CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Draft Measure Information Template – Single Family Water Heating Distribution System Improvements

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team May 2011

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1. Purpose

This document describes recommended changes to single family water heating mandatory and prescriptive requirements, as well as ACM modeling rule modifications for the 2013 Title 24 – Part 6 Building Energy Efficiency Standards. The focus of this CASE study is on distribution system performance.

2. Overview

Complete the following table, providing responses for each category of information.

a. Measure Title	Single Family Water Heating Distribution System Improvements
b. Description	This proposal utilizes new field information and more advanced evaluation tools to generate new prescriptive and mandatory requirements affecting single family water heating. In addition to these new requirements, ACM modifications are proposed to bring projected annual DHW energy usage closer in line to RASS data, and to update the distribution system multipliers for alternative distribution systems. The specific proposals include: Mandatory requirements: All hot water piping ¾” or greater must be insulated Limit 1” piping to a maximum length of ten feet in all non-recirculating systems Prescriptive requirements: Compact hot water distribution systems (HWDS) will define the standard budget

c. Type of Change	This proposal would modify current ACM **modeling** rules, and adjust the distribution system multipliers which characterize single family distribution system performance. It also expands optional HERS inspections to water heating measures to insure proper installation and consistency with eligibility criteria. The following describes the types of changes in more detail: **Mandatory Measure –** Require that all piping ¾" or greater, be insulated. Require that the total length of 1" piping be limited to a total of 10 feet in all non-recirculating systems (excepting tubs that may require 1" piping under some scenarios). **Prescriptive Requirement –** This proposal includes the following prescriptive requirement to improve the performance of the hot water distribution systems in single family homes: Require that a compact HWDS design become the standard, to reduce the energy and water waste associated with inefficient, oversized distribution systems. The combined effect of these mandatory and prescriptive requirements would be to improve distribution system efficiency, saving both energy and water, as well as reducing hot water wait times. **Compliance Option -**With changes in the prescriptive requirement as well as improved modeling capabilities, a revised set of distribution system multipliers (DSMs) are proposed to replace the current 2008 values. **Modeling –** ACM modeling changes are required based on updated findings from the field, as well as improved modeling tools and assumptions. The research indicates that distribution losses are higher than previously assumed. Also, RASS data suggests that overall ACM projected water heating energy use should be reduced by ~15%. To accommodate these two effects, the assumed "useful" hot water consumed at the use points must be reduced. **Other -** ACM Manuals will need to be updated to reflect the proposed modeling changes. HERS inspections will be required on a sampling basis to verify that the plumbing layout meets the compact HWDS criteria. Optional HERS inspections for credits exceeding default insulation installation are proposed for "quality" pipe insulation installation.

d. Energy Benefits

The energy benefits shown in the table below are based on HWSIM model runs based on identified prototype homes, or actual homes observed in field survey work. The calculated savings are relative to a minimum efficiency gas storage water heater.

	Electricity Savings (kwh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
Mandatory Measure: Insulated Piping (all piping ¾" or larger)					
Average Savings for 6 Prototypes[2]	n/a	n/a	11.0	n/a	$304
Mandatory Measure: Limit 1" piping to 10 foot maximum length					
"Lot 53"	n/a	n/a	7.4	n/a	$204
Prescriptive Requirement: Compact Hot Water Distribution System					
Average Savings for 4 Prototypes[2]	n/a	n/a	24.2	n/a	$670

One of the proposed ACM modeling changes will affect the overall water heating budget. Lowering the hot water setpoint from 135°F to 124.2°F will reduce projected water heating energy use by ~15%, bringing usage in better alignment with current RASS data. This realignment is important to insure that the water heating energy use and projected credits for water heating improvements generate realistic impacts.

e. Non-Energy Benefits

Improved hot water distribution systems not only save energy, but also reduced hot water waste and waiting time. In most cases, the proposed measures will reduce the amount of piping installed in homes.

f. Environmental Impact

Improved HWDS will reduce the load on the water heater and the resulting energy consumed by the standard gas storage water heater. The table below summarizes emission impacts based on emission rates of 0.00175 lbs of NOx per therm of natural gas and 0.00585 tons of CO_2 per therm.

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year-house)

	Mercury	Lead	Copper	Steel	Plastic	NOx (lbs/yr)	CO2 (lbs/yr)
Insulated Piping (all piping ¾" or larger)	NC	NC	NC	NC	NC	0.019 (D)	129 (D)
Limit 1" piping to 10' maximum length	NC	NC	NC	NC	NC	0.013 (D)	87 (D)
Compact HWDS	NC	NC	NC	NC	NC	0.042 (D)	283 (D)

Water Consumption: (savings per home)

	On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Year)
Insulated Piping (all piping ¾" or larger)	1825 gal/yr
Limit 1" piping to 10' maximum length	730 gal/yr
Compact HWDS	2550 gal/yr

Water Quality Impacts:
No impact on water quality.

g. Technology Measures

Measure Availability:
The key element of this proposal relies on attention to detail, beginning with the architectural design of the house. We have surveyed ~130 homes over the past several years to better understand how plumbers install HWDS in new homes. If the house design begins with minimal attention paid to where the water heater and hot water use points are located, it becomes much more likely that the overall HWDS performance will be poor. The only product which will be prescriptively required is pipe insulation, which is currently widely available from several manufacturers. Elements of this proposal will require a greater element of HERS rater involvement for verification purposes. The impact on the HERS industry should not be significant, as the inspections are visual in nature.

Useful Life, Persistence, and Maintenance:
No issues.

h. Performance Verification of the Proposed Measure	HERS inspections are recommended to demonstrate that prescriptive requirements are being met, or for verifying installation practice (quality pipe insulation credit, for example). Verification of the criteria associated with the compact hot water distribution system design should be demonstrated on a sampling basis.

i. Cost Effectiveness

a	b	C		d		e		f	g	
Measure Name	Measure Life (Years)	Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($)		Additional Cost[2]– Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional[3] Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of[4] Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
		Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Unit	Per Proto Building		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
Pipe Insulation	30	n/a	199	n/a	199	n/a	0	305	106	106
Limit 1" Piping to Ten Feet	30	n/a	131	n/a	131	n/a	0	233	102	102
Compact HWDS	30	n/a	318	n/a	318	n/a	0	670	352	352

1. **Current Measure Costs -** as is currently available on the market, and
2. **Post Adoption Measure Costs -** assuming full market penetration of the measure as a result of the new Standards, resulting in mass production of the product and possible reduction in unit costs of the product once market is stabilized. Provide estimate of current market share and rationale for cost prediction. Cite references behind estimates.
3. **Maintenance Costs -** the initial cost of both the basecase and proposed measure must include the PV of maintenance costs (savings) that are expected to occur over the assumed life of the measure. The present value (PV) of maintenance costs (savings) must be calculated using the discount rate (d) described in the 2013 LCC Methodology. The present value of maintenance costs that occurs in the n^{th} year is calculated as follows (where d is the discount rate):

$$\text{PV Maint Cost} = \text{Maint Cost} \times \left\lfloor \frac{1}{1+\text{d}} \right\rfloor^{n}$$

4. **Energy Cost Savings -** the PV of the energy savings are calculated using the method described in the 2013 LCC Methodology report.

j. Analysis Tools	The HWSIM hot water distribution system model was used to simulate six house plans in various climates, with various distribution layouts. HWSIM was developed to provide detailed modeling of the interaction of the plumbing layout with varying piping materials, use patterns, and user behaviors. The tool was developed with DOE Building America funding, as well as with funding from the CEC's PIER program. The current ACM modeling tools are not sufficiently detailed to model the short time duration events associated with hot water draws in single family homes, since daily hot water draw events total 30-60 minutes in duration, on average.
k. Relationship to Other Measures	The realignment of the ACM projected water heating energy use will reduce the water heating budget, and therefore the overall household TDV budget.

3. Methodology

The recommendations presented in this CASE proposal are based on field research completed over the past five years and modeling using the HWSIM distribution system model. HWSIM was developed with DOE Building America funding, as well as with funding from the Commission's PIER program. HWSIM is able to simulate the interactive effects of the following elements which influence the hot water system distribution loss:

1. Layout of the plumbing system
2. Piping materials used -- length, diameter, location (attic, crawlspace, conditioned space)
3. Presence of insulation
4. The (hourly) temperature of the thermal environment in which the pipe is located
5. Heat transfer relationships to determine pipe heat loss as a function of conditions
6. Schedule of hot water use in the house (can vary for the seven days of the week)
7. Behavioral assumptions on how hot water is used

Given the short duration of hot water flows in a typical house (30 to 60 minutes per day), the interaction of these effects is critical and highly variable. Although much still needs to be learned on the hot water use patterns and behavioral issues, significant progress has been made on understanding what plumbers are installing in California homes. A 2006 PIER study (Lutz, 2010) physically inspected HWDS installations (pre-drywall) to determine pipe materials, lengths, and diameters for all hot water piping in 60 homes statewide. A current follow-on field study (part of the Gas Technology Institute's Advanced Gas Water Heating PIER Project) is currently 2/3 completed in augmenting the 2006 data with an additional 100 homes. Findings from the 2006 study were used to develop six prototype single family homes with standard distribution layouts. These six prototypes, listed in Figure 1, were utilized to model standard and alternative HWDS as part of this evaluation. Both of these studies can be found in ***Section 7: Appendices***.

Figure 1: HWSIM Prototypes

	Occupancy Type	Area (ft2)	Number of Stories	Other Notes
Prototype 1	Res	1,367	1	From 2006 60 Home Field Survey
Prototype 2	Res	1,430	2	From 2006 60 Home Field Survey
Prototype 3	Res	2,010	1	From 2005 Title 24 Evaluation
Prototype 4	Res	2,881	2	From 2005 Title 24 Evaluation
Prototype 5	Res	3,080	1	From 2005 Title 24 Evaluation
Prototype 6	Res	4,402	2	From 2006 60 Home Field Survey

Total household water heating energy use, as reflected as "property line" in Figure 2 below, is comprised of the hot water consumed at the fixtures, the distribution losses resulting from moving the hot water from the water to the use points, the water heater combustion inefficiencies, and the associated standby losses.

Figure 2: Characterization of Water Heating Energy Flows

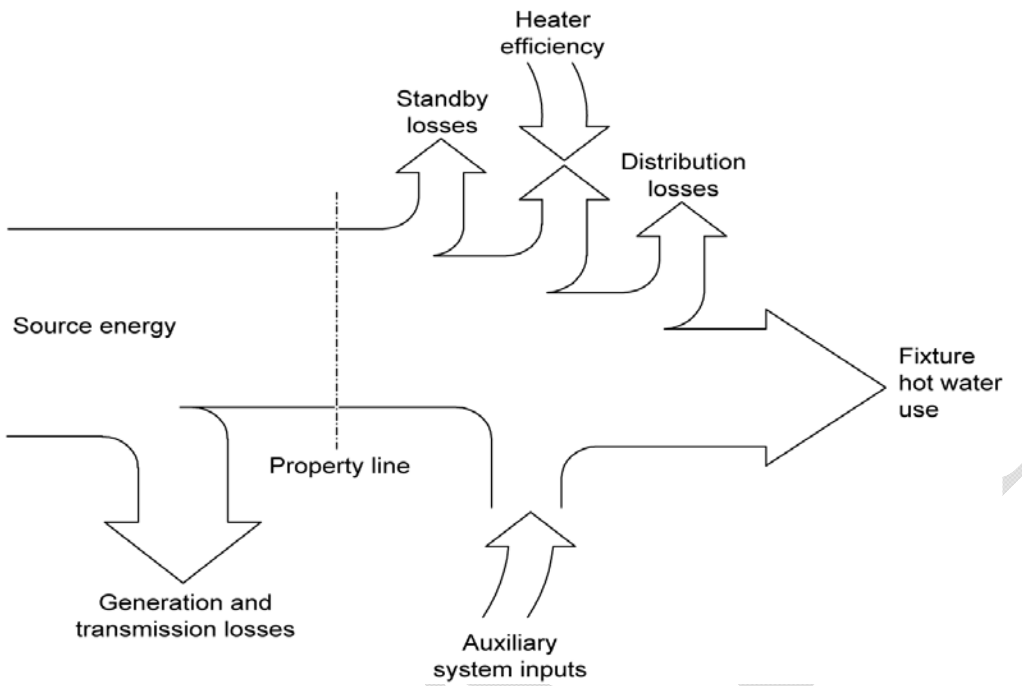


Figure 3 shows a representative breakdown of the four key components for two cases with non-recirculating distribution systems: a 2,010 ft^2 home with daily hot water loads of approximately 60 gallons per day (on the left), and a 3,080 ft^2 house with hot water loads of ~ 80 gallons per day (on the right). Both HWSIM simulations were completed using Sacramento environment and inlet cold water conditions. Resulting annual water heating energy use is projected at 210 therms for the 2,010 ft^2 home and 264 therms for the 3,080 ft^2 home. The leftmost pie chart shows projected use point energy equal to 46% of the total energy consumed by the 0.60 EF storage water heater, with the remaining items each representing roughly 1/3 of the remaining energy. The rightmost pie chart shows lower % use point energy, considerably higher distribution loss (due to a larger, less efficient distribution system), slightly higher combustion inefficiency (due in increased recovery load), and lower standby loss. What is evident in these two pie charts is that site to site variations can be significant, before even accounting for use quantity and behavioral patterns.

The distribution loss component is comprised of three terms:

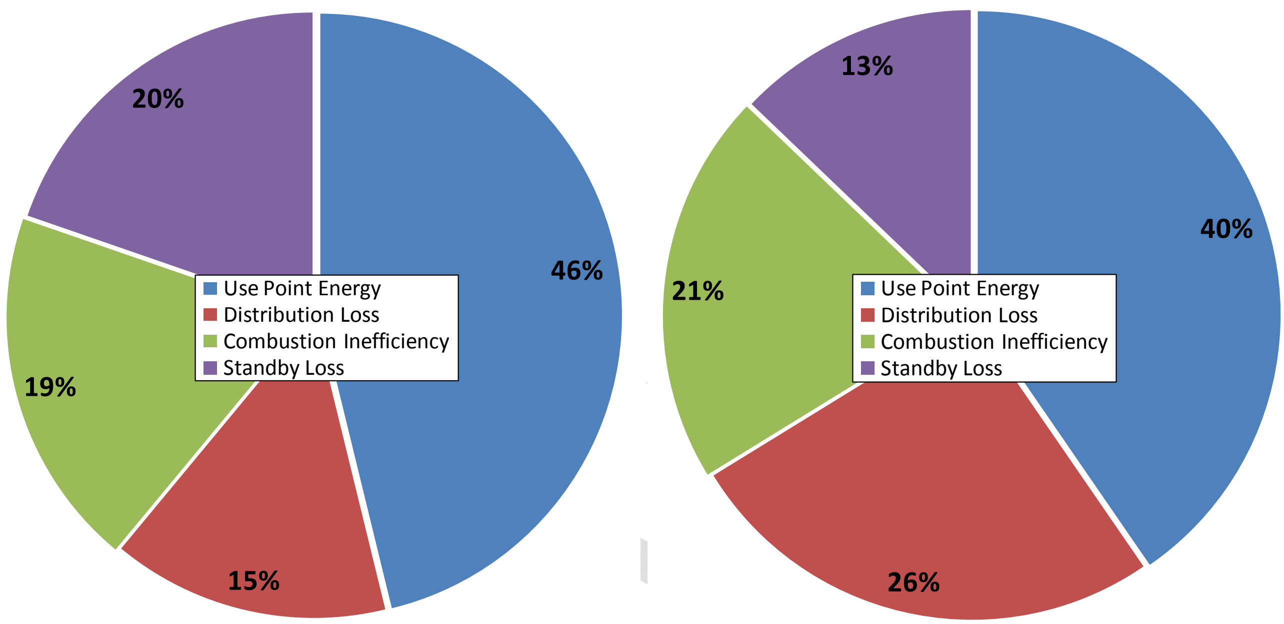
- The heat lost during the hot water draw
- The heat lost between draws as the pipe cools down as it approaches the environment temperature
- The energy contained in the hot water line that is not of sufficient quality for the next use (i.e. tepid water dumped between shower draws this water volume must be dumped in most cases[1])

The latter two terms represent the majority of distribution heat loss in most situations, and are highly

[1] Although appliances won't care about the temperature of the water, shower uses certainly will,with sink and tub uses somewhere in between.

influenced by use pattern and behavior.

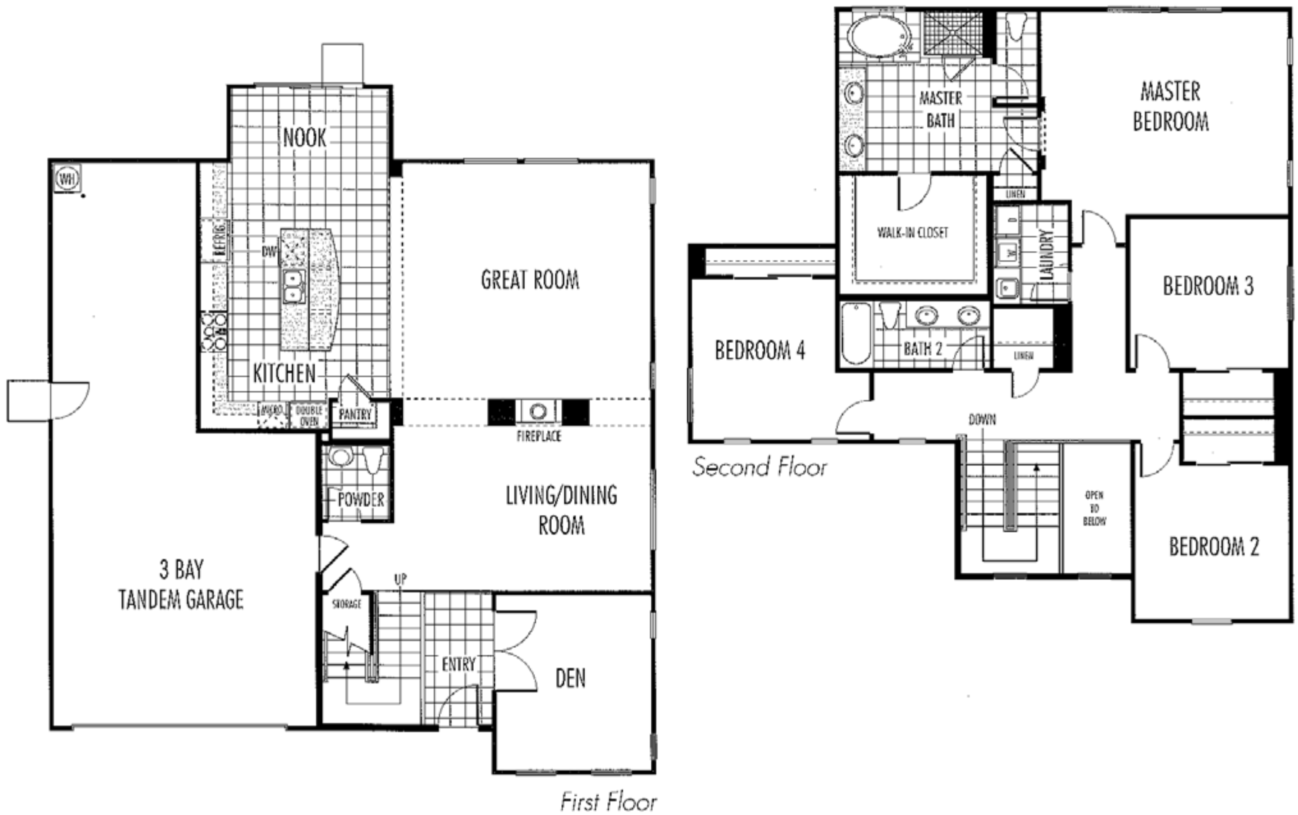
Figure 3: DHW Energy Breakdown for 2,010 (left) and 3,080 (right) Prototype Floor Plans



Field studies of plumbing installations throughout California have found a high degree of randomness in terms of how distribution systems are installed. Plumbing designs are rarely completed in the residential market, allowing the plumber the freedom to connect Point A (i.e. the water heater) to all the hot water use points in the home without restrictions. The widespread use of PEX piping has reduced plumbing material and installation costs, but also provided the installer with an easily manipulated product which provides for total freedom in laying out the system, for better or for worse.

With that in mind, the first key element in getting an efficient distribution system is designing a floor plan with some attention paid to where the water heater is located and where hot water use points are located. Making the distribution system more compact is the first step in improving the performance of the system. Figure 4 shows a floor plan for a 2,768 ft^2 home that shows, by design or by chance, a potentially compact distribution system. One significant further improvement would be to relocate the water heater from the far left corner of the garage, to the corner abutting the powder room and kitchen. Although the floor plan depicted is relatively compact, it is easy to reconfigure this house into a much more distributed system by switching the Great Room and the Kitchen, Master Bedroom and Master Bath, and moving Bath2 to where the Bedroom closets are located.

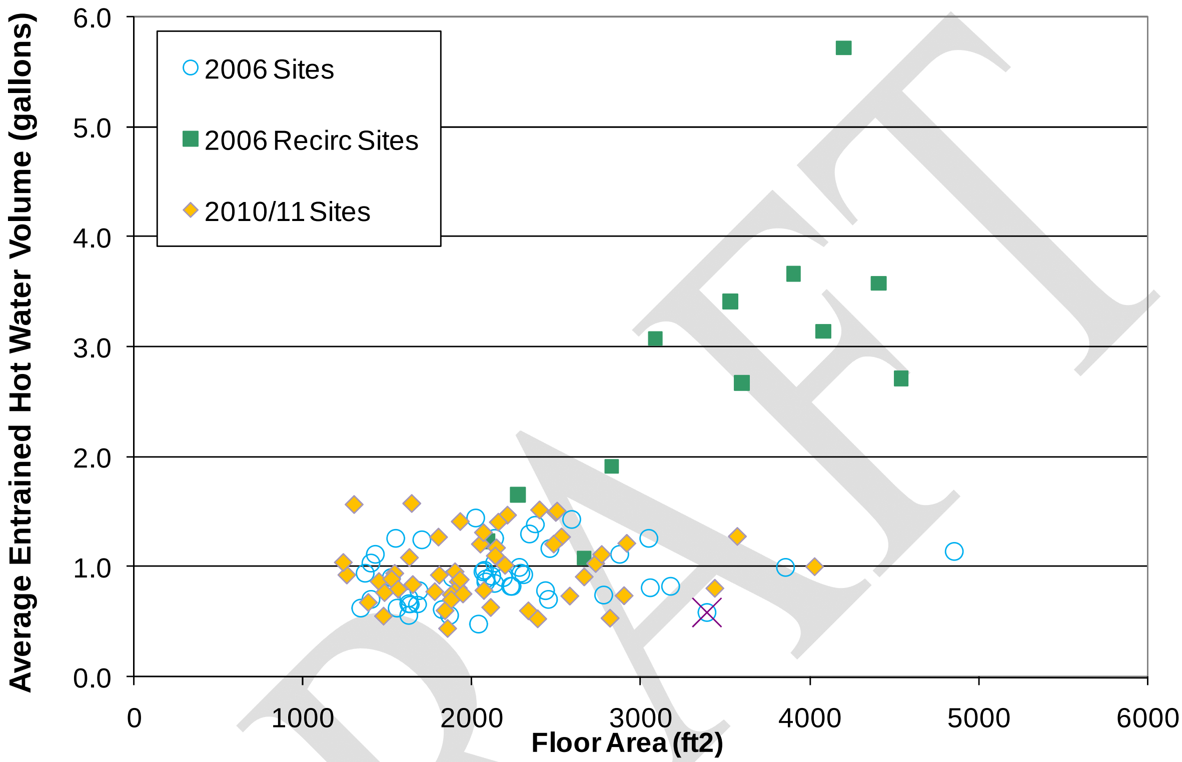
Figure 4: Compact Distribution System Layout



Even with a good floor plan, things can still go wrong based on how the installer lays out the system. Although variations in city water pressure can influence the use of larger diameter piping in some situations, there is still a significant variation in how efficiently systems are laid out. One plumber commented in the field that they liked to use ¾" and 1" piping, "because it gets water to the fixtures faster". Often installations show circuitous paths through the house. This is clearly highlighted in Figure 5 which plots the measured volume of water between the water heater and the hot water use points at each of the ~130 new home sites surveyed in both 2006 and over the past year. The volume plotted represents the entrained pipe volume averaged for all hot water use points in the house. On average, one gallon represents a good approximation for all non-recirculation sites. Recirculation systems, which have the advantage of bringing the hot water close to the use points, were found to exhibit much higher entrained volumes due to lengthy and large diameter recirculation loops. These large loops translate into high heat loss during periods of recirculation. Demand recirculation systems certainly fair better, but still suffer significant thermal losses when the large volume of water in the loop cools off between draws.

The key information to be gleaned from Figure 5 is the wide range of observed entrained volume for any given house size. The range in volume is roughly a ratio of 3:1, indicating the impact of both house design and plumbing layout. The one 2006 site with an "X" is one of the best performers of the group: a 3,400 ft2 house with an indoor mechanical closet.

Figure 5: Entrained Pipe Volume Derived from California Statewide Field Inspections



The most common distribution plumbing technique observed in the field utilizes distributed manifolds as shown in Figure 6 below. These hot water "mini-manifolds", typically two to four found in typical houses, are distributed in various locations through the house, feeding individual fixture groups. This plumbing technique has replaced the more common central manifold home run system[2] identified in the 2006 survey, due primarily to first cost concerns. From an energy and water waste viewpoint, these manifolds should be close to the water heater.

Using the six prototype floor plans, a total of about 200 HWSIM runs were completed to assess the impacts of various distribution system types and different climate zones. Climate, a second order effect, impacts performance in two ways: cold water inlet temperatures affect the mix of hot and cold water to achieve "comfort conditions" at showers and sinks, and seasonally (and hourly) varying attic and garage temperatures affect pipe heat loss rates.

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[2] Installed within ten feet of the water heater

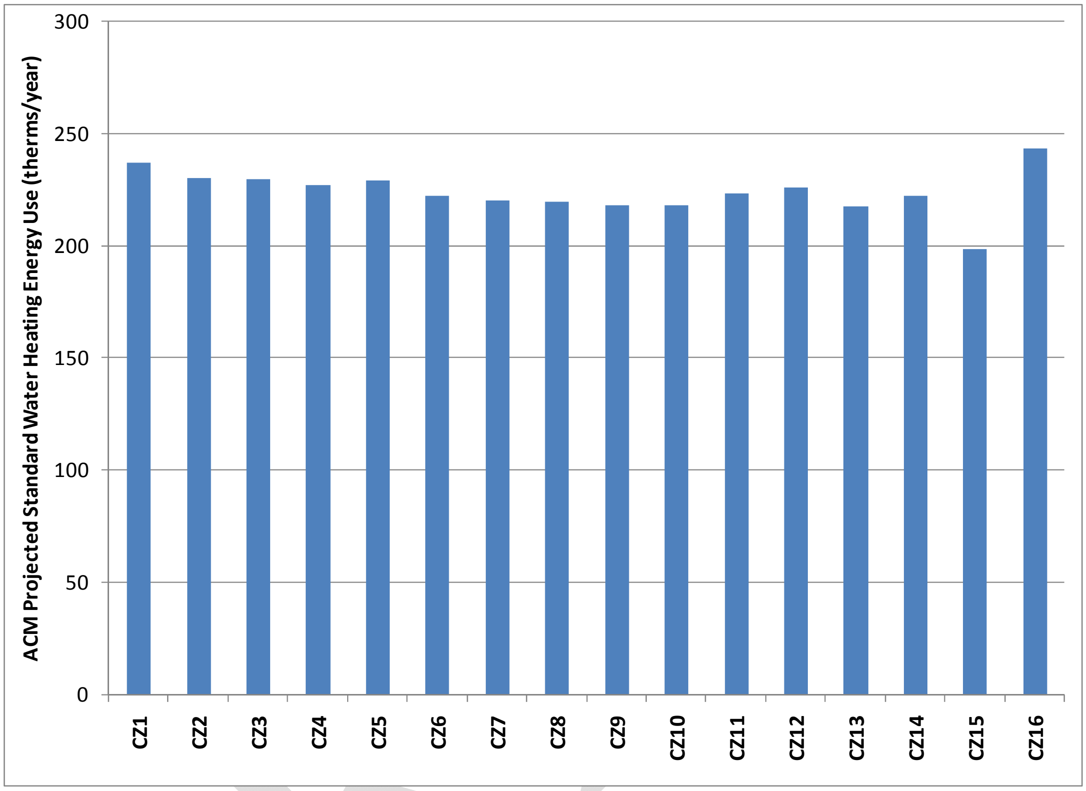
Figure 6: Installed Mini-Manifolds

The HWSIM analysis completed in this CASE evaluation resulted in significantly higher projected distribution losses than identified in the 2005 and 2008 evaluations. The new prototype floor plans identified in Figure 1 combined with larger than assumed distribution system layouts (Lutz, 2008)[3] are the primary factors driving higher distribution losses. As distribution losses increase, the load on the water heater increases. Given the lack of robust California new home hot water usage data, the Commission's current position is not to adjust the water heater recovery load assumed in the ACM. Therefore, as the distribution losses increase, the "useful" hot water delivered at the fixtures must correspondingly decrease.

In addition to the HWSIM evaluations, we investigated the current ACM projected water heater energy use to Residential Appliance Saturation Survey (RASS) data. Current Title 24 compliance software generates water heating energy consumption that is considerably higher than current RASS estimate which show a statewide gas water heating usage of 195 therms per year. Figure 7 plots projected use for the 16 climate zones for the CEC 1,761 ft^2 prototype house. Average ACM projected usage of 224 therms/year is 15% higher than the RASS estimate. Several possible explanations for this discrepancy include hot water usage, and water heater cold water inlet and setpoint temperature assumptions. In the Analysis and Results section, we make recommendations to improve the alignment of the ACM results with actual data.

[3] See Appendix G of Lutz report

Figure 7: Current ACM Standard DHW Annual Energy Use by Climate Zone (1,761 ft² Prototype)



4. Analysis and Results

The results presented below are based on HWSIM simulations, costing (based on 2011 RS Means, web searches for materials, and plumber input for PEX installation labor estimates), and life cycle value for residential natural gas based on the AEC 2011 study. Based on that study a 30 year life cycle value of $27.68/therm saved is being assumed. HWSIM was used to generate the savings projections and present value (PV) of savings was determined using the $27.68 life cycle value. First costs were computed, with no additional cost due to replacement and/or maintenance for the measures utilized in this study. The life cycle cost (LCC) is then defined as the PV minus the total costs. Positive LCC denotes cost effectiveness as per the CEC evaluation criteria. An overall benefit cost ratio (BCR) was calculated by summing the PV benefits and dividing by the total costs.

Sections 4.1 through 4.3 cover the mandatory and prescriptive requirements including insulated piping, limiting 1" piping to a maximum of ten feet in length, and centrally located water heating system design. Section 4.4 addresses the proposed ACM modifications.

4.1 Insulated Piping

Hot water piping loses heat during hot water draws and also between draws. Insulation reduces the heat loss during flow and delays the cool down time of piping between draws, resulting in a two to three times increase in the amount of time that a hot pipe will remain at a useful temperature for the subsequent use (Hiller, 2006). Prior Title 24 Standards cost-effectiveness evaluations of pipe insulation on non-recirculating systems have limited their application to the first five feet from the water heater and for any lines leading to the kitchen with diameters of ¾" or larger (Lutz, 2008)[4]. The advent of higher life cycle cost values (AEC, 2011) for natural gas and improved evaluation tools have allowed us to revisit pipe insulation.

The six house prototypes described in the Appendices were evaluated under two scenarios: <u>all</u> piping insulated and all piping of ¾" and larger insulated. The former was not found to be cost effective, as ½" pipe is more challenging to justify since hot water flow in the individual ½" piping runouts is considerably less than in the main trunk lines. Figure 8 presents the insulation results for the six prototypes for all piping of size equal to ¾" or larger. Costs were based on 2011 RS Means for installation costs and web surveys for pipe insulation costs. The resulting cost of $3.87 per foot was assumed for both ¾" and 1" piping. Three of the six prototypes show strongly positive LCC results, while three show LCC values close to neutral. Overall the LCC value is positive with a combined benefit cost ratio over the six cases of 1.53.

Based on these findings, the proposal is to make pipe insulation a mandatory measure for all hot water lines with a diameter of ¾" or larger.

[4] See Appendix O of Lutz report.

Figure 8: Results Summary on Pipe Insulation (3/4" or larger pipe)

Prototype	Length of Piping (¾" or larger)	Projected Annual Savings (therms)	PV* of savings	Addl Cost †	LCC
1367	21.5	4.0	$111	$83	$28
1430	32	2.8	$78	$124	($46)
2010	44	13.5	$374	$170	$204
2881	71	14.9	$412	$275	$137
3080	50	18.6	$515	$194	$221
4402	90	12.2	$338	$348	($10)

"*" at $27.68 per therm 30 year residential value
" † " $3.87/foot

4.2 Maximum Ten Foot Length of 1" Piping (non-recirculating systems)

As observed in the field survey work, many plumbing installations feature an excessive amount of large diameter piping. To analyze the impact of limiting the length of 1" piping, we evaluated a specific house plan encountered in the field to assess the potential energy savings associated with reducing large diameter piping. Figure 9 represents the plumbing layout which shows the water heater feeding two separate manifolds located in the house. The numerical values shown in black above the horizontal lines represent the field-measured piping lengths. For example, the distance between the water heater and Manifold 1 totals 26.5 feet of 1" PEX. The red values represent the adjustment made to achieve the ten foot maximum length. In this example, the distance between the water heater and Manifold 1 is reduced by 17.5 feet, and the distance between Manifold 1 and 2 is reduced by 5'. As the manifolds are brought closer to the water heater, the ½" lines from each manifold are correspondingly increased in length. In this example, all the ½" lines from Manifold 1 are now 16 feet longer, and the lines from Manifold 2 are 21 feet longer.

Costs were calculated based on 1" PEX piping at $.75 per foot, ½" PEX piping at $.25 per foot, and additional labor estimated at two hours[5] at an RS Means apprentice plumber rate of $46.25 per hour. With 30% builder markup, total costs are projected at $131. The resulting LCC shows a positive $102, with a resulting BCR of 1.78. The results shown in Figure 10, although based on one specific plan, are universal, since shortening the 1" main lines and lengthening the ½" runouts, will have relatively consistent savings and costs.

Based on these findings, the proposal is to create a mandatory measure limiting the length of 1" or larger piping in single family homes to a maximum length of ten feet[6].

[5] Discussions with a production plumber indicated typical hot and cold water plumbing installation for a 2000 ft2 home required two person days of labor. Our conservative estimate was that extending the ½" lines from each manifold would take an additional two hours of time.

Figure 9: Lot 53 Plumbing Layout Schematic

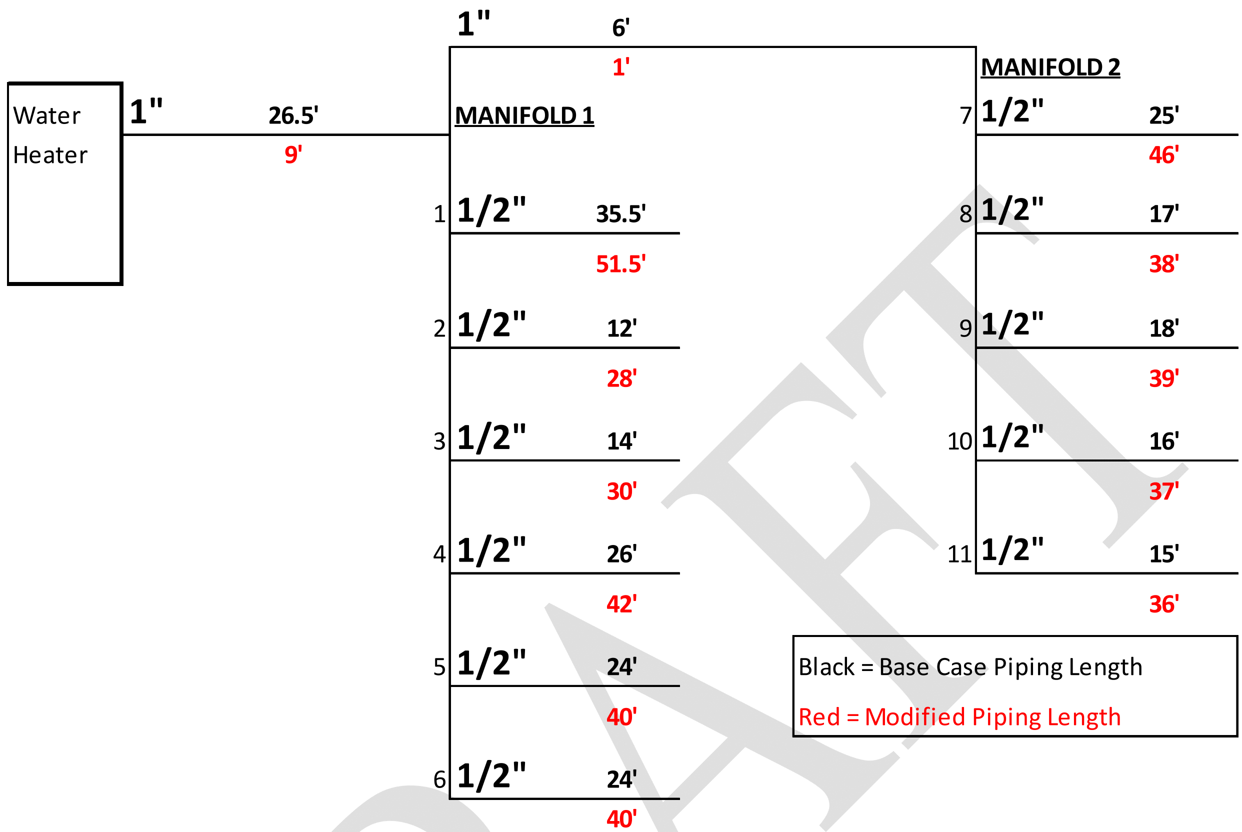


Figure 10: Results Summary on Limiting 1" Piping to a Maximum of 10 feet

Prototype	Reduced Length of 1" Piping	Added Length of ½" Piping	Projected Annual Savings (therms)	PV* of savings	Addl Cost	LCC
Field Site	22.5'	185'	8.4	$233	$131	$102

4.3 Compact Hot Water Distribution System (HWDS)

The goal of a compact HWDS is to bring the fixtures in closer proximity to the water heater. Proposed mandatory requirements limiting 1" piping length and requiring insulation on all ¾" or larger piping will push the industry towards more efficient installation practices. A prescriptive

[6] The one exception to this requirement would be for high flow tubs, provided the plumber can justify the sizing based on the length and the specified water pressure. In that case a dedicated 1" line could be run, although the ten foot maximum length requirement would still be in effect for all other use points.

proposal for compact HWDS will take the process one step further by setting the standard budget at a level consistent with a compact design. There are two elements to a compact HWDS: the design of the house in terms of intelligently locating bathrooms, kitchen, and laundry; and locating the water heater closer to the use points. The latter point will typically result in moving water heaters from exterior garage walls to a preferred garage location on an interior wall, but could also result in optimally located indoor water heaters or exterior closets. A more compact configuration will result in less plumbing pipe, but generally a longer gas line and more vent piping. For the results presented in Figure 11, conservative cost assumptions were based on:

- adding 30 feet of gas line piping (water heater relocation)
- adding 15 feet of water heater vent pipe
- reduce PEX piping length (varies by plan from 21' to 158')

Costs were based on RS Means for gas and vent piping modifications, $7.27/ft and $11.44/ft[7], respectively. PEX piping cost savings due to reduced lengths were based on at $1.75 per foot for 1", $1.34 for 3/4", and $1.07 for ½" PEX.

The resulting LCC shows a positive value for all case. The combined BCR for the four cases was found to be 2.11.

Figure 11: Summary of Results on Compact HWDS

Prototype	Projected Annual Savings (therms)	PV* of savings	Added Cost (gas + vent pipe)	Cost Impact (reduced PEX piping)	Total Addl Cost	LCC
2010	19.8	$548	$390	($28)	$362	$186
2811	30.7	$850	$390	($183)	$207	$643
3080	16.8	$465	$390	($35)	$355	$111
4402	29.5	$817	$390	($44)	$346	$471

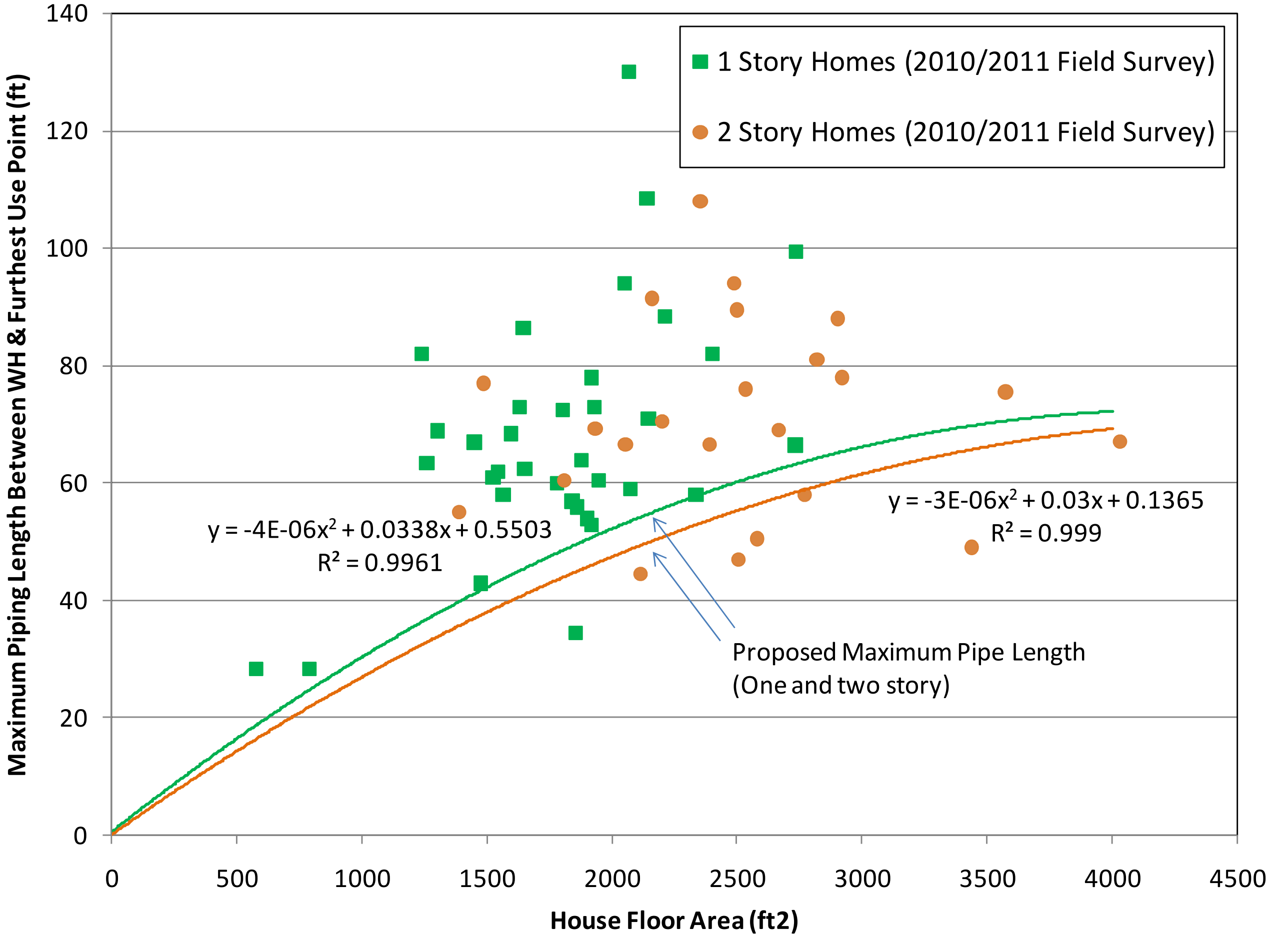
The criteria for defining the maximum piping length are shown as the solid lines in Figure 12 for both one and two-story homes. Datapoints shown represent individual house plans surveyed in the current plumbing field survey work. Some of the houses surveyed were found to already fall below the proposed criteria, while others will require a combination of water heater relocation, architectural redesign, and improved plumbing layout. To handle house sizes at the extreme floor area ranges, we propose a minimum piping length of 20' and also a maximum length of 60-65'. This would provide additional flexibility for small units, and force large houses to more aggressively design, or put in a second water heater[8].

[7] Including 30% builder markup.

[8] The current ACM rules allow for multiple water heaters. The methodology credits for the smaller assumed distribution system size, but also penalizes for added water heater standby energy, if two storage water heaters are installed.

The net effect will be significant reductions in energy use and water waste. Combined with the prior two mandatory measures, plumbing systems will become smaller in length, better insulated, and incorporate smaller diameter pipe. As a prescriptive requirement, this approach is not required, and can be traded off with other efficiency improvements.

Figure 12: Compact HWDS Proposed Criteria Relative to Recent New Home Sample



4.4 ACM Modifications

ACM predicted "standard" water heating energy use exceeds RASS usage data by ~15%. Two issues are likely at play. First, the assumed cold water temperatures by climate zone, shown in Figure 13, are likely lower than real inlet water temperatures. Second, the 135°F hot water setpoint assumption may well be high for most California households.

Figure 14 plots average cold water inlet temperatures from eighteen households monitored as part of the Gas Technology Institute's Advanced Gas Water Heating Project currently underway. The monitored temperatures represent the average inlet water temperature measured only during times when cold water is flowing to the water heater. Each of the three plotted lines (LA, PG&E, and San Diego) represents an average of six sites in each location. As a reference, monthly ACM temperatures from the nearby climate zone are plotted. In all cases, the ACM-assumed temperature is cooler than the actual monitored temperature. This is most pronounced in summer in the southern California areas, where inlet water temperatures are 10-15°F warmer than assumed, likely due to heating of the water in warm garages.

The GTI cold water inlet monitored temperatures are limited in geographic scope, so it is difficult to extrapolate the Figure 14 findings to all sixteen California climate zones. An alternative approach is to modify the assumed water heater temperature setpoint. DOE, in the development of the 2001 RECS, utilized a survey of over 340 plumbing and hydronic heating contractors nationwide to determine typical hot water setpoints. Results of the survey indicated a "typical" estimated water heater setpoint of 124.2ºF. Lowering ACM-assumed water heater setpoint from 135ºF to 124.2 ºF will reduce climate zone water heating budgets by an average of 15% as shown in Figure 15, with reductions ranging from 13-18%.

We propose that a change in water heater setpoint to 124.2ºF be implemented to better align ACM projected hot water usage with actual usage.

Figure 13: Current ACM Assumed Monthly Cold Water Inlet Temperatures

Climate Zone	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	52.2	51.5	51.4	51.8	53.1	54.5	55.6	56.4	56.4	55.8	54.7	53.4
2	53.3	51.5	51.4	52.2	55.6	58.9	61.8	63.6	63.8	62.3	59.5	56.3
3	55.1	54.1	54.0	54.5	56.5	58.5	60.3	61.4	61.5	60.6	58.9	56.9
4	55.5	54.0	53.9	54.6	57.5	60.3	62.8	64.3	64.5	63.2	60.8	58.0
5	55.7	54.8	54.7	55.2	56.9	58.7	60.2	61.1	61.2	60.4	59.0	57.3
6	59.1	58.1	58.0	58.5	60.4	62.4	64.0	65.1	65.2	64.3	62.7	60.8
7	60.1	59.1	59.0	59.5	61.5	63.4	65.2	66.2	66.3	65.5	63.8	61.9
8	60.0	58.8	58.7	59.2	61.6	63.9	66.0	67.3	67.4	66.3	64.3	62.1
9	60.5	59.1	59.0	59.7	62.2	64.8	67.1	68.5	68.6	67.5	65.3	62.8
10	59.4	57.6	57.4	58.3	61.8	65.2	68.2	70.1	70.2	68.7	65.8	62.4
11	54.9	52.4	52.2	53.4	58.2	63.0	67.2	69.8	70.0	67.9	63.8	59.2
12	54.6	52.5	52.3	53.3	57.3	61.3	64.8	67.0	67.2	65.4	62.0	58.1
13	57.5	54.7	54.5	55.8	61.0	66.2	70.6	73.5	73.7	71.4	67.0	62.0
14	54.2	51.2	51.0	52.4	58.2	63.9	68.8	72.0	72.2	69.7	64.8	59.3
15	66.8	64.0	63.8	65.1	70.4	75.8	80.4	83.3	83.6	81.2	76.7	71.5
16	44.4	41.8	41.6	42.8	47.7	52.6	56.8	59.5	59.7	57.5	53.4	48.7

Figure 14: Monitored Cold Water Inlet Temperature vs. ACM

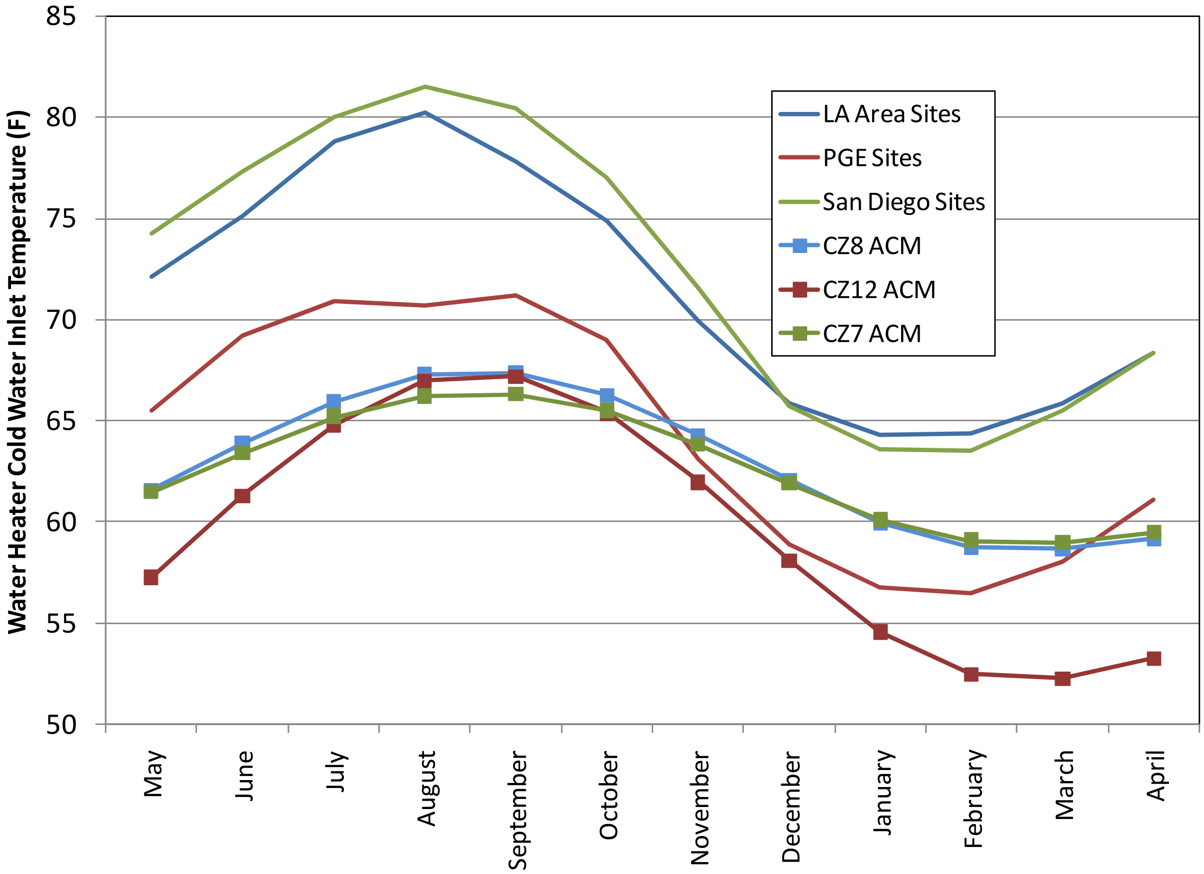


Figure 15: Impact of Water Heater Setpoint on Recovery Load

Climate Zone	Percent Reduction in Annual Water Heater Recovery Load
1, 16	13%
2-5, 12	14%
6-11, 13, 14	15%
15	18%
Average	15%

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

Section 150 of the standards will be updated to include the mandatory measures for pipe insulation and maximum 1" pipe length in non-recirculating hot water systems, as well as for defining the prescriptive requirement for compact hot water distribution systems.

Recommended changes:

Section 150 (j) is currently entitled Water System Pipe and Tank Insulation and Cooling Systems Line Insulation. It is proposed to retitle 150(j) to Water System Piping and Insulation for Piping, Tanks, and Cooling System Lines

Add a subitem #5 in 150(j).

5. The maximum length of 1" piping in a non-recirculating domestic hot water distribution system shall be limited to a total length of ten feet.

EXCEPTION 1 to Section 150(j)5: A dedicated 1" line feeding a high flow tub fixture (or tub fixtures) can be installed provided all other fixtures meet the requirement of 150(j)5.

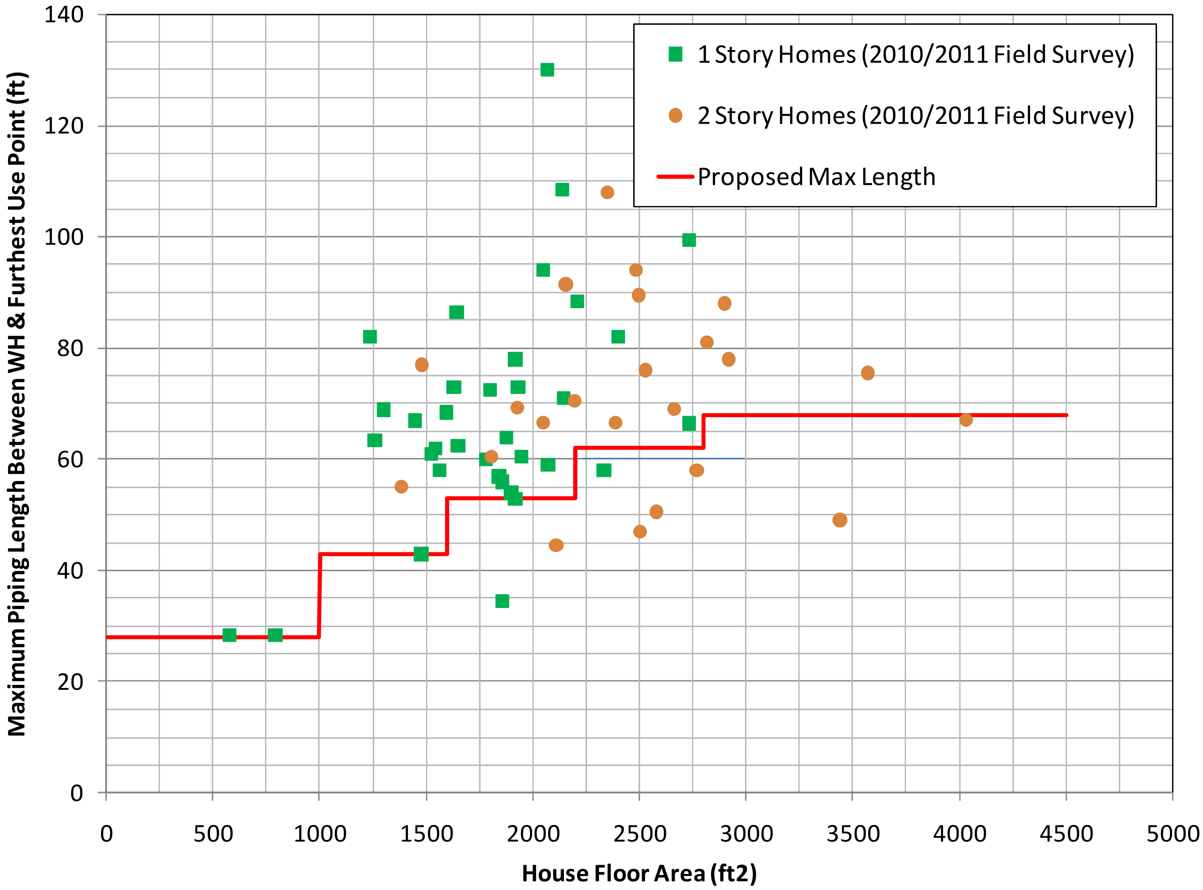
Add a subitem #6 in 150(j).

6. The prescriptive standard for distribution system performance will be based on a compact hot water distribution system approach which limits the maximum length of distribution piping between the water heater and the furthest use point in the house. The table below defines the maximum pipe length as a function of Floor Area Served, where Floor Area Served equals the conditioned floor area divided by the number of installed water heaters.

Floor Area Served (ft^2)	Maximum Length
< 1000	28 ft
1001-1600	43 ft
1601-2200	53 ft
2201-2800	62 ft
>2800	68 ft

The table above was derived from the regression relationship in Figure 12 and is graphically represented below in Figure 16.

Figure 16: Proposed Compact HWDS Maximum Length vs. Field Data



Upon acceptance of the compact HWDS approach as the prescriptive standard, modifications will need to be made to Appendix RE of the Residential ACM to redefine the standard distribution losses, as well as the Table RE-2 which defines the distribution system multipliers (DSMs) for alternative distribution system types. It is premature to develop Table RE-2 until the prescriptive standard is defined, since all evaluations must be completed relative to the prescriptive standard. Figure 17 presents a proposed format for the 2013 Table RE-2, with the 2008 values shown for comparison purposes.

Figure 17: Comparison of 2013 and 2008 DSM Table RE-2

	2008 - Existing		2013 - Proposed
Distribution System Measure	**Code**	**DSM**	**DSM**
Pipe Insulation (all lines)	PIA	0.9	tbd
Uninsulated Pipe below Grade	UPBG	3.8	tbd
Insulated and Protected pipe below grade	IPBG	1.0	tbd
Point of Use	POU	0.0	tbd
Standard pipes with kitchen lines insulated	SKLI	1.0	tbd
Standard pipes with no insulation	SNI	1.2	tbd
Compact HWDS	CHWDS_STD		1.0
Parallel Piping	PP	1.0	tbd
Recirculation (no control)	RNC	4.5	tbd
Recirculation + timer control	RTm	3.0	tbd
Recirculation + temperature control	RTmp	3.7	tbd
Recirculation + timer/temperature	RTmTmp	2.5	tbd
Recirculation + demand manual control	RDmm	0.9	tbd
Recirculation + demand motion-sensor control	RDms	1.0	tbd
Temperature Buffering Tank	TBT	1.2	delete?
HERS Inspections Required (Added for 2013)			
Pipe Insulation (all lines)	H_PIA	n/a	tbd
Parallel Piping (5' WH to manifold)	H_PP	n/a	tbd
Recirculation (no control)	H_RNC	n/a	tbd
Recirculation + timer control	H_RTm	n/a	tbd
Recirculation + temperature control	H_RTmp	n/a	tbd
Recirculation + timer/temperature	H_RTmTmp	n/a	tbd
Recirculation + demand manual control	H_RDmm	n/a	tbd
Recirculation + demand motion-sensor control	H_RDms	n/a	tbd
POU water heater (max 1 quart to all use points)	H_POUWH	n/a	tbd

6. Bibliography and Other Research

Architectural Energy Corporation. Life-Cycle Cost Methodology. 2013 California Building Energy Efficiency Standards. January 16, 2011. Prepared for California Energy Commission.

Hiller, C.C., “Hot Water Distribution System Piping Heat Loss Factors – Phase I Test Results:, ASHRAE paper no. CH-06-4-3, January 2006.

KEMA, Inc. 2010. *2009 California Residential Appliance Saturation Study*. California Energy Commission. Publication number: CEC- 200-2010-004-ES.

Lutz J.D. (Lawrence Berkeley National Laboratory). 2008. *Water Heaters and Hot Water Distribution Systems*. California Energy Commission, PIER Buildings End-Use Energy Efficiency. CEC-500-2005-082.

Springer, D., Rainer, L., Hoeschele, M., and Scott, R., “HWSIM: Development and Validation of a Residential Hot Water Distribution System Model,” *Proceedings of the 2008 ACEEE Summer Study on Energy Efficiency in Buildings.*

7. Appendices

DAVIS ENERGY GROUP INCORPORATED

Field Survey Report:

Documentation of Hot Water Distribution Systems in Sixty New California Production Homes

Report Issued:	March 6, 2006 Revised March 21, 2006
Presented to:	Jim Lutz, Contract Manager Lawrence Berkeley National Laboratory
Subcontract #:	6803947
Prepared by:	Davis Energy Group, Inc. Chitwood Energy Management

Legal Notice

8. Background and Objectives

The efficiency of delivering hot water in single family hot water distribution systems is dependent upon many factors including:

- hot water usage characteristics (magnitude, profile, flow rates, use temperature)
- the configuration of the hot water distribution system (HWDS)
- piping installation issues (layout, pipe material type and diameter, insulation)
- location of hot water piping and heat loss environment surrounding the pipes
- water heater setpoint
- location of hot water fixtures relative to the water heater(s)
- recirculation system controls

All these factors play a role in determining how efficiently hot water is transported from the water heater to the end use points. Hot water distribution system performance is a complex issue since the same house may perform very differently based on household usage characteristics (time of day usage patterns, clustering of draws, use temperature, use of tubs vs. showers, etc.)

New homes being built in California are significantly larger and have more amenities than homes built twenty to thirty years ago. One trend that has been occurring is an increase in the number of hot water consuming fixtures. Homes with four and five bathrooms are not uncommon. In addition, multi-head showers and large whirlpool tubs are increasing in popularity. More use points, high flow rate fixtures, and increased house size all contribute to more and larger diameter hot water piping in new homes. This has implications both in terms of energy usage (greater heat loss), customer satisfaction (longer hot water wait times), and water waste (more water is dumped before hot water arrives at the fixture).

To better understand how hot water distribution systems (HWDS) are being installed, Chitwood Energy Management and Davis Energy Group completed a field survey of sixty new production homes. The goal of the survey was to quantitatively characterize the HWDS plumbing layout as well as to collect data on the type of water heater being installed, hot water fixture characteristics, and gather anecdotal feedback from plumbers and building superintendents on industry trends.

In this study we have characterized HWDS as one of the four following types:

- conventional trunk and branch (either copper or PEX[9])
- PEX parallel piping systems with a central manifold feeding either 3/8" and ½" lines or exclusively ½" lines

[9] PEX is a plastic cross-linked polyester piping material common to much of California. There are several building jurisdictions (e.g. Los Angeles and San Diego) that do not allow PEX for potable water applications.

- Hybrid systems (a variation of the trunk and branch system that includes a main trunk(s) and either in-line mini-manifolds or Tees with branches and mini-manifolds)
- Recirculation systems (a central loop with a pump and controls that activate pump operation based on either a timer, temperature input, or an occupant initiated demand for hot water)

9. Field Survey Methodology

The goal of the field survey was to gather a statewide snapshot of current HWDS installation practice in California production homes. Although not statistically significant, it does capture current industry trends and installation practices.

For site selection, the following target geographic breakdown was developed.

Northern Sacramento Valley: ~5 houses
Greater San Francisco Bay Area (S.F, East Bay, South Bay): 5 to 10 houses
Central Valley (Sacramento to Bakersfield): 20 to 25 houses
Southern California coastal (L.A. and San Diego): 5 to 15 houses
Southern California inland (Riverside to desert regions): 10 to 15 houses

As part of the development of the field survey plan, we further segmented the sixty home sample into the following subgroup targets:

- All single family detached homes
- Conditioned floor area (ranging from 1,200 – ~4,000 ft^2, average of 2,200-2,500)
- A goal of no more than three houses per plumbing contractor, although in some markets one or two large contractors may dominate the scene
- Target survey segmentation into the following subsets
    - One and two-story houses: Total of 60, with minimum of 20 each
    - Conventional main and branch systems: 20-35 sites
    - Hybrid systems: ~5-15 sites
    - Parallel piping systems: ~5 sites
    - Recirculation systems: 5-15 sites, with 2-5 demand recirculation
    - Largely underslab piping: ~5-10 sites

The survey will focus on the following key elements:

- Site characterization: location, builder, plumber, floor area, 1 or 2 story, etc
- Water heater characteristics: size, type, volume, location, etc

- Piping system: sketch and tabulation of each installed "segment"[10] of hot water line from the water heater to the end use point
- Hot water use points: fixture type
- Recirculation system type (if installed): make/model #, pump specification, control type
- Underslab pipe description: soil characteristics surrounding underslab piping

Two methods were used to locate and obtain access to the construction sites. The first approach involved using industry contacts to obtain access to sites. HERS raters involved in construction quality verification proved to be the best industry contacts. The HERS raters close connection to projects was useful in identifying sites at the appropriate stage in various subdivisions. Allen Amaro (Amaro Construction Services) helped locate homes in the Sacramento area and Scott Johnson (Maximum Home Performance) helped locate homes in Southern California. Davis Energy Group's work with builders also provided several Northern California sites. The second approach to finding survey sites involved driving onto active job sites to see if they met the site selection criteria and then obtaining permission to survey the site. Permission to survey the site from the superintendent or the plumbing foreman was never denied.

The majority of the construction sites had on-site model homes. The models provided information about how the homes would be finished and the floor plans for the homes to be surveyed. The sales literature provided contained the floor plans for all of the homes in the subdivision, floor plan options, and a description of the energy features and construction methods. The make and model number of water heater was obtained from the water heaters installed in the models except when the garages were locked. Plumbing fixture information (faucet types and shower head type) was also obtained from the models. This information was further documented by taking pictures of the fixtures in the models. Generally the model homes had upgrade fixtures installed. Discussions with sales staff or the plumbing contractor was used to determine typical fixture types.

The key survey element involved measuring every section of installed hot water piping in the home with a tape measure or a measuring wheel and recording the measurement on the field data sheet. Additional data collected included pipe material type, diameter, location, and the presence of thermal insulation. The location of major components such as the water heater, trunks, manifolds, etc. were sketched on the floor plan. Pictures were also taken to document each site. Digital pictures of; installation quality, hot water draw points, underslab terminations, pipe locations, bundling of tubing, and any special features or characteristics further document each site.

All measurements reflect actual installed piping lengths with one exception. An additional 1.5 feet of length was added to the as-built measurement to account for piping

[10] A "segment" includes a unique description of the following: pipe material, diameter, environmental location (e.g. under slab, attic, interior wall, etc), and presence of insulation. With this definition a single ¾" pipe may be divided into multiple segments as it moves through, for example, different environments.

to be installed from the garage stub-out to the water heater. The additional 1.5 feet of pipe was assumed to be the same diameter as the pipe penetrating the garage drywall. For manifold systems, the measurement of the main line from the water heater to the manifold terminated at mid-height of the manifold. An additional volume was added to account for the larger internal manifold diameter relative to the main line[11].

10. Results

The sixty houses surveyed included installations from 19 different plumbing contractors. Sites were geographically located as described in Table 1. The majority of the sites were located in climate zone 12. Although no sites were surveyed in the southern San Joaquin Valley, the geographic range in zone 12 extended from the San Francisco Bay Area commuting communities of San Ramon and Tracy eastward to El Dorado Hills in the Sierra foothills. Nine southern California coastal sites were survey as well as fifteen sites in the greater Palm Springs area. A California climate zone map in Appendix A shows the approximate locations of the sixty sites.

Table 1: Site Location Summary

Climate Zone	Number Of Sites	Location
6	6	San Juan Capistrano, Costa Mesa
8	3	Tustin
10	1	Menifee
11	6	Lincoln, Redding
12	29	Woodland, El Dorado Hills, Elk Grove, Rancho Cordova, San Ramon, Tracy, Mountain House
15	15	Indio, Palm Springs, Desert Hot Springs

Figure 1 plots the conditioned floor area for the sixty houses based on floor plans typically provided as part of the builder sales literature. Conditioned floor area averaged 2,432 ft^2. Twenty-five of the houses were single story (average floor area equal to 2,209 ft^2) and 35 were two-story (average floor area equal to 2,590 ft^2). On average there were 2.84 bathrooms per house and 12.85 hot water use points[12]. Figures 2 and 3 plot the bathroom and use point data as a function of floor area.

[11] To account for an estimated 1.5 feet of 1.25" distribution manifold, 0.07 gallons were added for a ¾" main line and 0.05 gallons were added for a 1" main line.

[12] Combination tub/shower were treated as two use points.

Figure 1: Floor Area Distribution

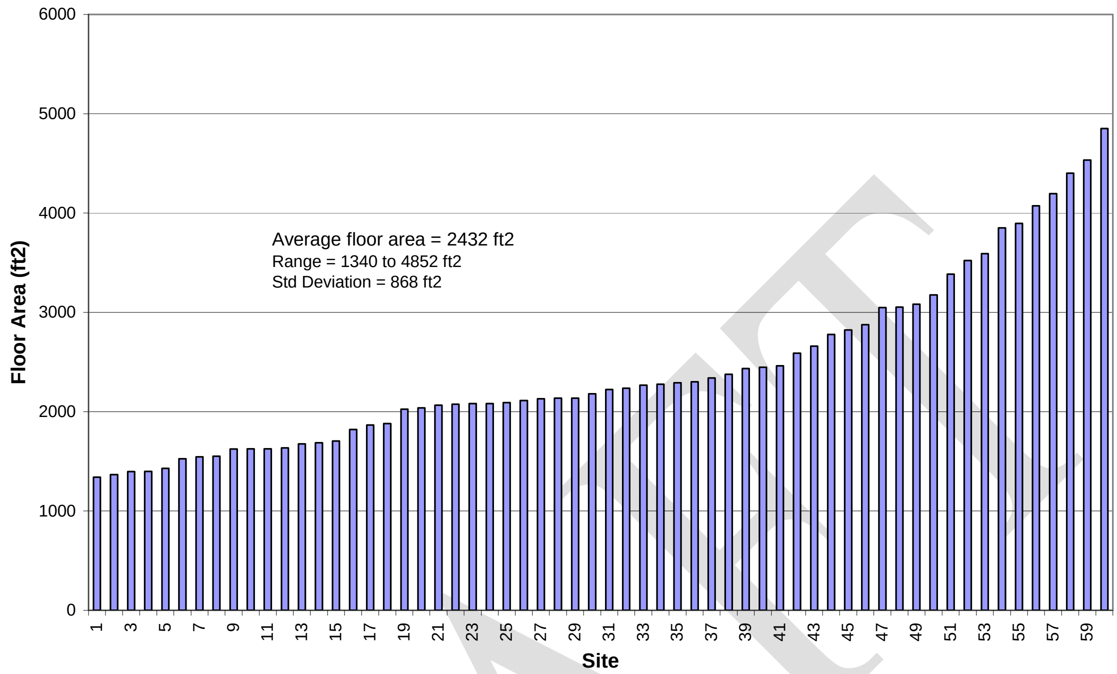


Figure 2: Number of Bathrooms as a Function of Floor Area

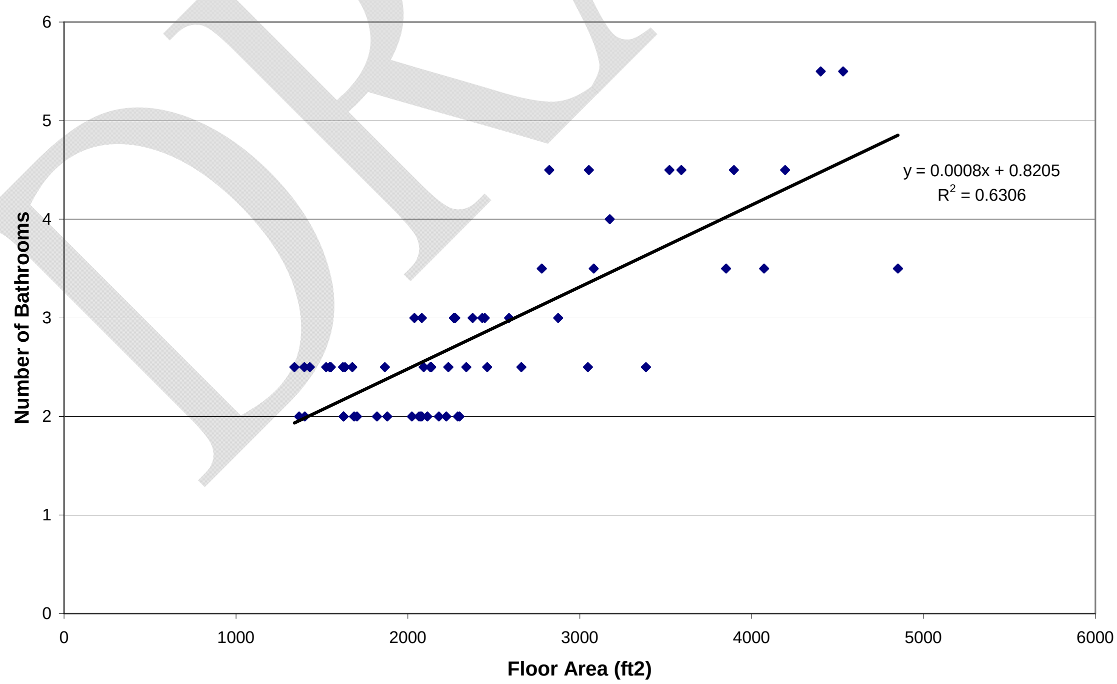


Figure 3: Number of Hot Water Use Points as a Function of Floor Area

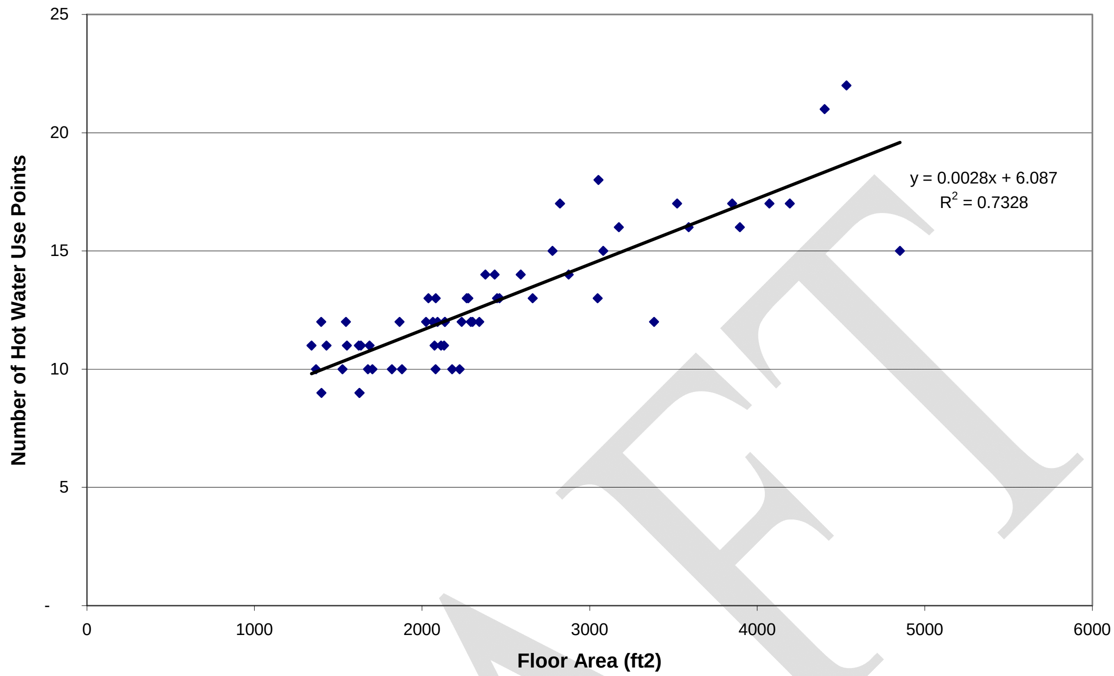


Table 2 summarizes the pipe materials installed in the sixty home sample. A total of 21,996 feet of pipe were measured in the sixty homes (average of 367 feet per house). PEX was the most common material installed (84% by length). None of the 35 houses surveyed north of the Tehachapis utilized copper as the primary piping material. In southern California, nine of the 25 systems were copper systems. No other piping materials besides copper and PEX were found. The righthand column in Table 2 represents the length of piping corresponding to one gallon of entrained volume. For copper piping values are shown for both Type M (typical thin wall pipe) and Type L (required for underslab plumbing). PEX piping, with its greater wall thickness, has roughly 40% less volume per foot than copper piping. This is beneficial from a waiting time and heat loss perspective (assuming all the stored heat is lost between draws), but also results in a faster cool-down time between draws.

Table 2: Breakdown of Pipe Characteristics

Pipe Material	Field Measurements		Feet of Pipe Per gallon
	By Length	By Volume	
1” Copper	3%	10%	22.0 (23.3) *
¾” Copper	5%	10%	37.2 (39.8) *
½” Copper	9%	9%	75.8 (82.5) *
1” PEX	2%	6%	32.0
¾” PEX	9%	15%	52.8
½” PEX	41%	35%	104.2
3/8” PEX	32%	15%	189.1

“*” Volumetric data is reported in terms of Type M with Type L in parentheses

HWDS type was disaggregated into the four categories: conventional trunk and branch, PEX parallel piping systems with a central manifold, hybrid systems, and recirculation systems. Table 3 summarizes the HWDS types found in the field survey.

Table 3: Observed HWDS Types

System Type	Number
Conventional Trunk and Branch (copper)	3
Conventional Trunk and Branch (PEX)	9
Manifold w/ PEX Parallel Piping	23
Hybrid Systems w/ PEX Piping	13
Recirculation Systems (copper)	6
Recirculation Systems (PEX)	6

Pipe location was disaggregated into five categories: Attic, exterior wall cavity, garage, interior cavity (interior walls or between first and second floor), and underslab. In terms of both length and entrained volume, most of the piping (45%) was located in interior wall cavities with the attic space (37%) close behind. Exterior wall cavities, garage, and underslab each accounted for between 5 and 8% of pipe length and entrained volume.

Table 4 breaks down the pipe location data further into one and two-story categories. One-story homes primarily had piping in the attic (62% by length) and secondarily in interior wall cavities (21%). Although attic piping was the second most common pipe location for two-story homes (22%), most of the piping in two-story homes was located in interior cavities including floor cavities (59%).

Table 4: Pipe Location Variations with Number of Stories

Pipe Location	One-Story		Two-Story	
	By Length	By Volume	By Length	By Volume
Attic	62%	64%	22%	21%
Exterior Wall	7%	7%	9%	9%
Garage	4%	4%	6%	5%
Interior Cavity	21%	18%	59%	61%
Underslab	6%	7%	4%	4%

Table 5 reports the average volume of water entrained in the piping between the water heater and the end use points for the different HWDS types. For all sites, the average volume between the water heater and an end use point was 1.30 gallons. The average entrained volume for all non-recirculation systems was fairly comparable (0.86 to 0.97 gallons), although once adjusting for floor area, the parallel piping sites were ~20% less volume than the conventional systems and 9% less than the hybrid systems. The recirculation systems had by far the highest entrained volume. After normalizing by floor area, the average volume was nearly double that of the non-recirculating system types, without accounting for return line volume (average of 0.29 gallons per 1000 ft^2).

It is important to note that the volumetric data does not directly correlate to HWDS efficiency since the delivery characteristics of the various system types is very different. For example, parallel piping systems usually have a dedicated line from the hot water manifold[13] to the end use point requiring the complete purging of the line (from the manifold) before the first pulse of hot (or warm) water arrives from the water heater. This is in contrast to conventional and most hybrid systems that often share a main trunk line among most or all of the end use points. Recirculation systems also demonstrate favorable water waste and wait time benefits by effectively bringing the water heater in close proximity to the end use points[14].

Table 5: Average Entrained Hot Water Volume to End Use Points

System Type	Avg Pipe Length (ft)	Avg Volume (gallons)	Avg Vol per 1000 ft^2 of Floor Area
Conventional Trunk and Branch	185	0.86	0.49
Manifold w/ PEX Parallel Piping	499	0.97	0.39
Hybrid Systems w/ PEX Piping	227	0.89	0.43
Recirculation Systems	385	2.82	0.82

Figure 4 further disaggregates the data by HWDS type and number of stories (one and two-story denoted by “1S” and “2S”, respectively). The recirculation systems consistently demonstrate the largest entrained volume of the sample. All the other system types cluster fairly closely to an average entrained volume of 1 gallon, although the parallel piping systems demonstrate little sensitivity to floor area. This is largely due to the consistently observed characteristic of the manifold systems where excessive amounts of ¾” or 1” piping is used to connect the water heater to the manifold[15].

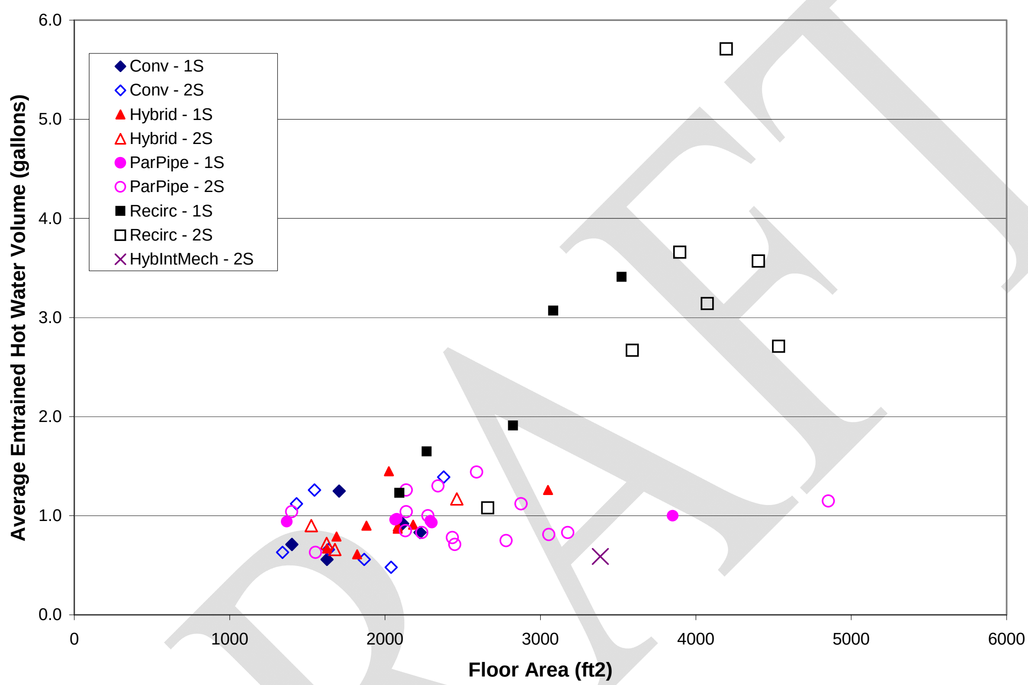
For 41 of the 60 houses surveyed, the water heater types could be precisely determined based on equipment installed in the models or information provided by plumbers and/or building superintendents. Of the 41, twenty-five were 50 gallon gas storage water heaters, six were 40 gallon gas storage units, five were 75 gallon gas storage units, and five were instantaneous gas units. It was not possible to definitively verify the remaining nineteen water heaters due to garages being locked in the model homes and lack of input from the builder.

In terms of hot water fixtures there were two key areas of interest. One concerned the installation of high-volume shower systems that use water at a significantly higher rate than conventional showerheads. None of these systems were found. In four large high-

[13] Some plumbers may utilize Tees at bathroom sinks to allow sharing of one line.
[14] There is, of course, an energy impact in keeping the recirculation loop hot.
[15] On average, the twenty three manifold sites were found to have 24 feet of ¾” or 1” piping between the water heater and manifold.

end houses we did find master showers with dual showerheads. The second fixture type of interest was the kitchen and lavatory sinks. The presence of single lever control (vs. dual handle) could be a factor in higher hot water use and energy waste since the natural position of the control is in the mixed (centered) position. As a general rule, we found bath lavatories to be dual handle control and kitchen sinks single lever.

Figure 4: Average Entrained Hot Water Volume vs. Floor Area



11.   Conclusions and Recommendations

The following conclusions were generated based on the field experiences during the sixty home survey:

1. PEX has achieved significant market share in the last few years with a strong trend from copper piping to PEX piping. This was especially true in Northern California. All areas of the state where PEX is allowed show fairly rapid transition to this material. The input from plumbers who have switched to PEX is that the system is cheaper to install, can utilize less skilled labor, and is less prone to leaks.

2. Plumbers cite two reasons in not changing to PEX. First, the City of Los Angeles does not allow PEX in their jurisdiction and that prevents some other southern California jurisdictions from allowing PEX. Secondly, many plumbing

contractors are reluctant to install newer products for fear of future liability and specifically cite the polybutylene failures from the 1980's as the reason not to switch to PEX. These two reasons are slowing the transition to PEX in Southern California.

3. Systems of all types were generally not efficiently installed. The following summarizes findings on each of the system types:

Trunk & Branch and Hybrid Systems
Eliminating excessive pipe length is most important improvement that could be implemented in both trunk & branch and the hybrid system types. Installers seem to put little value on reducing pipe length despite the benefits of reduced hot water waiting time (less callbacks). Designing a system with an emphasis on reducing piping length would have lower material costs, lower installation labor costs, and would provide better performance. For some reason installers tend to run trunks parallel to framing rather than straight to where the hot water is needed. This trend adds about 40% to the length of the trunk. This isn't a trend with forced air duct systems why is it typical with plastic piping?

Parallel Piping - Manifold Systems
Eliminating excessive pipe length is also the most important improvement that can be made to parallel piping systems, but the improvement is much easier. The majority of the excess pipe length is found in the main between the water heater and the manifold. The water heater and the manifold are typically located adjacent to each other but the piping that connects the two is often routed by other than a direct route. In one case there was 24 feet of one-inch pipe between the water heater and the manifold. On average, reducing the observed length to a maximum of 10 feet would reduce the entrained volume of the manifold systems by 26%. (Reducing this length by running the main out the side of the manifold cabinet and directly to the water heater could reduce this length to about 3 feet.)

Another pipe length reduction opportunity exists for two-story houses. Some, but not all, plumbers tend to run the piping to the attic and them back down to the first floor – even if the draw point is only 10 feet away. The preferred approach would be to remain between floors.

One issue that needs further study is the energy impact of tightly bundling hot and cold piping together. This was seen in some cases. The bundling was apparently done to consolidate the tubing in one location and make the piping installation look better.

Hot Water Recirculation Systems
Eliminating excessive pipe length is also a major issue for recirculation systems. In fact the problem is more significant than for other system types since excess pipe length is usually large diameter piping (3/4" or 1"). For the twelve recirculation sites surveyed, the average recirc loop entrained volume was found to be 4.42 gallons. Return line sizing was found to average 0.99 gallons and runouts (from the loop to the fixtures) were 0.17 gallons on average. For continuous or timer controlled loops, the large loop size has

significant energy impacts. For the preferred demand recirculation approach, the data reinforces the need to fully understand how these systems are installed and controlled.

The poorest performing systems in the recirculation sample appear to the three systems that were designed as hot water circulation systems but the actual installation of the pump is an option. The circulation return line is terminated inside the wall so no one but the builder can install the optional circulation pump. From our vantage point, it did not appear that the recirculation loops were to be installed. Without a pump, these oversized lines would take a minimum of seven minutes to fill the hot water line to the kitchen sink.

4. Although parallel piping systems utilize roughly twice the length of piping relative to conventional plumbing practice, the entrained volume (per unit of floor area) was the least of the four system types. Additional significant volume reductions can be achieved with parallel piping systems by shortening the length of the main line between the water heater and the manifold. A 26% average volume reduction was calculated for the manifold systems if the length of the main could be reduced to 10 feet.

5. Title 24 eligibility criteria for all system types should be carefully reviewed to insure that the systems being installed are properly credited or penalized.

6. Six house plans will be developed for use in the Title 24 analysis process. Our proposal is to have one-story plans with floor areas of 1367, 2010, and 3,080 ft^2 and two-story plans with floor areas of 1,408, 2,811, and 4,402 ft^2. The "volume/1000 ft^2" metric presented in Table 5 should be used as guidance in determining pipe lengths and pipe diameters in laying out the plumbing system.

APPENDIX A:

Site Field Summary

Site	FA	# stories	Number of Bathrooms	UsePoints[1]	Water Heater Outlet Pipe Size	AvgVol[2]	Distribution System Description
1	3385	2	2.5	12	0.75	0.59	Interior WH, Manifold System (1/2" PEX) with some Tees
2	2024	1	2	12	1.00	1.45	Main with Tees and Distributed Manifolds (PEX)
3	2462	2	2.5	13	1.00	1.17	Main with Tees and Distributed Manifolds (PEX)
4	1687	1	2	11	1.00	0.79	Main with Tees and Distributed Manifolds (PEX)
5	3851	1	3.5	17	1.00	1.00	Parallel Piping Manifold System (3/8' & 1/2" PEX)
6	4852	2	3.5	15	1.00	1.15	Parallel Piping Manifold System (3/8' & 1/2" PEX)
7	2075	1	2	11	1.00	0.97	Parallel Piping Manifold System (3/8' & 1/2" PEX)
8	2301	1	2	12	1.00	0.93	Parallel Piping Manifold System (3/8' & 1/2" PEX)
9	2875	2	3	14	1.00	1.12	Parallel Piping Manifold System (3/8' & 1/2" PEX)
10	2065	1	2	12	1.00	0.96	Parallel Piping Manifold System (3/8' & 1/2" PEX)
11	2291	1	2	12	1.00	0.95	Parallel Piping Manifold System (3/8' & 1/2" PEX)
12	3175	2	4	16	1.00	0.83	Parallel Piping Manifold System (3/8' & 1/2" PEX)
13	2113	1	2	11	0.75	0.92	Conventional Trunk and Branch (PEX)
14	1704	1	2	10	0.75	1.25	Conventional Trunk and Branch (PEX)
15	2377	2	3	14	0.75	1.39	Conventional Trunk and Branch (PEX)
16	2236	2	2.5	12	0.75	0.83	Parallel Piping Manifold System (3/8' & 1/2" PEX)
17	2433	2	3	14	0.75	0.78	Parallel Piping Manifold System (3/8' & 1/2" PEX)
18	2779	2	3.5	15	0.75	0.75	Parallel Piping Manifold System (3/8' & 1/2" PEX)
19	2589	2	3	14	1.00	1.44	Parallel Piping Manifold System (3/8' & 1/2" PEX)
20	3053	2	4.5	18	1.00	0.81	Parallel Piping Manifold System (3/8' & 1/2" PEX)
21	1866	2	2.5	12	0.75	0.56	Conventional Trunk and Branch (PEX)
22	1677	2	2.5	10	0.75	0.66	Main with Tees and Distributed Manifolds (PEX)
23	2038	2	3	13	0.75	0.48	Conventional Trunk and Branch (PEX)
24	1552	2	2.5	11	0.75	0.63	Parallel Piping Manifold System (3/8' & 1/2" PEX)
25	1367	1	2	10	0.75	0.94	Parallel Piping Manifold System (3/8' & 1/2" PEX)
26	2131	2	2.5	11	0.75	0.85	Parallel Piping Manifold System (3/8' & 1/2" PEX)
27	1340	2	2.5	11	0.75	0.63	Conventional Trunk and Branch (PEX)
28	1525	2	2.5	10	0.75	0.90	Main with In-line Manifolds (PEX)
29	1623	2	2.5	11	0.75	0.72	Main with In-line Manifolds (PEX)
30	2136	2	2.5	12	0.75	1.04	Parallel Piping Manifold System (3/8' & 1/2" PEX)
31	2448	2	3	13	0.75	0.71	Parallel Piping Manifold System (3/8' & 1/2" PEX)
32	2276	2	3	13	0.75	1.00	Parallel Piping Manifold System (3/8' & 1/2" PEX)
33	1398	2	2.5	12	1.00	1.04	Parallel Piping (Interior) Manifold System (1/2" PEX)
34	2136	2	2.5	12	1.00	1.26	Parallel Piping (Interior) Manifold System (1/2" PEX)
35	2341	2	2.5	12	1.00	1.30	Parallel Piping (Interior) Manifold System (1/2" PEX)
36	1400	1	2	9	0.75	0.71	Conventional Trunk and Branch (PEX)
37	1626	1	2	9	0.75	0.56	Conventional Trunk and Branch (PEX)
38	2224	1	2	10	0.75	0.83	Conventional Trunk and Branch (PEX)
39	2082	1	3	13	0.75	0.89	Main with Tees and Distributed Manifolds (PEX)
40	1820	1	2	10	0.75	0.61	Main with Tees and Distributed Manifolds (PEX)
41	1626	1	2	9	0.75	0.67	Main with Tees and Distributed Manifolds (PEX)
42	3082	1	3.5	15	1.00	3.07	Pre-Plumbed Recirc Loop with In-line Manifolds (PEX)
43	2823	1	4.5	17	1.00	1.91	Pre-Plumbed Recirc Loop with In-line Manifolds (PEX)
44	3522	1	4.5	17	1.00	3.41	Pre-Plumbed Recirc Loop with In-line Manifolds (PEX)
45	2092	1	2.5	12	0.75	1.23	Underslab Recirc Loop (PEX) w/ Time/Temp
46	2267	1	3	13	0.75	1.65	Underslab Recirc Loop (PEX) w/ Time/Temp
47	2660	2	2.5	13	0.75	1.08	Underslab Recirc Loop (PEX) w/ Time/Temp
48	2081	1	2	10	0.75	0.87	Hybrid System with Trunks, Tees, and Manifolds
49	1880	1	2	10	0.75	0.90	Hybrid System with Trunks, Tees, and Manifolds
50	2180	1	2	10	0.75	0.91	Hybrid System with Trunks, Tees, and Manifolds
51	3048	1	2.5	13	1.00	1.26	Hybrid System with Trunks, Tees, and Manifolds
52	3591	2	4.5	16	1.00	2.67	Demand Recirc System (Copper)
53	3897	2	4.5	16	1.00	3.66	Demand Recirc System (Copper)
54	4195	2	4.5	17	1.00	5.71	Demand Recirc System (Copper)
55	1545	2	2.5	12	0.75	1.26	Conventional Trunk and Branch (Copper)
56	1635	2	2.5	11	0.75	0.66	Conventional Trunk and Branch (Copper)
57	1430	2	2.5	11	0.75	1.12	Conventional Trunk and Branch (Copper)
58	4073	2	3.5	17	1.00	3.14	Overhead Recirc Loop (Copper) w/ Time/Temp
59	4402	2	5.5	21	1.00	3.57	Overhead Recirc Loop (Copper) w/ Time/Temp
60	4533	2	5.5	22	1.00	2.71	Overhead Recirc Loop (Copper) w/ Time/Temp
Avg	2432	1.58	2.84	12.85	0.86	1.30	
StDev	868						
Max	4852						
Min	1340						

1=	includes all hot water use points; combination tub/shower is treated as individual use points
2=	average volume between the water heater and all hot water use points in the house

DAVIS ENERGY GROUP INCORPORATED

Prototype Floor Plans –

Hot Water Distribution

System Layouts

Report Issued: May 25, 2006

Presented to: Jim Lutz, Contract Manager
Lawrence Berkeley National Laboratory

Subcontract #: 6803947

Prepared by: Davis Energy Group, Inc.

Legal Notice

12. Overview

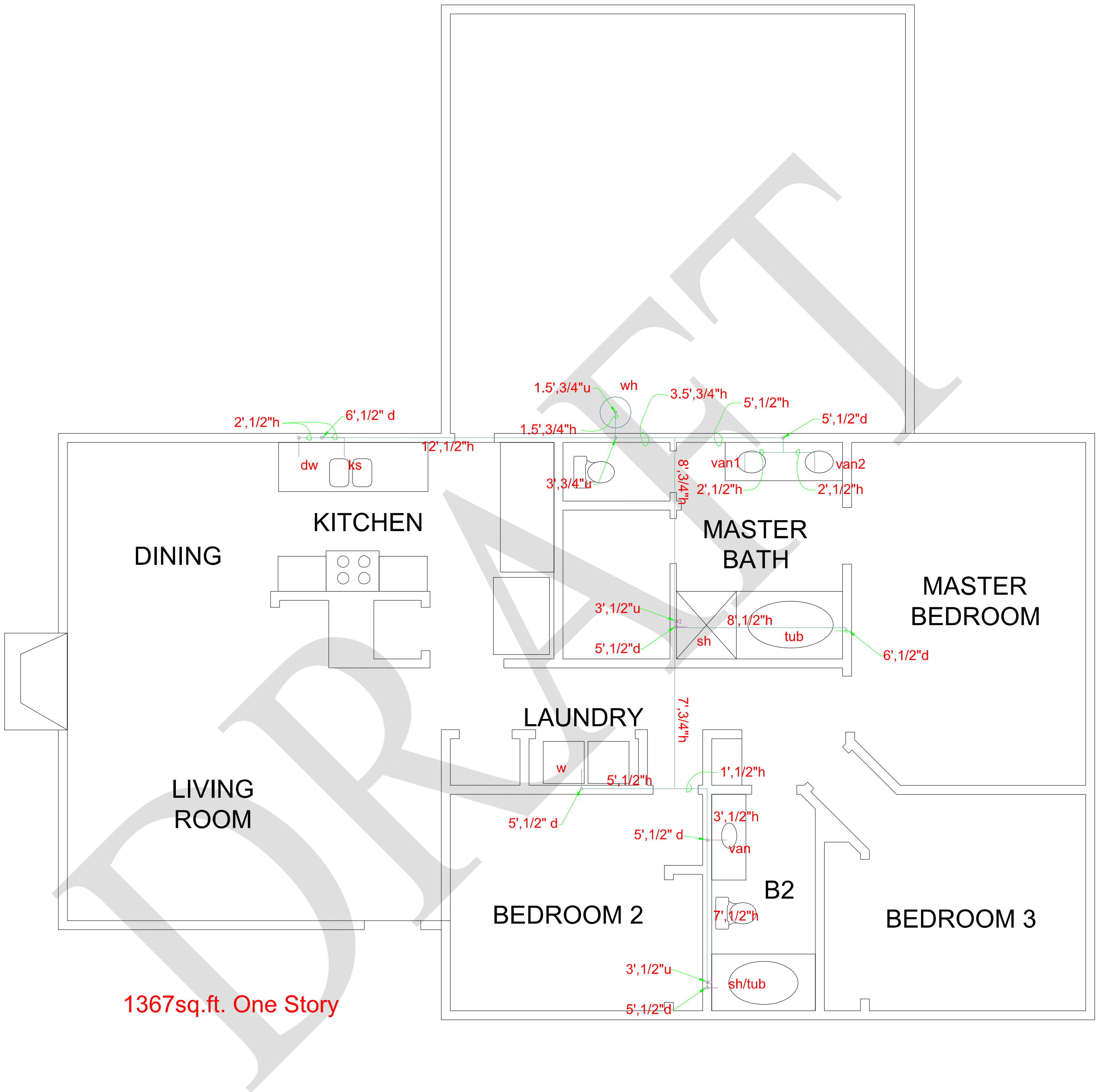
As part of Subtask 2.3 of the PIER Hot Water project, six prototype floor plans were to be developed with "typical" hot water distribution system layouts. This report documents the floor plans and piping layouts for the six houses. All of the six prototypes are based on real production home floor plans. The six selected floor plans were either part of the sixty sample field survey completed as part of Subtask 2.3 or were previously analyzed as part of the 2005 Title 24 Standards process for water heating distribution system performance. Based on current new home construction characteristics, three of the floor plans were selected to be single story homes and the remaining three were selected as two-story. The selected floor area ranges were intended to bracket reasonable floor area ranges for one and two-story homes, respectively, and also provide a midpoint house size. Table 1 summarizes the six house plans.

Table 1: Description of Prototype Floor Plans

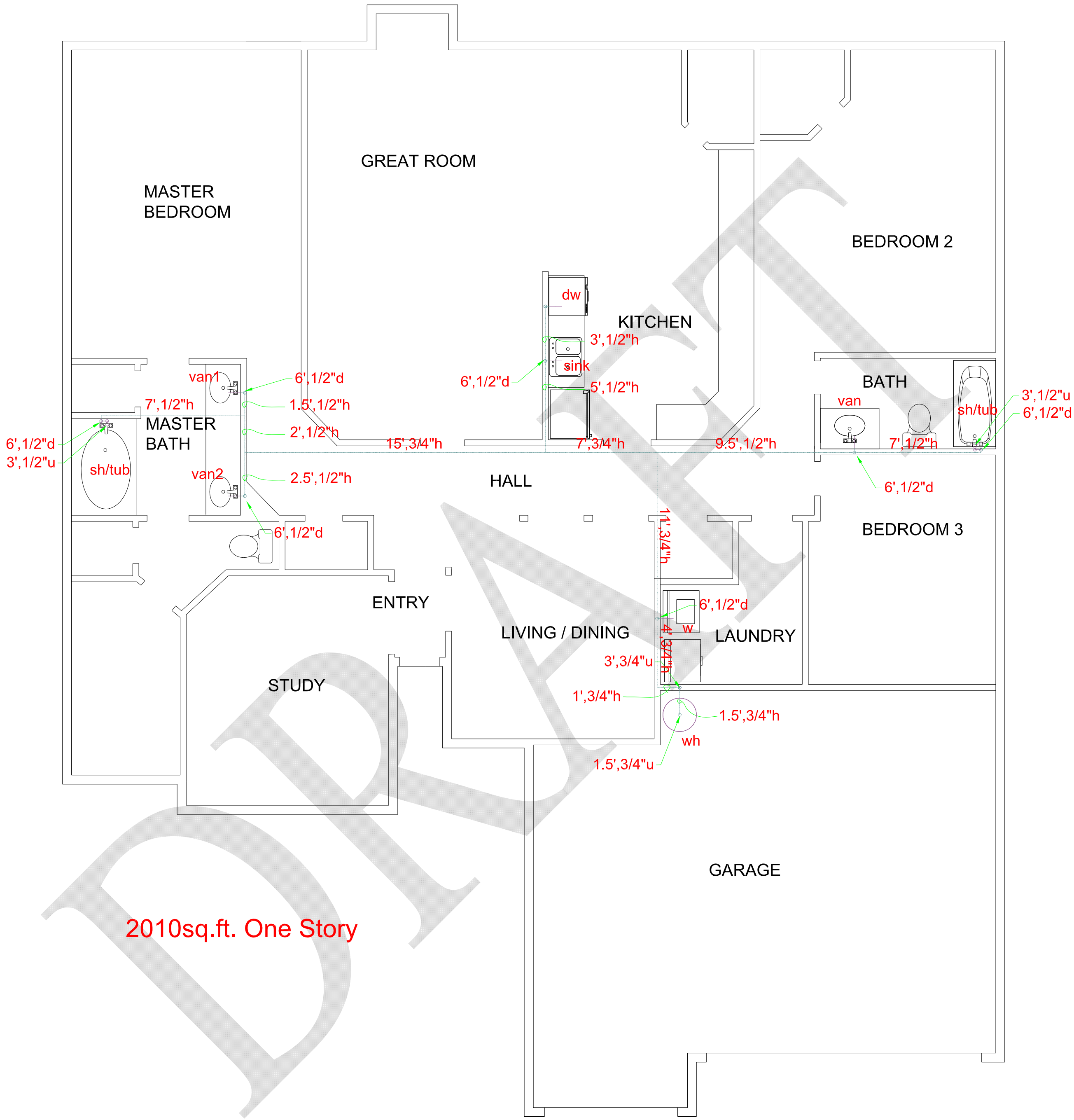
Plan Floor Area (ft^2)	Number of Stories	*Source of House Plan*
1,367	One	2006 Sixty Home Survey
2,010	One	2005 Title 24 Evaluation
3,080	One	2005 Title 24 Evaluation
1,430	Two	2006 Sixty Home Survey
2,811	Two	2005 Title 24 Evaluation
4,402	Two	2006 Sixty Home Survey

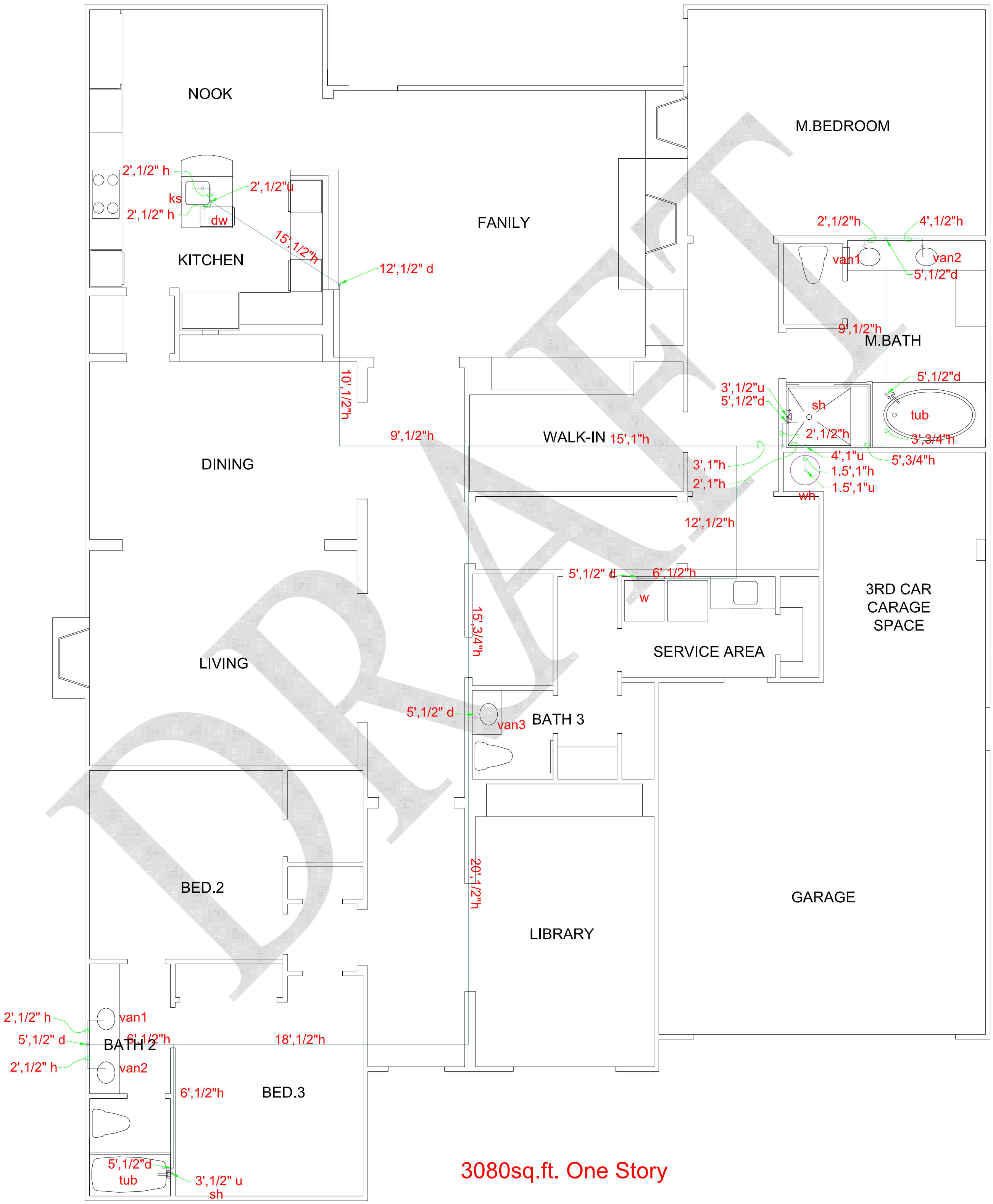
Characterization of "typical" layouts was based on volumetric data reported in the sixty home field survey (Task 2.3 project report entitled *Field Survey Report: Documentation of Hot Water Distribution Systems in Sixty New California Production Homes*). The field survey report found that the average entrained volume[16] for conventional trunk and branch plumbing systems was 0.49 gallons per 1,000 ft^2 of conditioned floor area. Using this as a goal, the attached plumbing layouts were generated. In some cases garage water heater locations were shifted to allow the resulting average volume to come in within 5% of the goal. The resulting layouts are presented in the following pages. The three single story layouts are followed by the two-story layouts that include an isometric drawing.

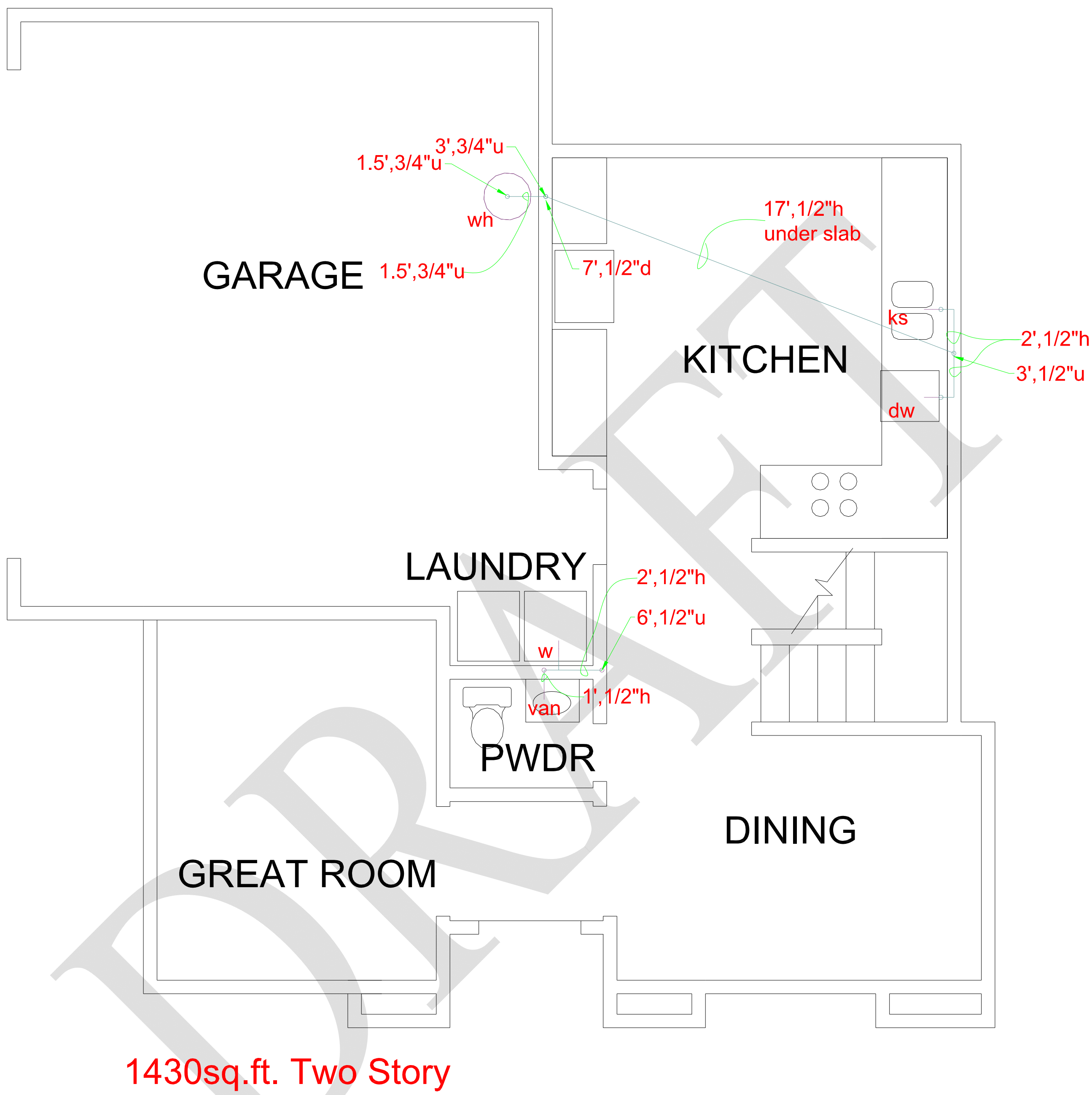
[16] between the water heater and hot water end use points

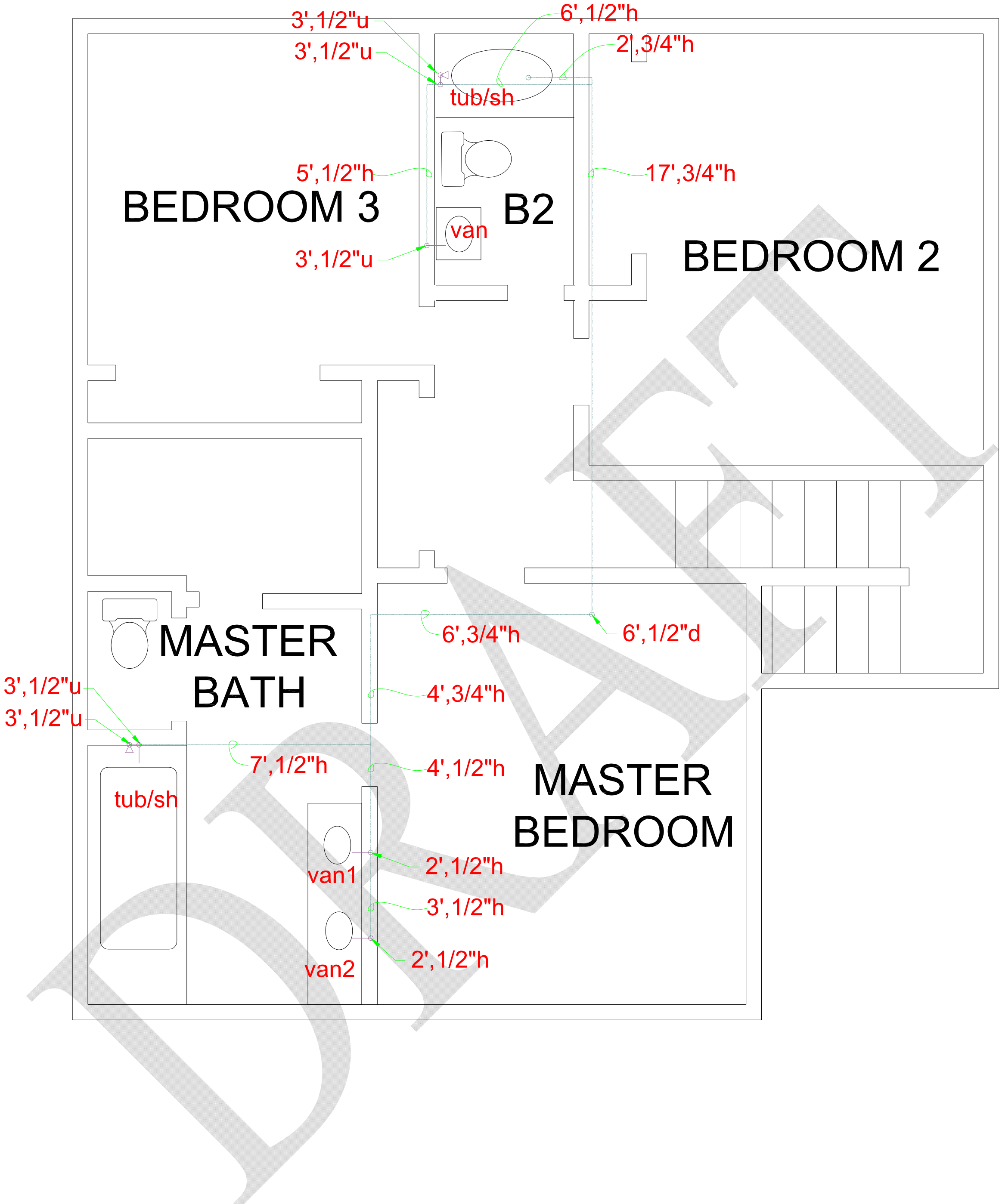


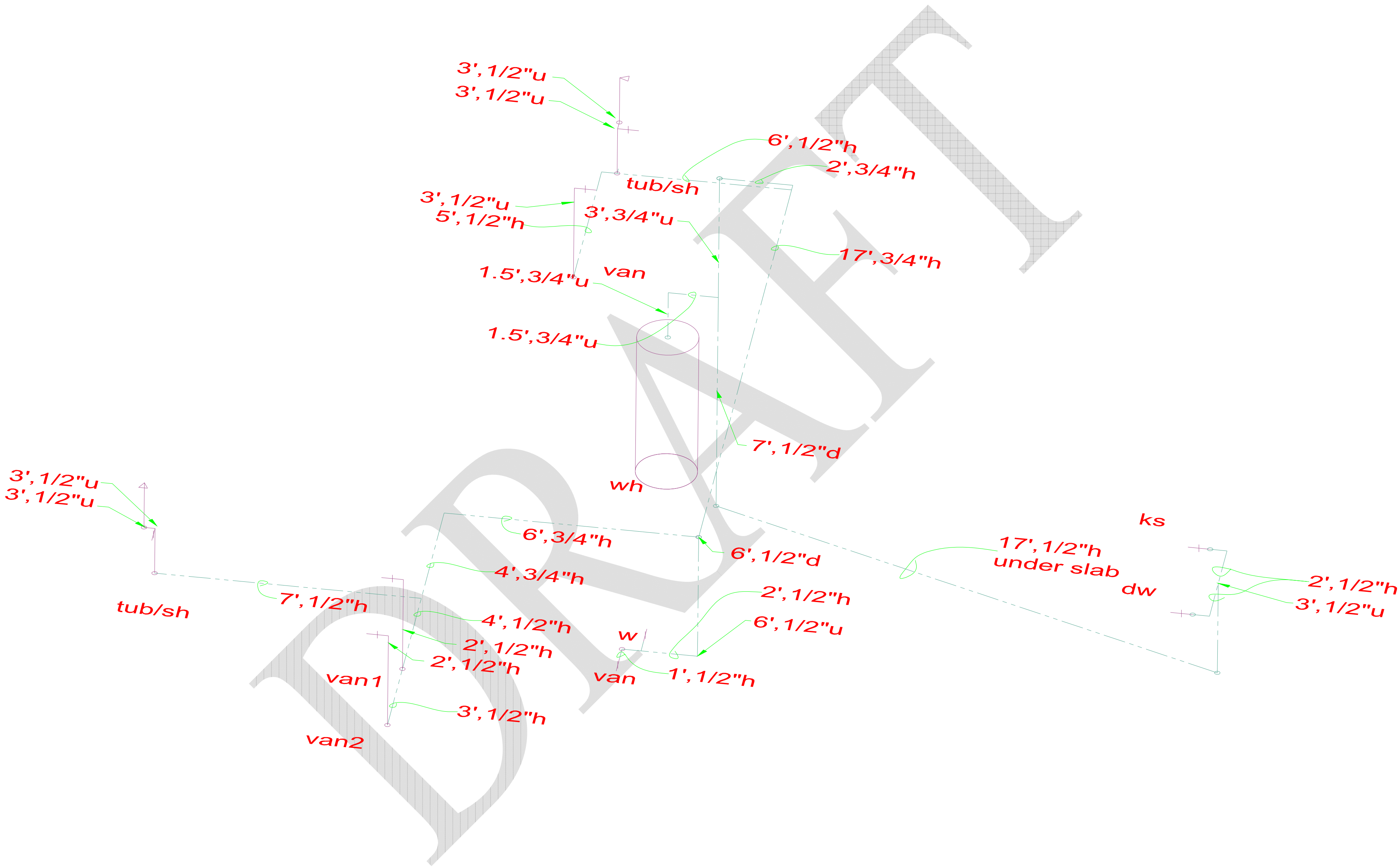
DRAFT
1.5',3/4"u
wh
3.5',3/4"h
5',1/2"h
5',1/2"d
2',1/2"h
6',1/2" d
1.5',3/4"h
12',1/2"h
dw
ks
3',3/4"u
8',3/4"h
van1
van2
2',1/2"h
2',1/2"h
KITCHEN
DINING
MASTER
BATH
MASTER
BEDROOM
3',1/2"u
8',1/2"h
sh
tub
5',1/2"d
6',1/2"d
LAUNDRY
7',3/4"h
w
5',1/2"h
1',1/2"h
LIVING
ROOM
5',1/2" d
3',1/2"h
5',1/2" d
van
B2
BEDROOM 2
7',1/2"h
BEDROOM 3
3',1/2"u
sh/tub
5',1/2"d
1367sq.ft. One Story

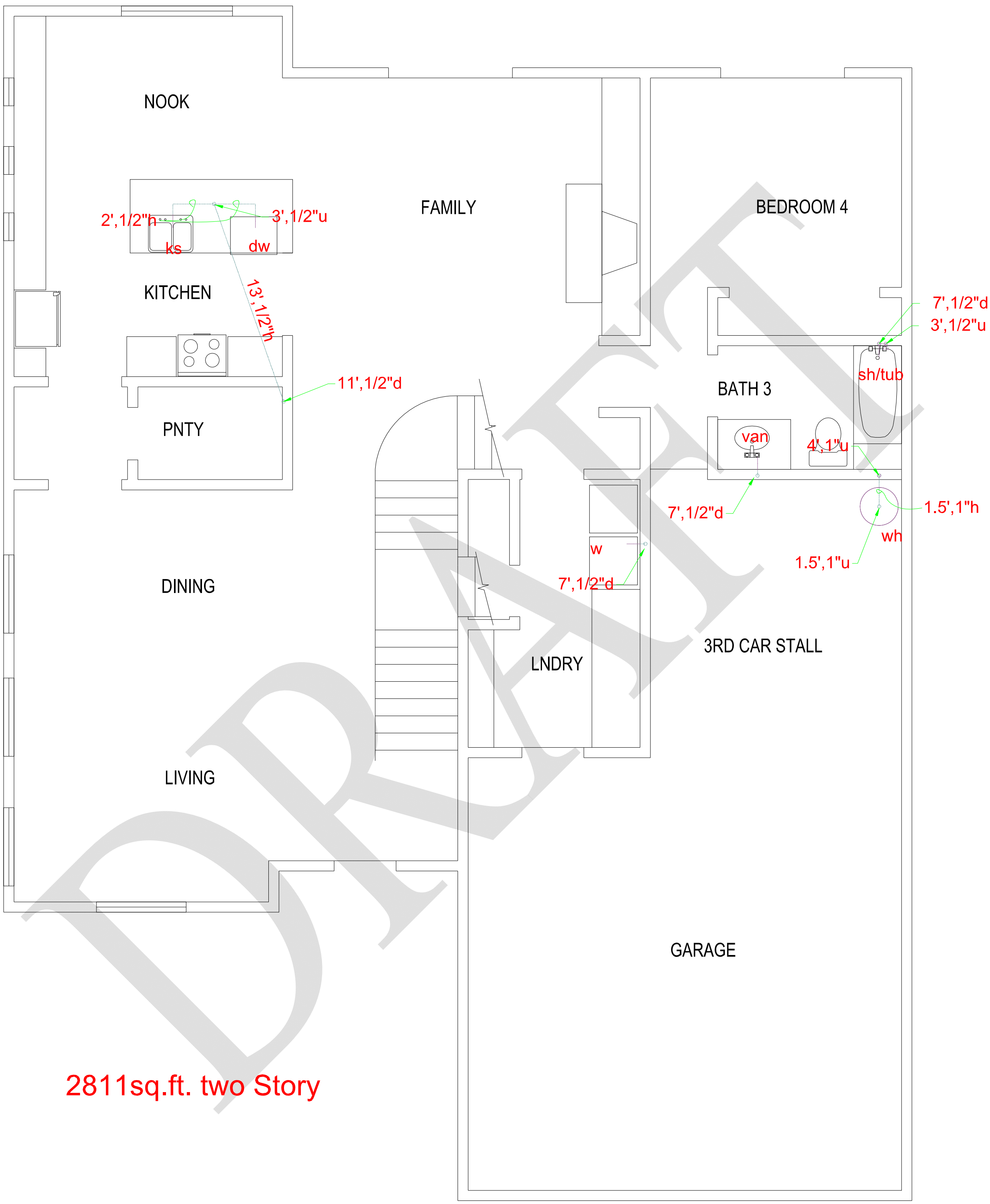

GREAT ROOM
MASTER BEDROOM
BEDROOM 2
KITCHEN
dw
3',1/2"h
sink
5',1/2"h
6',1/2"d
van1
6',1/2"d
7',1/2"h
1.5',1/2"h
MASTER BATH
2',1/2"h
15',3/4"h
7',3/4"h
9.5',1/2"h
BATH
van
sh/tub
3',1/2"u
6',1/2"d
7',1/2"h
6',1/2"d
3',1/2"u
sh/tub
van2
2.5',1/2"h
HALL
6',1/2"d
6',1/2"d
BEDROOM 3
11',3/4"h
6',1/2"d
ENTRY
LIVING / DINING
w
LAUNDRY
3',3/4"u
4',3/4"h
STUDY
1',3/4"h
1.5',3/4"h
wh
1.5',3/4"u
GARAGE
2010sq.ft. One Story


NOOK
KITCHEN
FANILY
M.BEDROOM
M.BATH
WALK-IN
DINING
LIVING
SERVICE AREA
3RD CAR CARAGE SPACE
BATH 3
BED.2
LIBRARY
GARAGE
BATH 2
BED.3
ks
dw
van1
van2
van3
sh
tub
wh
w
2',1/2" h
2',1/2"u
15',1/2"h
12',1/2" d
10',1/2"h
9',1/2"h
15',1"h
2',1/2"h
4',1/2"h
5',1/2"d
9',1/2"h
3',1/2"u
5',1/2"d
3',3/4"h
5',3/4"h
4',1"u
1.5',1"h
1.5',1"u
3',1"h
2',1"h
12',1/2"h
5',1/2" d
6',1/2"h
15',3/4"h
20',1/2"h
18',1/2"h
6',1/2"h
5',1/2" d
3',1/2" u
DRAFT
3080sq.ft. One Story

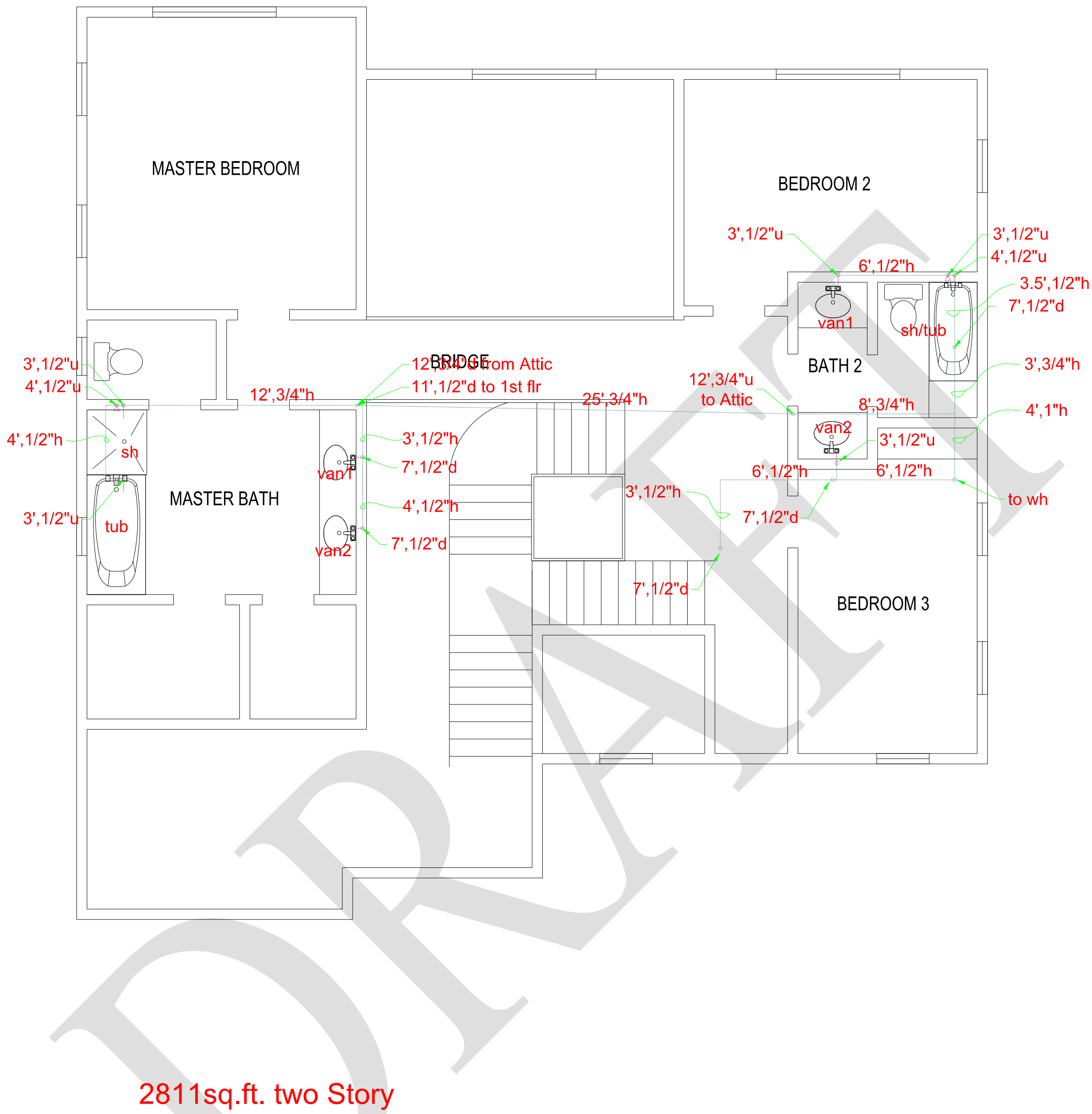

GARAGE
1.5',3/4"u
3',3/4"u
wh
1.5',3/4"u
7',1/2"d
17',1/2"h
under slab
KITCHEN
ks
2',1/2"h
3',1/2"u
dw
LAUNDRY
2',1/2"h
6',1/2"u
w
van
1',1/2"h
PWDR
DINING
GREAT ROOM
1430sq.ft. Two Story

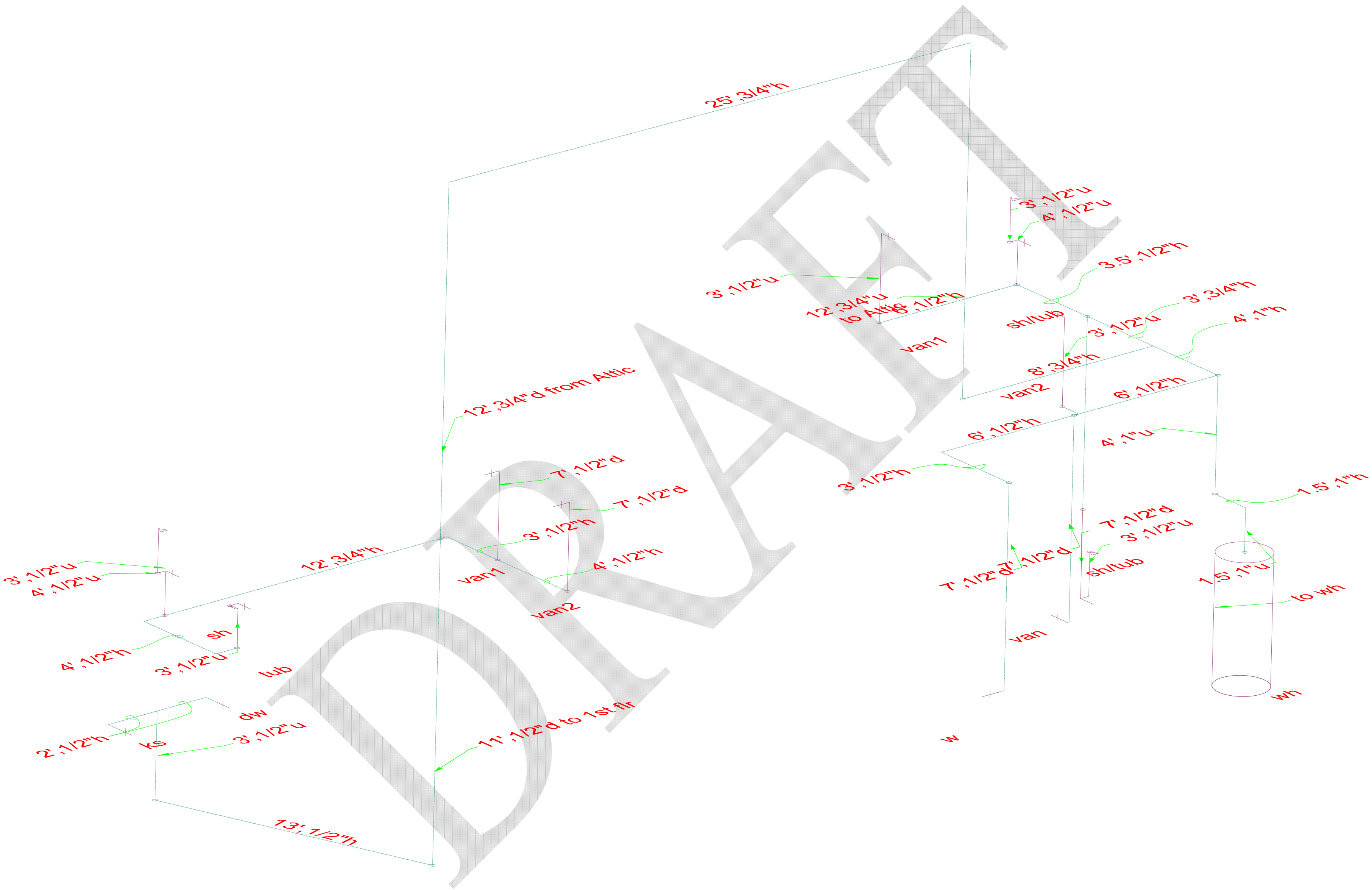

3',1/2"u
3',1/2"u
6',1/2"h
2',3/4"h
tub/sh
5',1/2"h
17',3/4"h
BEDROOM 3
B2
van
3',1/2"u
BEDROOM 2
MASTER
BATH
6',3/4"h
6',1/2"d
3',1/2"u
3',1/2"u
4',3/4"h
7',1/2"h
4',1/2"h
tub/sh
MASTER
BEDROOM
van1
2',1/2"h
3',1/2"h
van2
2',1/2"h
DRAFT

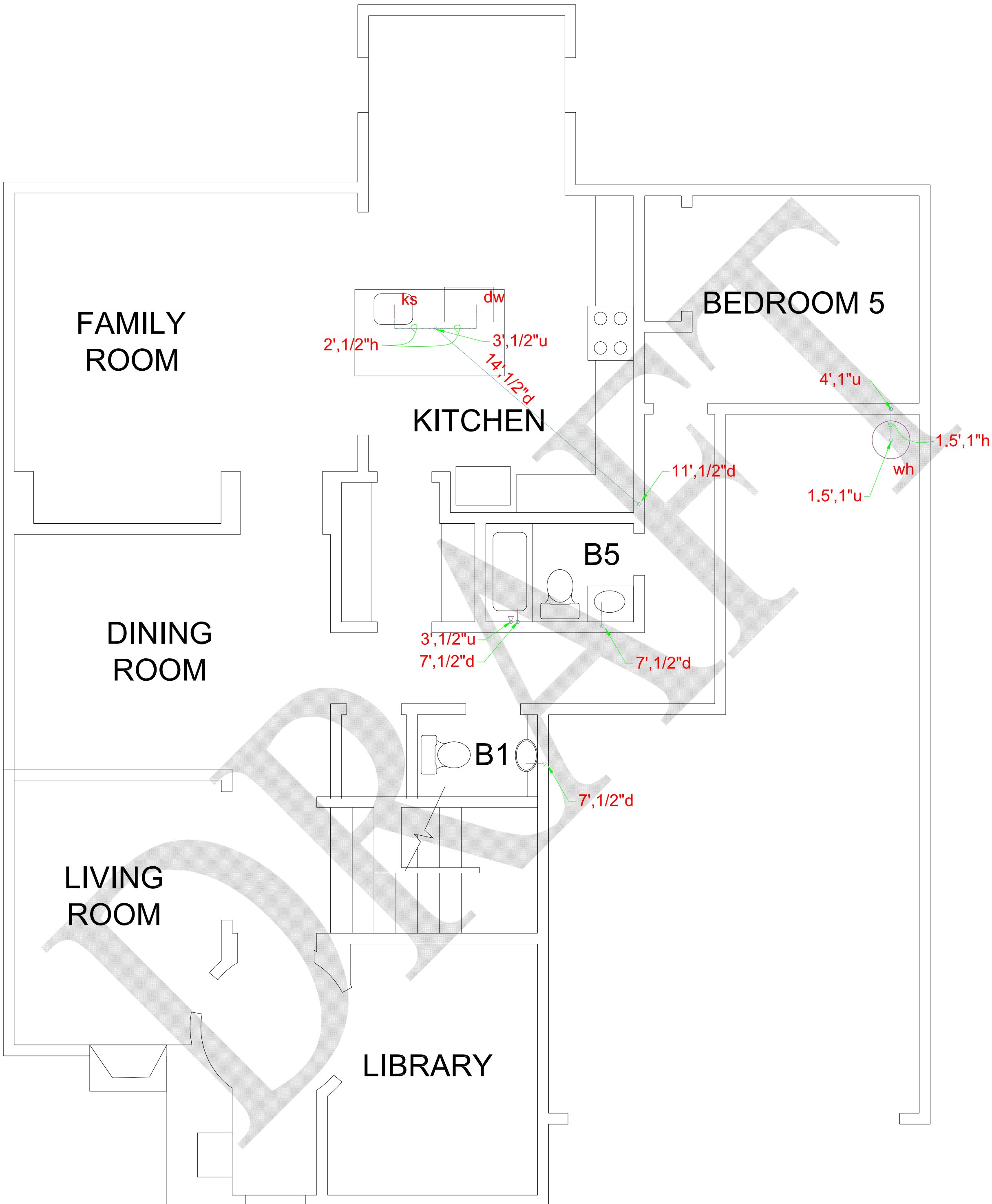

3',1/2"u
3',1/2"u
6',1/2"h
2',3/4"h
tub/sh
3',1/2"u
5',1/2"h
3',3/4"u
17',3/4"h
1.5',3/4"u
van
1.5',3/4"u
7',1/2"d
wh
3',1/2"u
3',1/2"u
ks
6',3/4"h
6',1/2"d
17',1/2"h
under slab
4',3/4"h
2',1/2"h
dw
tub/sh
7',1/2"h
2',1/2"h
3',1/2"u
6',1/2"u
4',1/2"h
2',1/2"h
w
2',1/2"h
van1
van
1',1/2"h
3',1/2"h
van2
DRAFT



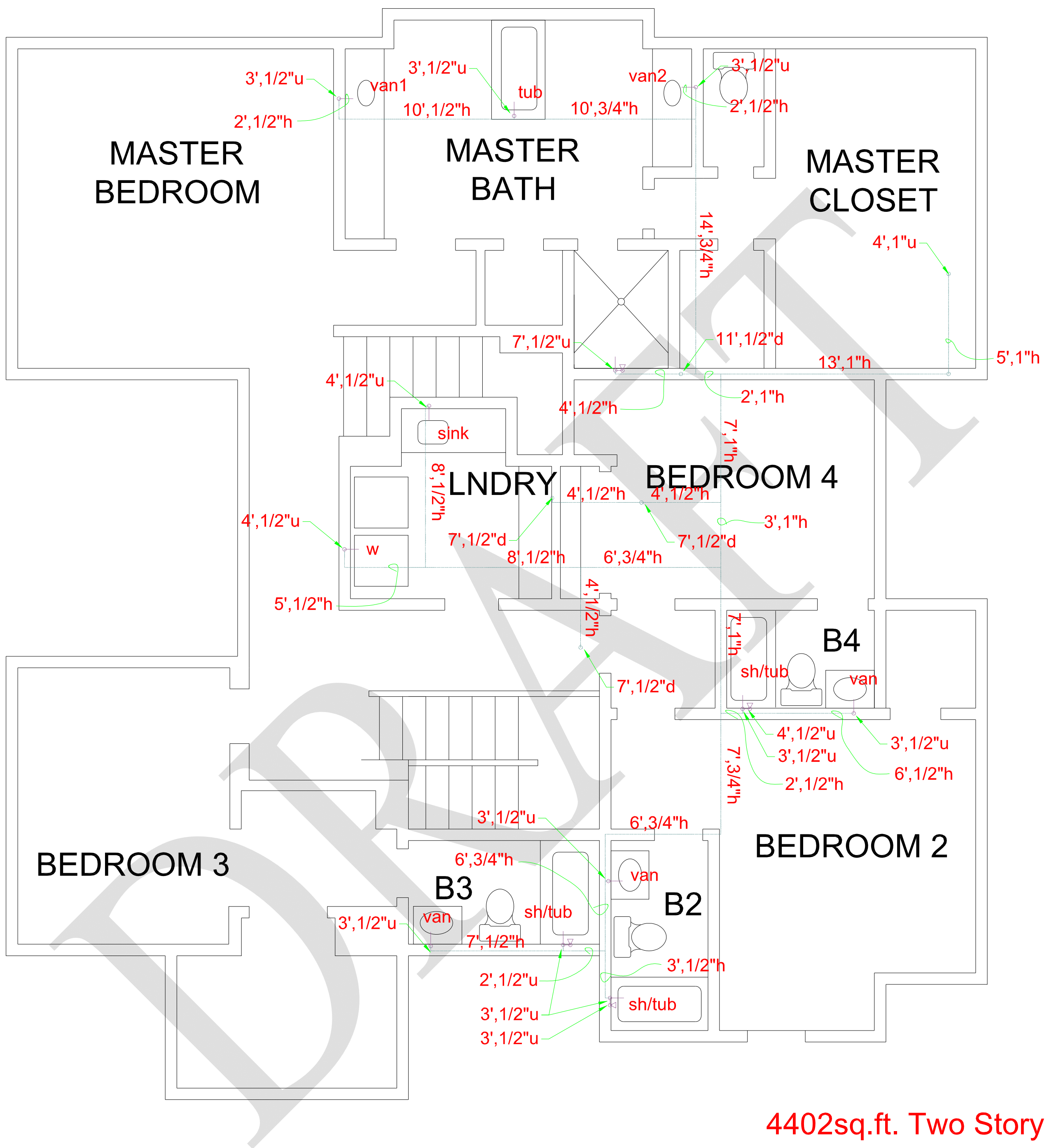
2811sq.ft. two Story


MASTER BEDROOM
BEDROOM 2
BRIDGE
BATH 2
MASTER BATH
BEDROOM 3
3',1/2"u
4',1/2"u
4',1/2"h
sh
3',1/2"u
tub
12',3/4"h
12',3/4"u from Attic
11',1/2"d to 1st flr
3',1/2"h
van1
7',1/2"d
4',1/2"h
van2
7',1/2"d
25',3/4"h
12',3/4"u
to Attic
3',1/2"u
6',1/2"h
van1
sh/tub
3',1/2"u
4',1/2"u
3.5',1/2"h
7',1/2"d
3',3/4"h
8',3/4"h
van2
4',1"h
3',1/2"u
6',1/2"h
6',1/2"h
to wh
3',1/2"h
7',1/2"d
7',1/2"d
2811sq.ft. two Story


25' ,3/4"h
12' ,3/4"d from Attic
11' ,1/2"d to 1st flr
12' ,3/4"h
13' ,1/2"h
van1
van2
sh/tub
wh
to wh
DRAFT



4402sq.ft. Two Story



4402sq.ft. Two Story