, Uninsulated	5,500	2.763	15,197	4,236	23
Total MBTU Savings/Year (This House Type)			**565,097**		**1,024**

House #7 Reference Point: Conventional, CU, Interstitial, Uninsulated					
Strategy	Housing Units/Year	MBTU Savings Unit/Year	Total MBTU Savings/Year	Gals Saved/ Unit/Year	Mgals Water Saved/Year
Add: Demand Recirc.to Existing CU Conventional System	150,000	3.856	578,400	5,196	779
Substitute: Parallel Pipe, PEX, Interstitial, Uninsulated	5,500	3.538	19,459	4,212	23
Total MBTU Savings/Year (This House Type)			**597,859**		**803**

Total Energy Savings (MBTU) Per Year in California	**1,701,391**
Natural Gas Savings (MBTU) Per Year in California	**1,446,182**
Electricity Savings (MBTU - End Use) Per Year in California	**255,209**
Total Water Savings (Mgals) Per Year in California	**2,674**

Table 6.2 Statewide Impact Assuming Clustered Water Use Pattern (For New Housing)

House #1 Reference Point: Conventional, CU, In Attic , Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Conventional with Central WH, PEX, In Attic, Unins	6,750	0.614	4,145	936	6
Substitute: Demand Recirc., CPVC, In Attic, Uninsulated	38,250	0.089	3,420	1,416	54
Total MBTU Savings/Year (This House Type)			**7,564**		**60**

House #2 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Parallel Pipe, PEX, In Attic, Uninsulated	5,000	1.936	9,680	3,024	15
Substitute: Demand Recirc., CPVC, In Attic, Uninsulated	10,000	2.198	21,980	3,420	34
Total MBTU Savings/Year (This House Type)			**31,660**		**49**

House #3 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Demand Recirc., CPVC, In Attic, Uninsulated	30,000	0.449	13,470	696	21
Total MBTU Savings/Year (This House Type)			**13,470**		**21**

House #4 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Conventional, CPVC, In Attic, Uninsulated	15,000	0.131	1,965	132	2
Total MBTU Savings/Year (This House Type)			**1,965**		**2**

House #5 Reference Point: Conventional, CU, In Attic, Uninsulated					
Strategy	**Housing Units/Year**	**MBTU Savings Unit/Year**	**Total MBTU Savings/Year**	**Gals Saved/ Unit/Year**	**Mgals Water Saved/Year**
Substitute: Parallel Pipe, PEX, In Attic, Uninsulated	45,000	0.038	1,710	84	4
Total MBTU Savings/Year (This House Type)			**1,710**		**4**

Table 6.2 Statewide Impact Assuming Clustered Water Use Pattern - Continued (Existing Housing)

House #6 Reference Point: Conventional, CU, Crawl Space, Uninsulated					
Strategy	Housing Units/Year	MBTU Savings Unit/Year	Total MBTU Savings/Year	Gals Saved/ Unit/Year	Mgals Water Saved/Year
Add: Demand Recirc.to Existing CU Conventional System	150,000	1.880	282,000	3,108	466
Substitute: Parallel Pipe, PEX, Attic, Uninsulated	5,500	1.071	5,891	1,740	10
Total MBTU Savings/Year (This House Type)			**287,891**		**476**

House #7 Reference Point: Conventional, CU, Interstitial, Uninsulated					
Strategy	Housing Units/Year	MBTU Savings Unit/Year	Total MBTU Savings/Year	Gals Saved/ Unit/Year	Mgals Water Saved/Year
Add: Demand Recirc.to Existing CU Conventional System	150,000	1.129	169,350	1,524	229
Substitute: Parallel Pipe, PEX, Interstitial, Uninsulated	5,500	0.466	2,563	408	2
Total MBTU Savings/Year (This House Type)			**171,913**		**231**

Total Energy Savings (MBTU) Per Year in California	**546,949**
Natural Gas Savings (MBTU) Per Year in California	**464,906**
Electricity Savings (MBTU - End Use) Per Year in California	**82,042**
Total Water Savings (Mgals) Per Year in California	**843**

6.2 Implementation Plan to Guide Further Energy Commission Activities

This section identifies seven action areas which could materially impact the use of more efficient residential hot water distribution systems within the state. Several action areas (e.g. Plumbing and Building Code Acceptance, Pursue Additional Research,) could be addressed through the Energy Commission working in concert with other groups and agencies since the tasks are national in scope. In the other action areas the Energy Commission could individually accomplish the task (e.g., Title 24 Revisions) or work with others within California to bring about the needed changes (e.g., Educate California contractors and homeowners).

1. Plumbing and Building Code Acceptance of Technologies

The Energy Commission could work with applicable code organizations on revisions that permit the use of non-conventional hot water distribution systems and materials where these have demonstrated the potential to significantly impact the overall distribution systems performance. The Energy Commission could also support efforts to update the current methodology of sizing of plumbing systems to reflect current fixture consumption rates, water use patterns (draw cycles), and the demographics of current California housing.

2. Assessment and Ranking of Technologies by State Building Code (Title 24)

The Energy Commission could develop assessment methodologies that appropriately reflect the performance of non-conventional distribution systems. The Energy Commission could also support efforts to validate and refine current computer simulation models that will contribute to this assessment effort, in particular under-slab installations and those with insulation. Finally, the Energy Commission could implement these assessments in future versions of Title 24 to appropriately credit the better alternative systems and materials. Specific areas in which the conclusions of this study appear to differ with the current draft Title 24 include:

- The insulation of demand “recirculation” systems does not appear warranted regardless of system location.
- The cost/benefit of using insulation on under-slab piping is not compelling, based on simulation results in this study. For a copper pipe distribution system with a gas water heater the simple payback from adding insulation ranged from ~4 years to ~8 years depending on the house being evaluated, and for CPVC pipe the paybacks were longer.
- The Demand Side Management (DSM) factors applied to demand recirculation systems, continuous recirculation, and parallel pipe systems should be adjusted to better reflect each system’s performance.

3. Pursue Additional Research Needs

Appendix C contains descriptions of the additional research needed to enhance the knowledge of residential hot water distribution systems. This enhanced knowledge is needed to better understand what the most important energy efficiency and water efficiency issues are and pursue them effectively. This understanding is central to enabling the following areas to be effectively accomplished.

4. Development of Efficient Hot Water Distribution Technologies

This research has shown that more efficient residential hot water distribution system technologies are needed in the marketplace. What follows is a short and unprioritized list of hot water distribution system technologies that may improve residential water and/or energy use efficiencies:

- A high market demand for shortened waiting periods is driving the installation of continuous recirculation systems. Methods to conserve energy while using continuous recirculation systems should be investigated and, where cost-effective, mandated. The primary focus should be on automated controls based on time, temperature, and/or occupancy. Current controls need to be refined and their use mandated.
- Another technology useful for recirculation systems could be to develop significantly more effective pipe insulation materials than those currently available, in order to improve the performance of these systems.
- The current demand control recirculation systems are beginning to evolve from manual actuation to activation by motion sensors. Automating these systems would eliminate a complaint voiced by some that they either forget to activate the systems or don't like the requirement that they do so.
- The tubing size used in the parallel pipe manifold systems is believed to be somewhat oversized for low-flow applications. Development and testing of a ¼" diameter tube may provide still further improvement in efficiency from the use of these systems.
- The integration of effective thermal insulation into the manufacture of tubing such as PEX might reduce the cost of insulating distribution systems and thereby increase the cost effectiveness of this potential conservation strategy.
- Point-of-use electric water heating for remote and low demand locations could be developed to reduce the length of hot water distribution systems and thereby also reduce the waiting period. Combining point-of-use heaters with waste heat recovery devices could make relatively modest capacity units effective in serving showers.

5. Establish a Collaborative Relationship with Water-Related Stakeholders

The Energy Commission should work through California government agencies and other interested residential water system stakeholders such as the Urban Water Conservation Council (CUWCC). Such groups could be coordinated to carry out cooperative research that would ultimately result in one or more Best Management Practices (BMP) being added to the California list of water-related BMPs. A collaborative relationship with a group such as the CUWCC would also benefit the process of addressing the two proposed education and technology acceptance activities that follow.

6. Contractor Education and Acceptance of Technologies

Awareness of efficient alternative hot water distribution systems and materials is mixed at best among the plumbing and general contracting community. . In addition, incentives to change current practices have not been clearly demonstrated and code acceptance varies widely, all of which make adopting alternative distribution systems an impediment to getting the job done. Contractors must have confidence in the performance of any alternative systems or materials because their profitability depends on minimizing "call-backs" to correct defective items. In the highly competitive residential marketplace, material availability and cost as well as potential labor training requirements and cost impact the contractors' selection process. The Energy Commission should consider collaborating with trade organizations, materials suppliers and others to increase contractor awareness and acceptance of alternative systems and materials.

7. Homeowner Education and Acceptance of Technologies

Hot water distribution system performance is also very important to the homeowner. The distribution system is expected to provide a reasonable flow of hot water within a short time and at reasonable water and energy costs. Unfortunately, homeowners evaluate their distribution system's performance based primarily on flow and wait times, since these factors are immediately evident. The other performance factors of energy cost and water cost are delayed until the utility bills are received, well after the actual use of the hot water. The homeowner is rarely aware of what alternatives are available and how they perform. The Energy Commission could assist in the dissemination of information on the performance of alternative hot water distribution systems and materials. Some possible methods include teaming with utilities and/or municipalities to distribute information to consumers via their utility billing process or using the Energy Commission website to provide tips to homeowners on the topic.

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8. References

The following documents were reviewed in the preparation of this report. They are listed in reverse chronological order.

Lutz, J. D., G. Klein, D. Springer, and B. D. Howard. "Residential Hot Water Distribution Systems: Roundtable Session," presented at 2002 ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, CA, 2002

Wiehagan, J. and Sikora, J. "Performance Comparison of Residential Hot Water Systems" NAHB Research Center, Inc. for NREL, November 2002

Wiehagan, J. and Sikora, J. "Domestic Hot Water System Modeling for the Design of Energy Efficient Systems" NAHB Research Center, Inc. for NREL, April 2002

G. Henze, D. Tiller, M. Fischer, and M. Rieger. "Comparison of Event Inference and Flow Trace Signature Methods for Hot Water End Use Analysis," ASHRAE Transactions, 2002

Mayer, P.W., et al "Residential End Uses of Water" American Water Works Association, Denver, CO, 1999

Stewart, W.E., Saunders, C.K., and Dona, C.L. "Evaluation of Service Hot Water Distribution System Losses in Residential and Commercial Installations: Part 1 – Field/Laboratory Experiments and Simulation Model" ASHRAE Transactions 1999, V.105, Pt.1, 1999

Stewart, W.E., Saunders, C.K., and Dona, C.L. "Evaluation of Service Hot Water Distribution System Losses in Residential and Commercial Installations: Part 2 – Simulations and Design Practices" ASHRAE Transactions 1999, V.105, Pt.1, 1999

Abrams D.W., "Field Test Results from Residential Electric Water-heating Systems" ASHRAE Transactions, Vol.104, Part 1B, 1998

Hiller, C.C. "New Hot Water Consumption Analysis and Water Heating System Sizing Methodology" ASHRAE Transaction Symposia, pp. 1864-1877, March 1998

Lowenstein, A., and Hiller, C.C. "Disaggregating Residential Hot Water Use – Part II" ASHRAE Transaction Symposia, pp. 1852-1863, February 1998

Abrams, D.W., and Shedd, A.C., "Effect of Seasonal Changes in Use Patterns and Cold Inlet Water Temperature on Water-heating Loads", ASHRAE Transactions, Vol. 102, Part 1, 1996

DeOreo, W.B., Heaney, J.P., and Mayer, P.W., "Flow Trace Analysis to Assess Water Use", Journal of the American Water Works Association, Vol. 88, No.1, 1996

Lowenstein, A., and Hiller, C.C. "Disaggregating Residential Hot Water Use" ASHRAE Transaction Symposia pp. 1019-1026, January 1996

Paul, D.D., Ide, B.E., and Hanford, P.A. “Residential Hot Water Usage: A Review of Published Metered Studies”, GRI Report No. GRI-94/0442, Battelle, 1994

Becker, B.R., Thrasher, W.H., and DeWerth, D.W. “Comparison of Collected and Complied Existing Data on Service Hot Water Use Patterns in Residential and Commercial Establishments”, ASHRAE Transactions, Vol.96, Part 2, 1991

___, "Volume I: Final Report Residential Water Heating Study," Davis Energy Group, Davis California Energy Commission Contract 400-88-003, March 31, 1991

___, "Volume II: Appendices Residential Water Heating Study," Davis Energy Group, Davis California Energy Commission Contract 400-88-003, March 31, 1991.

Becker, B.R., and Stogsdill, D.E. “Domestic Hot Water Use Database” ASHRAE Journal, pp. 21-25, September 1990

Perlman, M., and Mills, B.E. “Development of Residential Hot Water Use Patterns” ASHRAE Transactions 91:2, pp. 657-679, 1985

Cooper, K., and Johnson, G. “Hot Water Demand Patterns for 12 Units in Matheson Heights Vancouver” NRC Research Report OSX81-00179, 1983

Schultz, W.W., and Goldschmidt, V.W., “Distribution Efficiency and Characteristics of Start-up and Shutdown of Flow in Hot Water Distribution Lines”, ASHRAE Transactions 89:10, pp. 42-59, 1983

Stevenson, D.H., “Residential Hot Water Use Patterns”, CEA Research Report 111U268, 1983

Schultz, W.W., and Goldschmidt, V.W., “Effect of Distribution on Stand-by Loss of Service Water Heater”, ASHRAE Transactions, 84:1, pp. 256-263, 1978

Hunter, R. B., "Methods for Estimating Loads in Plumbing Systems", National Bureau of Standards BMS-65, 1940

9. Glossary

Clustered use draw cycle – Assumes that individual hot water draws are clustered in the early morning and late afternoon/evening hours as might be expected from a family that spent the middle of the day away from their home.

Cold start draw cycle – Assumes that the water in the pipe cools down to the ambient temperature surrounding the pipe before each subsequent use as might be expected if hot water uses were separated by many hours.

Continuous recirculation system – A distribution system that has supply and return pipes that form a loop from the water heater. A pump usually near the water heater continuously circulates hot water through the loop. Individual fixtures are served from branches off the loop.

Conventional trunk and branch system – A distribution system that uses one or more larger pipes (trunks) from the water heater to feed a series on smaller pipes (branches) to serve individual fixtures.

CPVC – Chlorinated Poly Vinyl Chloride, one type of rigid plastic pipe of various sizes.

CU – Copper, both rigid pipe and flexible rolled tubing of various sizes.

Demand recirculation system – A conventional trunk and branch distribution system which has a demand actuated pump to transfer "cool" water in the hot water line to the cold water line usually at the fixture that is furthest from the water heater.

DSM – Demand Side Management

EF – U.S. Department of Energy's energy factor for electric and gas water heaters

HWDS – Hot water distribution systems

OH&P – Overhead and Profit, a percentage added to the direct labor and materials costs by contractors

ORNL – Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831

Parallel pipe manifold system – A distribution system that locates a manifold near the water heater and provides individual, small diameter, lines from the manifold to each individual fixture.

PEX – Cross-linked Polyethylene, one type of flexible plastic tubing of various sizes.

Appendices

Appendix A. - Representative Housing Results

A plan of representative new California houses #1 - #5 are shown in this appendix, along with several different hot water distribution system layouts for the House #1 plan. Plans of representative existing California houses # 6 and #7 are also shown in this appendix. For each of the seven representative California houses (new and existing), construction costs for that house plus charts of Monthly Water and Energy Waste for both a cold start draw cycle and a clustered draw cycle are presented.

The data provided from these computer analyses provides a relative ranking of the various systems and options. Since each is based on a specific set of modeling assumptions regarding hot water use, system layout, and the environmental conditions around the distribution systems, the savings associated with the various alternatives should not be viewed as either absolute or directly transferable to another house. However, trends identified by these simulations are useful in identifying those systems and options that are relatively more efficient and therefore likely to produce actual savings under "real world" conditions. These projected savings should also be verified through field monitoring of actual installations.

Representative Housing Results - New Construction

House #1 – Single Family, Three Bedroom, Two Bath, One Story, 2010 ft^2
This unit represents a typical single story house. It contains a laundry room, one bath with a combined tub and a shower along with two lavatories, and another full bath with a tub/shower and one lavatory. The kitchen includes a sink and dishwasher. The water heater is in the garage. The layout of the house spreads hot water consuming devices throughout the house.

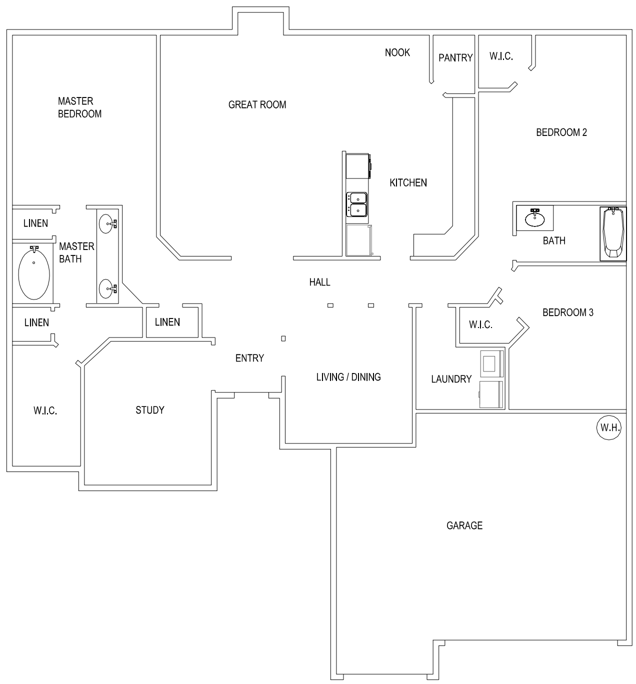

Figure A-1 House #1 - Floor Plan

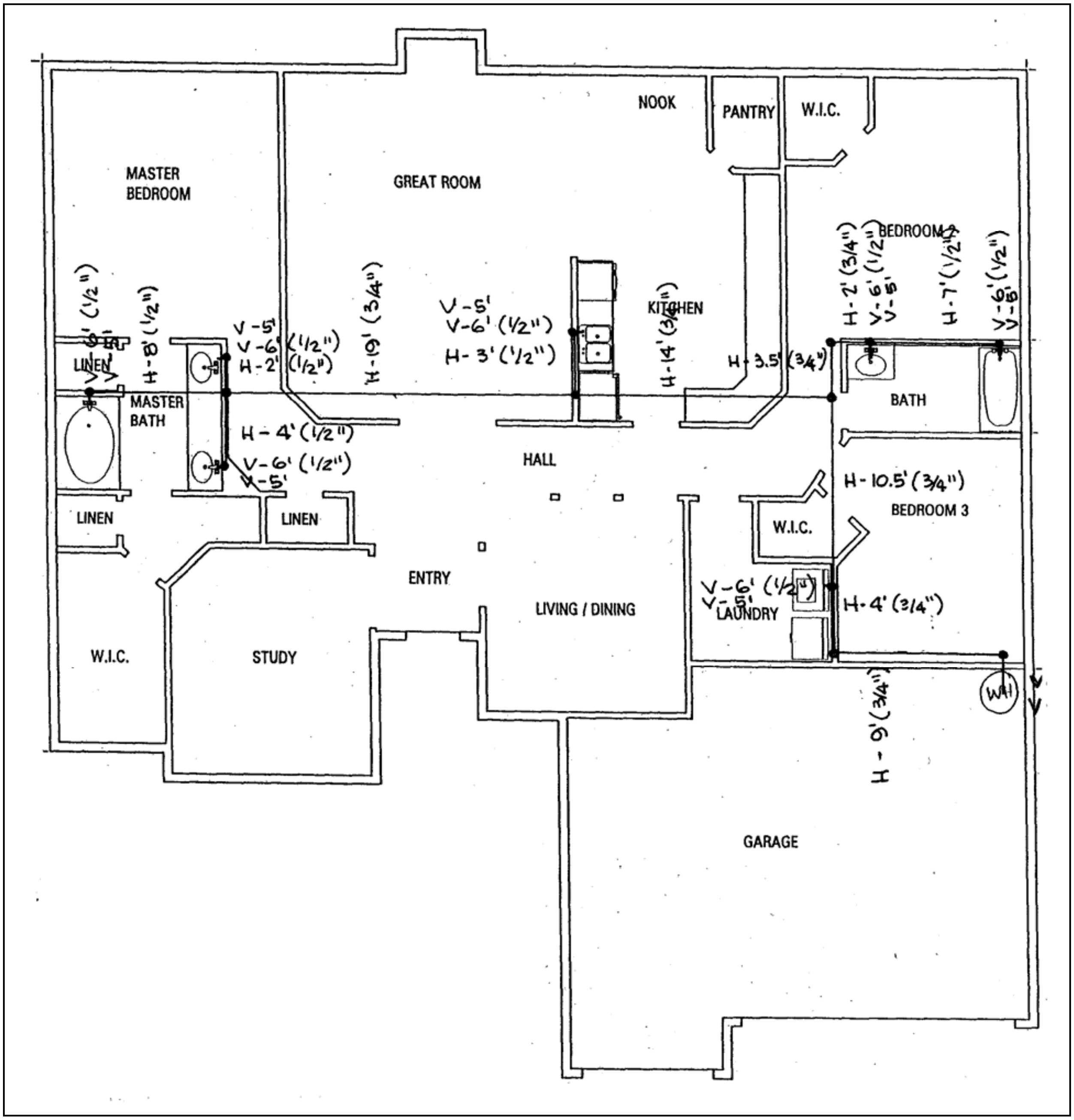

Figure A-2 House #1 - Conventional Distribution System

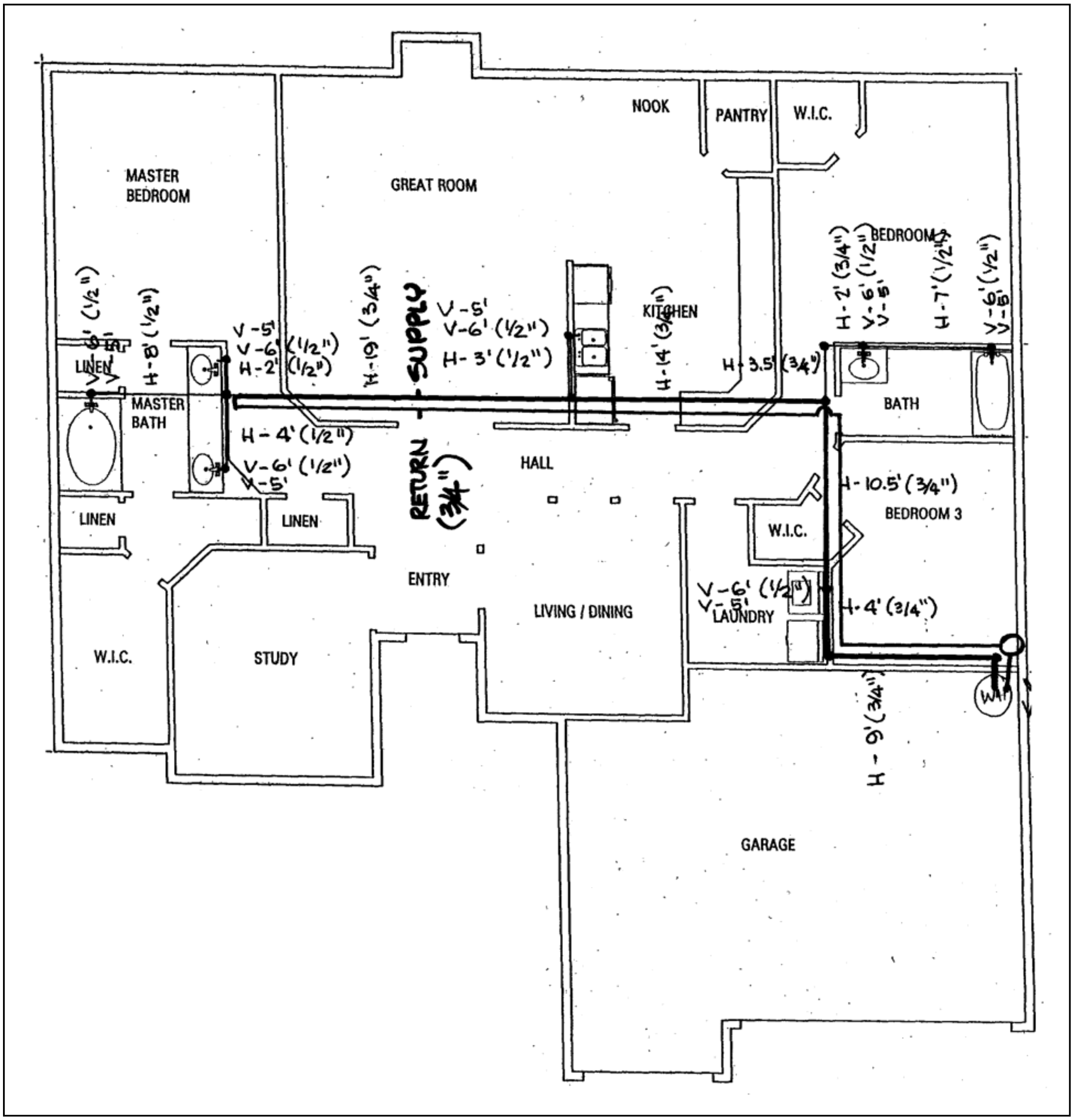

Figure A-3 House #1 - Continuous Recirculation Distribution System

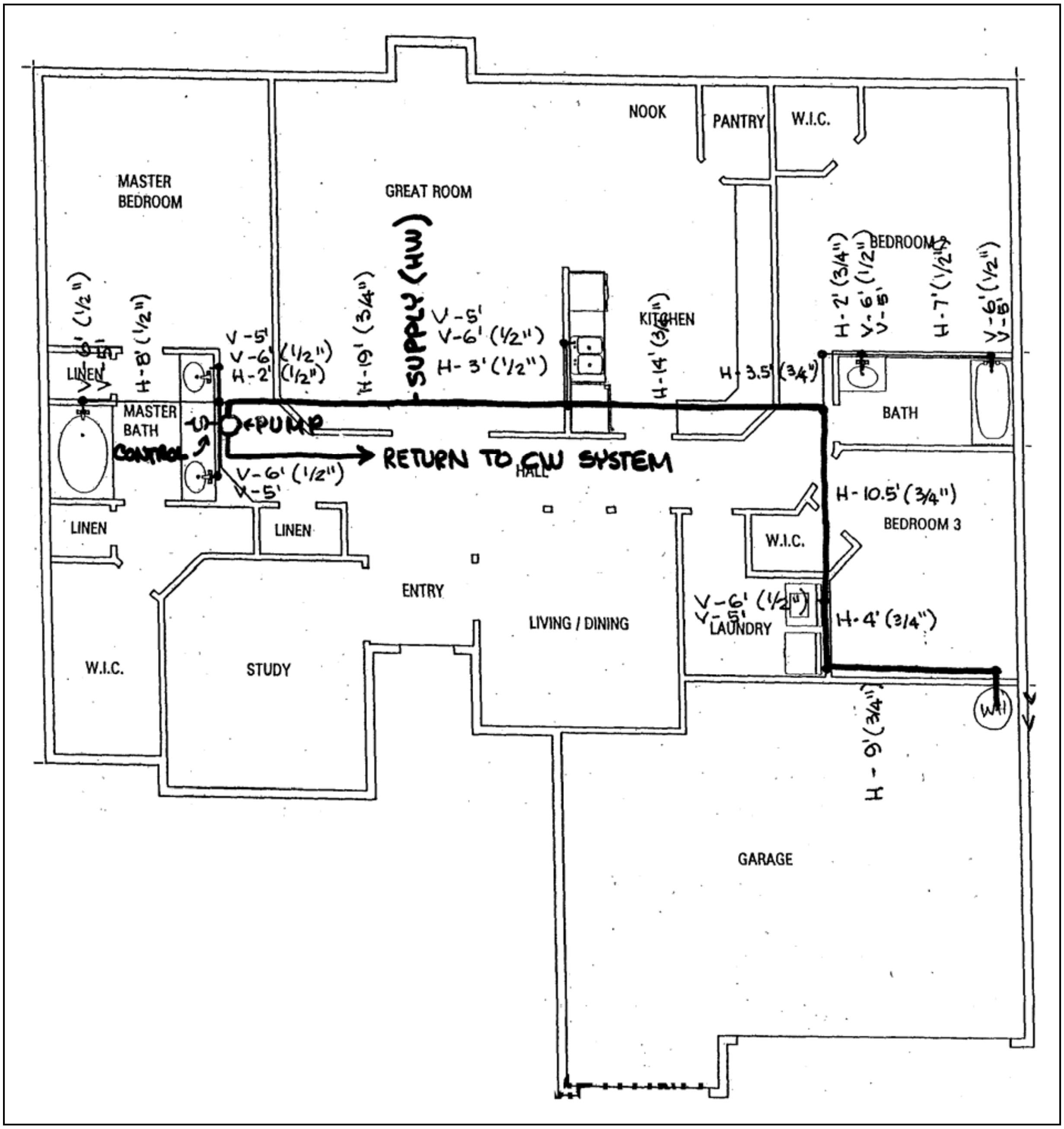

Figure A-4 House #1 - Demand Actuated Recirculation Distribution System

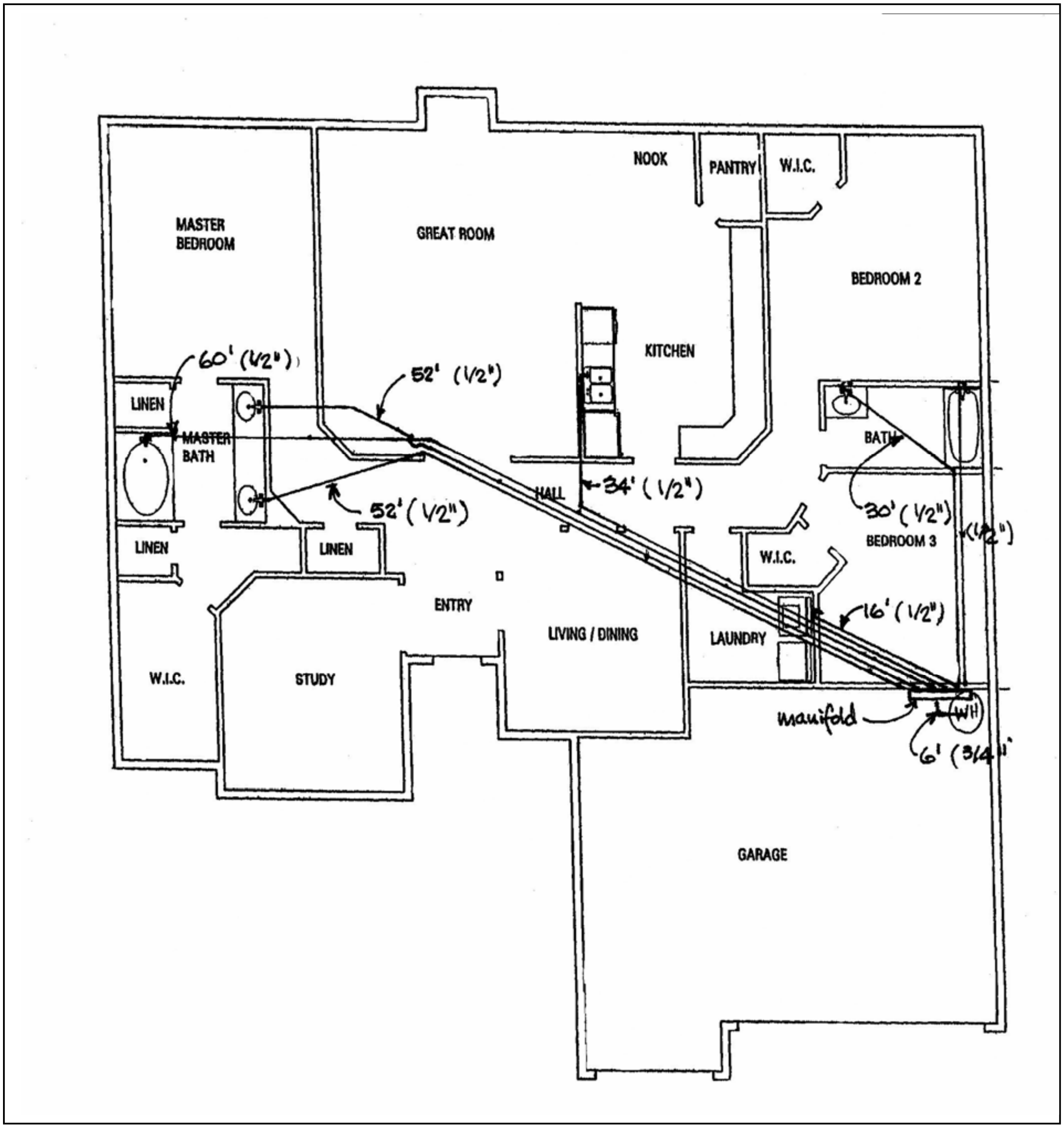

Figure A-5 House #1 - Parallel Pipe/Manifold Distribution System

Table A-1 Construction Costs for House #1

Scenario	Cost
Conventional, Central WH Location, Copper, attic, uninsulated	$1150
Conventional, Central WH Location, CPVC, attic, uninsulated	$787
Conventional, Copper, attic or crawl space, uninsulated	$1271
Conventional, Copper, attic or crawl space, insulated	$1552
Conventional, CPVC, attic or crawl space, uninsulated	$866
Conventional, CPVC, attic or crawl space, insulated	$1147
Conventional, Copper, under-slab, uninsulated	$1556
Conventional, Copper, under-slab, insulated	$1838
Conventional, CPVC, under-slab, uninsulated	$1086
Conventional, CPVC, under-slab, insulated	$1368
Conventional w/ Demand Recirculation, Copper, attic or crawl space, uninsulated	$1880
Conventional w/ Demand Recirculation, Copper, under-slab, insulated	$2447
Conventional w/ Demand Recirculation, CPVC, attic or crawl space, uninsulated	$1475
Conventional w/ Demand Recirculation, CPVC, under-slab, insulated	$1978
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$1226
Parallel Pipe/Manifold System, PEX tubing, under-slab, uninsulated	$1443
Conventional w/ Continuous Recirculation, Copper, attic or crawl space, insulated	$2559
Conventional w/ Continuous Recirculation, Copper, under-slab, insulated	$2861
Conventional w/ Continuous Recirculation, CPVC, attic or crawl space, insulated	$1965
Conventional w/ Continuous Recirculation, CPVC, under-slab, insulated	$2185

Table A-2 House #1 - Monthly Water and Energy Waste (Cold Start Draw Cycle)

House-1	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	11	42	43	435	256,948	23,606	0.49	10.80	3.37
Conv Attic CPVC - Central	11	41	42	426	251,851	10,119	0.48	10.08	3.15
Conv Attic Cu	37	60	103	882	521,391	50,105	1.00	22.00	6.87
Conv Attic Cu-Ins	37	60	104	883	522,140	51,092	1.00	22.07	6.89
Conv Attic CPVC	35	57	99	839	496,431	26,163	0.95	20.11	6.28
Conv Attic CPVC-Ins	35	57	99	839	496,431	26,433	0.95	20.12	6.28
Conv CS Cu	37	60	104	892	527,612	58,810	1.01	22.58	7.05
Conv CS Cu-Ins	37	60	104	892	527,612	57,115	1.01	22.52	7.03
Conv CS CPVC	35	57	100	849	501,902	29,741	0.96	20.46	6.39
Conv CS CPVC-Ins	35	57	100	849	501,902	29,494	0.96	20.45	6.39
Conv Slab Cu	38	63	111	932	551,223	114,335	1.06	25.66	8.01
Conv Slab Cu-Ins	37	60	104	884	522,890	79,804	1.00	23.22	7.25
Conv Slab CPVC	36	58	100	862	509,998	35,439	0.98	20.99	6.56
Conv Slab CPVC-Ins	36	58	100	862	509,998	30,818	0.98	20.81	6.50
Demand Recir Attic Cu *	5	6	9	99	58,390	67,669	0.11	4.89	1.53
Demand Recir Slab Cu *	4	5	8	83	48,871	157,283	0.09	8.02	2.50
Demand Recir Attic CPVC *	5	6	9	100	59,140	26,594	0.11	3.31	1.03
Demand Recir Slab CPVC *	4	5	8	85	50,295	38,218	0.10	3.43	1.07
Parallel Attic PEX	12	23	36	314	185,440	20,911	0.36	7.95	2.48
Parallel Slab PEX	12	24	38	324	191,362	26,747	0.37	8.40	2.62

NOTES:
* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

Table A-3 House #1 - Monthly Water and Energy Waste (Clustered AM & PM Draw Cycle)

House-1	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	2	5	40	117	69,334	6,847	0.13	2.93	0.92
Conv Attic CPVC - Central	2	5	39	119	70,458	3,342	0.14	2.84	0.89
Conv Attic Cu	2	5	99	196	115,881	11,435	0.22	4.90	1.53
Conv Attic Cu-Ins	1	5	99	195	115,207	11,145	0.22	4.86	1.52
Conv Attic CPVC	2	5	95	191	113,108	6,200	0.22	4.59	1.43
Conv Attic CPVC-Ins	2	5	95	191	113,108	6,151	0.22	4.59	1.43
Conv CS Cu	3	9	103	410	242,631	22,360	0.47	10.20	3.19
Conv CS Cu-Ins	2	5	102	203	119,854	12,837	0.23	5.11	1.60
Conv CS CPVC	2	8	98	359	212,499	12,196	0.41	8.65	2.70
Conv CS CPVC-Ins	2	5	98	200	118,205	7,305	0.23	4.83	1.51
Conv Slab Cu	32	54	109	845	499,878	90,351	0.96	22.75	7.10
Conv Slab Cu-Ins	2	4	102	192	113,708	16,245	0.22	5.01	1.56
Conv Slab CPVC	28	50	98	767	453,631	31,538	0.87	18.67	5.83
Conv Slab CPVC-Ins	2	5	98	192	113,783	7,076	0.22	4.65	1.45
Demand Recir Attic Cu *	2	5	9	77	45,273	12,030	0.09	2.21	0.69
Demand Recir Slab Cu *	2	4	8	66	39,052	17,997	0.08	2.20	0.69
Demand Recir Attic CPVC *	2	5	9	78	46,397	6,418	0.09	2.03	0.64
Demand Recir Slab CPVC *	2	4	8	70	41,600	7,826	0.08	1.90	0.59
Parallel Attic PEX	2	11	36	196	115,881	15,042	0.22	5.04	1.57
Parallel Slab PEX	9	19	38	286	168,875	24,098	0.32	7.43	2.32
Recir Attic Cu-Ins **	2	5	9	77	45,273	267,509	0.09	12.18	3.80
Recir Slab Cu-Ins **	2	4	8	66	39,052	872,443	0.08	35.55	11.10
Recir Attic CPVC-Ins **	2	5	9	78	46,397	291,240	0.09	13.15	4.11
Recir Slab CPVC-Ins **	2	4	8	70	41,600	790,345	0.08	32.45	10.13

NOTES:
* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.
** Energy supplied to the continuous recirculation system pump is calculated as 755.55 kWh/year or 62.9 kWh/month, which equals approximately $7.30/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

House #2 – Single Family, Four Bedroom, 2½ Bath, One Story, 3080 ft^2
This unit represents a larger single-story house than House #1 (by 50%). It contains a laundry room, one bath with a separate tub and a shower stall along with two lavatories, a half bath (lavatory only), and another full bath with a tub/shower and two lavatories. The large kitchen includes a sink and dishwasher. The water heater is in the garage. The house's layout spreads the hot water consuming devices to the four corners of the house.

Figure A-6 House #2 – Floor Plan

Table A-4 Construction Costs for House #2

Scenario	**Cost**
Conventional, Central WH Location, Copper, attic, uninsulated	$1971
Conventional, Central WH Location, CPVC, attic, uninsulated	$1337
Conventional, Copper, attic or crawl space, uninsulated	$1960
Conventional, Copper, attic or crawl space, insulated	$2446
Conventional, CPVC, attic or crawl space, uninsulated	$1306
Conventional, CPVC, attic or crawl space, insulated	$1793
Conventional, Copper, under-slab, uninsulated	$2586
Conventional, Copper, under-slab, insulated	$3072
Conventional, CPVC, under-slab, uninsulated	$1787
Conventional, CPVC, under-slab, insulated	$2199
Conventional w/ Demand Recirculation, Copper, attic or crawl space, uninsulated	$2569
Conventional w/ Demand Recirculation, Copper, under-slab, insulated	$3581
Conventional w/ Demand Recirculation, CPVC, attic or crawl space, uninsulated	$1916
Conventional w/ Demand Recirculation, CPVC, under-slab, insulated	$2808
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$1578
Parallel Pipe/Manifold System, PEX tubing, under-slab, uninsulated	$2038
Conventional w/ Continuous Recirculation, Copper, attic or crawl space, insulated	$3548
Conventional w/ Continuous Recirculation, -Copper, under-slab, insulated	$4097
Conventional w/ Continuous Recirculation, CPVC, attic or crawl space, insulated	$2707
Conventional w/ Continuous Recirculation, CPVC, under-slab, insulated	$3113

Table A-5 House #2 - Monthly Water and Energy Waste (Cold Start Draw Cycle)

House-2	Wait Time for HW (Sec.)			Water Wasted	Energy Loss Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	18	35	98	789	466,673	46,409	0.90	19.75	6.17
Conv Attic CPVC - Central	17	34	94	765	452,432	23,852	0.87	18.33	5.72
Conv Attic Cu	10	49	171	1,111	657,210	62,495	1.26	27.71	8.65
Conv Attic Cu-Ins	10	49	171	1,111	657,210	63,592	1.26	27.75	8.67
Conv Attic CPVC	10	48	164	1,070	633,075	31,211	1.22	25.56	7.98
Conv Attic CPVC-Ins	10	48	164	1,070	633,075	31,466	1.22	25.57	7.99
Conv CS Cu	10	50	173	1,123	664,106	72,095	1.28	28.35	8.85
Conv CS Cu-Ins	10	50	173	1,129	667,854	71,267	1.28	28.46	8.89
Conv CS CPVC	10	49	166	1,080	638,546	34,997	1.23	25.92	8.09
Conv CS CPVC-Ins	10	49	166	1,080	638,546	34,782	1.23	25.91	8.09
Conv Slab Cu	10	52	189	1,198	708,555	135,721	1.36	32.54	10.16
Conv Slab Cu-Ins	10	50	173	1,123	664,106	99,622	1.28	29.42	9.19
Conv Slab CPVC	10	49	168	1,089	644,018	40,728	1.24	26.35	8.23
Conv Slab CPVC-Ins	10	49	168	1,088	643,643	36,349	1.24	26.17	8.17
Demand Recir Attic Cu *	6	8	49	241	142,640	91,988	0.27	9.07	2.83
Demand Recir Slab Cu *	5	8	52	246	145,564	200,882	0.28	13.44	4.20
Demand Recir Attic CPVC *	6	9	48	245	144,889	43,292	0.28	7.26	2.27
Demand Recir Slab CPVC *	6	9	52	256	151,560	65,263	0.29	8.37	2.62
Parallel Attic PEX	9	21	52	382	225,916	27,880	0.43	9.77	3.05
Parallel Slab PEX	9	21	56	394	232,887	36,675	0.45	10.39	3.24

NOTES:
* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

Table A-6 House #2 - Monthly Water and Energy Waste (Clustered AM & PM Draw Cycle)

House-2	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	2	13	92	377	222,993	22,729	0.43	9.46	2.95
Conv Attic CPVC - Central	2	13	89	355	210,175	11,535	0.40	8.53	2.66
Conv Attic Cu	2	9	114	445	263,244	26,332	0.51	11.15	3.48
Conv Attic Cu-Ins	2	9	114	446	263,918	26,533	0.51	11.18	3.49
Conv Attic CPVC	2	9	110	431	254,849	13,601	0.49	10.33	3.23
Conv Attic CPVC-Ins	2	9	109	430	254,099	13,733	0.49	10.31	3.22
Conv CS Cu	0	32	111	643	380,549	38,185	0.73	16.12	5.04
Conv CS Cu-Ins	2	9	117	455	269,390	29,049	0.52	11.49	3.59
Conv CS CPVC	0	31	102	609	359,936	19,229	0.69	14.59	4.56
Conv CS CPVC-Ins	2	10	112	439	259,646	14,932	0.50	10.57	3.30
Conv Slab Cu	10	49	174	1,108	655,336	116,268	1.26	29.73	9.29
Conv Slab Cu-Ins	2	9	117	450	266,392	39,223	0.51	11.77	3.68
Conv Slab CPVC	2	46	157	978	578,432	42,297	1.11	23.89	7.46
Conv Slab CPVC-Ins	2	10	113	433	255,973	15,462	0.49	10.45	3.26
Demand Recir Attic Cu *	2	7	45	158	93,170	21,829	0.18	4.43	1.38
Demand Recir Slab Cu *	2	7	51	217	128,324	193,741	0.25	12.50	3.90
Demand Recir Attic CPVC *	2	8	44	160	94,669	11,778	0.18	4.10	1.28
Demand Recir Slab CPVC *	2	8	51	223	131,697	84,515	0.25	8.36	2.61
Parallel Attic PEX	2	9	46	193	113,932	14,311	0.22	4.94	1.54
Parallel Slab PEX	8	20	50	348	205,528	31,526	0.39	9.13	2.85
Recir Attic Cu-Ins **	2	19	53	317	187,464	360,666	0.36	21.28	6.65
Recir Slab Cu-Ins **	2	19	52	311	183,866	1,101,737	0.35	50.07	15.64
Recir Attic CPVC-Ins **	2	5	51	203	120,304	374,577	0.23	19.24	6.01
Recir Slab CPVC-Ins **	2	5	51	205	121,053	1,005,310	0.23	43.89	13.71

NOTES:

* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

** Energy supplied to the continuous recirculation system pump is calculated as 755.55 kWh/year or 62.9 kWh/month, which equals approximately $7.30/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

House #3 – Single Family, Four Bedroom, Three Bath, Two Story, 2810 ft^2
This unit represents a moderately sized two-story house. It contains a laundry room, one full bath with tub/shower, and a moderately sized kitchen with sink and dishwasher on the first floor. The second floor includes two full baths. One bath has a tub/shower and two lavatories. The other bath has both a tub and a shower stall along with two lavatories. The water heater is located in the garage adjacent to the laundry room. The hot water distribution system layout is fairly compact for the area of the unit.

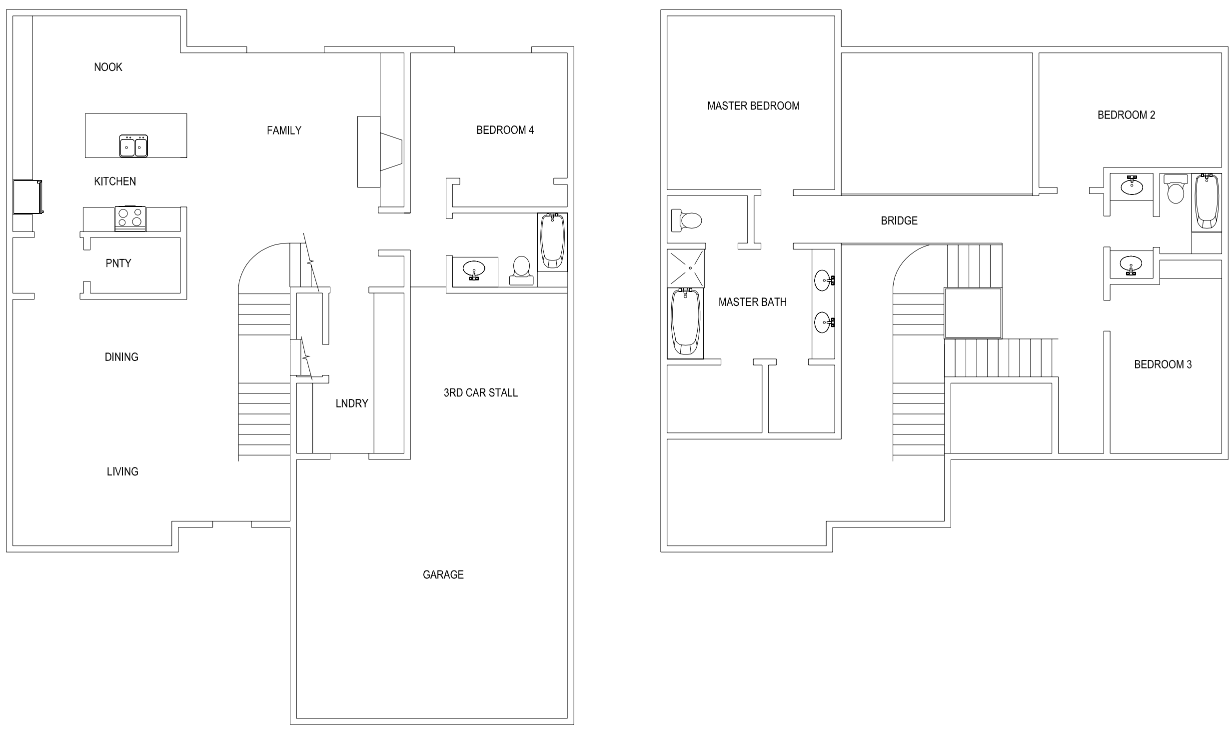

Figure A-7 House #3 - Floor Plan (first floor/left, second floor/right)

Table A-7 Construction Costs for House #3

Scenario	Cost
Conventional, Central WH Location, Copper, attic, uninsulated	$1931
Conventional, Central WH Location, CPVC, attic, uninsulated	$1038
Conventional, Copper, attic or crawl space, uninsulated	$1716
Conventional, Copper, attic or crawl space, insulated	$2103
Conventional, CPVC, attic or crawl space, uninsulated	$1144
Conventional, CPVC, attic or crawl space, insulated	$1531
Conventional, Copper, under-slab, uninsulated	$1896
Conventional, Copper, under-slab, insulated	$2283
Conventional, CPVC, under-slab, uninsulated	$1293
Conventional, CPVC, under-slab, insulated	$1680
Conventional w/ Demand Recirculation, Copper, attic or crawl space, uninsulated	$2326
Conventional w/ Demand Recirculation, Copper, under-slab, insulated	$2892
Conventional w/ Demand Recirculation, CPVC, attic or crawl space, uninsulated	$1754
Conventional w/ Demand Recirculation, CPVC, under-slab, insulated	$2289
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$1729
Parallel Pipe/Manifold System, PEX tubing, under-slab, uninsulated	$1927
Conventional w/ Continuous Recirculation, Copper, attic or crawl space, insulated	$2978
Conventional w/ Continuous Recirculation, Copper, under-slab, insulated	$3170
Conventional w/ Continuous Recirculation, CPVC, attic or crawl space, insulated	$2249
Conventional w/ Continuous Recirculation, CPVC, under-slab, insulated	$2398

Table A-8 House #3 - Monthly Water and Energy Waste (Cold Start Draw Cycle)

House-3	Wait Time for HW (Sec)			Water Wasted	Energy Loss From (Btu)		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	22	49	82	709	419,076	39,824	0.81	17.67	5.52
Conv Attic CPVC - Central	21	47	78	729	431,219	21,356	0.83	17.41	5.44
Conv Attic Cu	33	58	101	907	536,232	52,131	1.03	22.65	7.07
Conv Attic Cu-Ins	33	58	101	908	536,982	53,212	1.03	22.72	7.10
Conv Attic CPVC	32	56	97	870	514,420	27,424	0.99	20.85	6.51
Conv Attic CPVC-Ins	32	56	97	870	514,420	27,704	0.99	20.86	6.52
Conv CS Cu	34	59	103	924	546,501	61,208	1.05	23.40	7.31
Conv CS Cu-Ins	34	59	103	925	547,250	59,424	1.05	23.36	7.30
Conv CS CPVC	33	57	98	886	524,239	31,072	1.01	21.37	6.67
Conv CS CPVC-Ins	33	57	98	886	524,239	30,820	1.01	21.36	6.67
Conv Slab Cu	35	62	109	968	572,435	118,562	1.10	26.64	8.32
Conv Slab Cu-Ins	34	59	103	924	546,501	83,684	1.05	24.28	7.58
Conv Slab CPVC	33	57	99	891	526,863	37,016	1.01	21.70	6.78
Conv Slab CPVC-Ins	33	57	99	891	526,863	32,025	1.01	21.51	6.72
Demand Recir Attic Cu *	4	8	33	204	120,379	73,892	0.23	7.51	2.35
Demand Recir Slab Cu *	4	7	32	197	116,256	149,061	0.22	10.29	3.21
Demand Recir Attic CPVC *	4	8	35	212	125,401	30,955	0.24	6.03	1.88
Demand Recir Slab CPVC *	4	8	35	212	125,401	35,023	0.24	6.19	1.93
Parallel Attic PEX	15	24	38	371	219,620	26,512	0.42	9.48	2.96
Parallel Slab PEX	15	24	40	379	224,417	34,381	0.43	9.97	3.11

NOTES

* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

Table A-9 House #3 - Monthly Water and Energy Waste (Clustered AM & PM Draw Cycle)

House-3	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu - Central	2	5	63	168	99,241	9,775	0.19	4.20	1.31
Conv Attic CPVC - Central	2	5	61	164	96,768	4,928	0.19	3.91	1.22
Conv Attic Cu	2	5	79	187	110,709	10,931	0.21	4.68	1.46
Conv Attic Cu-Ins	2	5	79	187	110,709	10,711	0.21	4.67	1.46
Conv Attic CPVC	2	6	76	184	108,910	5,739	0.21	4.41	1.38
Conv Attic CPVC-Ins	2	6	76	184	108,910	5,699	0.21	4.41	1.38
Conv CS Cu	3	10	83	357	211,375	19,875	0.41	8.90	2.78
Conv CS Cu-Ins	2	6	83	197	116,781	12,058	0.22	4.96	1.55
Conv CS CPVC	2	9	79	327	193,685	11,468	0.37	7.89	2.47
Conv CS CPVC-Ins	2	6	79	192	113,708	6,491	0.22	4.63	1.44
Conv Slab Cu	29	56	100	871	515,020	92,551	0.99	23.41	7.31
Conv Slab Cu-Ins	2	6	82	194	114,682	15,894	0.22	5.03	1.57
Conv Slab CPVC	2	52	92	770	455,655	33,252	0.88	18.82	5.88
Conv Slab CPVC-Ins	2	6	79	192	113,708	6,661	0.22	4.63	1.45
Demand Recir Attic Cu *	3	8	28	173	102,464	17,200	0.20	4.61	1.44
Demand Recir Slab Cu *	3	7	28	167	98,716	24,431	0.19	4.75	1.48
Demand Recir Attic CPVC *	2	4	30	129	76,380	7,850	0.15	3.24	1.01
Demand Recir Slab CPVC *	2	4	30	129	76,380	8,956	0.15	3.29	1.03
Parallel Attic PEX	2	13	35	227	134,545	17,966	0.26	5.87	1.83
Parallel Slab PEX	12	22	37	342	202,005	30,791	0.39	8.97	2.80
Recir Attic Cu-Ins **	2	3	32	99	58,390	189,801	0.11	9.65	3.01
Recir Slab Cu-Ins **	2	3	32	99	58,765	585,618	0.11	25.12	7.84
Recir Attic CPVC-Ins **	2	3	31	101	59,440	186,923	0.11	9.58	2.99
Recir Slab CPVC-Ins **	2	4	32	103	60,939	528,692	0.12	22.98	7.18

NOTES:
* Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.
** Energy supplied to the continuous recirculation system pump is calculated as 755.55 kWh/year or 62.9 kWh/month, which equals approximately $7.30/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

House #4 - Apartment, One Bedroom, One Bath, One Story, 580 ft^2
This unit is representative of small apartments and elderly housing. It contains a small kitchen (with sink and dishwasher) and single bath with a shower stall (no tub). The water heater is located in a closet off the balcony/patio, and there are no provisions for a clothes washer within the unit. While the hot water distribution system layout is compact, the external location of the water heater significantly increases the overall system length.

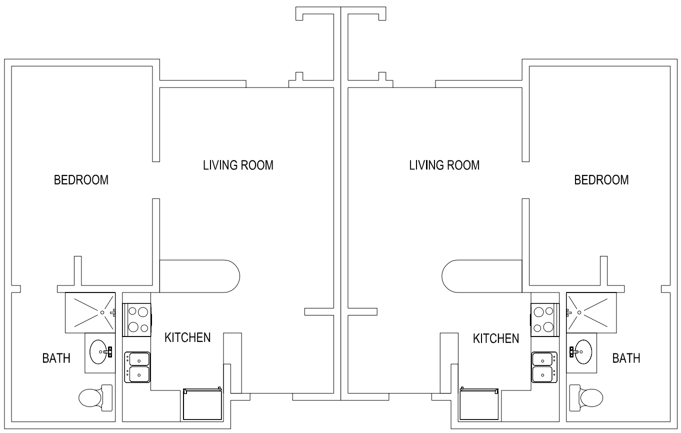

Figure A-8 House #4 – Apartment Floor Plan (two units shown)

Table A-10 Construction Costs for House #4

Scenario	Cost
Conventional, Copper, attic or crawl space, uninsulated	$722
Conventional, Copper, attic or crawl space, insulated	$850
Conventional, Copper, under-slab, uninsulated	$833
Conventional, Copper, under-slab, insulated	$961
Conventional, CPVC, attic or crawl space, uninsulated	$494
Conventional, CPVC, attic or crawl space, insulated	$622
Conventional, CPVC, under-slab, uninsulated	$581
Conventional, CPVC, under-slab, insulated	$692
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$545
Parallel Pipe/Manifold System, PEX tubing, under-slab, uninsulated	$786

Table A-11 House #4 - Monthly Water and Energy Waste (Cold Start Draw Cycle)

House-4	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	17	31	58	532	314,439	29,602	0.60	13.25	4.14
Conv Attic Cu-Ins	17	31	58	538	318,186	30,146	0.61	13.41	4.19
Conv Attic CPVC	16	30	56	518	306,418	12,931	0.59	12.29	3.84
Conv Attic CPVC-Ins	16	30	56	518	306,418	12,968	0.59	12.29	3.84
Conv CS Cu	17	32	59	547	323,283	33,421	0.62	13.73	4.29
Conv CS Cu-Ins	17	32	59	547	323,283	33,301	0.62	13.73	4.29
Conv CS CPVC	17	30	57	524	310,091	13,924	0.60	12.47	3.89
Conv CS CPVC-Ins	17	30	57	524	310,091	13,946	0.60	12.47	3.89
Conv Slab Cu	18	32	61	559	330,554	57,488	0.64	14.95	4.67
Conv Slab Cu-Ins	17	31	59	545	322,534	46,154	0.62	14.20	4.44
Conv Slab CPVC	17	31	57	534	315,938	15,192	0.61	12.74	3.98
Conv Slab CPVC-Ins	17	31	57	534	315,938	14,533	0.61	12.71	3.97
Parallel Attic PEX	9	17	30	271	160,480	16,403	0.31	6.81	2.13
Parallel Slab PEX	9	17	31	275	162,729	20,378	0.31	7.05	2.20

Table A-12 House #4 - Monthly Water and Energy Waste (Clustered AM & PM Draw Cycle)

House-4	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	2	7	29	134	79,228	7,461	0.15	3.34	1.04
Conv Attic Cu Ins	2	7	29	133	78,853	7,330	0.15	3.32	1.04
Conv Attic CPVC	2	7	29	123	72,557	3,238	0.14	2.92	0.91
Conv Attic CPVC Ins	2	7	29	123	72,557	3,238	0.14	2.92	0.91
Conv CS Cu	2	10	51	229	135,670	10,438	0.26	5.62	1.76
Conv CS Cu Ins	2	8	31	138	81,477	7,480	0.16	3.42	1.07
Conv CS CPVC	2	9	50	210	124,426	5,219	0.24	4.99	1.56
Conv CS CPVC Ins	2	8	30	131	77,279	3,452	0.15	3.11	0.97
Conv Slab Cu	20	27	55	486	287,155	40,872	0.55	12.64	3.95
Conv Slab Cu Ins	2	7	31	137	81,102	9,604	0.16	3.49	1.09
Conv Slab CPVC	2	25	53	425	251,626	12,429	0.48	10.16	3.17
Conv Slab CPVC Ins	2	8	30	131	77,279	3,476	0.15	3.11	0.97
Parallel Attic PEX	2	9	27	138	81,776	8,847	0.16	3.49	1.09
Parallel Slab PEX	8	14	29	236	139,792	16,970	0.27	6.04	1.89

House #5 – Apartment or Condominium, Two Bedroom, Two Bath, One Story, 960 ft^2
This unit is representative of mid-sized apartments or condominium units. It contains a modest kitchen (with sink and dishwasher) and two baths, both with tub/shower. The water heater is located in a closet off the balcony/patio, and a closet is provided to permit a small, stacked, clothes washer/dryer unit. The distribution system layout is fairly compact for the area of the unit.

Figure A-9 House #5 – Condominium Floor Plan (four units shown)

Table A-13 Construction Costs for House #5

Scenario	Cost
Conventional, Copper, attic or crawl space, uninsulated	$929
Conventional, Copper, attic or crawl space, insulated	$1098
Conventional, Copper, under-slab, uninsulated	$1063
Conventional, Copper, under-slab, insulated	$1231
Conventional, CPVC, attic or crawl space, uninsulated	$639
Conventional, CPVC, attic or crawl space, insulated	$807
Conventional, CPVC, under-slab, uninsulated	$729
Conventional, CPVC, under-slab, insulated	$897
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$1040
Parallel Pipe/Manifold System, PEX tubing, under-slab, uninsulated	$1078

Table A-14 House #5 - Monthly Water and Energy Waste (Cold Start Draw Cycle)

House-5	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	34	37	66	427	252,675	23,928	0.49	10.65	3.33
Conv Attic Cu-Ins	34	37	66	427	252,675	24,361	0.49	10.67	3.33
Conv Attic CPVC	32	35	63	405	239,333	11,639	0.46	9.66	3.02
Conv Attic CPVC-Ins	32	35	63	405	239,333	11,714	0.46	9.66	3.02
Conv CS Cu	34	37	67	431	254,849	27,533	0.49	10.87	3.40
Conv CS Cu-Ins	34	37	68	433	256,348	27,391	0.49	10.93	3.41
Conv CS CPVC	33	36	64	415	245,255	13,156	0.47	9.94	3.11
Conv CS CPVC-Ins	33	36	64	415	245,255	13,154	0.47	9.94	3.11
Conv Slab Cu	36	39	71	455	269,015	52,934	0.52	12.41	3.88
Conv Slab Cu-Ins	34	37	67	431	254,849	38,377	0.49	11.30	3.53
Conv Slab CPVC	33	36	65	417	246,754	15,032	0.47	10.07	3.15
Conv Slab CPVC-Ins	33	36	65	417	246,754	13,780	0.47	10.03	3.13
Parallel Attic PEX	12	12	24	151	89,047	8,774	0.17	3.77	1.18
Parallel Slab PEX	12	12	24	151	89,047	10,619	0.17	3.84	1.20

Table A-15 House #5 - Monthly Water and Energy Waste (Clustered AM & PM Draw Cycle)

House-5	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	2	4	64	111	65,661	6,308	0.13	2.77	0.87
Conv Attic Cu Ins	2	4	64	110	64,911	6,130	0.12	2.74	0.85
Conv Attic CPVC	2	4	62	108	63,937	3,358	0.12	2.59	0.81
Conv Attic CPVC Ins	2	4	61	107	63,562	3,285	0.12	2.57	0.80
Conv CS Cu	2	18	67	224	132,671	12,674	0.25	5.60	1.75
Conv CS Cu Ins	2	4	67	115	68,210	7,262	0.13	2.91	0.91
Conv CS CPVC	2	17	64	216	127,574	6,653	0.25	5.16	1.61
Conv CS CPVC Ins	2	4	64	111	65,736	3,898	0.13	2.68	0.84
Conv Slab Cu	30	37	70	408	241,282	41,483	0.46	10.90	3.40
Conv Slab Cu Ins	2	4	66	115	67,835	9,595	0.13	2.98	0.93
Conv Slab CPVC	26	34	65	376	222,393	13,375	0.43	9.07	2.83
Conv Slab CPVC Ins	2	4	64	111	65,736	3,959	0.13	2.68	0.84
Parallel Attic PEX	2	12	24	104	61,688	7,080	0.12	2.65	0.83
Parallel Slab PEX	9	12	24	137	80,802	10,092	0.16	3.50	1.09

Representative Housing Results - Existing Housing

House #6 – Single Family, Three Bedroom, Two Bath, One Story, 1100 ft^2
This unit represents a modestly sized existing single story house. The laundry is located in the garage. There is one bath with a tub/shower along with a lavatory. A second bath contains a shower stall and lavatory. The compact kitchen includes a sink, but has no provision for a dishwasher. The water heater is in the garage. The house layout is fairly compact and keeps hot water consuming devices in the same general area of the house.

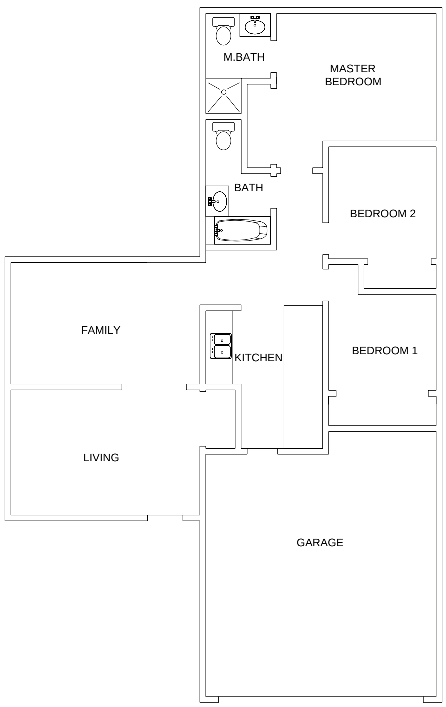

Figure A-10 House #6 – Floor Plan

Table A-16 Construction Costs for House #6

Scenario	Cost
Conventional, Copper, attic or crawl space, uninsulated	$1023
Conventional, Copper, attic or crawl space, insulated	$1217
Conventional, CPVC, attic or crawl space, uninsulated	$702
Conventional, CPVC, attic or crawl space, insulated	$896
Conventional with Demand Recirculation, Copper, attic or crawl space, uninsulated	$694*
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$944

* Demand recirculation system reuses existing piping system and includes pump and controls only.

Note: Actual existing housing costs will vary upwards from those shown because of differing field circumstances, the plumbing contractors' view of potential uncertainties, and the need to involve other crafts to open and restore walls to provide access for the plumbers to work. The costs shown above are best viewed a probable minimum costs.

Table A-17 House #6 - Monthly Water and Energy Waste (Cold Start Draw Cycle)

House-6	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	22	59	78	594	351,467	33,458	0.68	14.82	4.63
Conv Attic Cu Ins	22	59	78	594	351,467	34,139	0.68	14.85	4.64
Conv Attic CPVC	21	56	76	570	337,000	16,855	0.65	13.62	4.25
Conv Attic CPVC Ins	21	56	76	570	337,000	16,987	0.65	13.62	4.25
Conv CS Cu	22	60	80	603	356,713	38,644	0.69	15.22	4.75
Conv CS CPVC	21	57	77	577	341,423	18,590	0.66	13.85	4.33
Conv CS Cu Ins	22	60	80	603	356,713	37,939	0.69	15.20	4.75
Conv CS CPVC Ins	21	57	77	577	341,423	18,564	0.66	13.85	4.33
Demand Recir Attic Cu	2	3	5	47	27,734	55,293	0.05	3.22	1.01
Demand Recir CS Cu	2	3	5	47	27,734	62,107	0.05	3.49	1.09
Parallel Attic PEX	11	25	33	250	147,962	17,181	0.28	6.36	1.99
Parallel CS PEX	11	25	34	251	148,337	17,459	0.28	6.38	1.99

Table A-18 House #6 - Monthly Water and Energy Waste (Clustered AM & PM Draw Cycle)

House-6	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv Attic Cu	2	4	76	150	88,522	8,856	0.17	3.75	1.17
Conv Attic Cu Ins	2	4	75	149	88,148	8,678	0.17	3.73	1.16
Conv Attic CPVC	2	4	74	149	88,223	4,722	0.17	3.58	1.12
Conv Attic CPVC Ins	2	4	74	148	87,548	4,678	0.17	3.55	1.11
Conv CS Cu	2	18	79	296	175,171	15,121	0.34	7.33	2.29
Conv CS Cu Ins	2	4	79	155	91,446	9,642	0.18	3.89	1.22
Conv CS CPVC	2	12	77	259	153,284	8,112	0.29	6.21	1.94
Conv CS CPVC Ins	2	4	77	157	92,570	5,211	0.18	3.76	1.18
Demand Recir Attic Cu *	2	2	5	37	21,962	6,155	0.04	1.08	0.34
Demand Recir CS Cu *	2	2	5	37	21,962	11,590	0.04	1.30	0.41
Parallel Attic PEX	2	9	30	151	89,197	11,814	0.17	3.89	1.22
Parallel CS PEX	7	18	30	213	126,075	14,570	0.24	5.42	1.69

NOTES: * Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

House #7 – Single Family, Four Bedroom, 2½ Bath, Two Story, 1960 ft^2
This unit represents a moderately sized existing two-story house. The laundry is located in the garage. There is a ½ bath with a lavatory, and a modestly sized kitchen with sink and dishwasher on the first floor. A second bath containing a tub/shower and lavatory, and a third bath with a shower stall and lavatory is located on the second floor. The water heater is in the garage. The layout is fairly compact and keeps hot water consuming devices in the same general area of the house.

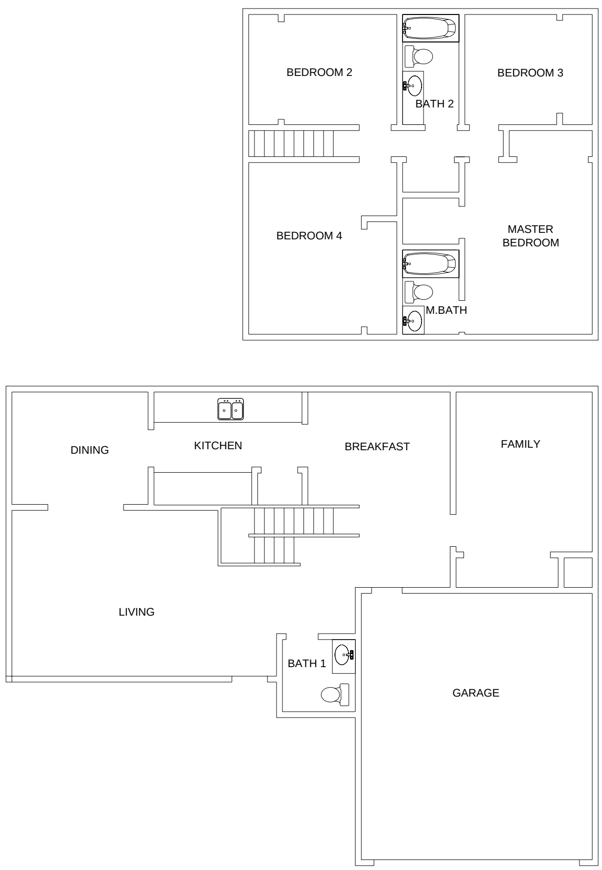

Figure A-11 House #7 – Floor Plan (first floor below, second floor above)

Table A-19 Construction Costs for House #7

Scenario	Cost
Conventional, Copper, attic or crawl space, uninsulated	$1402
Conventional, Copper, attic or crawl space, insulated	$1709
Conventional, CPVC, attic or crawl space, uninsulated	$949
Conventional, CPVC, attic or crawl space, insulated	$1256
Conventional with Demand Recirculation, Copper, attic or crawl space, uninsulated	$694*
Parallel Pipe/Manifold System, PEX tubing, attic or crawl space, uninsulated	$1157

* Demand recirculation system reuses existing piping system and includes pump and controls only.

Note: Actual existing housing costs will vary upwards from those shown because of differing field circumstances, the plumbing contractors' view of potential uncertainties, and the need to involve other crafts to open and restore walls to provide access for the plumbers to work. The costs shown above are best viewed a probable minimum costs.

Table A-20 House #7 - Monthly Water and Energy Waste (Cold Start Draw Cycle)

House-7	Wait Time for HW (Sec.)			Water Wasted	Energy Loss From (Btu)		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv CS Cu	37	51	73	797	471,096	51,334	0.91	20.12	6.28
Conv CS Cu Ins	37	51	73	797	471,096	50,644	0.91	20.09	6.27
Conv CS CPVC	35	49	69	764	452,057	23,744	0.87	18.31	5.72
Conv CS CPVC Ins	35	49	69	764	452,057	23,735	0.87	18.31	5.72
Conv Interstitial Cu	28	51	58	693	409,782	43,089	0.79	17.44	5.45
Conv Interstitial Cu Ins	28	51	58	693	409,782	43,022	0.79	17.43	5.45
Conv Interstitial CPVC	27	49	55	675	399,138	19,276	0.77	16.10	5.03
Conv Interstitial CPVC Ins	27	49	55	675	399,138	19,300	0.77	16.10	5.03
Demand Recir Interstitial Cu *	4	10	51	260	153,584	47,542	0.30	7.76	2.42
Demand Recir CS Cu *	4	10	51	260	153,584	58,439	0.30	8.19	2.56
Parallel Interstitial PEX	15	29	30	342	202,155	25,445	0.39	8.77	2.74
Parallel CS PEX	15	30	30	346	204,404	25,732	0.39	8.86	2.77

Table A-21 House #7 - Monthly Water and Energy Waste (Clustered AM & PM Draw Cycle)

House-7	Wait Time for HW (Sec.)			Water Wasted	Energy Loss (Btu) From		Water Cost ($)	Energy Cost ($)	
	Min	Typical	Max	(gallons)	Previously Heated Water Wasted	Pipe	Wasted Water	Electric	Gas
Conv CS Cu	4	15	70	362	214,298	17,894	0.41	8.94	2.79
Conv CS Cu Ins	2	11	70	239	141,216	13,286	0.27	5.95	1.86
Conv CS CPVC	2	16	67	336	198,932	9,297	0.38	8.01	2.50
Conv CS CPVC Ins	2	11	67	225	133,121	6,446	0.26	5.37	1.68
Conv Interstitial Cu	4	14	54	327	193,685	15,609	0.37	8.06	2.52
Conv Interstitial Cu Ins	2	11	54	218	128,774	11,914	0.25	5.42	1.69
Conv Interstitial CPVC	2	13	53	302	178,544	7,903	0.34	7.17	2.24
Conv Interstitial CPVC Ins	2	11	53	206	122,103	5,619	0.23	4.91	1.53
Demand Recir Interstitial Cu *	2	10	51	198	117,156	20,979	0.23	5.32	1.66
Demand Recir CS Cu *	2	10	51	199	117,530	24,168	0.23	5.46	1.71
Parallel Interstitial PEX	10	22	30	293	173,072	20,243	0.33	7.44	2.33
Parallel CS PEX	11	22	30	296	174,946	20,511	0.34	7.53	2.35

NOTES: * Energy supplied to the demand recirculation system pump is calculated as 2.62 kWh/year or 0.22 kWh/month, which equals approximately $0.02/month. This cost should be added to energy cost figures in the last two columns above to get the total energy cost.

Appendix B. – Sample Questionnaire Given to Plumbing Contractors

California Residential Plumbing Systems

Purpose:

The California Energy Commission (Energy Commission) is sponsoring an evaluation of Residential Hot Water Piping Systems in California by Oak Ridge National Laboratory. This study will investigate the energy and water impact as well as the usage and market penetration of different systems. As part of this study, barriers to the utilization of alternative hot water distribution systems are being identified and methods of addressing these barriers proposed. Your input to this questionnaire will enable the project to identify these barriers from the viewpoint of the key participant in the installation and repair processes - you, the plumbing contractor. It will also assist the Energy Commission in evaluating future codes and standards. Participants will receive a copy of the analysis and summary of this survey.

1. Your Firm

Name of Firm_____________________ Contact Person__________________________

Address__________________________ Phone Number__________________________

___________________________ E-Mail________________________________

New Home Construction: Yes____ No_____ Number of houses per year_____________

Existing Homes: Yes____ No_____ Number of service calls per Year____________

Your approximate market-share in local area, if known (%): _____________

Would you like your firm to be identified in the final report? Yes____ No_____

2. Rank the importance of each of the following <u>to you</u> as a Plumbing Contractor (1 lowest – 5 highest importance)

______ a. Low Cost

______ b. Reliability/Durability

______ c. Local Code Acceptance/Compliance

______ d. Energy and Water efficiency

______ e. Other (please specify) ____________

____

3. Rank your view of the importance of the following <u>to your customers</u> for New Home Construction (1 lowest – 5 highest importance)

______ a. Initial cost of system affecting the overall home cost

______ b. Durability/Reliability

______ c. Adequacy of flow (pressure)

______ d. Length of time before hot water is available at fixture

______ e. Conserving water

______ f. Conserving energy

4. Rank your view of the importance of the following <u>to your customers</u> for Existing Homes (1 lowest – 5 highest importance)

______ a. Time delay between failure and repair

______ b. Time to fix the problem too long and have to take time off work

______ c. Cost of repairs/modifications

______ d. Durability/Reliability

______ e. Adequacy of flow (pressure)

______ f. Conserving water

g. Conserving energy

5. Your current practice for Hot Water Systems in new construction

a. Materials (% used) copper_____ PVC_____ CPVC_____ PEX_____ steel_____

Other _____ (material?) ___________________________

b. Location of pipes (%) attic_____ crawl space ____ floor slab ____ between floors____

c. Recirculating systems usage (% installed) on-demand_____ continuous_____

d. Pipe insulation (0 – 100% of installed piping insulated) ______

e. Water heater location (%) garage ____ laundry room ____ utility closet ____ other____

f. Water heater type usage (% installed) ____ gas with storage tank

___ gas instantaneous (no tank) like Rinnia or Takagi ___electric resistance with storage tank

___ heat-pump with storage tank ___ point of use heaters (electric) like EemaX

6. Your familiarity with, and use of, Alternative Hot Water Systems

a. Are you familiar with the following alternative systems (circle yes or no):

- Recirculating systems: On-demand like Metlund D'MAND - yes/no, or
  Continuous full time or time/temp activated - yes/no
- Parallel pipe manifold systems (single dead-end hot lines to fixture from water heater) - yes/no
- Point of use heating (like EemaX for individual fixtures) - yes/no
- Waste water heat recovery (like GFX) – yes/no

b. How did you learn of these systems (mark all that apply)?

Sales people____ Plumbing catalogs____ Trade shows_____ Other _____

c. Do your customers request them or do you market them to your customers (circle request or market)?

d. Do employees attend training or seminars on the alternative systems? Yes___ No____

e. What are the alternative systems you install (mark all that apply)?

Recirculating systems (on-demand _____ continuous_____)

Parallel pipe manifold systems _____

Point of use heating _____

Waste-water heat recovery _____

f. How often are they installed (% of total installations)? New____ Existing ____

Your view of the barriers to increased use of these alternative systems (mark "X" in box for all that apply)

	Recirculating Systems		Parallel Pipe Manifold Systems	Point of Use Heating	Waste Water Heat Recovery
	On-Demand	Continuous			
a. Cost					
b. Complexity of systems					
c. Customer's interest					
d. Code issues					
e. Plumbers training					
f. Reliability					
g. Ease of repair					
h. Other (describe)					

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Appendix C. – Additional Research Needs

The following discussion of hot water distribution system research needs is the result of collaborative discussions between ORNL (Bob Wendt and John Tomlinson), LBNL (Jim Lutz), Energy Commission (Gary Klein), TVA (John Richardson) and others. These discussions were in response to growing interest among various state and federal agencies, utilities, and research organizations in pursuing this topic and were not directly related to this project.

What we know…

Everyone agrees that water is wasted in waiting for hot water to arrive at a fixture. Moreover, everyone agrees that all of the water that is wasted during the wait left the water storage tank at about the set point temperature of the storage tank. We also know that there is great variability in hot water consumption from one house to another and from day-to-day even when we try to account for numbers of persons, ages, season, etc.

What we do not know…

- How many gallons of water are actually wasted while waiting,
- How much embodied energy is lost in the wasted water, and,
- How much energy was lost by conduction/convection to ambient through the pipe walls.

What we know in these areas is based on the projections from largely un-validated models.

Approach to Understanding:

Our difficulty in understanding these losses is caused by several uncertainties: (1) we do not know in any draw whether "hot" water is wasted or put to good use; (2) we do not know the purpose for each draw (i.e. whether for bathing, hand washing, etc.). We feel that future study of hot water distribution systems needs the following elements if it is to provide useful, quantified information:

1) Develop a comprehensive plan or roadmap to guide multiple research projects, using a thorough review of existing information as a starting point.

2) Develop a data acquisition system to measure hot water consumption and patterns of use. Conduct field monitoring of a number of houses through partners in this Program is a core element of this Program. How water is used (and wasted) in homes can be best determined through measurements. This task is to develop the instrumentation and distributed data acquisition system for hot water flow and temperature characterization in the field. The Data Acquisition System (DAS) ideally should employ wireless remote non-intrusive sensors so that installation into houses can be done quickly and without pipe penetrations. Steps include DAS development followed by production of systems for use in the field.

3) Provide field measurements for a large number of "real-world" houses. Characterize each house by occupant number, ages, types of fixtures and appliances (e.g. showers, washing machines). For each house, measurements of H/C flows, flow duration, timing, and H/C delivery temperatures at each fixture will be done for 2-week periods four times a year using the DAS technology developed in (1). Analyze data by draws to determine type of draw (e.g. bath), total water in draw, mixed temperature in draw, flow of hot water in draw before CW was added for tempering.

4) Complete flow/temperature simulation model to analyze piping systems (started at ORNL).

5) Provide controlled laboratory experiments to determine the essential parameters of hot water distribution systems for use in the simulation model. Perform experiments in the laboratory according to the table below. This represents a large number of runs. Leverage work already done by National Association of Home Builders Research Center for the tree and parallel configurations for 2-story layouts. Take temperature, flow and energy data.

6) Calibrate the hot water distribution system model. From flow/temperature and energy measurements in (item 3, above), calibrate the hot water distribution model developed in (item 4, above) for the different piping networks tested.

Pipe	Diameter	Layouts	Surroundings	Draws	Heater
Copper PEX CPVC	0.375” 0.5” 0.75” 1.0”	Straight Tree Parallel Recirculation	Still air Moving air Dry sand Wet sand Concrete Insulated Uninsulated Range of temperature	Range of flows, durations, quiescent periods, operating pressures	NAECA std. gas or electric Instantaneous gas or electric

7) Use the calibrated model to predict energy and water savings for virtually any piping configuration. Exercise the model through analytic studies over a wide range of piping layouts, distances, water consumption patterns, etc. These studies should include the optimization of the various systems including the conventional trunk and branch system.

8) Analyze the impact of varying occupant behavior on different hot water distribution systems. Perform a behavior analysis to determine how customers change how they use water if hot is readily available at fixture.

9) Develop and implement market useful tools. Produce and package information from the model studies that can be used by industry and water and energy utilities to speed hot water delivery to end-uses while at the same time reducing energy and water consumption. Groups such as the American Society of Plumbing Engineers, NAHB, Heating and Piping Magazine, and other trade associations should become involved with the findings.

Appendix D. - Recommendations for Home Designers

Based on the findings of this report the following recommendations are offered for consideration by home designers. The outcome of using these recommendations may vary from the outcomes identified in this report because of variation in house size, layout, and number of occupants, as well as the occupant water use patterns. All of these factors will impact the total energy and water waste from a particular system. The home designer should also note that the quality and performance of a particular material or system may vary among manufacturers and this could impact other performance factors such as cost and durability.

- Consolidate bathrooms and other hot water consuming activities into the same area(s) of the house to minimize overall system length. This could reduce the initial cost of the system and will reduce energy and water waste.
- Consider centralizing the location of water heater to minimize piping trunk lengths. Shorter piping runs to the fixtures will reduce waiting and energy and water waste. This recommendation is primarily applicable to homes that are intended to use electric water heaters. The costs associated with flues, combustion air, and gas piping required by gas water heaters to discount the other benefits.
- Locate plumbing in attic for single story homes and interstitial space between floors for multi-story homes. These locations minimize the energy loss through the pipe and improve access for repair or modification should that ever be required.
- Do not oversize piping. Use code permitted minimums. Bigger isn't better. Some communities will permit "under sized pipe" if adequate flow and pressure can be demonstrated. For large housing developments, it may be worth the effort to obtain approval for downsized piping. Smaller diameter pipe costs less, and reduces energy and water waste as well as the wait for hot water.
- Consider a demand recirculation system in lieu of a continuous recirculation system where waiting times for hot water will be a problem. Demand recirculation systems cost less, and reduce energy and water waste as well as the wait for hot water.
- Consider CPVC or PEX plastic piping in lieu of copper regardless of system type (conventional, recirculation, or parallel pipe) when appropriate quality and durability can be demonstrated for the products in question. This change will reduce the initial cost of the system as well as reduce energy and water waste.

Appendix E. - Recommendations for Plumbing and General Contractors

Based on the findings of this report, the following recommendations are offered for consideration by plumbing and general contractors. The outcome of using these recommendations may vary from the outcomes identified in this report because of variations in house size, layout, and number of occupants, as well as the occupant water use patterns. All of these factors will impact the total energy and water waste from a particular system. Contractors should also note that the quality and performance of a particular material or system may vary among manufacturers and this could impact other performance factors such as cost and durability.

New Homes

- Do not oversize piping. Use code permitted minimums. Bigger isn't better. Some communities will permit "under sized pipe" if adequate flow and pressure can be demonstrated. For large developments in may be worth the effort to obtain approval for downsized piping. Smaller diameter pipe costs less, and reduce energy and water waste as well as the wait for hot water.
- Layout systems with all hot water pipe runs as short as possible. Shorter pipe runs costs less in material, and reduce energy and water waste as well as the wait for hot water.
- Locate plumbing in attic for single story homes and interstitial space between floors for multi-story homes. These locations minimize the energy loss through the pipe and improve access for repair or modification should that ever be required.
- Use the blown-in attic insulation to insulate piping system. Assure complete coverage of pipe with a minimum of 6" of insulation. Do not add foam plastic pipe insulation if the pipes are covered by blown-in insulation because it adds cost and is of no benefit to the energy and water performance of the system.
- Consider CPVC or PEX plastic piping in lieu of copper regardless of system type (conventional, recirculation, or parallel pipe) when appropriate quality and durability can be demonstrated for the products in question. This change will reduce the initial cost of the system as well as reduce energy and water waste.
- Install a demand recirculation system in lieu of continuous recirculation where waiting times for hot water will be a problem. Demand recirculation systems cost less, and reduce energy and water waste as well as the wait for hot water.

Existing Homes

- Install a demand recirculation pump and controls on existing systems if waiting times are excessive. These provide hot water faster and will provide lower utility costs.
- Replace defective existing systems with CPVC or PEX plastic piping in lieu of copper whenever appropriate quality and durability can be demonstrated for the products in question. These will have lower initial costs and somewhat lower utility costs.
- Consider replacing defective existing systems with a parallel pipe/manifold system using PEX tubing. This will have lower initial costs and potentially somewhat lower utility costs.

Appendix F. - Recommendations for Homeowners

Based on the findings of this report the following recommendations are offered to the homeowner. The outcome of using these recommendations may vary from the outcomes identified in this report because of variations in house size, layout, and number of occupants, as well as the occupant water use patterns. All of these factors will impact the total energy and water waste from a particular system.

New Homes:

- Look for houses that consolidate bathrooms and other hot water consuming activities into the same area(s) of the house. These will typically have lower utility costs and shorter waiting period for hot water to arrive at the fixture.
- Look for centralized location of water heater. This also will typically have lower utility costs and shorter waiting period for hot water to arrive at the fixture.
- Inquire into whether the plumbing is located in the attic for single story homes or in the interstitial space between floors for multi-story homes. These distribution systems also will have lower utility costs and will be easier to access than systems built underneath floor slabs should repair or modification ever be needed.
- Request a demand recirculation system rather than a continuous recirculation system. These will have lower initial costs and much lower utility costs. Both save about the same amount of water.
- Request CPVC or PEX plastic piping in lieu of copper whenever appropriate quality and durability can be demonstrated for the products in question. These will have lower initial costs and somewhat lower utility costs.

Existing Homes

- Consider installing a demand recirculation pump and controls on your existing system if waiting times are excessive. These provide hot water faster and will provide lower utility costs. This approach is most beneficial for large houses (>2500 SF) or houses with very long hot water pipe truck lines (>75ft). Houses with electric water heaters are likely to save enough in utilities to pay back the cost of installation in 10-15 years. Smaller houses and ones with gas water heaters would typically not save enough to pay for the system within the expected life of its equipment.
- Replace defective existing systems with CPVC or PEX plastic piping in lieu of copper whenever appropriate quality and durability can be demonstrated for the products in question. These will have lower initial costs and somewhat lower utility costs.
- Consider replacing defective existing systems with a parallel pipe/manifold system using PEX tubing. This will have lower initial costs and for some distribution system layouts potentially reduce utility costs.