Cost Estimation for Materials and Installation of Hot Water Piping Insulation

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By

Gary Klein, Managing Partner
Affiliated International Management, LLC
P.O. Box 11752
Newport Beach, CA 92658-5040

Telephone: 916-549-7080
Email: gary@aim4sustainability.com

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Introduction

The 2012 International Energy Conservation Code (IECC) requires R-3 insulation on most hot water pipes in low-rise residential buildings. Certain exceptions are allowed if the pipes are sufficiently short in total length (from the water heater to the point of use) and have a sufficiently small diameter.

The purpose of this report is to provide an estimate for national average construction costs for installing R-3 insulation on hot water pipes as required by the 2012 IECC. Costs will include materials, labor, overhead and profit from the plumbing contractor to the builder. A typical 2400 ft^2 house, usually detached, both one-story and two-story will be evaluated. A 1200 ft^2 apartment as part of a multi-family complex will also be evaluated. Each unit will be one-story within an up-to-three-story building. The source of hot water can be either a water heater or a branch line off a central circulation loop.

The report will also provide an estimate of the hot water energy savings that can be attributed to meeting the R-3 pipe insulation requirements in the 2012 IECC.

2012 IECC Pipe Insulation Requirements

R403.4.2 Hot water pipe insulation (Prescriptive). Insulation for hot water pipe with a minimum thermal resistance (*R*-value) of R-3 shall be applied to the following:

1. Piping larger than 3/4 inch nominal diameter.
2. Piping serving more than one dwelling unit.
3. Piping from the water heater to kitchen outlets.
4. Piping located outside the conditioned space.
5. Piping from the water heater to a distribution manifold.
6. Piping located under a floor slab.
7. Buried piping.
8. Supply and return piping in recirculation systems other than demand recirculation systems.
9. Piping with run lengths greater than the maximum run lengths for the nominal pipe diameter given in Table R403.4.2.

All remaining piping shall be insulated to at least R-3 or meet the run length requirements of Table R403.4.2.

TABLE R403.4.2 MAXIMUM RUN LENGTH (feet)[a]

Nominal Pipe Diameter of Largest Diameter Pipe in the Run (inch)	3/8	1/2	3/4	>3/4
Maximum Run Length	30	20	10	5

For SI: 1 inch = 25.4 mm, 1 foot 304.8 mm.

a. Total length of all piping from the distribution manifold or the recirculation loop to a point of use.

The key thing to note in this section is that it is not required to insulate all hot water piping. Large diameter, long lengths, pipe under or in a slab, pipes serving multiple dwelling units, pipe outside the thermal envelope and piping to the kitchen sinks and dishwashers must be insulated; also any hot water piping longer than the lengths shown in the table.

So, while it is possible to minimize the number of feet of pipe that need to be insulated by locating all hot water outlets close to a single water heater in any of the floor plans we have examined, this analysis assumes that all hot water piping will be insulated.

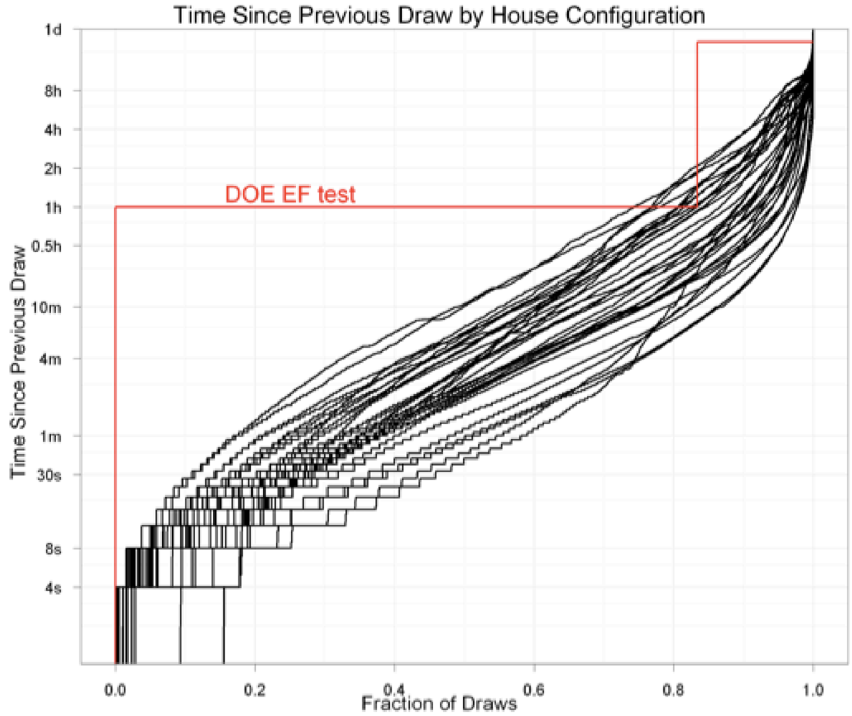
Prior versions of the IECC and the International Plumbing Code (IPC) have required R-2 pipe insulation (roughly 3/8 inch wall thickness) on circulation loops. Circulation loops are not typical in single family housing unless the house size is large, say over 3600 ft^2. This report only examines one-way (non-recirculated) systems and does not consider circulating systems. However, circulation loops connected to central water heating systems are a common practice in apartment buildings, and pipe insulation has been required on these loops for some time.

In addition, one interpretation of the IPC requires pipe insulation on the first eight feet on any non-circulating line from the source of hot water. Circulation loops are defined as a source of hot water. Therefore, it is possible to require that the first eight feet of any branch off the loop be insulated. It is unlikely that this provision is typically enforced.

Benefits of Pipe Insulation

A recent study of 18 households (Gas Technology Institute Residential Water Heating Program funded by the California Energy Commission, contract number CEC 500-08-060; report not yet complete) found that roughly 70-95 percent of all hot water events occurred within 60 minutes of each other. The figure below shows this as the cumulative distribution of time from the previous draw. This clustered hot water draw pattern matches what water utilities tell us about water use patterns which are dominated by morning peaks of 1-2 hours duration and evening secondary peaks of 3-5 hours duration during the work and school week and more spread-out use on the weekends, including lunch time and washing machine uses.

The clustering of hot water events is important relative to pipe insulation because the water in uninsulated ½ inch nominal pipe surrounded by room temperature air cools down from 120F to 105F in about 10 minutes; in ¾ inch nominal pipe it cools down in about 15 minutes. R-3 pipe insulation roughly doubles the cool down time to 20 minutes for ½ inch piping and roughly triples it to 45 minutes for ¾ inch piping. When the time between hot water events exceeds one hour, the water in the insulated pipes is likely to cool down back to ambient, minimizing the benefit of pipe insulation for spread out draws.

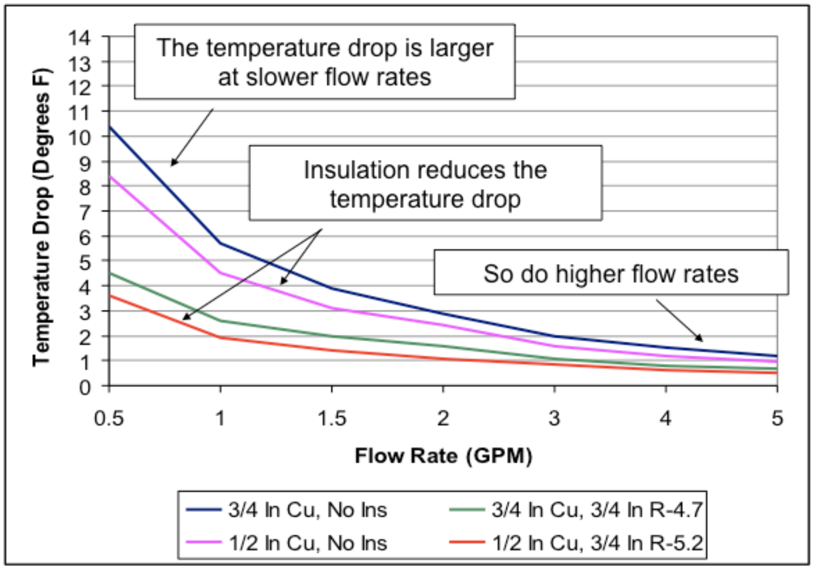


By increasing the cool-down time, insulation increases the number of “hot starts”-draws where the water in the pipe is hot enough for the next use-which reduces the amount of water that runs down the drain before hot water arrives at the fixtures. This reduces the time-to-tap (for hot water to arrive), water waste and operating costs. The measurements in the CEC project were taken at the water heater, so it is not known on which trunk or branch the sequential draws occurred. This is important, because the benefits of pipe accrue when the sequential draws are on the same branch. The piping configuration used in this analysis was selected so that there is one trunk line for all hot water outlets; each outlet has its own relatively short branch from this trunk.

Another benefit of pipe insulation is that it reduces the temperature drop over a given distance of pipe to roughly half of what it would be at a given flow rate in uninsulated pipe. This can be seen in the figure below. As an example, assuming a flow rate of 1 gpm in 100 feet of ¾ inch piping the temperature drop in uninsulated pipe would be about 5.5 F. Pipe insulation reduces this to about 2.75 F.

This is important because reducing the temperature drop over the length of piping in the building means that would be possible to reduce the temperature at the water heater. Reducing the set-point temperature of a storage water heater by 1F will reduce the stand-by heat losses by at least 1 percent.

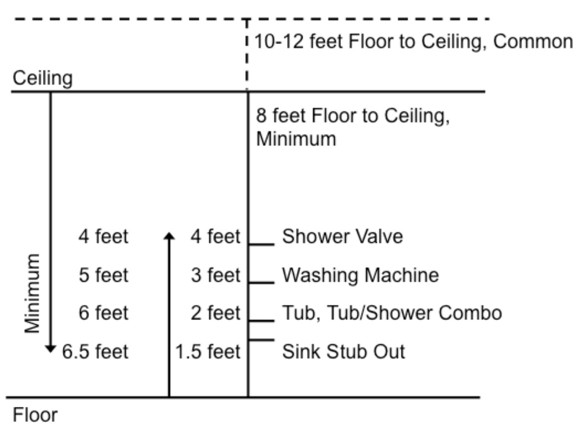
Floor plans and piping configurations that reduce the number of feet of piping also reduce the temperature drop, while at the same time reducing installation costs for both piping and pipe insulation.



Both benefits are greater when the piping runs through harsher environments such as vented crawl spaces or attics in winter, unconditioned basements in cold climates and under slab foundations.

Estimated Feet of Pipe and Associated Pipe Insulation

Three floor plans have been included in this analysis: one-story 2400 ft^2 single family home, two-story 2400 ft^2 home and one-story 1200 ft^2 apartment. All three of these floor plans are assumed to have a trunk and branch hot water distribution system with a single trunk line routed so that the branch lines from the trunk to the fixture fittings can be no longer than 10-11 feet long. This results in the fewest feet of piping that needs to be insulated. The figure below shows the approximate distance from either the floor or the ceiling to fixture fittings found in a home. In general, it is shorter to reach the fixture fitting from below.



Each floor plan is described below.

One-story 2400 ft² home

This is the most stretched out case, meaning that the distance from the water heater to the furthest fixture was the largest, resulting in the most linear feet of piping and associated pipe insulation. Key assumptions:

1. 60 ft by 40 ft layout. The water heater is assumed to be located in garage, next to the firewall at the opposite corner of the house from the master bathroom. The assumption is reasonable since more than 80 percent of new single family homes do not have basements; the foundation is either a slab or a crawl space. If there is a basement, it should be possible to locate the water heater closer to the hot water locations, which would reduce the feet of pipe and associated insulation. However, experience shows that this is often not the case.
2. The approximate horizontal distance from the water heater to the furthest fixture fitting is 60 ft. plus 40 ft.
3. The vertical distance includes getting the trunk line from the water heater up to the attic or down below the floor, plus the distance from the trunk line to each fixture fitting.
    a. Assuming the trunk line will be below the floor then the vertical portion of the trunk line is up and into wall (2 ft.); down and under floor and over to connect to the horizontal trunk (8+2+2=12 ft.). The branch lines run over and up to the fixture fittings and range in length as follows: sink (2+2+2=6 ft.), shower (2+4+3=9 ft.) (last 3 feet is from valve to shower head). The total is 100 feet horizontal plus 14 feet vertical (trunk) plus 6-9 feet vertical (branch) = 120-123 feet.
    b. Assuming the trunk line runs above the ceiling, then the vertical portion of the trunk line is up and into wall (2 ft.); up and over to connect to trunk (3+2=5 ft.). The branch lines run over and down to the fixture fittings: sink (2+8=10 ft.), shower (2+6+3=11 ft.) (last 3 feet is from valve to shower head). The total distance to the furthest fixture is 100 feet horizontal plus 7 feet vertical (trunk) plus 10-11 feet vertical (branch) = 117-118 feet.
4. The trunk line length ranges from 107-114 feet; to be conservative this analysis assumes a length of 115 feet. Each hot water outlet is roughly 6-11 ft. from the trunk line. Calculations assume a conservative length of 10 ft.

Two-story 2400 ft² home

Taking the same area and building it in two stories can bring the hot water locations closer to the water heater. For this analysis, the distance has been reduced even further to show the benefits of a compact layout and close proximity to the water heater. The result is that the distance from the water heater to the furthest fixture fittings is relatively small, resulting in a smaller number of linear feet of piping and associated pipe insulation. Key assumptions:

1. 30 ft by 40 ft layout per floor. The water heater is in the garage next to the firewall. The furthest hot water fixture fitting locations (one upstairs and one downstairs) are roughly half the perimeter distance on each side and there is a single path for the trunk line from the water heater to these locations.

2. The approximate horizontal distance to the furthest fixture fitting is 15 feet plus 20 feet.
    a. The horizontal portion of the trunk line is assumed to be located between the first and second floor. The vertical portion of the trunk line is up and into wall (2 ft.); up and over to connect to trunk (3+2=5 ft.). The vertical distance for the branch lines in 1st floor locations is 10 -11 ft. and for 2nd floor locations 6-9ft.
    b. The total is 35 feet horizontal plus 7 feet vertical (trunk) plus 6-11 feet vertical (branch) = 48-53 feet. This is less than half the length in the single story layout.
3. Each hot water outlet is roughly 6-11 feet from the trunk line. Calculations use the length appropriate to each fixture fitting based on whether it is upstairs or downstairs.

One-story 1200 ft^2 apartment

The relative distance from the water heater (or the circulation loop) to the furthest hot water locations was chosen to be very similar to the layout in the two-story 2400 ft^2 house. It is possible to have layouts that are more compact or more spread out, the feet of pipe would decrease or increase accordingly. Key assumptions:

1. Each unit is assumed to be a single story 30 ft wide, by 40 ft deep. The furthest hot water fixture fitting location is roughly half the perimeter distance on each side of the apartment and there is a single path for the trunk line from the water heater (or circulation loop) to these locations.
2. The number of hot water outlets is less than in the 2400 ft^2 floor plan, because there is no powder room, laundry sink, or stand-alone tub in the master bath.
3. The approximate horizontal distance to the furthest fixture is 15 ft plus 20 ft.
    a. Piping is assumed to run down from above, similar to houses with slab foundations. The reason for this is that fire code rules often result in concrete floors between units. This assumption is conservative in that it increases the length of the branch lines serving each fixture fitting.
    b. The vertical portion of the trunk line is up and into wall (2 ft.); up and over to connect to trunk (3+2=5 ft.). The branch lines run over and down to the fixture fittings: sink (2+8=10 ft.), shower (2+6+3=11 ft.) (last 3 feet is from valve to shower head).
    c. The total is 35 feet horizontal plus 7 feet vertical (trunk) plus 10-11 feet vertical (branch) = 52-53 ft, which is rounded to 55 feet for this analysis.
4. Each hot water outlet is roughly 10-11 feet from the trunk line. Calculations use 10 feet.

These plumbing configurations were selected to explore the likely range of costs for insulating all of the hot water piping in the dwelling unit. This was done, even though it is possible to have a combination of floor plan, water heating location(s) and hot water distribution system piping configurations that could take advantage of close proximity between the water heater(s) and many if not all of the fixture fittings and therefore it would not be required to insulate all of the hot water piping. Doing so would lower the estimated costs of compliance.

The table below shows the feet of pipe insulation estimated for each floor plan. The feet of pipe insulation corresponds to the feet of pipe.

	Feet of Pipe Insulation		
	2400 ft2		1200 ft2
	1-story	2-story	1-story
Trunk	115	42	42
Kitchen			
sink	10	10	10
dishwasher	0	0	0
Laundry			
washing machine	10	10	10
sink	10	10	0
Master Bathroom			
sink 1	10	6	10
sink 2	10	6	10
tub	10	6	0
shower	10	9	10
Bathroom 2			
sink	10	6	10
tub/shower combination	10	9	10
Powder Room			
sink	10	10	0
Total Feet	**215**	**124**	**112**
Number of elbows and tees	**36**	**36**	**27**

Estimated Insulation Costs

The table below shows the estimated feet of pipe and for each configuration and the costs associated with each of three pricing assumptions. The cost estimates assume the use of R-3, roughly 1/2 inch wall thickness, pipe insulation on all hot water piping. It would be possible to reduce costs by surrounding the piping in the attic with blown-in attic insulation.

The costs per foot for the low cost column were obtained by asking one of Northern California's largest residential new construction plumbing installers for price estimates. The costs per foot for the high cost column were obtained from three plumbers that work in the Orlando, Florida residential new construction market. Both of these costs are significantly lower than costs obtained from RS Means and are judged to be much more realistic of actual pipe installation costs in residential new construction. All of the costs assume the use of foam, not rubber or fiberglass pipe insulation. Foam is the least expensive and the one most commonly used when plumbers bid on installing pipe insulation.

	Estimates		
	Feet of Pipe Insulation	Installed Cost	
		Low	High
1-story 2400 sf	215	$ 236.50	$ 322.50
2-story 2400 sf	124	$ 136.40	$ 186.00
1-story 1200 sf	112	$ 123.20	$ 168.00

To be conservative, the analysis assumed a relatively stretched out piping configuration for the 1-story 2400 ft^2 house; more feet, more cost. The 2-story 2400 ft^2 house has roughly half as many feet of pipe as the 1-story house; the piping configuration is much more compact. The 1-story 1200 ft^2 apartment piping configuration has the same "compactness" as the 2-story 2400 ft^2 house; the smaller number of feet are due to fewer fixture fittings. A 2-story 1200 ft^2 apartment could have an even more compact configuration and fewer feet of piping and associated insulation.

One important conclusion from this analysis is that it is possible to have a compact piping configuration in any size dwelling. The closer the hot water locations are to each other and to the water heater(s)that serve them, and the more directly the hot water piping is run from the water heater(s) to the fixture fittings, the fewer feet of pipe and therefore pipe insulation. The fewer feet, the less it costs to install.

Conversely, it is possible to install more feet of pipe and therefore pipe insulation than was assumed in this analysis. A more pipe-intensive hot water distribution method, such as a home-run manifold system could be chosen, or unnecessarily long trunks and branches could be installed in the system that was analyzed. More pipe means more pipe insulation. The more feet, the more it costs to install. It is unclear why this is beneficial to either the plumber or the builder, but unfortunately excessively long hot water distribution systems are often found in new construction.

Estimated Energy Savings

To estimate the energy savings it is reasonable to assume that the average length to the fixtures in the house is half the trunk length plus the length of the branch to the fixtures. The 1-story house has an average length of 67 feet; the 2-story house and the apartment have an average length of 31 feet. For simplicity we will use a range of 30-60 feet. The average volume in the 1-story house is about 1.5 gallons; the average volume in the 2-story house and the apartment is about 0.6 gallons.

The temperature drop without insulation over this distance ranges from 1.5-3.0 F. Insulation will reduce this to 0.75-1.5F. This analysis will assume insulation reduces the temperature drop by 1F.

Reducing the temperature drop by 1F reduces the stand-by heat losses by at least 1 percent. A typical gas storage water heater uses about 5,000,000 Btu per year for stand-by losses; an electric water heater uses about 1,000,000 Btu per year. This means the savings will be 50,000 Btu per year for natural gas and 10,000 Btu per year for electricity.

Based on the CEC research findings, the typical house has about 60 hot water events each day. About 30 percent, or 18 of the draws are within 10 and 60 minutes apart (see figure on time between draws in earlier section). Pipe insulation will eliminate most of the water and energy wasted while waiting for all of these hot water draws. When water is run down the drain waiting for hot water to arrive, new water enters the water heater to be heated. This means that it is necessary to account for the energy attached to this water by using the temperature difference between incoming cold-water temperatures and the water heater set point temperature. To be conservative, this analysis will assume that this temperature difference is only 50F, which is reflective of a warm climate.

Other research sponsored by the CEC (reported by Hiller in ASHRAE) has shown that more water than is in the pipes comes out of the pipes before hot water arrives at the fixture fitting; for flow rates between 1 and 2 gpm, the additional waste ranges from 1.5 – 1.25 times the volume, respectively. Yes, the waste increases as the flow rate goes down. To be conservative, this analysis will not include this additional volume in the calculations.

The following figure converts volumetric waste into energy wasted. To find the range of potential savings we need to find the average volume that might be wasted per event (ranging from 0.6-1.5 gallons per event); follow that down until it intersects with the number of such events (18) and go over to the left to determine the number of Btus. Interpolation between 0.5 and 0.75 gallons per event is necessary. Based on the assumptions in this analysis, the energy lost due to wasting water while waiting for the hot water to arrive ranges from 1,500,000 to 4,000,000 Btu per year.

			Volume in Pipe That Cools Down							
		Gallons	0.0625	0.125	0.25	0.5	0.75	1	1.5	2
		Cups	1	2	4	8	12	16	24	32
Heat Loss										
Btu/Year	Btu/Day		Number of Times Per Day that Water in Pipe Cools Down							
500,000	1,370		53	26	13	7	4.4	3.3	2.2	1.6
1,000,000	2,740		105	53	26	13	9	7	4.4	3.3
1,500,000	4,110		158	79	39	20	13	10	7	5
2,000,000	5,479		210	105	53	26	18	13	9	7
2,500,000	6,849		263	132	66	33	22	16	11	8
3,000,000	8,219		316	158	79	39	26	20	13	10
3,500,000	9,589		368	184	92	46	31	23	15	12
4,000,000	10,959		421	210	105	53	35	26	18	13
4,500,000	12,329		474	237	118	59	39	30	20	15
5,000,000	13,699		526	263	132	66	44	33	22	16
5,500,000	15,068		579	289	145	72	48	36	24	18
6,000,000	16,438		631	316	158	79	53	39	26	20

The reduction in volumetric losses dominates the savings due to pipe insulation, so we will use those values to estimate the savings potential.

Assuming the typical household uses 60 gallons per day of hot water and the temperature is raised from 50 to 130F (a greater temperature rise than was assumed for the cool-down losses) it takes 14.6 million Btu a year to heat the water, not including the inefficiencies of the water heater. If the savings due to pipe insulation ranges from 1.5 to 4.0 million Btu per year, the percent savings ranges from 10.2 to 27.4 percent.

This estimate is conservative for at least two reasons. First, the typical home has more stretched out piping than was assumed in the 2-story house and the 1-story apartment, so the volume of wasted water will be larger than estimated for the lower end of the range of volumetric losses. Second, the actual temperature difference between incoming cold water and the hot water set point is often less than 80F, so the energy needed to heat the water that has been wasted is likely to be smaller than estimated. Both of these factors will result in larger percentage savings.

In addition to the energy savings at the house, reducing water use saves energy by not having to treat and deliver cold water to the home and by not having to remove, treat and discharge the waste water. This energy savings generally does not occur at the home, unless one has a well. This is on the order of 5 kWh/1000 gallons for urban water and waste water systems combined; these energy savings were not included in this analysis.