The use phase needs to be whatever length it takes to perform the task for which hot water is desired. The cool down phase begins the moment the fixture is turned off. If the time until the next hot water event is short enough, the water in the pipes all the way back to the water heater will be hot enough to use. If it is too long, water coming from the water heater will be run down the drain until water hot enough to use arrives at the fixture.

At the fixture, hot water is generally mixed with cold water to reach the desired useful hot water temperature. The thermostat on the water heater needs to be set high enough to overcome the heat losses in the piping system and still provide water that is hot enough to be mixed at the farthest fixture with the highest desired useful hot water temperature. For purposes of our experiments, we selected 105°F as the nominal useful hot water temperature.

From our research, we have learned about all three phases of this process.

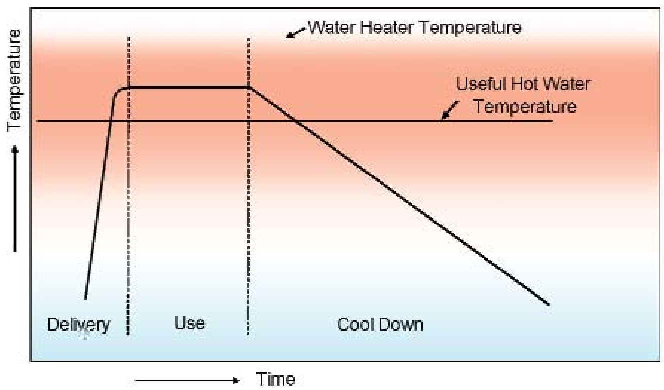

Figure 1. *Hot Water Event Schematic*

The Test Rig

We set up a test rig to measure the performance. This is shown schematically in Figure 2 and in pictures in Figures 3 and 4.

Calculations and observations helped us decide to test roughly 120 foot-long sections of pipe. Since our lab was only 40 feet long, we needed to create a serpentine piping layout. When we used hard copper pipe, the long legs were nominally 20 feet long (the pipe is actually a bit longer) and the short legs were roughly 18 inches long. Temperature sensors were located at the beginning and end of the serpentine shape and at the center of each short leg.

We thought these two layouts, one for hard pipe and one for flexible pipe, were essentially identical. It turns out that they weren't identical and we learned a great deal from this mistake.

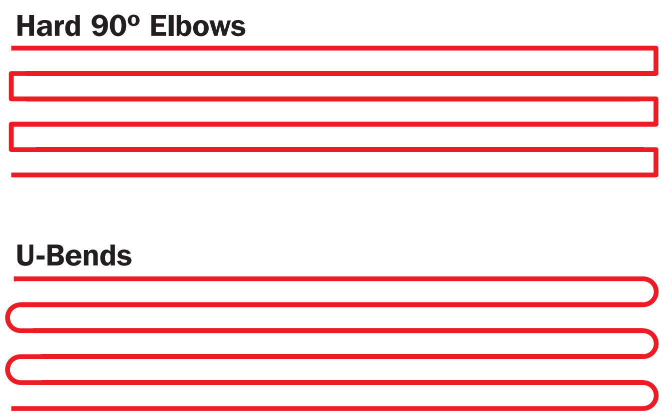

Figure 2. *Serpentine Test Rig Schematic*

Figure 3. *Test Rig for Uninsulated (Top) and Insulated (Bottom) Copper Piping*

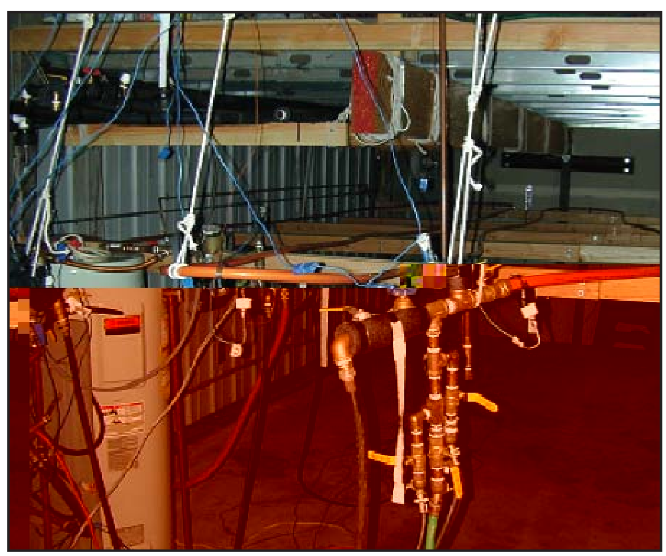

Figure 4. *Test Rig for Uninsulated PEX-Al-PEX*

The Delivery Phase

We learned three things from our research about the delivery phase:

During the delivery phase, hot water acts differently than cold water.

Low flow rates (< 1 gpm) waste much more water than high flow rates (> 4 gpm).

At typical fixture flow rates (1-3 gpm), sharp (standard) 90-degree elbows increase turbulence, heat loss and water waste.

Perhaps one of the most surprising things that we learned is that it is possible for significantly more water to come out of the pipe before hot water gets from the water heater to the fixture than is actually in the pipe. During the

4 Insulation decreases the temperature drop at a given flow rate.

Figure 6 shows the comparison between nominal 3/4-inch PEX-Al-PEX and 3/4-inch copper piping over a length of 100 feet. The figure is based on steady state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F. The water in the uninsulated PEX-Al-PEX pipe lost more temperature at the same flow rate than did the water in the copper pipe. We suspect that this additional heat loss is due to a combination of two effects: the nominal 3/4-inch PEX-Al-PEX pipe has a larger surface area than the nominal 3/4-inch copper pipe – once it is hot there is more surface area to lose heat; and because the PEX-Al-PEX has a larger internal diameter than the copper piping, the face velocity of the water in the PEX-Al-PEX is slower and the rate of heat loss is greater than it is in copper. Once the pipes were insulated, the difference in temperature drop essentially disappeared.

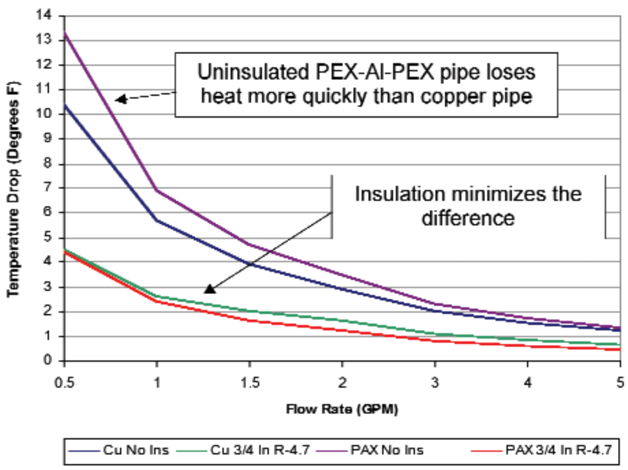

Figure 6. *Comparison of Nominal 3/4-Inch PEX-Al-PEX and 3/4-Inch Copper Piping*

We did not have enough funding to run tests on 1/2-inch PEX-Al-PEX. Based on the fact that uninsulated copper performed better than PEX-Al-PEX and, with insulation, the performance was very similar, we think we can use the performance of copper pipe at 1/2- and 3/4-inch, with and without insulation, as a reasonable first order proxy to better understand what generally happens in hot water piping.

Figure 7 compares the performance of nominal 1/2- and 3/4-inch diameter copper piping, both insulated and uninsulated. As in the prior figure, the graph is based on steady state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F over a length of 100 feet.

At a given flow rate, the temperature drop in 1/2-inch nominal piping is less than in 3/4-inch nominal piping. This is due to the increased face velocity of the water, which reduces the heat loss rate. While from a thermal perspective it is beneficial to use the smallest pipe diameter possible, frictional losses increase exponentially with increased face velocity and result in increased pressure drop over a given length. We did not measure pressure drop during the tests. Future tests should do this so as to better understand its impacts.

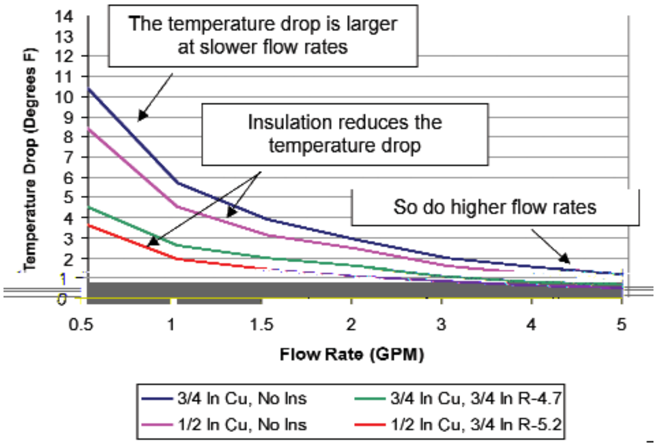

Figure 7. *Comparison of Nominal 1/2- and 3/4-Inch Copper Piping*

The temperature drop over a given distance is greater at low flow rates than at high flow rates. At 2.5 gpm, the highest flow rate allowed for showerheads, the temperature drop in uninsulated copper piping is between 2°F and 2.5°F. At 1 gpm, the temperature drop in uninsulated pipe climbs to between 4.5°F and 5.5°F. At 5 gpm, the temperature drop goes down to roughly 1°F, and the difference between 1/2- and 3/4-inch diameter goes away.

There is a significant difference in the rate of change of the temperature drop at flow rates below 1 gpm. At 0.5 gpm, the temperature drop almost doubles. The curve will get even steeper if the flow rate is reduced still further and, for a given length at some low flow rate, hot water will never reach the fixture. The same thing would happen if length was increased while flow rate was held constant, or if the piping was located in a higher heat loss environment, say in damp soil under a slab or between buildings in a campus situation.

Insulation reduces the heat loss overall and, for a given flow rate, the temperature drop is cut roughly in half. Insulation also reduces the difference in temperature drop between 1/2- and 3/4-inch diameter piping.

The Cool Down Phase

We learned three things about the cool down phase:

1. If the time between hot water events is long enough, the pipes cool down to below the useful hot water temperature for the next hot water event.
2. Larger diameter pipes cool down more slowly than smaller diameter pipes.
3. Insulation extends the time it takes for the pipes to cool down to a given temperature.

The first point seems obvious, since if you wait long enough, the temperature of the water in the pipes will eventually reach equilibrium with the ambient temperature surrounding the pipes. The real question is: how long does it take to cool down to a non-useful hot water temperature? This depends upon the starting temperature of the water in the pipes, the diameter of the pipes, the amount of pipe insulation, the environmental conditions in which the pipes are located, and the temperature of water needed for the next hot water event.

Figure 8 compares how long it took for the water in 3/4-inch diameter copper pipes to cool down from a given starting temperature to 105°F. The ambient temperature surrounding the pipes was between 65°F and 70°F and the pipes were located in air. Without insulation, it took between 5 and 22 minutes for the temperature to reach 105°F. The hotter the water began, the longer it took.

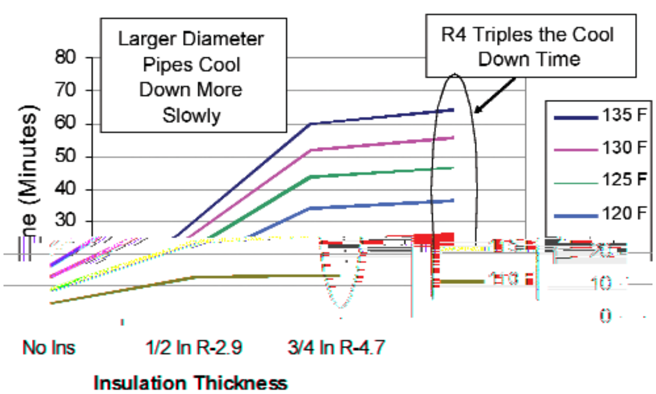

Figure 8. *Time Required for 3/4-Inch Diameter Pipes to Cool Down to 105°F With and Without Pipe Insulation*

When 1/2-inch wall thickness and 3/4-inch wall thickness insulation were added, it took significantly longer for the water to cool down to 105°F. Use of the 3/4-inch thick insulation (>R-4) roughly tripled the cool down time. The 1/2-inch wall thickness insulation did almost as well.

Figure 9 compares how long it took for the water in 1/2-inch diameter copper pipes to cool down from a given starting temperature to 105°F. As with the tests on 3/4-inch diameter pipe, the ambient temperature surrounding the pipes was between 65°F and 70°F and the pipes were located in air. Without insulation, it took between 5 and 20 minutes for the temperature to reach 105°F, almost exactly the same as for the uninsulated 3/4-inch piping. Use of the 3/4-inch thick insulation (>R-4) roughly doubled the cool down time. The 1/2-inch wall thickness insulation did almost as well.

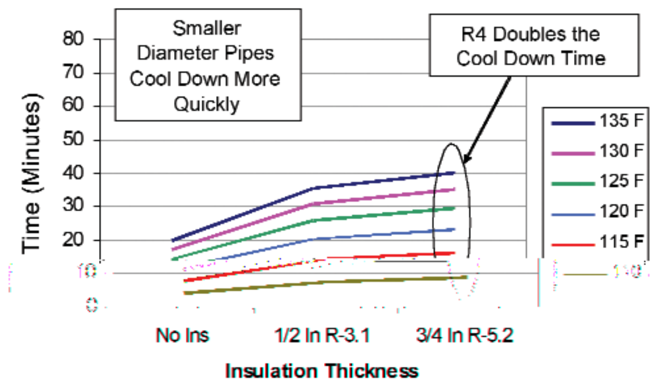

Figure 9. *Time Required for 1/2-Inch Diameter Pipes to Cool Down to 105°F With and Without Pipe Insulation*

Although the time it took the water in the uninsulated pipes to cool down was very similar for the 1/2-inch and 3/4-inch diameter pipes, when insulation was added, the water in the 3/4-inch pipes took roughly 1.5 times as long to reach the same temperature as the 1/2-inch pipes.

If the pipes were located in a colder environment, such as in a crawl space or an attic, used at night or early in the morning, or throughout much of the winter, they would have cooled down much more quickly. If the pipes were in a high heat loss environment, such as in the damp soil under a concrete slab, they would cool off even faster. If the ambient temperature were higher, such as in an attic in the middle of a summer afternoon, the pipes would take much longer to cool down. (On the other hand, the water in the cold water pipes might be too hot to use!)

In future articles in this series, we will apply the lessons learned to improving the performance of hot water distribution systems. We will also look at possible changes that might be made in plumbing and energy codes to take advantage of what we have learned and identify some additional research that should be done. Finally, we will look at the implications of making these improvements on the overall connection between water and energy use.

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in Lesotho, the rest in the USA. Gary has a passion for hot water: getting into it, getting out of it, and efficiently delivering it to meet customers' needs. He currently helps administer California's Public Interest Energy Research program and chairs the recently formed Task Force on Residential Hot Water Distribution Systems. He can be contacted at Gklein@energy.state.ca.us