NAHB RESEARCH CENTER

# PATH Field Evaluation

## Task 1

## Evaluation of Residential Water Distribution Piping Installation

## Time, Cost & Performance Comparison

## PEX & Copper

## Liberty Village
## Lincoln, Nebraska

## September 2006

PATH Technologies:

Cross-linked Polyethylene Water Piping

Manifold Plumbing Systems

PATH
PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

## PATH PROGRAM

The Partnership for Advancing Technology in Housing (PATH) is a public/private partnership that joins together key agencies in the Federal government with leaders from the home building and related industries. The goal of this program is to accelerate the creation and widespread use of advanced technologies in order to improve the quality, durability, environmental and energy efficiency, disaster resistance, safety, and affordability of our nation's housing.

PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition to HUD, federal agencies participating in the program include the U.S. Departments of Agriculture, Commerce, Defense, Energy, Labor and Transportation, Environmental Protection Agency, Federal Emergency Management Agency, Federal Housing Finance Board, and White House Office of Science and Technology Policy. Private-sector members include leaders of the home building, product manufacturing, insurance, and financial industries.


## ACKNOWLEDGEMENTS

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Marie Del Bianco and Megan Inouye of the NAHB Research Center were the principal investigators and authors of this report. Megan Inouye and Joe Wiehagen designed the water distribution performance test and carried out testing. Pam Eggleston performed document design and formatting.


## DISCLAIMER



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# BACKGROUND

## Objective

According to the results of the *2005 Annual Builder Practices Survey*[1] copper pipe is the most readily available and widely used material for water supply lines in the United States – installed in 41 percent of new homes. An alternative to copper pipe, currently represented in just 19 percent of new homes, is cross-linked polyethylene (PEX) pipe. Studies in the past have shown evidence of savings by using PEX, but definitive results were sought to expand the knowledge of types of water supply systems that can be installed in single family homes. This study compares a traditional trunk and branch copper system to a PEX parallel piping system to gain a better understanding of the installation time, material cost, and system performance for each.

Figure 1. Front elevation of a house in Liberty Village

## PEX and Copper

The copper pipe used in residential applications is rigid and comes in lengths up to 20 feet, but is often cut to shorter lengths to facilitate transport. Pipe junctions are made by removing the burrs from the cut edges of pipe and fittings by sanding, cleaning the pieces with an emery cloth, applying flux to each end to be joined, connecting these with a union, and then soldering the pieces together. The heated solder melts at the pipe joint and is drawn into the gaps between pipe and fittings by capillary action. Once cooled, the solder forms a watertight joint. Joints occur where two pieces of pipe are coupled, where the pipe changes direction at tees and elbows, or where the pipe terminates with an end cap or stub ell. Copper pipes are secured to the building's frame at a maximum of six feet horizontally and 10 feet vertically with talons or pipe brackets.

PEX pipe is a flexible, plastic pipe that is approved for supply water piping in all model plumbing and mechanical codes across the United States. The flexible nature of PEX pipe, as well as its availability in rolls of continuous piping up to 1000' long, allows PEX pipe to be routed around framing and mechanical obstructions in gentle bends[2] reducing the need for fittings for either directional changes or length of the layout. PEX can be installed in place of rigid pipe on a size-

[1] NAHB Research Center, 2005.
[2] Manufacturers recommend bends that are at least 8 times the outside diameter of the pipe.

for-size basis in a trunk and branch design where a large diameter main pipe feeds smaller-diameter pipes that service a fixture group. PEX can also be installed in home-run or remote manifold designs which utilize manifolds to distribute dedicated lines to each fixture. It can be purchased in several colors; conventional practice has evolved to the use of red pipe for hot water and blue pipe for cold water distribution. PEX pipe requires re-support to the building frame at prescribed intervals of 32" horizontally and 5' vertically.

## WATER DISTRIBUTION SYSTEM INSTALLATION STUDY

### House Selection and Site Conditions

Six houses that were to be built in an urban infill subdivision of 16 single family homes were selected for this study in Lincoln, Nebraska. The houses were constructed during the fall of 2005 through the spring of 2006. The homes were approximately 1,500 sq. ft. with two full bathrooms on the second floor, a kitchen sink, powder room, two hose bibbs on the first floor, and clothes washer hookups in the basement.[3] All homes were of the same architectural plan (LV1) and the plumbing systems were designed and installed by the same plumbing general contractor's two- to four-person crews. The crews were experienced in both PEX and copper.

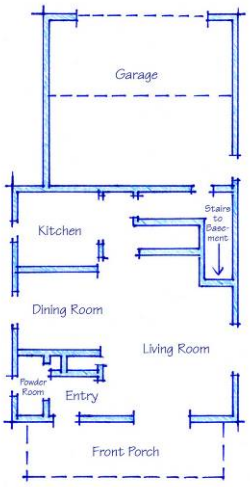



Figure 2. First floor plan

PEX was installed in the first three houses for the plumbing contractor's convenience (the team involved in the study selected the material). Two of the three, Lots 1 and 2 were plumbed in late October and early November of 2005 when temperatures were mild and ranged between 45°F and 65°F and the site was dry. Lot 4 was installed in late November 2005 when temperatures ranged from 20° F to 35°F and the site was muddy from snow and melting ice. Lots 6 and 8 were installed in early January and early February 2006 during cold (20-40°F), but dry site conditions. Lot 5 was plumbed with PEX (copper had been planned for this lot) at a time when no observer was present to record the time so it was eliminated from the study. Because there were only six LV1 houses in the project, an alternate for Lot 5 wasn't available. The role that weather or site conditions played in the final labor time that was recorded for these installations was not estimated.

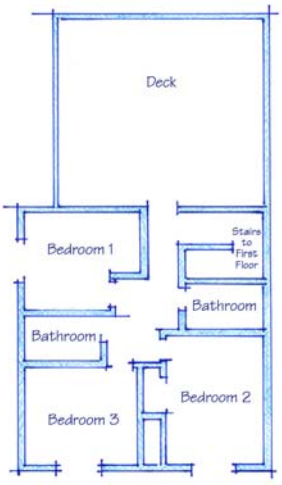



Figure 3. Second floor plan

[3] Detailed floor plans of the LV1 can be found in Appendix I.

## Copper Pipe

The plumbing supply lines in Lots 6 and 8 were installed in a trunk and branch design using 1/2- and 3/4-inch copper pipe. Pipe diameter size was determined by distance from the water service meter to the fixture and the number of fixtures being served. The main (trunk) supply lines were 3/4-inch in diameter, and the branch pipes were reduced to 1/2-inch pipe once two or fewer fixtures were being served by the line. Two 3/4-inch mains, one for hot and one for cold, served the whole house. These mains ran the length of the house horizontally, roughly 25', and vertically to each of the two baths on the second floor, roughly another 15'.

Figure 4. Copper mains and branches supplying the second floor

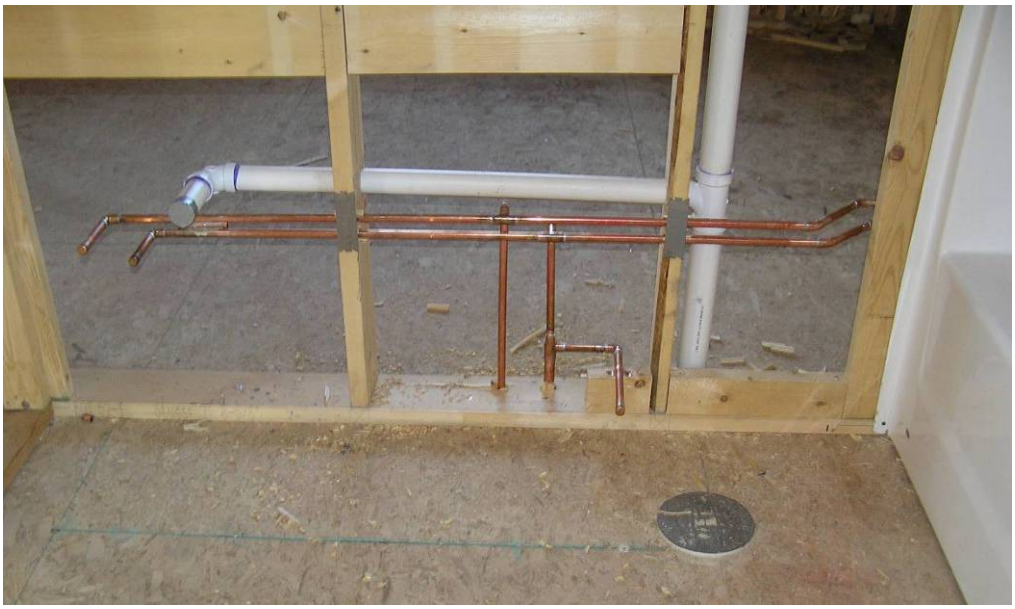


Figure 5. Copper branches to a second floor bathroom

## PEX Pipe

Figure 6. A plastic J turn-out clamp supports the PEX pipe where it comes through the bathroom wall to supply the sink

Lots 1, 2 and 4 contained PEX pipes that were installed in a parallel layout that started at a central manifold located in the below-grade basement near the front of the house. Each dedicated water supply line terminated at a fixture in one of the three baths, kitchen, laundry, or hose bibb locations that are the subcomponents in the plumbing labor study.

The manifolds, pipe, and crimp fittings used in Lots 1, 2, and 4 were manufactured by Vanguard Piping Systems, Inc. Called a *Manabloc*, the manifold can be ordered in different quantities and combinations of 1/2-inch or 3/8-inch ports for connection of the PEX supply lines. Specialty fittings allow the 1/2-inch ports to be reduced to 3/8-inch as necessary, as was the case in Lot 1. The manifolds contained integral valves, so that stops at the fixtures weren't necessary according to the current code requirements.[4] However, local interpretation required that the water closets be supplied with a stop valve convenient to the toilet.

Like traditional plumbing riser designs, pipe layout distance and fixture demand drive the PEX design. A parallel supply system does not experience pressure drop in the pipe as readily as a trunk and branch system because of its direct path to the fixture. Lavatories and water closets were piped with 3/8-inch pipe. The tubs, hose bibbs, clothes washer hookup, and kitchen faucet where the dishwasher water supply was integral were served with 1/2-inch PEX pipe.

Figure 7. PEX supply lines running parallel to the PVC drain waste line in the basement ceiling

[4] The International Residential Code 2003 (IRC) is cited here. Lincoln, NE had only adopted the Uniform Plumbing Code 2000 (UPC) at the time of this project. The latter code assumes a trunk and branch of a water supply system and prescribes minimum pipe diameter and stops at all fixtures. Provision for third party certified alternate systems is left to local officials in the UPC. The Manabloc is IAPMO approved.

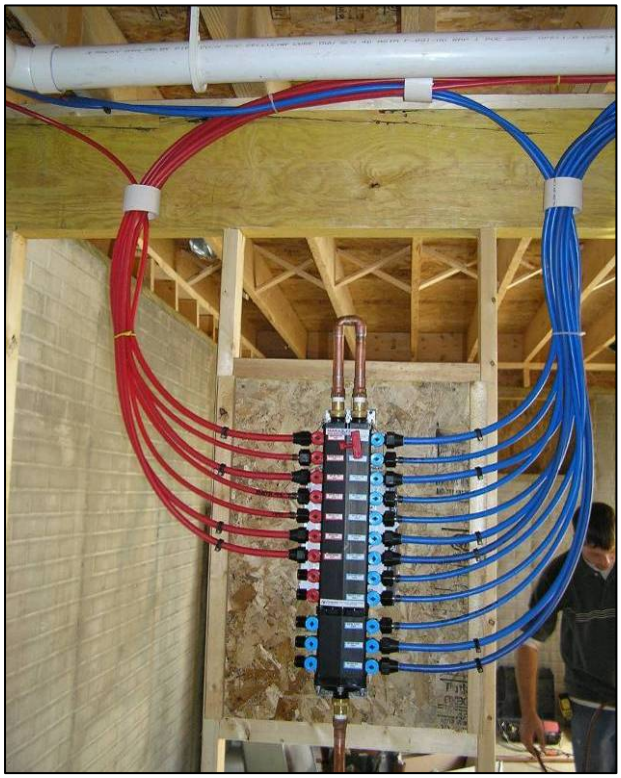


Figure 8. A Manabloc plastic manifold with parallel PEX system

## Water Distribution Piping Installation Time Study Results

A group timing technique (GTT) that documents the time and tasks that were undertaken to complete the installation of one phase of a trade person's work was used to perform the labor study. The GTT allows one observer using a watch and a tally sheet to make a detailed elemental time study on an entire work crew simultaneously. Activities were observed continually and entered at one or five-minute intervals, dependent upon the rate of change in the tasks being accomplished or the component (fixture) that was the target of the activity. Generally, there are two parts to the study – the task that is being performed and the component that each task is targeted to complete. The study was designed to capture a fine level of detail of the process and component parts of the work to provide a basis for a quantitative comparison of the two water distribution systems. Appendix II further explains the task descriptions.

At the outset, the activities associated with trimming out the rooms with plumbing fixtures, (sinks, toilets, etc.) were to be included in the time study in order to capture differences attributable to the two different materials at the final stage of plumbing system assembly. However, it was not possible to coordinate the installation and data collection schedules. The time to perform these activities was expected to be more uniform regardless of supply pipe material because of the similarity of systems from the "stub out" point to the fixtures.

Therefore, the time associated with installing plumbing trim items at the finish end of the houses was not captured and is not reported.

Table 1 shows the aggregated time in labor minutes for each task. The tasks *Connect Supply to Water Main*, *Break/Idle*, and *Check for Leaks* were not included in the analysis. The tasks *Connect Supply to Water Main* and *Check for Leaks* were not captured uniformly in all lots. *Break/Idle* was omitted because it varied considerably from house to house. Appendix III details the complete data set for each component. The numbering of the lots represents the sequence in which each lot was completed.

Table 1. Labor Time Required to Install the Rough-In Plumbing Portion of the Water Distribution Systems

| **Liberty Village Lot Number** | **1** | **2** | **4** | **6** | **8** |
|---|---|---|---|---|---|
| Type of System | PEX | PEX | PEX | Copper | Copper |
| Job/Tool Set Up/Clean Up | 100 | 135 | 215 | 281 | 280 |
| Obtain Materials | 55 | 95 | 55 | 50 | 35 |
| Install | 70 | 50 | 35 | 145 | 265 |
| Cut, Drill, Block, or Measure (structure) | 135 | 135 | 125 | 296 | 370 |
| Pull PEX Lines or Measure/Cut/Ream Copper Pipe | 350 | 165 | 245 | 684 | 650 |
| Install PEX Fittings/Flux Copper Pipe | 125 | 45 | 75 | 184 | 120 |
| Install Copper Fittings/Solder Copper Pipe | 245 | 230 | 105 | 144 | 175 |
| Install Pipe Supports | 135 | 205 | 205 | 207 | 90 |
| Plan Design and Talk Business | 30 | 40 | 35 | 35 | 70 |
| Clean Up Jobsite to Ready for Work | 0 | 0 | 0 | 50 | 0 |
| Rework | 0 | 15 | 15 | 117 | 75 |
| **Total Time (labor minutes)** | **1,245** | **1,115** | **1,110** | **2,193** | **2,130** |
| **Total Time (labor hours)** | **20.8** | **18.6** | **18.5** | **36.6** | **35.5** |
| **Average Time (labor hours)** | **19.3** | | | **36.1** | |

All lots were installed by the same plumbing crew. The crew consisted of an experienced team leader, who also was a principal in the company, and one to three other workers, depending on the day and task. For the most part, a three- or four-person team worked on the PEX and a two-person team worked on the copper systems. Appendix III also shows the installation crew size for each lot. There were two members of the company on site who were installing the drain waste vent (DWV) pipes in nearby units. These two people would come to the aid of the water distribution pipe installers as requested or when their own work had been completed or temporarily impeded by another trade's work. (HVAC ducting was sometimes installed at the same time as DWV or water supply pipes).

The results show with each additional house completed, the total time to install the rough plumbing portion of both systems improved. PEX systems saved an average of 16 labor hours over copper systems. The saved time represents a full day's work for a two-person crew. Time in transit from office to site and back was not captured in the study.

The task *Cut, Drill, Block, or Measure (structure)* represents the substantive actions of preparing the path along/through the subframe for the routing of the water distribution lines. Most of the PEX lines were routed through 3.5-inch PVC rings suspended from joist bottoms or in wall cavities. This made threading bundles of pipe practical and simplified the installation (see Figure 4). In these houses, the average labor required for this task was two and a half times more for a copper system than a PEX one. For the copper system the task associated with joining the pipes – cutting, sanding, preparing for solder and connecting – are covered within *Measure/Cut/Ream Copper Pipe*. Because none of these activities are required of the PEX system, the task *Pull PEX Lines* captures the time expended in pulling the PEX throughout the house. The difference in installing the pipe is also approximately two and a half times more labor intensive for a copper house.

The variances in time aggregated to each task that are apparent in Table 1 can be partially explained by the following details that were observed. The installation of distribution lines in Lot 1 started directly after the crew had completed the DWV pipes. Because all of the tools, ladders, etc. were already in the house, only cleanup time was allocated to the task *Setup/Cleanup* on the first day.

The plumbing distributor was not prepared with 3/8-inch PEX and fittings because the city inspector made a code exception from the UPC 2000 to allow 3/8-inch PEX pipes for the water closets and lavatories in this project. One worker traveled offsite to get additional 3/8-inch fittings for Lot 2 accounting for 50 minutes under the *Obtain Materials* task.

The *Rework* task in Lot 6 includes 40 minutes that were used to remove the horizontal trunk and reinstall it so it would meet the vertical main supply.

The installation crew for Lot 6 ran short of 20-foot lengths of 3/4-inch copper pipe and pieced shorter lengths together to feed the powder room/front hose bibb. Time was also added by the frustration of the limited access where the main trunk transitions from vertical to horizontal. Close proximity to the structural components of the house and the waste stack made soldering without charring these difficult.

## Water Distribution Piping Material Costs

The plumbing contractor provided the material costs which represent the marketplace in Lincoln, Nebraska during the last quarter of 2005 (PEX) and the first quarter of 2006 (copper).

Table 2 summarizes average costs of the piping material used for the rough plumbing in this study. Appendix IV contains quantity details for all lots.

Table 2. Average Material Costs by Category

| | PEX | Copper |
|---|---|---|
| Piping | $202.23 | $229.47 |
| Fittings and Parts | $117.90 | $94.35 |
| Central Manifold | $130.49 | $0.00 |
| Universal Components * | $54.50 | $54.50 |
| **Total** | **$505.12** | **$378.32** |

* Universal components include items that are identical regardless of the system- hose bibbs and washer box

The difference in material cost between PEX and copper is $126.80 per house. The cost of the central manifold accounted for a significant portion of the difference – representing nearly 26 percent of the material cost for a PEX house.

## Overall Cost of the Rough Plumbing Water Lines

Appling a cost to the labor time recorded for the rough-in plumbing component (Table 1) will aid in determining the overall cost for each piping system. However, regional labor rates and business structures for allocating indirect costs, like general and administrative and overhead expenses, can thwart a meaningful national comparison. To simplify, we developed a labor rate based on a hypothetical worker's hourly rate, basic perquisites for vacation and health insurance, and statutory perquisites like FICA, unemployment and worker's compensation insurance. So, the rates represented do not include allocated overhead or profit. Known rates can be substituted for these to approximate the cost to a given builder or subcontractor.

First, a labor rate was calculated that, when applied to the time documented in Table 1 and summed with the cost of materials in Table 2, would make each system cost the same, or break even in the comparison. The hourly rate at which either choice of piping material would cost the same, given the enumerated circumstances is $7.55. This approximates the federal minimum wage rate of $5.15 with a 46 percent add-on for perquisites. Because the rate paid to installers of plumbing systems nearly always exceeds minimum wage, it is reasonable to conclude that the labor costs for installing PEX in these circumstances were lower than copper.

The U.S. Department of Labor's, Bureau of Labor Statistics (BLS), 2005 Metro Area Wage Estimates[5] provided a reliable source for raw wage rates in Lincoln, NE. Statistics for the year indicate that *plumbers* earn an average of $19.71 an hour while their *trade helpers* earn $11.67.

[5] http://www.bls.gov/oes/current/oessrcst.htm

After applying 37%[6] to these numbers to cover perquisites the cost to an employer of these workers is $27.00 and $15.99, respectively. Results for the cost of labor at these two rates in the houses evaluated are presented in Figure 9.

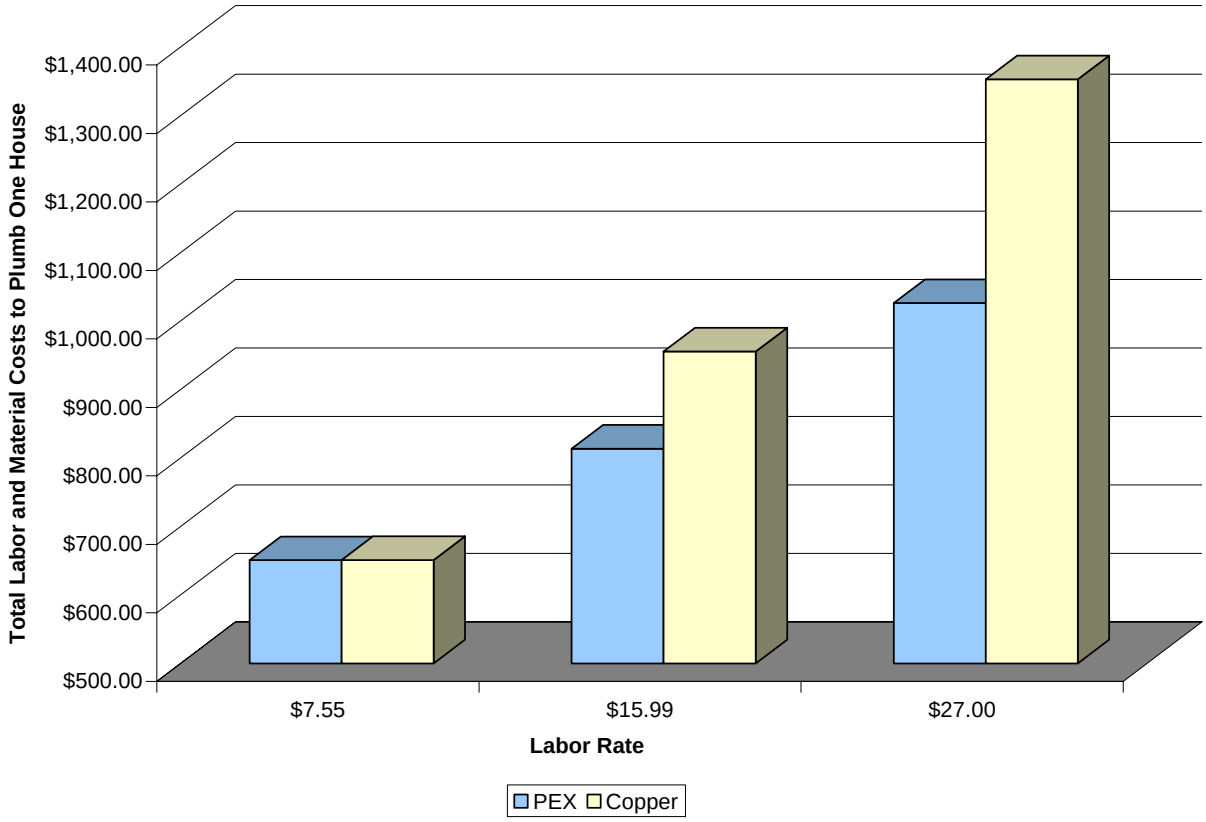



Figure 9. Average labor and material costs to install rough-in water supply

Since plumbing installers work in teams consisting of head plumbers and trade helpers, the average labor rate would fall in the range between $15.99 and $27.00. The $15.99 cost assumes all of the labor is performed by trade helpers and the $27.00 cost assumes all of the labor by head plumbers.

Because the team conducting the GTT study observed the plumbers to work in teams composed of an experienced plumber and a helper, an assumption was made that half of the labor time was allocated to a lead plumber and half to a trade helper. Table 3 shows the total labor and material costs for an average PEX and copper house.

[6] Accountants generally agree on a range from 37-46% as representative of the cost to cover statutory (20%) and other fringes (17%).

Table 3. Average Overall Cost of PEX and Copper Rough-in Water Distribution System

| | Plumbing System Cost | | | |
|---|---|---|---|---|
| | **Home Run PEX** | **Trunk & Branch Copper** | **Cost Difference** | |
| Average Materials | $505.12 | $378.32 | $126.80 | +34% |
| Average Labor | $414.85 | $775.97 | ($361.12) | -47% |
| **Total** | $919.97 | $1,154.29 | ($234.32) | -20% |

Based on the installation time that was recorded, the BLS wage rates for the area with the projected cost of fringe benefits and statutory perquisites, and reported material costs, the PEX rough supply installation was 20% less than copper on average in identical houses.

## WATER SUPPLY PERFORMANCE TESTING

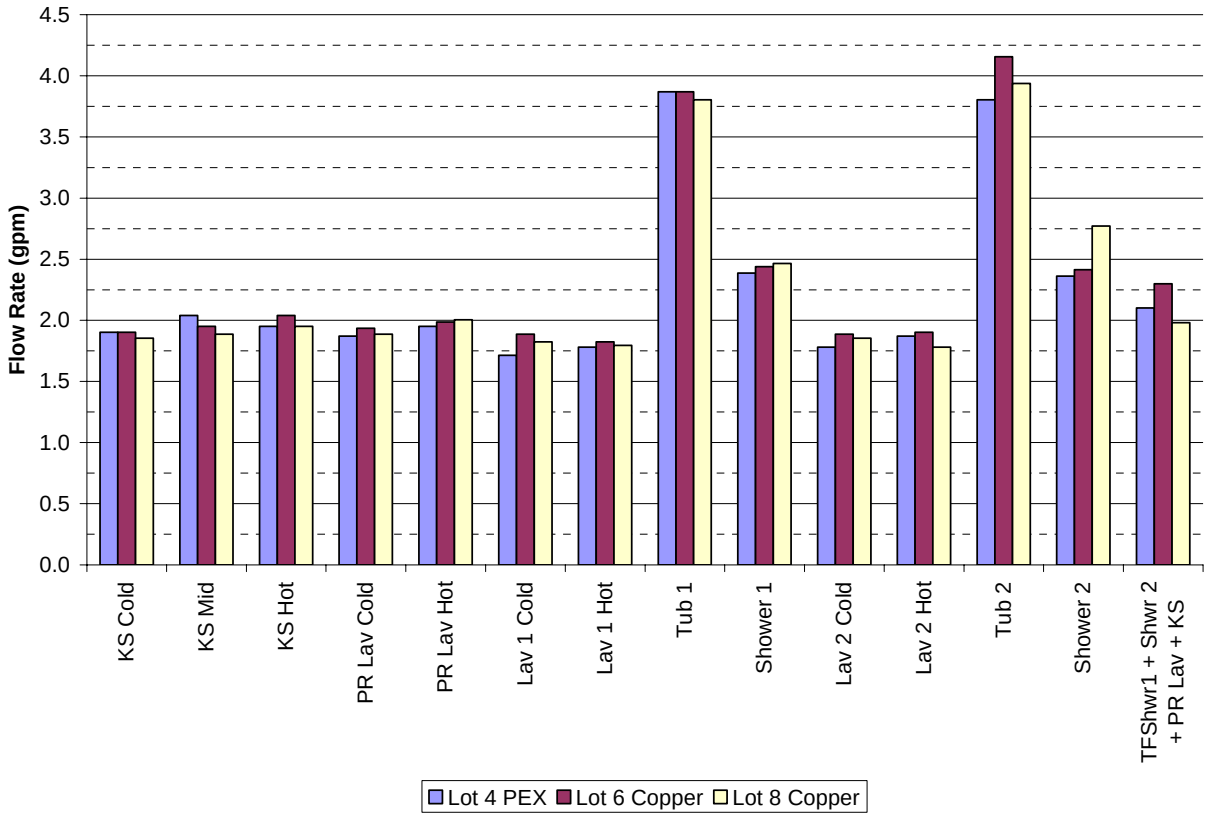
### Fixture Flow Rates

In addition to the installation time and material cost analysis, data was collected to compare the performance characteristics of each system. System pressure, flow rate, and delivery time of hot water data were recorded after the houses had been completed. The tests were performed in three of the five houses involved in the installation portion of the study. Lots 4, 6, and 8, one PEX system and two copper systems, respectively, were tested. Performance data was not collected in lots 1 and 2 due to homeowner occupancy.

The system pressure was established by attaching a pressure meter to the cold side of the clothes washer valve in the basement. As expected for a central pressurized urban water supply system, the pressure readings ranged from 61 to 62 psi for lots 4, 6, and 8.

The water flow rate was measured at the lavatory, tub, and shower in the bathrooms, the kitchen sink and the powder room lavatory. Flow rate data was also collected at the furthest shower while the other shower, the powder room lavatory and the kitchen sink were operating to collect simultaneous data as a "worst case" scenario.

The fixture flow rates were established using two methods. The first method involved timing how long it took to fill a bucket with the fixture full on and calculating the flow rate from the weight of the water. The second method relied on the house water service meter to establish the volume of water that flowed in a given time interval. Both methods produced similar data. The figure below shows the flow rates established using the water meter method for each fixture except for the simultaneous flow which was calculated with the bucket method.




Nomenclature: **KS** = kitchen sink, **PR** = powder room, **Lav 1** = furthest lavatory, **Tub 1** = furthest tub, **Shower 1** = furthest shower, **Lav 2** = other lavatory, **Tub 2** = other tub, **Shower 2** = other shower, **TFShwr1 + Shwr2 + PR Lav + KS** = test fixture shower 1 + shower 2 + powder room lavatory + kitchen sink mid, **cold** = cold on full, **mid** = both hot and cold on full or the lever at midpoint, **hot** = hot on full

Figure 10. Measured fixture flow rates

Fixtures denoted with the number 1 are located in the furthest bathroom from the water heater which corresponds to the longest pipe run from the water service entry. The graph shows that all systems perform similarly regardless of the piping material. There are minimal differences between the flow rates in each house and all fixtures operate adequately. The flow rate is restricted by the fixture and aerator, if applicable, not the piping material. The 2003 IRC mandates that the maximum flow rate is 2.2 gpm at 60 psi for a lavatory and sink faucet and 2.5 gpm at 80 psi for shower heads.

## Time to Deliver Hot Water

The most significant difference between the copper and PEX systems was highlighted in the test for delivery time of hot water to the first fixture. All of the water heaters' elements were adjusted to the same settings to provide a consistent hot water delivery temperature. The tests for each house were performed at the same time of day to allow the temperature of the

pipes to stabilize. Data was collected in sequence at the furthest lavatory, the second lavatory, the kitchen sink, and then the powder room lavatory.

For the time to hot water delivery tests, lot 7 was included to expand the test set. Lot 7 was plumbed with PEX piping and the same central manifold. This house was a slightly different floor plan but contained the same fixtures and comparable piping lengths as the other lots.

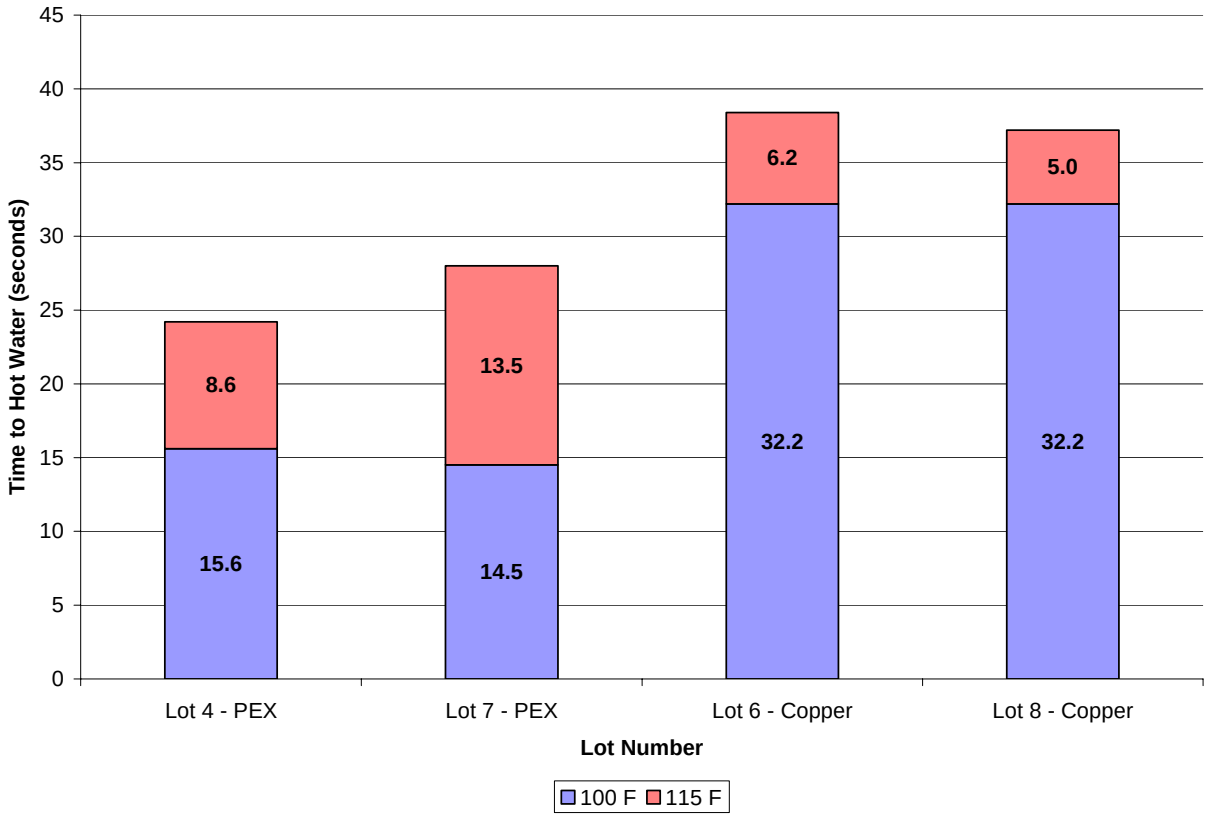



Figure 11. Average time to hot water for the furthest lavatory

Figure 8 depicts the time to deliver 100°F and then 115°F hot water to the furthest lavatory. This data represents the average of five tests for lots 4, 6 and 8 and two tests for lot 7. The PEX systems delivered 100°F hot water to the furthest fixture in approximately half the time as the copper systems. The average time for 100 degree water was 15 seconds for a PEX system and 32 for a copper system.

Wait time for hot water delivery correlates to the volume of water wasted purging the system. Using the time and flow rate for a particular fixture, the amount of cold water that is wasted waiting for hot water can be derived. For the furthest lavatory to reach 100°F, the average amount of wasted water was 0.45 gallons for a PEX system and 0.96 gallons for a copper system. The key to this savings is the 3/8-inch pipe used in the PEX houses because smaller diameter pipes hold less volume. In addition to the water savings, this is approximately the

same volume of hot water that is left in the system to cool down when the fixture is turned off, providing energy as well as water savings.

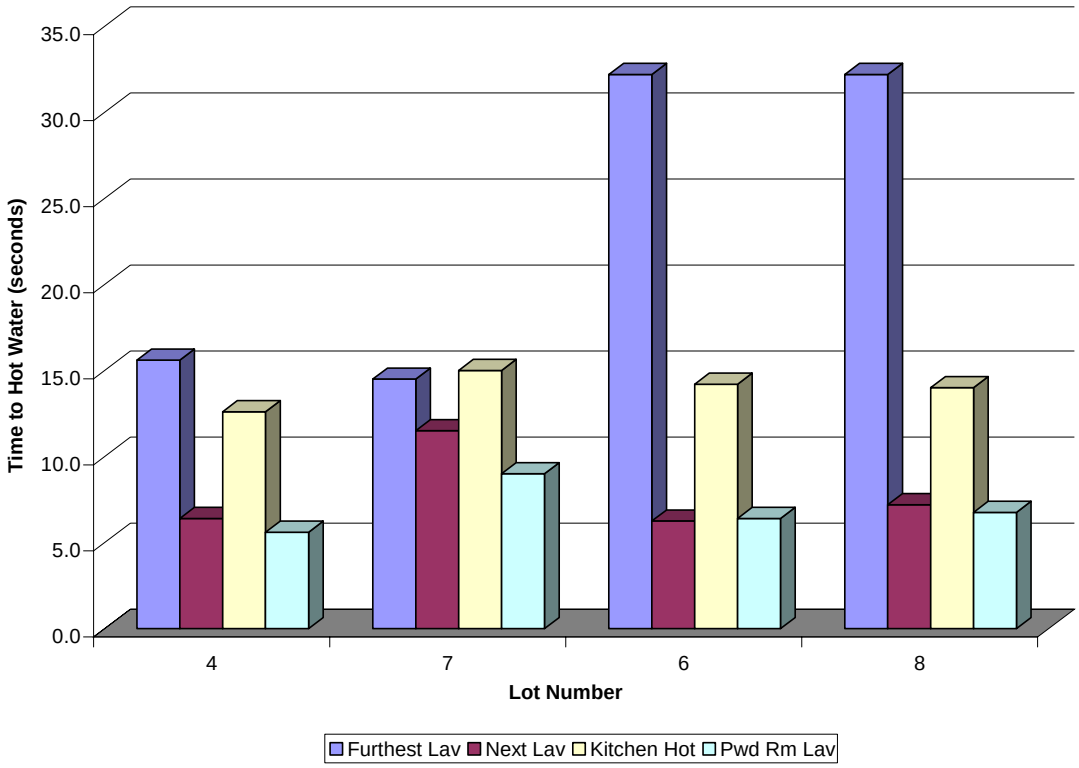



Figure 12. Average delivery time of 100°F hot water to four fixtures

Figure 9 shows the time to deliver 100°F hot water to the furthest lavatory, the next lavatory, the kitchen faucet on hot, and the powder room lavatory sequentially to simulate sequential usage. As shown in Figure 8, the time to deliver hot water to the initial fixture is dramatically different. However, the wait times for hot water to reach subsequent fixtures closer to the water heater within a short period of time (approximately 10 minutes) are negligible.

## CONCLUSION

A plumbing water supply system design with PEX pipe and a central manifold is a competitive alternative to a rigid copper pipe system. Time studies conducted indicate a potential savings of 16 labor hours which could easily offset the $130 difference in material cost between the two systems. Based on the installation time that was recorded, the BLS wage rates for the area with the projected cost of fringe benefits and statutory perquisites, and reported material costs, the PEX rough supply installation was 20% less than copper on average in identical houses. The home-run PEX system had the additional advantage of providing a dedicated supply line to each fixture and hence, allowed the use of smaller diameter pipe and eliminated hidden joints. The smaller pipe diameter used on some of the fixtures allowed hot water delivery to an initial fixture at a rate twice that of copper and at comparable rates for subsequent fixtures.

# APPENDIX I
# LV I FLOOR PLANS

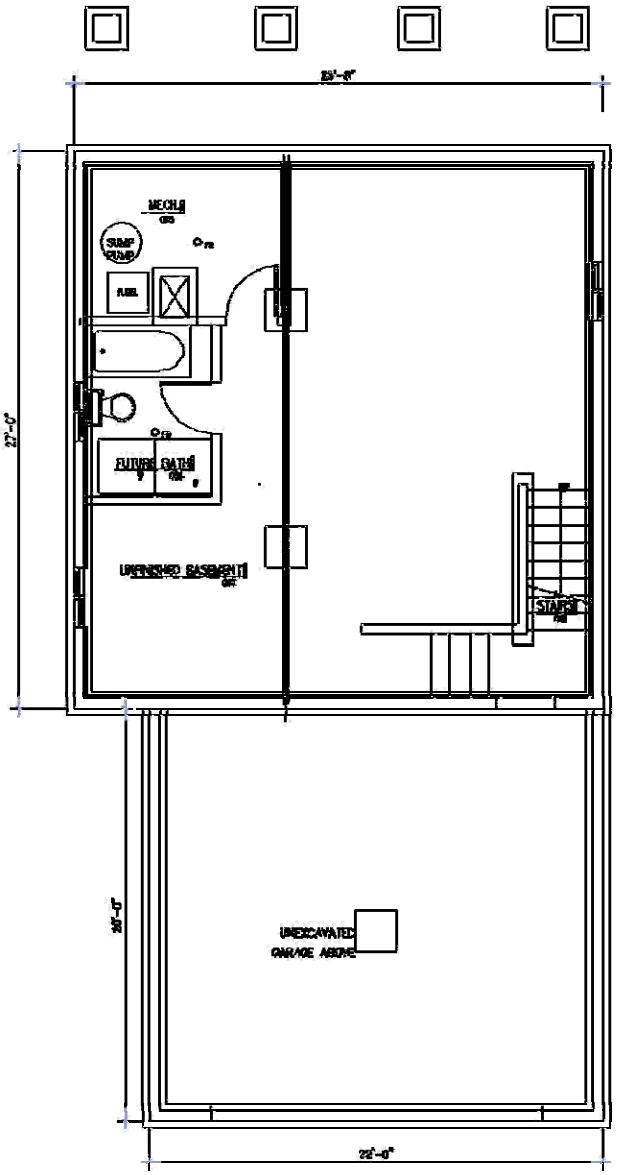



Figure 13. Basement floor plan

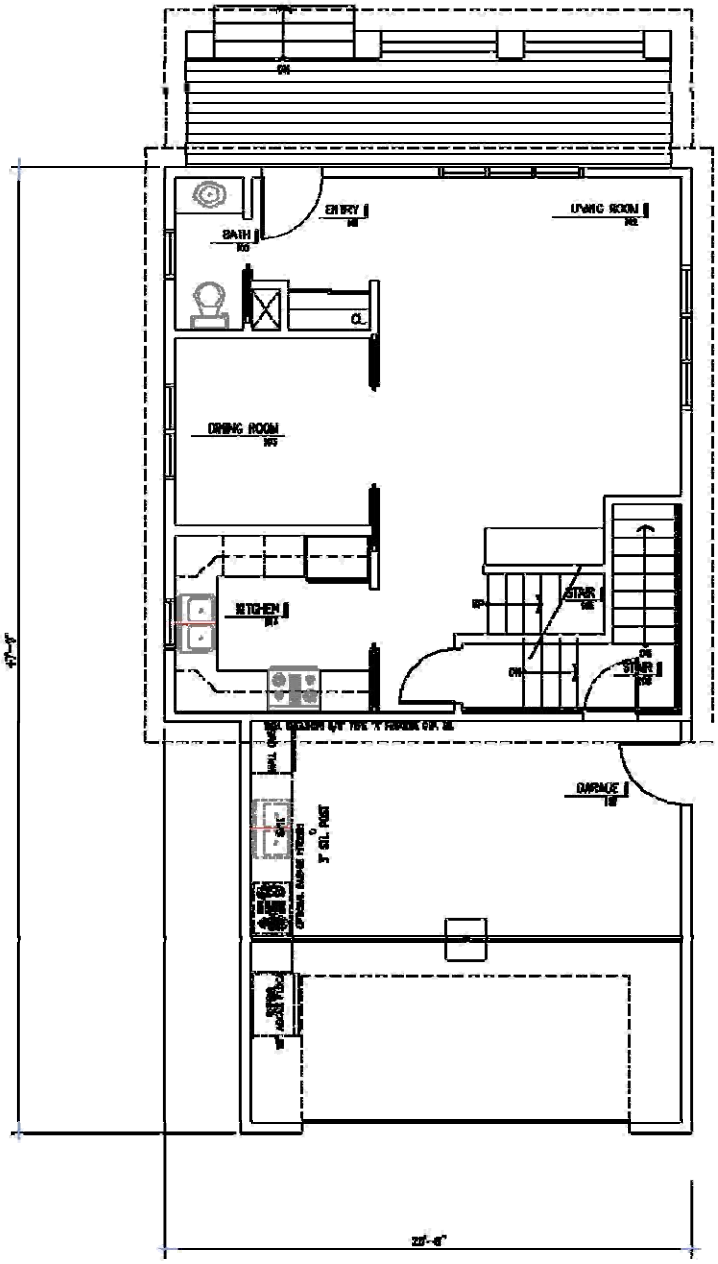



Figure 14. First floor plan

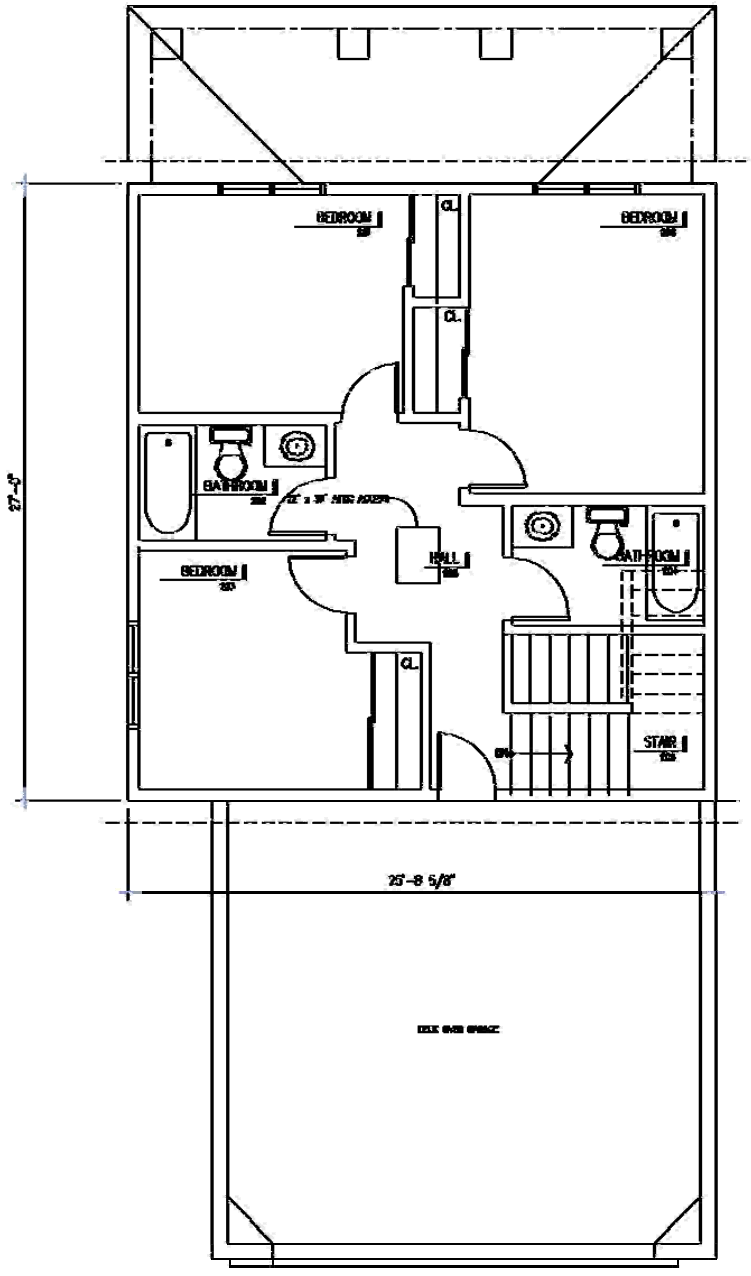



Figure 15. Second floor plan

# APPENDIX II
# TASK DESCRIPTIONS

The time study focused on 13 tasks that were selected as most recognizable and/or relevant to both an installation of PEX and copper pipe. In the first two time studies, conducted in Lots 1 and 2, the subcomponents were identified as each fixture in a bath or kitchen group. After those studies were completed it was determined that the location of the target fixture within the structure was the significant fact, so the subcomponents used on lots 4, 6, and 8 tally sheets were reduced to each water supply location group (bathrooms, kitchen, hose bibbs, or washer box), or eight subcomponents. The subcomponents have been further consolidated in this report to work that supported either the two second floor full baths or the first floor plumbing – kitchen, hose bibbs, and power room. All work to move mains from the basement to the upper floors was attributed to the first level.

The tasks were defined as follows:

*Job/Tool Set Up/Clean Up*: This task usually falls under the General component column and covers the time that it takes to get ready for work and preparing to leave the site for the day – bringing tools and materials from trucks and trailers to the house that will be plumbed (and back), plugging in electrical cords, and setting up ladders.

*Obtain Materials*: This activity includes retrieving piping, components, and any other item from a location outside of the house that is being worked in.

*Install*: The "Install" task has been used as a catchall category for activities that may not be directly related to the supply line activities. An example in the first study was mounting the washer hookup box and installing the shower handle. (The washer hookup box might be better defined as belonging to the Drain/Waste/Vent installation and the shower handle to final plumbing trim).

*Cut/Drill/Block/Measure*: This task is a catchall for the miscellaneous tasks that a plumber would do to the framework of the structure to facilitate the piping installation. It includes, for example, moving a stud at the integral tub/shower that would have blocked diverter installation, installing a piece of wood blocking to support the water closet (toilet) stop, and drilling holes in studs and joists for pipe runs. Measuring for these locations and cutting deck sheathing or wall plates to allow pipe passage are also included here.

*Pull PEX Lines or Measure/Cut/Ream Copper Pipe*: All tasks associated with installing pipe and getting pipe through holes, pipe supports, etc. are covered in this category. With a PEX installation, the process of moving the excess length back (after crimping at the fixture, which

activity is covered under "PEX Fittings") and cutting and attaching to the manifold are covered here. Copper includes the process of preparing the connections.

*Install PEX Fittings or Flux Copper Pipe*: The tasks of obtaining crimp rings and or tools, installing the crimped connection, and checking the effectiveness of the crimp (with a gauge) are covered here. J clamps that are installed to support PEX that comes through the wall to a fixture are also covered here. Figure 5 contains an example of a J Clamp. Talons and other methods of re-supporting pipe were grouped to the "*Install Pipe Support*" task. For copper houses this line was reserved for the activity of applying flux to the pipe and fitting to prepare for the solder connection.

*Copper Fittings/Solder Copper Pipe*: All of the work associated with copper connections in the PEX houses is noted under this task. Cutting, sweating, fluxing, and soldering the water closet, sink, and powder room pedestal stops, etc. The attachment of PEX to these (crimped connection) should be charged to PEX Fittings. For the copper houses, this line was reserved for the activity of soldering.

*Install Pipe Support*: This task includes cutting PVC sleeves for PEX and installing these. Talons, pipe clamps, pipe shields at wall plates, and wire ties at PEX bundles are also covered here.

*Connect Supply to Water Main*: This task will include all of the work from main service entry to manifold. The copper connection to the water heater and the jumper connection made to check the system continuity should be included in this task. Copper systems emanated from the water main, so time was captured under the tasks attendant to installing the pipe.

*Break/Idle*: Covers rests, personal telephone, bathroom breaks, and times when a team member is idle for more than five minutes and the down time is not due to waiting on a team member to perform a function. When the entire team took lunch together, the time that work stopped and restarted was recorded. Lunch time was not counted in this study.

*Check for Leaks*: Includes filling tubs with water and examining supplies and drains for leaks. Remediation, such as the replacement of a tub gasket at the overflow which had leaked, was included in this task. Cold weather air tests would also be included in this task.

*Plan Design and Talk Business*: is just that. The task can involve several team members mapping out a strategy for work or one lead person on a cell phone discussing business with the office or a supplier.

*Clean Up Jobsite to Ready for Work*: This task includes any sweeping, moving other trades materials, etc. that needs to be accomplished to assure a safe work site.

*Rework:* The task involves redoing work that was already completed. An example of this is if the HVAC contractor asked the plumbers to move pipes that were in their way.

# APPENDIX III
# INSTALLATION TIME SHEETS BY LOT

## Table 4. Rough-In Plumbing Time Details for Lot 1

Installation of Rough Plumbing Supply
Site: Lot 1 PEX
Date: 10/26/05 to 10/27/05
Crew: 4 workers both days
Minutes of labor for one crew member; noted at five minute intervals

Labor Minutes 1505
Labor Hours 25.08

| Component | | | | Supply to First Floor | | | | | Supply to Second Floor | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | General | Manifold | Washer | Powder Room | | Kitchen | Hose Bibs | | Front Bath | | | Rear Bath | | | |
| Task | | | | Vanity | WC | Sink | Front | Rear | Vanity | Tub | WC | Vanity | Tub | WC | |
| Job/Tool Set Up/Clean Up | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |
| Obtain Materials | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 10 | 55 |
| Install | 0 | 10 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 0 | 15 | 0 | 70 |
| Cut/Drill/Block/Measure | 60 | 35 | 0 | 10 | 10 | 10 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 5 | 135 |
| Pull PEX Lines | 0 | 0 | 20 | 20 | 15 | 10 | 25 | 30 | 20 | 65 | 15 | 30 | 85 | 15 | 350 |
| Install PEX Fittings= | 0 | 5 | 5 | 5 | 5 | 5 | 15 | 15 | 5 | 20 | 10 | 5 | 25 | 5 | 125 |
| Install Copper Fittings | 0 | 80 | 0 | 30 | 10 | 0 | 0 | 0 | 0 | 35 | 35 | 0 | 35 | 20 | 245 |
| Install Pipe Support | 90 | 0 | 15 | 0 | 0 | 0 | 10 | 10 | 0 | 10 | 0 | 0 | 0 | 0 | 135 |
| Connect Supply to Water Main | 0 | 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 140 |
| Break/Idle | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 |
| Check for Leaks | 70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 |
| Talk Business | 20 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 |
| Clean Up Jobsite to Ready for Work | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rework | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Totals | 425 | 270 | 70 | 65 | 40 | 35 | 50 | 55 | 25 | 145 | 75 | 35 | 160 | 55 | 1505 |

## Table 5. Rough-In Plumbing Time Details for Lot 2

Installation of Rough Plumbing Supply
Site: Lot 2 PEX
Date: 11-8-05 to 11-9-05
Crew: 4 men day one, 2 men day two
Minutes of labor for one crew member; noted at five minute intervals

Labor Minutes 1230
Labor Hours 20.50

| Component | | | | Supply to First Floor | | | | | | Supply to Second Floor | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | General | Manifold | Washer | General | Powder Room | | Kitchen | Hose Bibs | | General | Front Bath | | | Rear Bath | | | |
| Task | | | | | Vanity | WC | Sink | Front | Rear | | Vanity | Tub | WC | Vanity | Tub | WC | |
| Job/Tool Set Up/Clean Up | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 135 |
| Obtain Materials | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 95 |
| Install | 0 | 30 | 5 | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 50 |
| Cut/Drill/Block/Measure | 20 | 15 | 5 | 0 | 10 | 5 | 5 | 0 | 0 | 0 | 5 | 25 | 10 | 5 | 20 | 10 | 135 |
| Pull PEX Lines | 0 | 25 | 5 | 20 | 0 | 0 | 0 | 5 | 0 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 165 |
| Install PEX Fittings | 5 | 25 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 5 | 45 |
| Install Copper Fittings | 80 | 15 | 0 | 0 | 0 | 5 | 5 | 5 | 10 | 0 | 5 | 45 | 5 | 5 | 45 | 5 | 230 |
| Install Pipe Support | 165 | 5 | 5 | 20 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 205 |
| Connect Supply to Water Main | 0 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45 |
| Break/Idle | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45 |
| Check for Leaks | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| Talk Business | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 |
| Clean Up Jobsite to Ready for Work | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rework | 5 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| Totals | 605 | 160 | 20 | 40 | 15 | 10 | 20 | 20 | 20 | 120 | 10 | 75 | 20 | 10 | 65 | 20 | 1230 |

## Table 6. Rough-In Plumbing Time Details for Lot 4

Installation of Rough Plumbing Supply
Site: Lot 4 PEX
Date: 11-29-05 to 11-30-05
Crew: 2 men day one, 3 men day two
Minutes of labor for one crew member; noted at five minute intervals

Labor Minutes 1175
Labor Hours 19.58

| Component | | | | Supply to First Floor | | | | | | Supply to Second Floor | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | General | Manifold | Washer | General | Powder Room | | Kitchen | Hose Bibs | | General | Front Bath | | | Rear Bath | | | |
| Task | | | | | Vanity | WC | Sink | Front | Rear | | Vanity | Tub | WC | Vanity | Tub | WC | |
| Job/Tool Set Up/Clean Up | 215 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 215 |
| Obtain Materials | 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 55 |
| Install | 0 | 10 | 10 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 5 | 0 | 0 | 5 | 0 | 35 |
| Cut/Drill/Block/Measure | 5 | 10 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 30 | 15 | 5 | 30 | 20 | 125 |
| Pull PEX Lines | 5 | 0 | 25 | 0 | 15 | 15 | 50 | 15 | 15 | 0 | 20 | 15 | 10 | 20 | 30 | 10 | 260 |
| Install PEX Fittings | 5 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 5 | 5 | 5 | 5 | 0 | 75 |
| Install Copper Fittings | 0 | 0 | 0 | 0 | 10 | 10 | 0 | 10 | 10 | 0 | 5 | 25 | 5 | 5 | 20 | 5 | 105 |
| Install Pipe Support | 75 | 5 | 5 | 45 | 0 | 0 | 0 | 0 | 5 | 70 | 0 | 0 | 0 | 0 | 0 | 0 | 205 |
| Connect Supply to Water Main | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Break/Idle | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 65 |
| Check for Leaks | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Talk Business | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 35 |
| Clean Up Jobsite to Ready for Work | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rework | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 |
| Totals | 455 | 65 | 45 | 45 | 25 | 25 | 50 | 30 | 30 | 75 | 40 | 95 | 35 | 35 | 90 | 35 | 1175 |

## Table 7. Rough-In Plumbing Time Details for Lot 6

Installation of Rough Plumbing Supply
Site: Lot 6 COPPER
Date: 1-9-06 to 1-11-06
Crew: 2-4 workers day one, 2 workers days two and three
Minutes of labor for one crew member; noted at five minute intervals

Labor Minutes 2484
Labor Hours 41.40

| Component | | | | Supply to First Floor | | | | | | Supply to Second Floor | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | General | Manifold | Washer | General | Powder Room | | Kitchen | Hose Bibs | | General | Front Bath | | | Rear Bath | | | |
| Task | | | | | Vanity | WC | Sink | Front | Rear | | Vanity | Tub | WC | Vanity | Tub | WC | |
| Job/Tool Set Up/Clean Up | 231 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 281 |
| Obtain Materials | 25 | 0 | 11 | 0 | 5 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 |
| Install | 0 | 0 | 13 | 60 | 15 | 9 | 7 | 12 | 4 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 145 |
| Cut/Drill/Block/Measure (structure) | 0 | 0 | 6 | 79 | 32 | 50 | 30 | 17 | 5 | 0 | 15 | 32 | 0 | 10 | 20 | 0 | 296 |
| Measure/Cut/Ream Copper Pipe | 5 | 0 | 125 | 116 | 25 | 15 | 17 | 0 | 21 | 84 | 45 | 40 | 63 | 45 | 45 | 38 | 684 |
| Flux Copper Pipe | 0 | 0 | 0 | 54 | 7 | 0 | 11 | 0 | 13 | 41 | 0 | 20 | 10 | 3 | 15 | 10 | 184 |
| Solder Copper Pipe | 15 | 0 | 16 | 15 | 7 | 0 | 5 | 3 | 3 | 26 | 2 | 18 | 5 | 19 | 10 | 0 | 144 |
| Install Pipe Support | 0 | 0 | 0 | 9 | 24 | 3 | 6 | 5 | 0 | 95 | 0 | 5 | 0 | 50 | 10 | 0 | 207 |
| Connect Supply to Water Main | 0 | 145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 145 |
| Break/Idle | 70 | 0 | 45 | 28 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 146 |
| Check for Leaks | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Plan Design and Talk Business | 25 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 35 |
| Clean Up Jobsite to Ready for Work | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 |
| Rework | 0 | 0 | 9 | 58 | 2 | 0 | 0 | 0 | 0 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 117 |
| Totals | 421 | 145 | 225 | 479 | 120 | 77 | 76 | 37 | 55 | 319 | 62 | 115 | 78 | 127 | 100 | 48 | 2484 |

## Table 8. Rough-In Plumbing Time Details for Lot 8

Installation of Rough Plumbing Supply
Site: Lot 8 COPPER
Date: 2-7-06 to 2-9-06
Crew: 2 workers all days
Minutes of labor for one crew member; noted at five minute intervals

Labor Minutes 2150
Labor Hours 35.83

| Component | | | | Supply to First Floor | | | | | | Supply to Second Floor | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | General | Manifold | Washer | General | Powder Room | | Kitchen | Hose Bibs | | General | Front Bath | | | Rear Bath | | | |
| Task | | | | | Vanity | WC | Sink | Front | Rear | | Vanity | Tub | WC | Vanity | Tub | WC | |
| Job/Tool Set Up/Clean Up | 230 | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 280 |
| Obtain Materials | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 35 |
| Install | 110 | 0 | 15 | 20 | 0 | 5 | 10 | 5 | 5 | 30 | 10 | 10 | 0 | 30 | 15 | 0 | 265 |
| Cut/Drill/Block/Measure | 40 | 0 | 30 | 30 | 15 | 10 | 25 | 20 | 20 | 30 | 35 | 25 | 20 | 25 | 20 | 25 | 370 |
| Measure/Cut/Ream Copper Pipe | 200 | 0 | 45 | 115 | 0 | 15 | 25 | 0 | 0 | 45 | 30 | 40 | 30 | 40 | 30 | 35 | 650 |
| Flux Copper Pipe | 50 | 0 | 5 | 10 | 0 | 5 | 10 | 0 | 0 | 5 | 0 | 10 | 5 | 0 | 15 | 5 | 120 |
| Solder Copper Pipe | 30 | 0 | 5 | 40 | 0 | 25 | 25 | 0 | 0 | 0 | 15 | 10 | 5 | 5 | 10 | 5 | 175 |
| Install Pipe Support | 25 | 0 | 0 | 10 | 10 | 0 | 5 | 5 | 0 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 90 |
| Connect Supply to Water Main | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Break/Idle | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| Check for Leaks | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Talk Business | 25 | 0 | 0 | 35 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 70 |
| Clean Up Jobsite to Ready for Work | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rework | 0 | 0 | 0 | 0 | 0 | 45 | 0 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 75 |
| Totals | 725 | 0 | 100 | 285 | 25 | 105 | 100 | 30 | 25 | 220 | 120 | 95 | 60 | 100 | 90 | 70 | 2150 |

# APPENDIX IV
# COST BREAKDOWN

Table 9. Cost Breakdown for Materials in Each Lot

| |
|---|
| Piping |
| Fittings and Parts |
| Universal Components |

| | | Lot Part Amounts | | | | |
|---|---|---|---|---|---|---|
| **Part** | **Cost** | **1** | **2** | **4** | **6** | **8** |
| 3/8" Blue PEX | $0.29 | 200 | 200 | 200 | 0 | 0 |
| 3/8" Red PEX | $0.27 | 100 | 100 | 100 | 0 | 0 |
| 1/2" Blue PEX | $0.31 | 200 | 200 | 200 | 0 | 0 |
| 1/2" Red PEX | $0.31 | 100 | 100 | 100 | 0 | 0 |
| 3/8" M Copper | $0.38 | 2 | 2 | 2 | 0 | 0 |
| 1/2" M Copper | $0.78 | 18 | 17.5 | 16 | 165 | 173 |
| 3/4" M Copper | $1.26 | 8 | 8 | 8 | 80 | 75 |
| 3/8" pick-up talons plastic | $0.90 | 17 | 20 | 36 | 0 | 0 |
| 1/2" pick-up talons plastic | $0.90 | 21 | 20 | 8 | 17 | 16 |
| 1/2" pick-up talons metal | $0.70 | 16 | 16 | 7 | 0 | 6 |
| 3/4" pick-up talons plastic | $0.15 | 0 | 0 | 0 | 17 | 15 |
| 3/8" J turn outs | $2.25 | 4 | 4 | 4 | 0 | 0 |
| 1/2" copper caps | $0.25 | 2 | 5 | 2 | 8 | 11 |
| 1/2" copper stubout elbow bullet | $3.20 | 3 | 0 | 3 | 0 | 0 |
| 1/2" copper stubout elbow w/ nail plate | $3.05 | 2 | 2 | 2 | 0 | 0 |
| 3/8" to 1/2" copper elbow with crimp nipple | $3.20 | 3 | 3 | 0 | 0 | 0 |
| 3/8" copper caps | $0.30 | 6 | 0 | 2 | 0 | 0 |
| 3/8" copper stubout elbow with nail plate | $3.10 | 2 | 2 | 2 | 0 | 0 |
| 1/2" straights (pipe junction connects) | $0.30 | 0 | 0 | 0 | 2 | 0 |
| 3/4" straights (pipe junction connects) | $0.40 | 0 | 0 | 0 | 1 | 0 |
| 1/2" 45 degree elbow | $0.65 | 0 | 0 | 0 | 17 | 14 |
| 1/2" 90 degree elbow | $0.65 | 0 | 0 | 0 | 38 | 52 |
| 3/4" 45 degree elbow | $0.85 | 0 | 0 | 0 | 5 | 2 |
| 3/4" 90 degree elbow | $0.95 | 0 | 0 | 0 | 11 | 16 |

| | | Lot Part Amounts | | | | |
|---|---|---|---|---|---|---|
| **Part** | **Cost** | **1** | **2** | **4** | **6** | **8** |
| 1/2" tee | $0.95 | 0 | 0 | 0 | 3 | 7 |
| 3/4" tee | $1.25 | 0 | 0 | 0 | 3 | 4 |
| 1/2 to 3/4" tee | $1.75 | 0 | 0 | 0 | 4 | 5 |
| Manabloc | $130.49 | 1 | 1 | 1 | 0 | 0 |
| 3/8" adaptors for Manabloc | $3.75 | 9 | 9 | 9 | 0 | 0 |
| 1/2" crimp rings | $0.10 | 19 | 19 | 19 | 0 | 0 |
| 3/8" crimp rings | $0.10 | 9 | 9 | 9 | 0 | 0 |
| hose bibbs | $18.50 | 2 | 2 | 2 | 2 | 2 |
| washer box and brass stops | $17.50 | 1 | 1 | 1 | 1 | 1 |
| | **Total** | **$512.62** | **$503.38** | **$499.36** | **$368.90** | **$387.74** |

| |
|---|
| Piping |
| Fittings and Parts |
| Universal Components |