

# How Low Can We Go? How Close Can We Get?

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*Summary of Water-Energy  
Research for the  
California Energy Commission*

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# Acknowledgements

Code Changes and Implications of Residential  
Low Flow Hot Water Fixtures

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California Energy Commission

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# Background

1. Plumbing fixture flow rates, flush volumes and appliance fill volumes have been reduced every decade since the 1950s.
2. Pipe sizing rules have not been revisited since written down in the 1940s.
3. The median square footage of a house is roughly 1.5 times larger than it was in 1970.

## Result:

1. it takes much longer than it used to for hot water to arrive.
2. More energy is lost when the pipes cool down.
3. Dissatisfied occupants
4. Potentially unsafe conditions in the piping network

# Water Consumption 1980-2017

Water-using Fixture or Appliance	1980s Water Use (typical)	1990 Requirement (maximum)	EPAct 1992 Requirement (maximum)	2009 Baseline Plumbing Code (maximum)	"Green Code" Maximums (2017 CALGreen)	% Reduction in avg water use since 1980s
<b>Residential Bathroom Lavatory Faucet</b>	3.5+ gpm	2.5 gpm	2.2 gpm	2.2 gpm	1.2 gpm	66%
<b>Showerhead</b>	3.5+ gpm	3.5 gpm	2.5 gpm	2.5 gpm	1.8 gpm	49%
<b>Residential ("private") Toilet</b>	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
<b>Commercial ("public") Toilet</b>	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
<b>Urinal</b>	1.5 to 3.0+ gpf	1.5 to 3.0+ gpf	1.0 gpf	1.0 gpf	0.125 gpf	96%
<b>Commercial Lavatory Faucet</b>	3.5+ gpm	2.5 gpm	2.2 gpm	0.5 gpm	0.5 gpm	86%
<b>Food Service Pre-Rinse Spray Valve</b>	5.0+ gpm	No requirement	1.6 gpm (EPAct 2005)	No requirement	1.3 gpm	74%
<b>Residential Clothes Washing Machine</b>	51 gallons per load	No requirement	26 gallons per load (2012 std)	No requirement	12.6 gallons per load (Energy Star)	75%
<b>Residential Dishwasher</b>	14 gallons per cycle	No requirement	6.5 gallons per cycle (2012 std)	No requirement	3.5 gallons per cycle (Energy Star)	75%

**From 1980 to 2017: Reductions range from 49 to 96%**

# Relevant Codes and Standards

Appliance and Equipment Standards

Health Codes

Plumbing Codes

Energy Codes and Standards

Green Codes and Standards

Design Guides

Standards of Practice

Anything else?

*Unintended consequences due to separate development!*

# Agreement Goals

1. Develop code change recommendations based on comprehensive assessment of technical, economic, and market feasibility improvement strategies that can significantly increase hot water distribution system efficiency in new construction and existing buildings;
2. Characterize the impact of low flow fixtures on distribution system performance and determine the theoretical lowest flow possible for hot water fixtures.

# Ratepayer Benefits

This Agreement could result in the ratepayer benefits of annual savings of 4.6 million therms of natural gas, 7 million gallons of water, and \$4.6 million of utility bill reduction in 2030. The estimated savings and associated emission reductions are 24,500 metric tons of CO<sub>2</sub>e and 5,600 kg of NO<sub>x</sub>. These savings are projected from 2020 to 2030 based on improving Title 24 Building Standards on DHW systems in low-rise residential homes.

This is a low estimate of the potential savings.

# *How Close Can We Get?*

Analysis of Architectural Compactness

# New Single-Family Homes Completed in 2017

Median Home Size in Western United States  
-2,398 sq ft

Average Home Size in Western United States  
-2,548 sq ft

6% under 1,400

15% 1,400 to 1,799

29% 1,800 to 2,399

25% 2,400 to 2,999

17% 3,000 to ,3,999

8% 4,000 or more

(Source: United States Census Bureau)

# New Multi-Family Units Completed in 2017

Median Unit Size in Western United States  
-1,045 sq ft

Average Unit Size in Western United States  
-1,088 sq ft

42% under 1,000

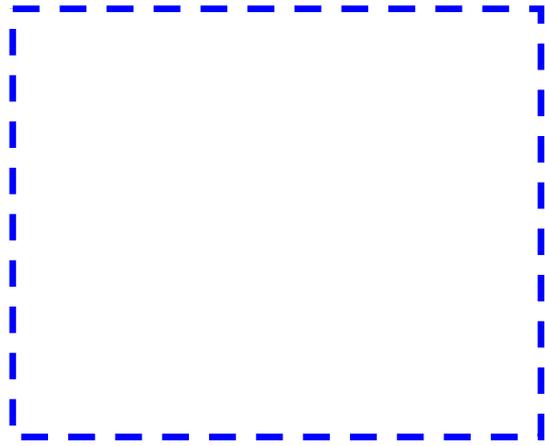
31% 1,000 to 1,199

15% 1,200 to 1,399

9% 1,400 to 1,799

4% 1,800 or more

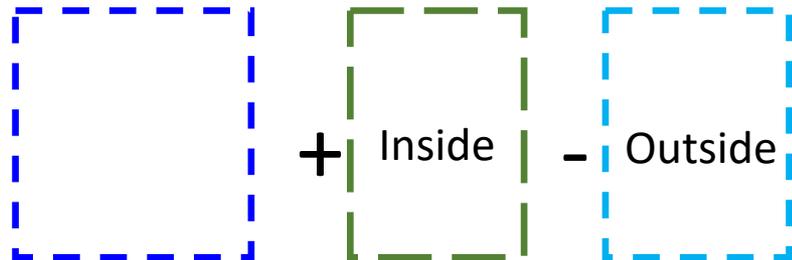
(Source: United States Census Bureau)



= Wet Room Rectangle

Ratio in Percent: Wet Room Rectangle/Floor Area x 100%

Use the dimensions available on the floor plan when available. Otherwise, determine the areas based on the formula below. The dimensions come from the drawing program.



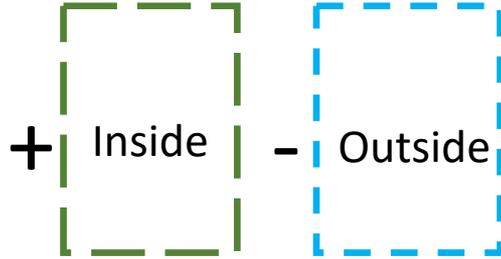
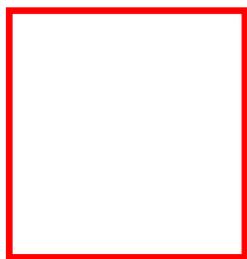
= Home Floor Area



= Hot Water System Rectangle

Ratio in Percent: Hot Water System Rectangle/Floor Area x 100%

Use the dimensions available on the floor plan when available. Otherwise, determine the areas based on the formula below. The dimensions come from the drawing program.



= Home Floor Area

Example:

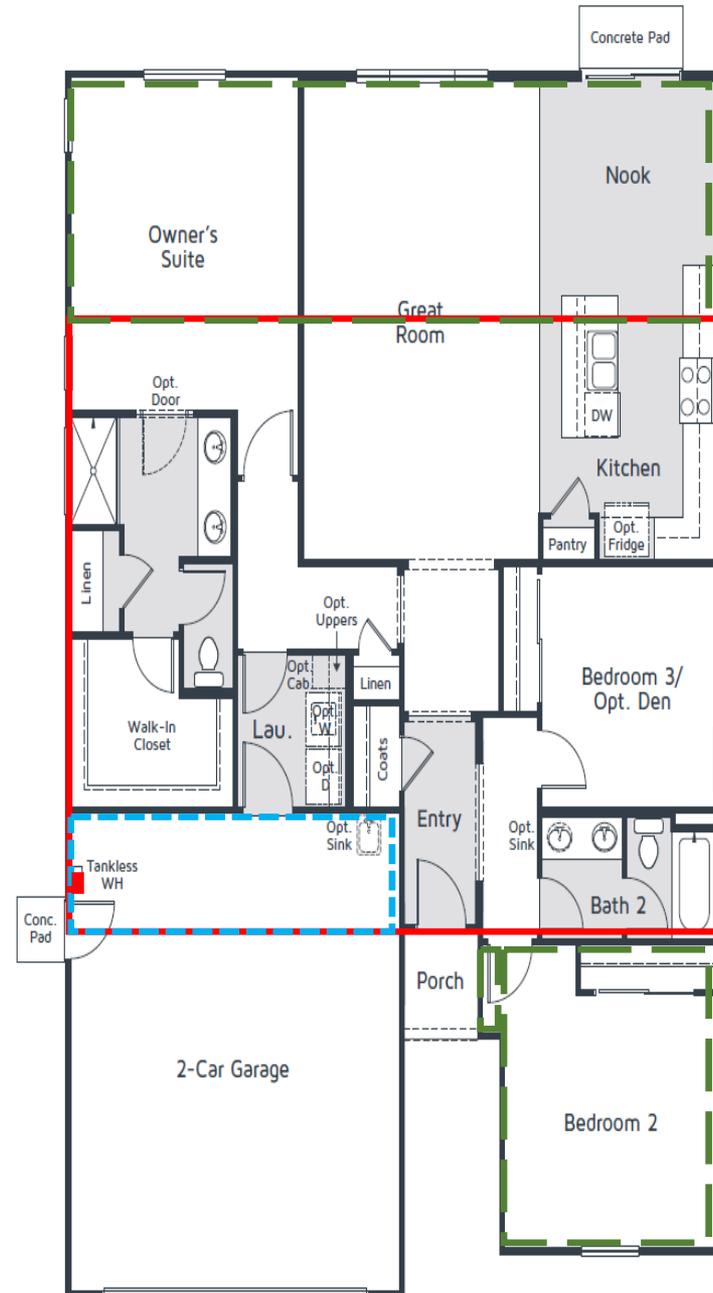
1 Story

3Br/2Ba

1,697 sq ft

Fresno, CA

~67% (1137 sq ft)



# Relationship between the Hot Water System and the Floor Area – The Logical Worst Case

Number of Stories	Hot Water System/ Floor Area (%)
1-story	100%
2-story	50%
3-story	33.3%
4-story	25%
5-story	20%

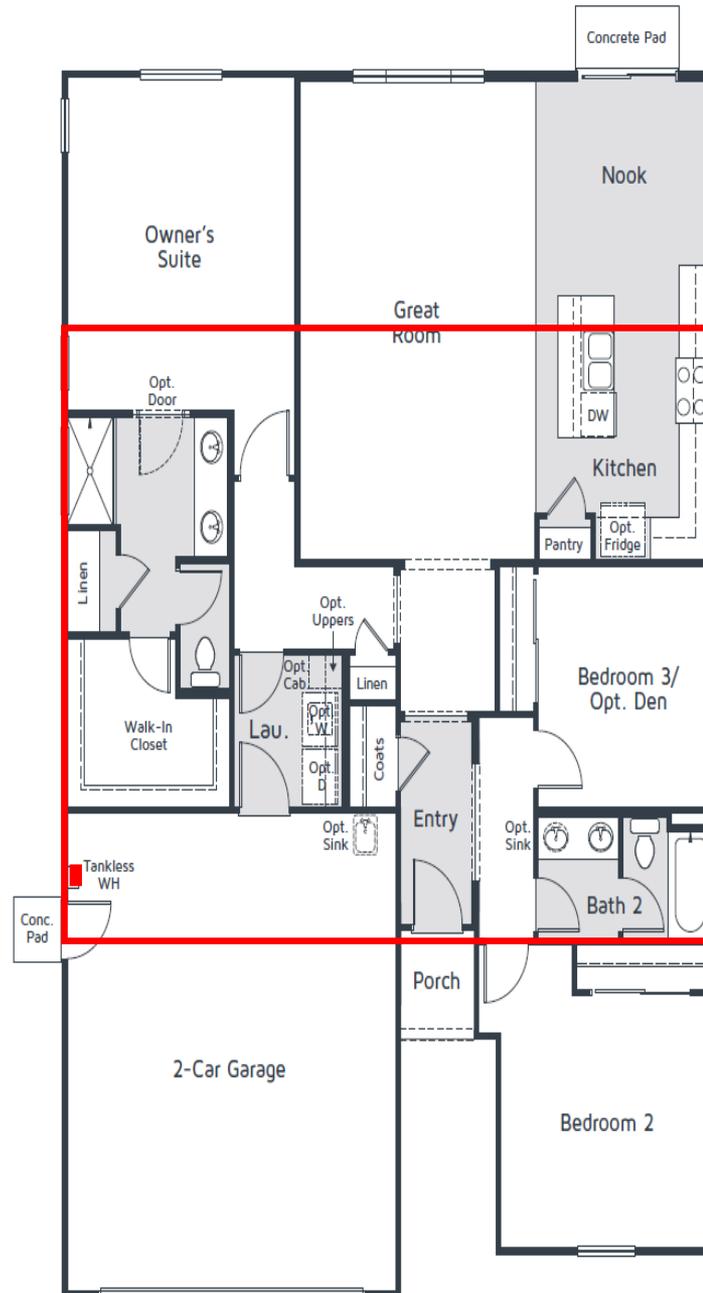
Basements count as stories if they contain wet rooms.

# 1-Story Floor Plans

- The wet room rectangle has the same area as the hot water system rectangle for all of the 1-story homes in this sample.

1 Story  
3Br/2Ba  
1,697 sq ft  
Fresno, CA

~67%  
(1,137 sq ft)



1 Story  
3Br/2.5Ba  
2,466 sq ft  
Roseville, CA

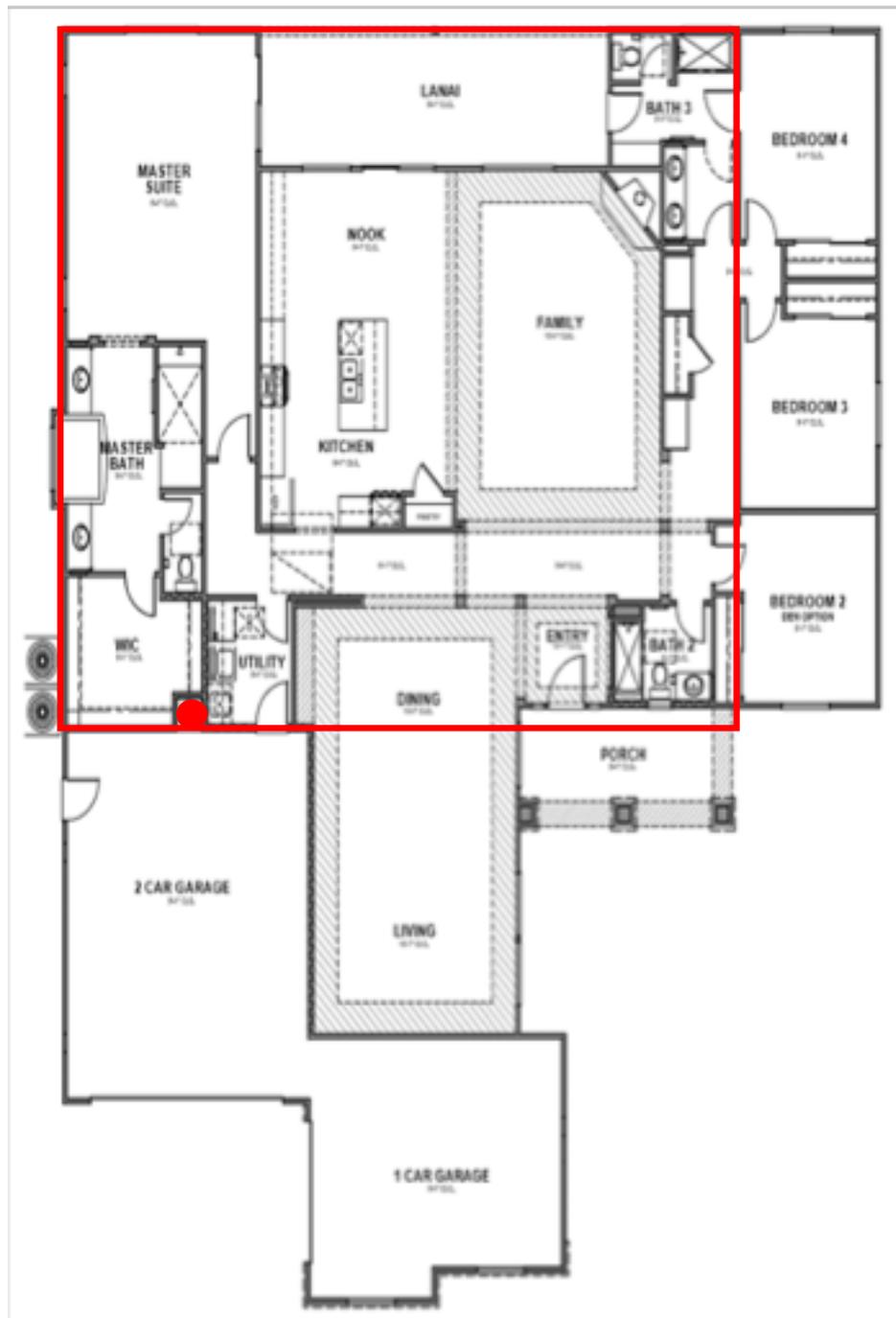
~75%  
(1,835 sq ft)



FLOOR PLAN

1 Story  
4Br/3Ba  
3,073 sq ft  
Chico, CA

~80%  
(2,459 sq ft)



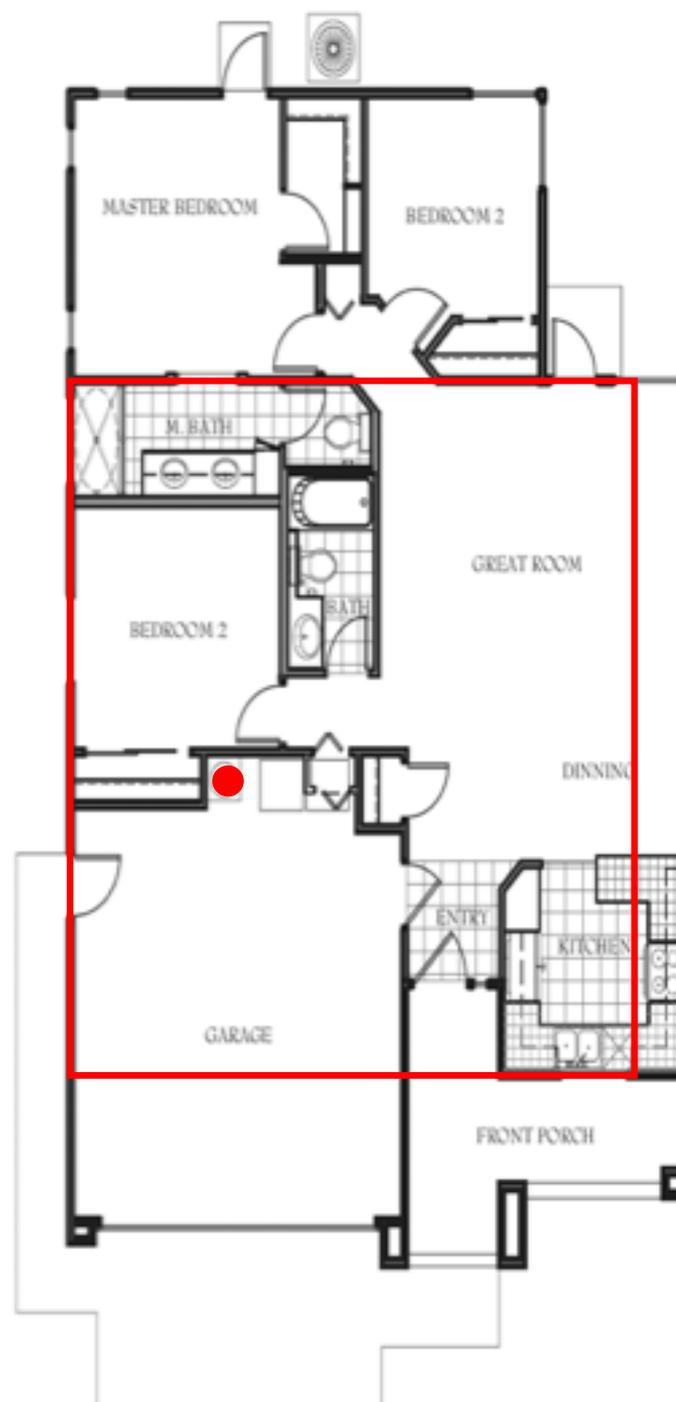
1 Story  
4Br/2Ba  
2,010 sq ft  
Fresno, CA

~81%  
(1,628 sq ft)



1 Story  
2 Br/2 Ba  
1,224 sq ft  
Chico, CA

~88%  
(1,077 sq ft)



1 Story  
4Br/3.5Ba  
2,952 sq ft  
Morgan Hill, CA

~105%  
(3,100 sq ft)





1 Story  
5 Br/5.5Ba  
4,467 sq ft  
San Diego, CA

~155%  
(6,924 sq ft)

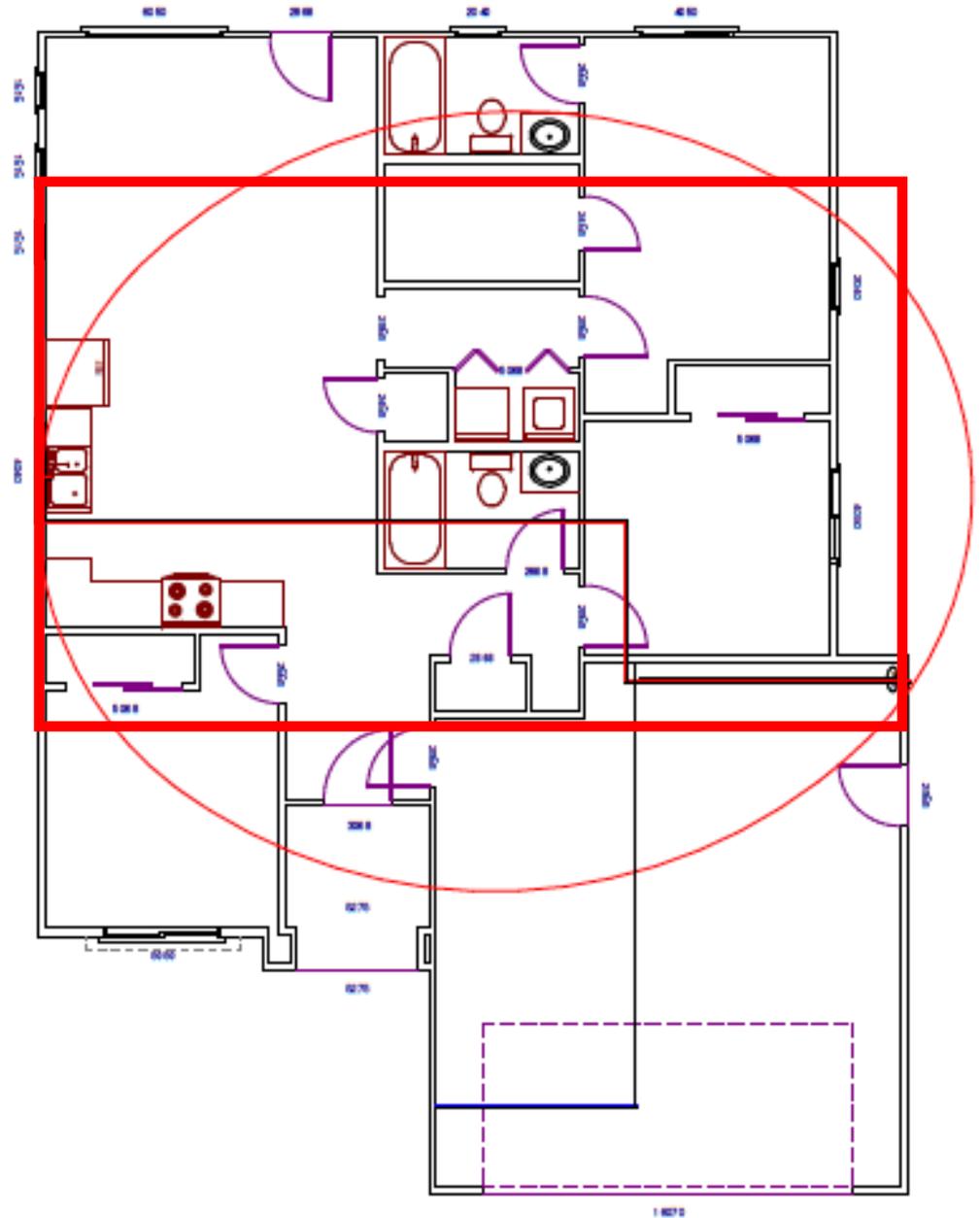


**Best 1-Story So Far...**

*In the beginning:*

1 Story  
3 Br/2 Ba  
1,619 sq ft  
Stockton, CA

~79%  
(1,279 sq ft)



# 1<sup>st</sup> iteration v1:

1 Story

3 Br/2 Ba

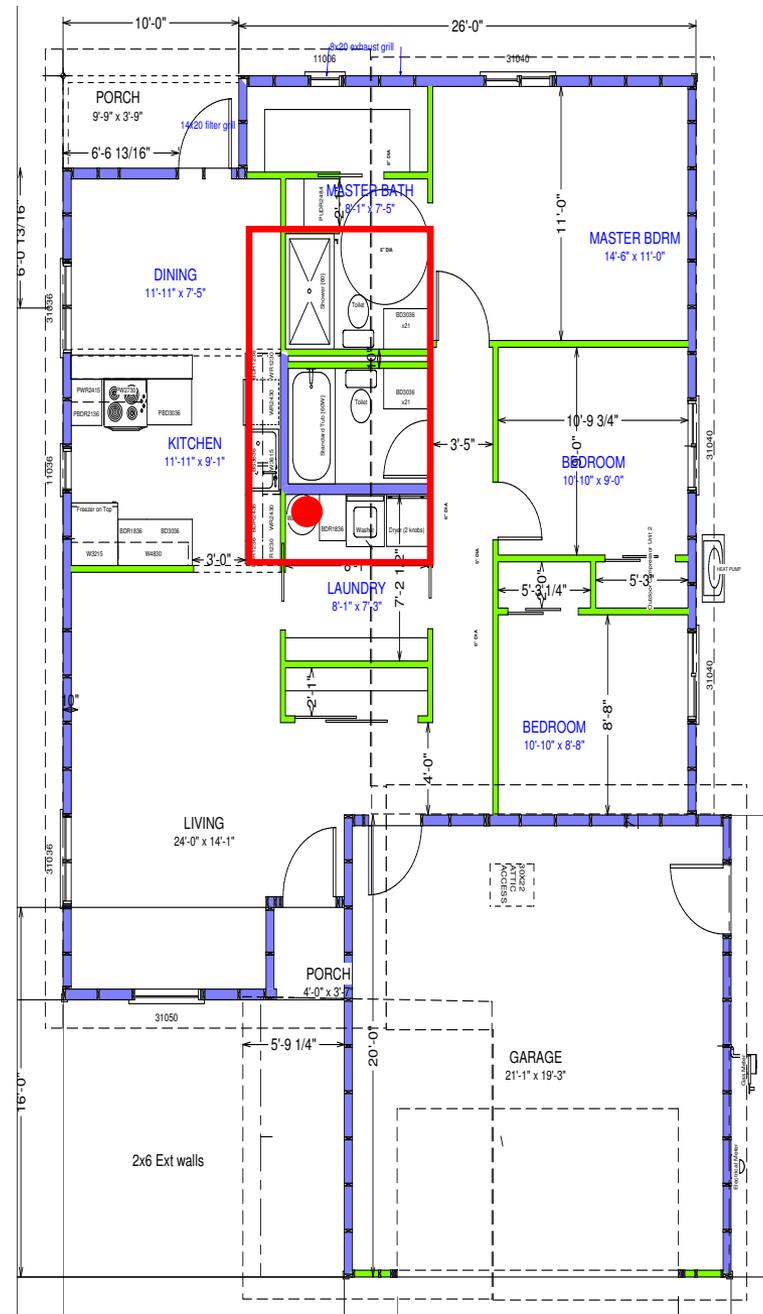
1,223 sq ft

Stockton, CA

~15%

(183 sq ft)

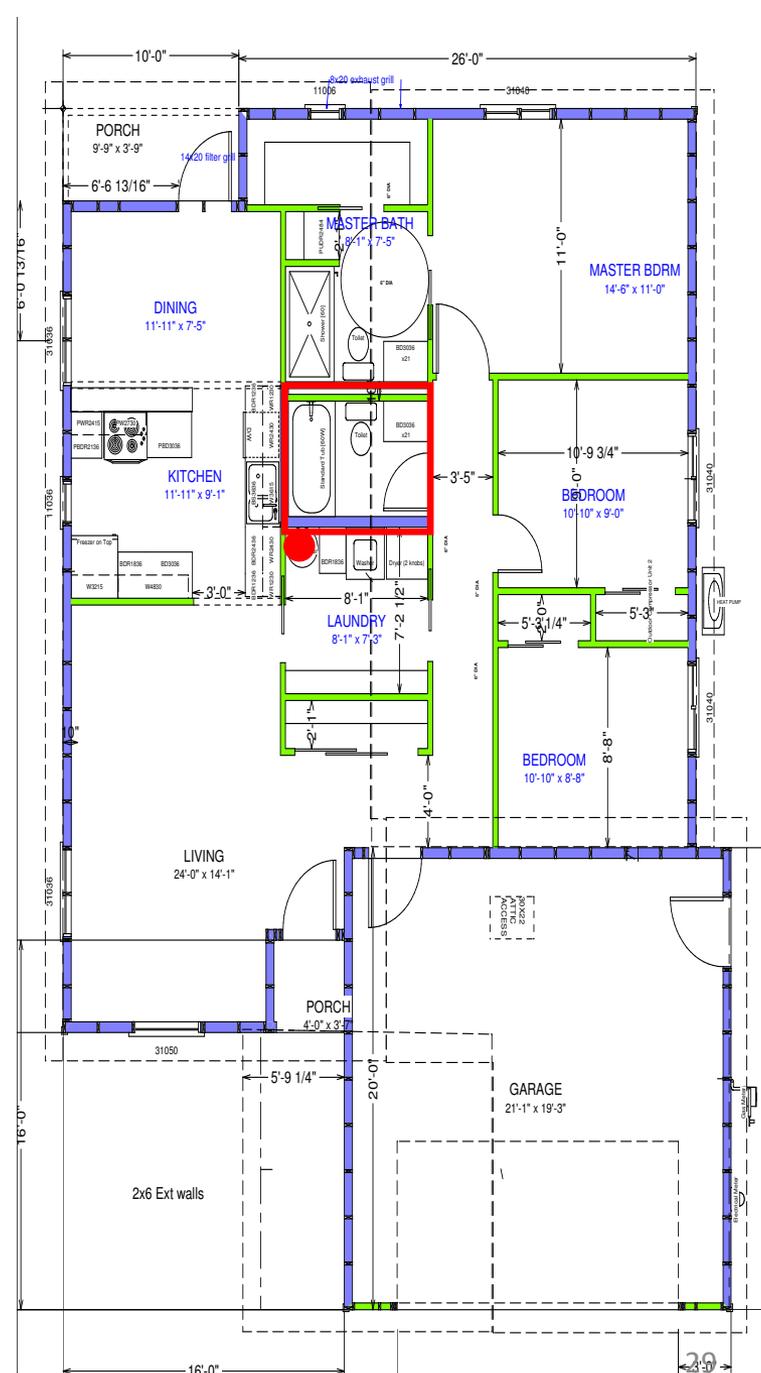
(when bounding the hot water plumbing fixtures and appliances)



# 1<sup>st</sup> iteration v2:

1 Story  
3 Br/2 Ba  
1,223 sq ft  
Stockton, CA

~4%  
(49 sq ft)  
(when bounding the  
plumbing walls)



## 2<sup>nd</sup> iteration:

1 Story  
3 Br/2 Ba  
1,223 sq ft  
Stockton, CA

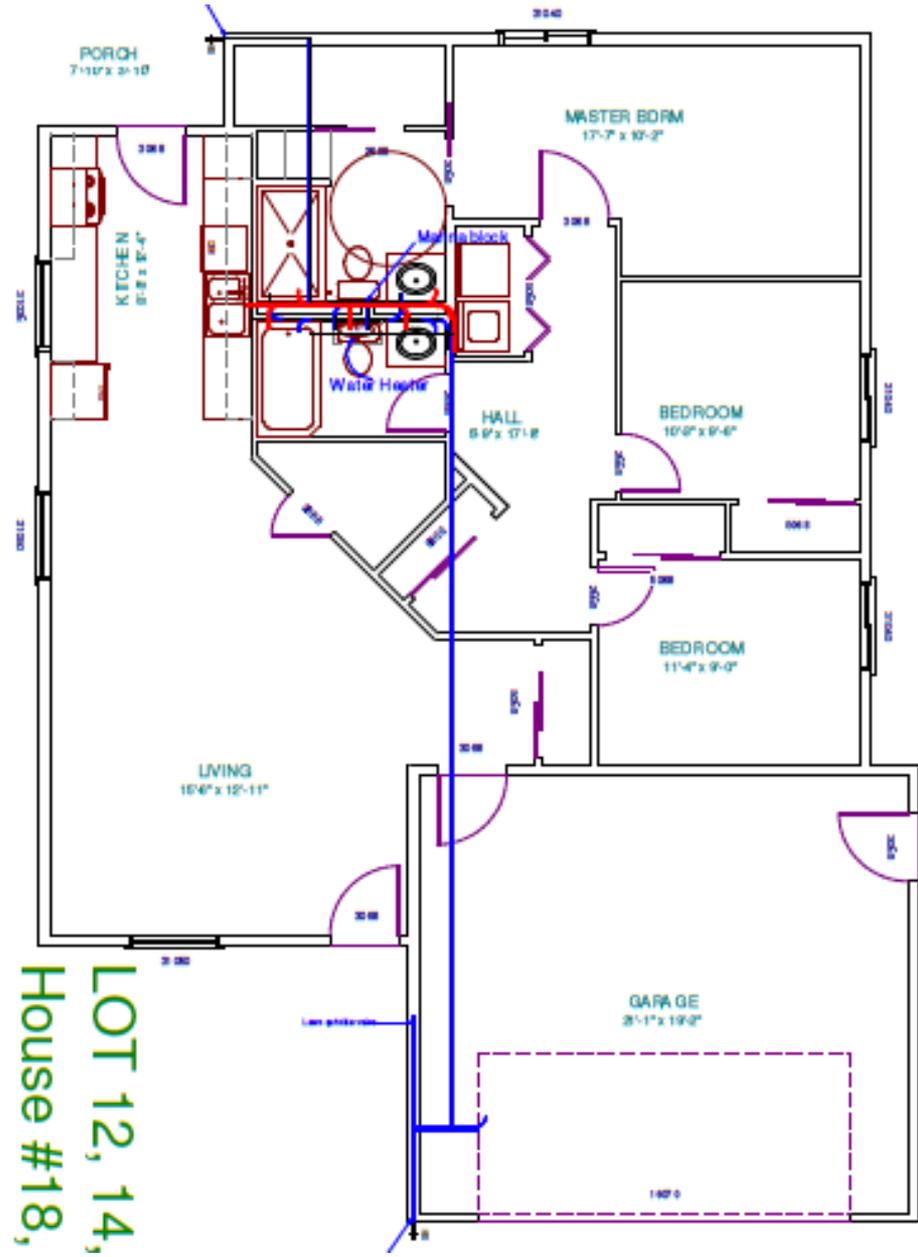
~2.5%  
(30 sq ft)  
(when bounding the  
plumbing walls)



3<sup>rd</sup> iteration:

1 Story  
3 Br/2 Ba  
1,245 sq ft  
Stockton, CA

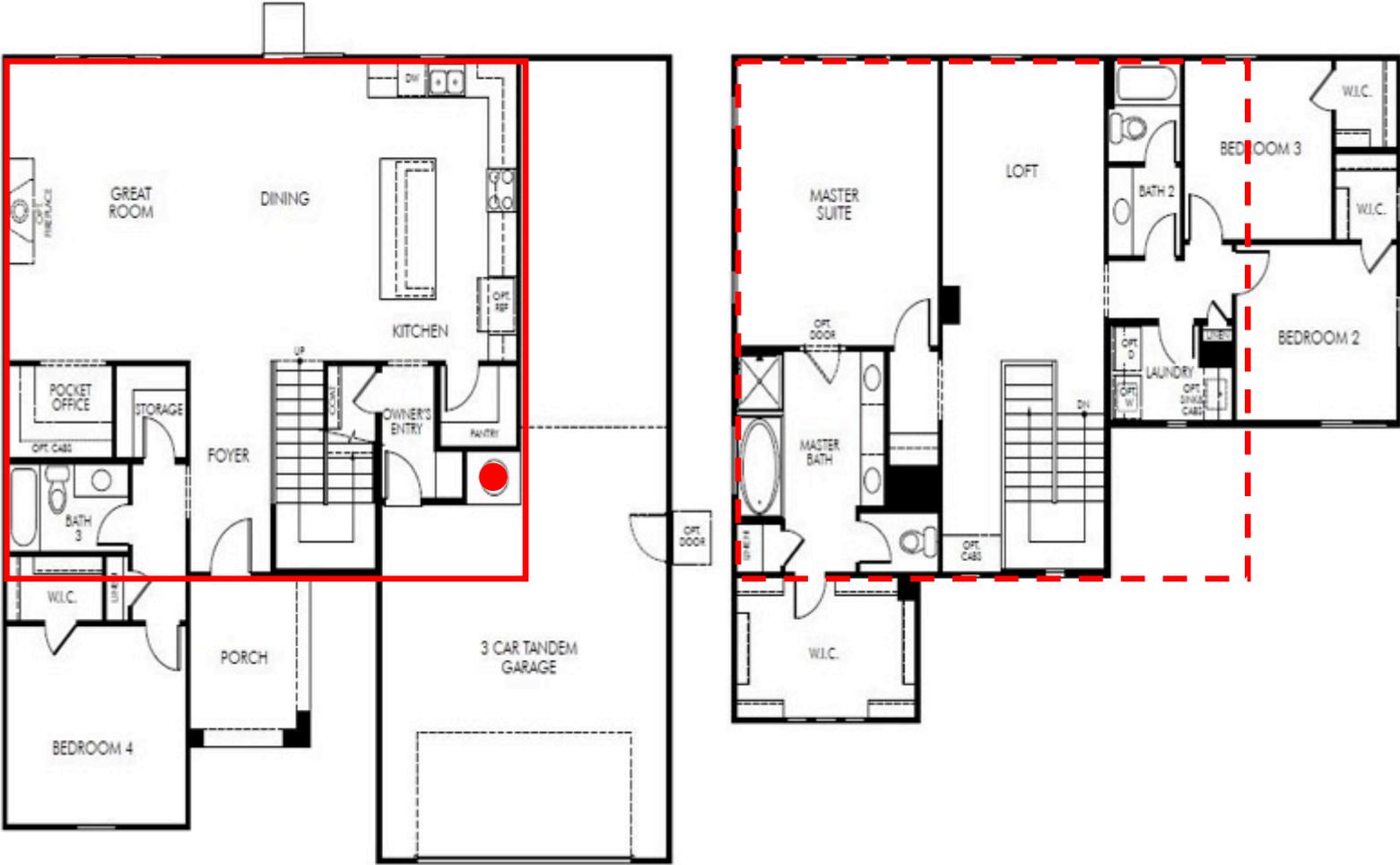
~0.8%  
( $< 10$  sq ft)  
(1 short plumbing wall)



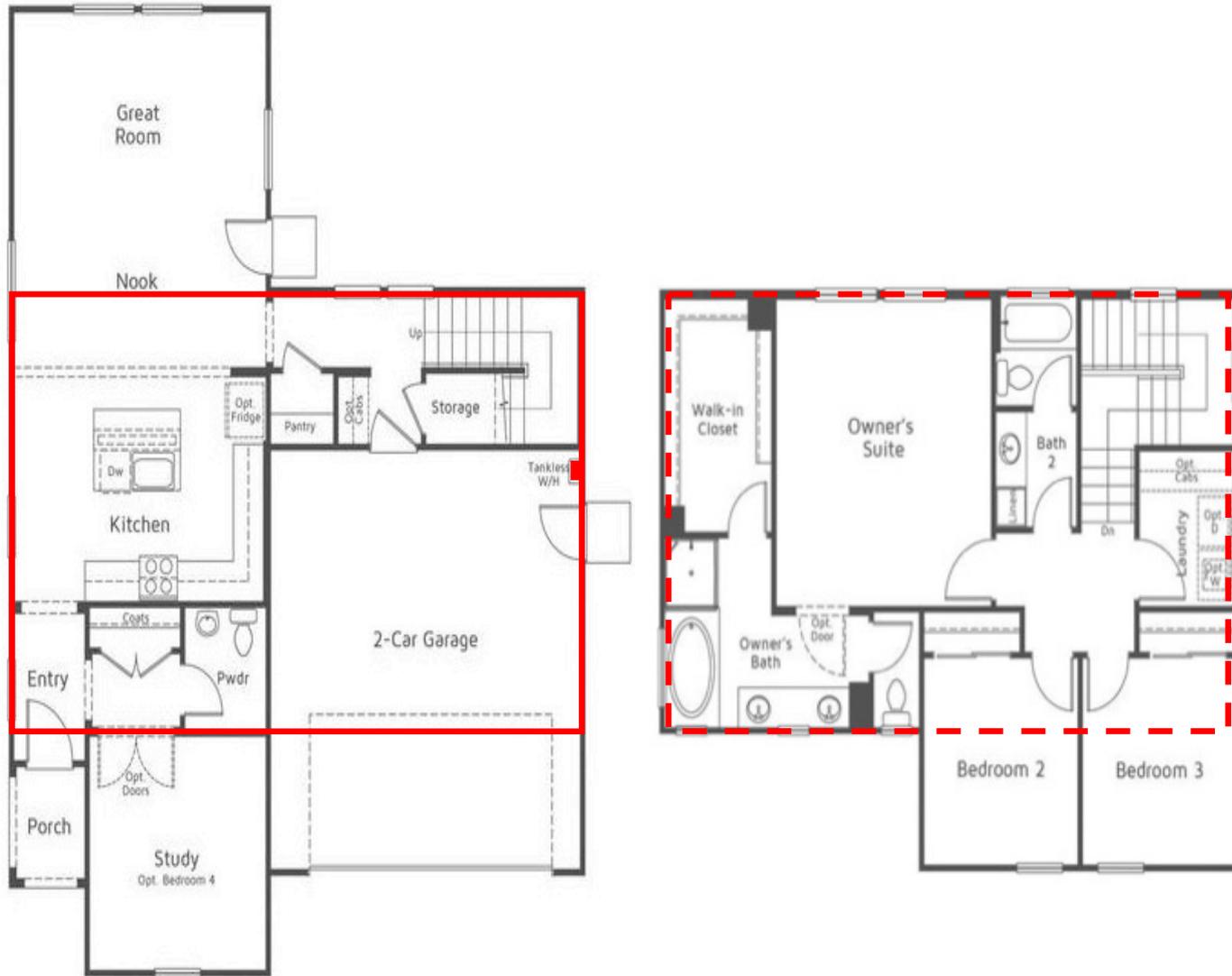
# 2-Story Floor Plans

The wet room rectangle has the same area as the hot water system rectangle for all of the 2-story homes in this sample.

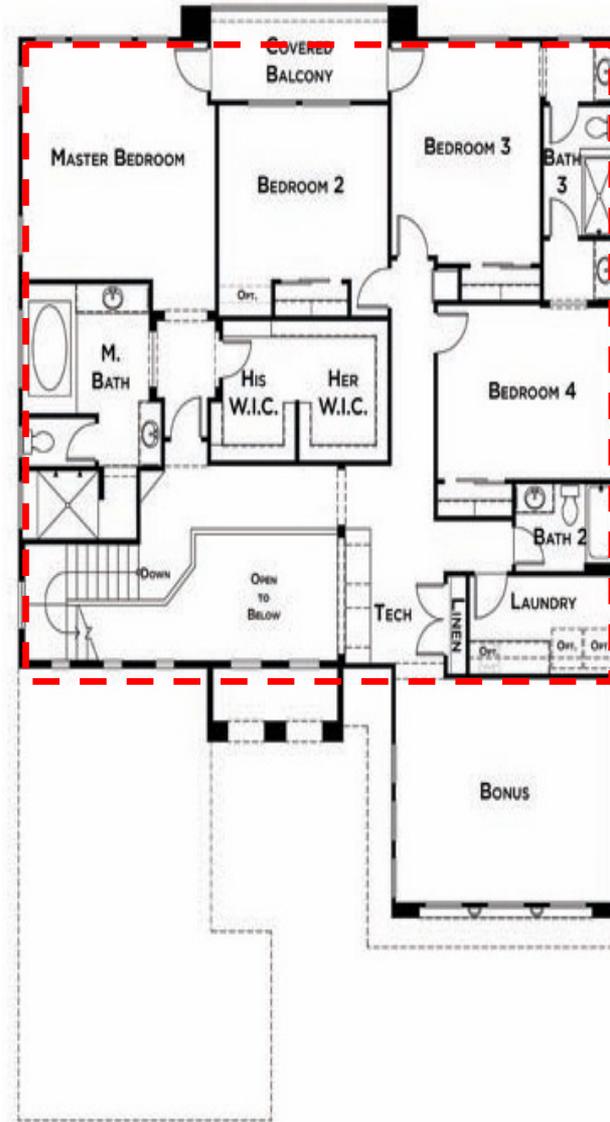
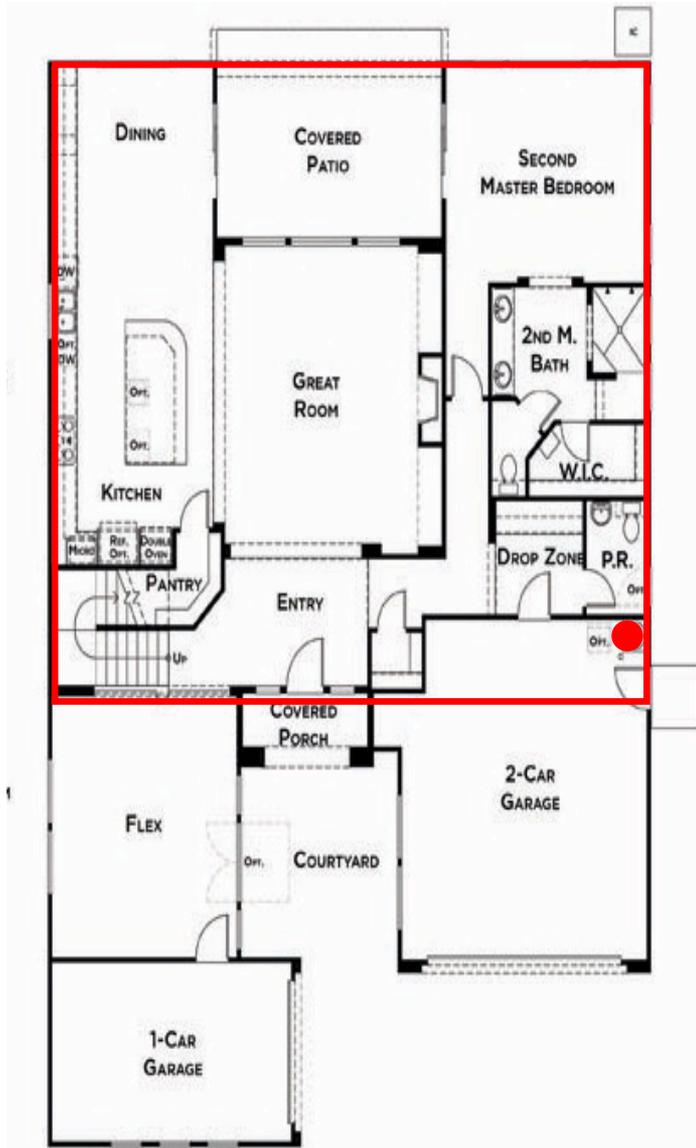
# 2 Story, 4 Br/3 Ba, 2,625 sq ft Bakersfield, CA ~37% (962 sq ft)



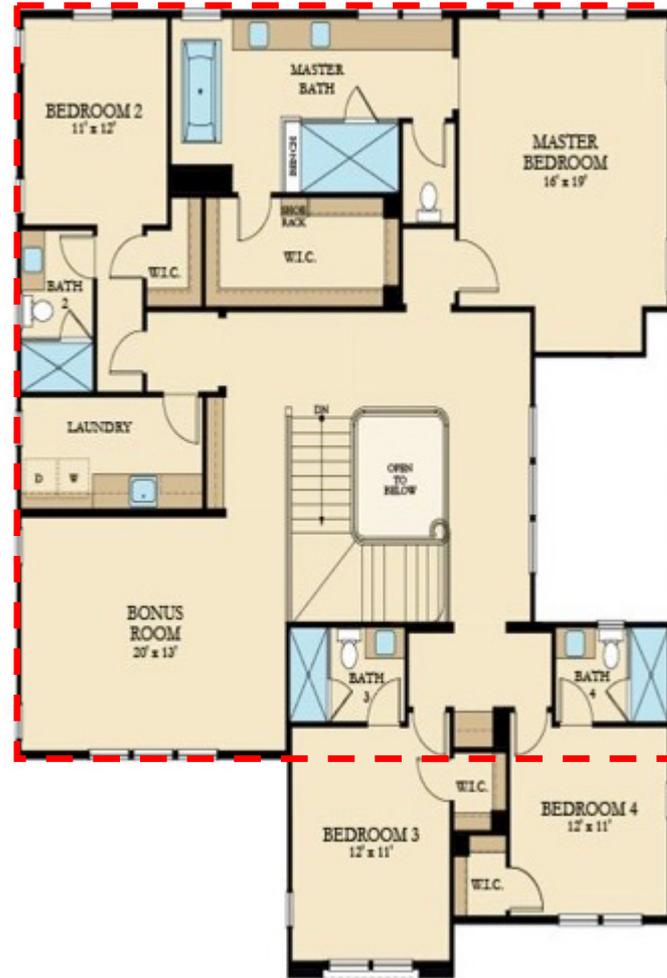
# 2 Story, 3 Br/2.5 Ba, 1,837 sq ft Salinas, CA ~48% (882 sq ft)



# 2 Story, 5 Br/4.5 Ba, 4,003 sq ft Rocklin, CA ~51% (2,042 sq ft)

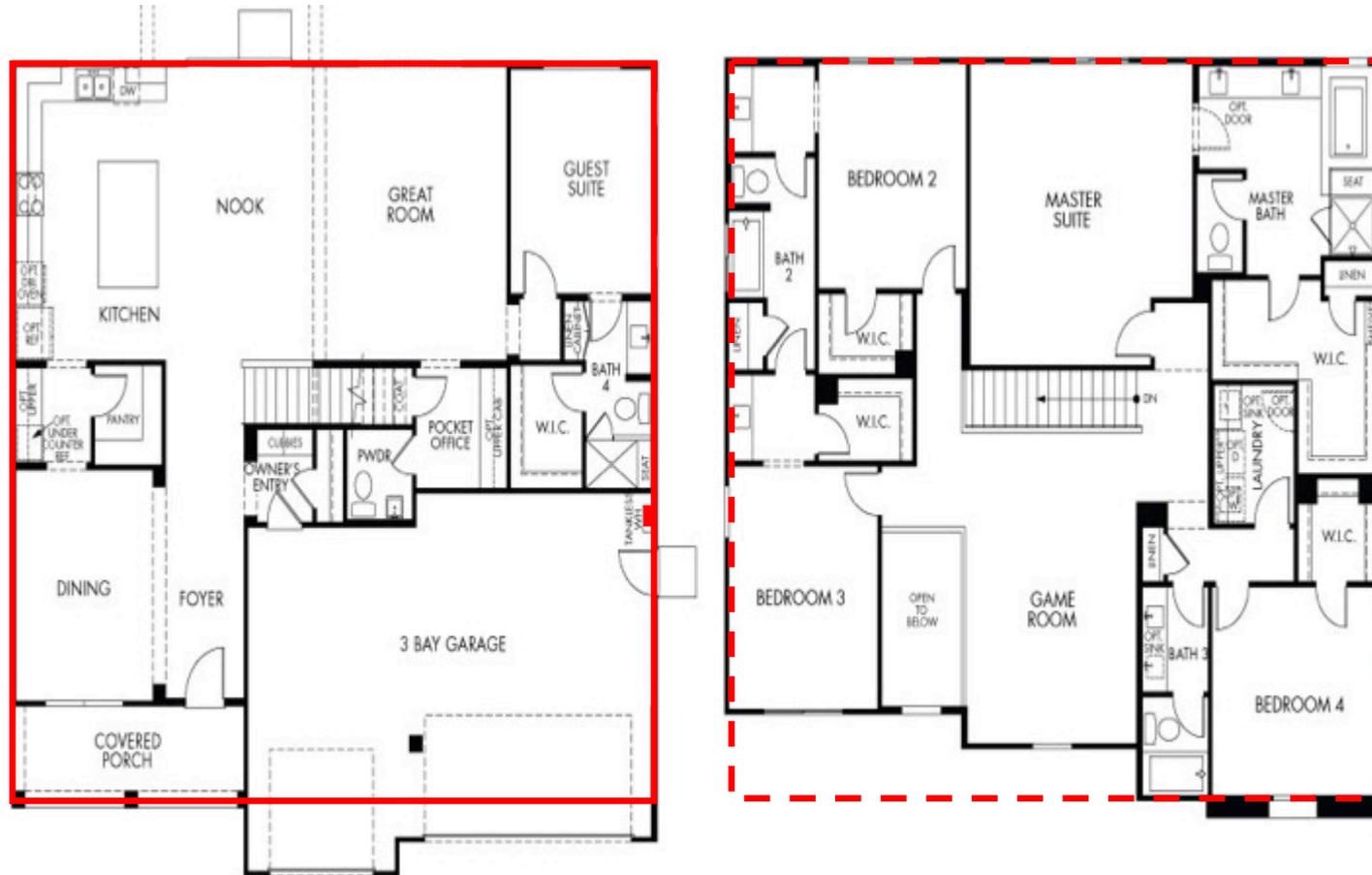


# 2 Story, 5 Br/5.5 Ba, 3,983 sq ft Irvine, CA ~58% (2,310 sq ft)





# 2 Story, 5 BR/4.5 Ba, 3,493 sq ft Manteca, CA ~63% (3,493 sq ft)

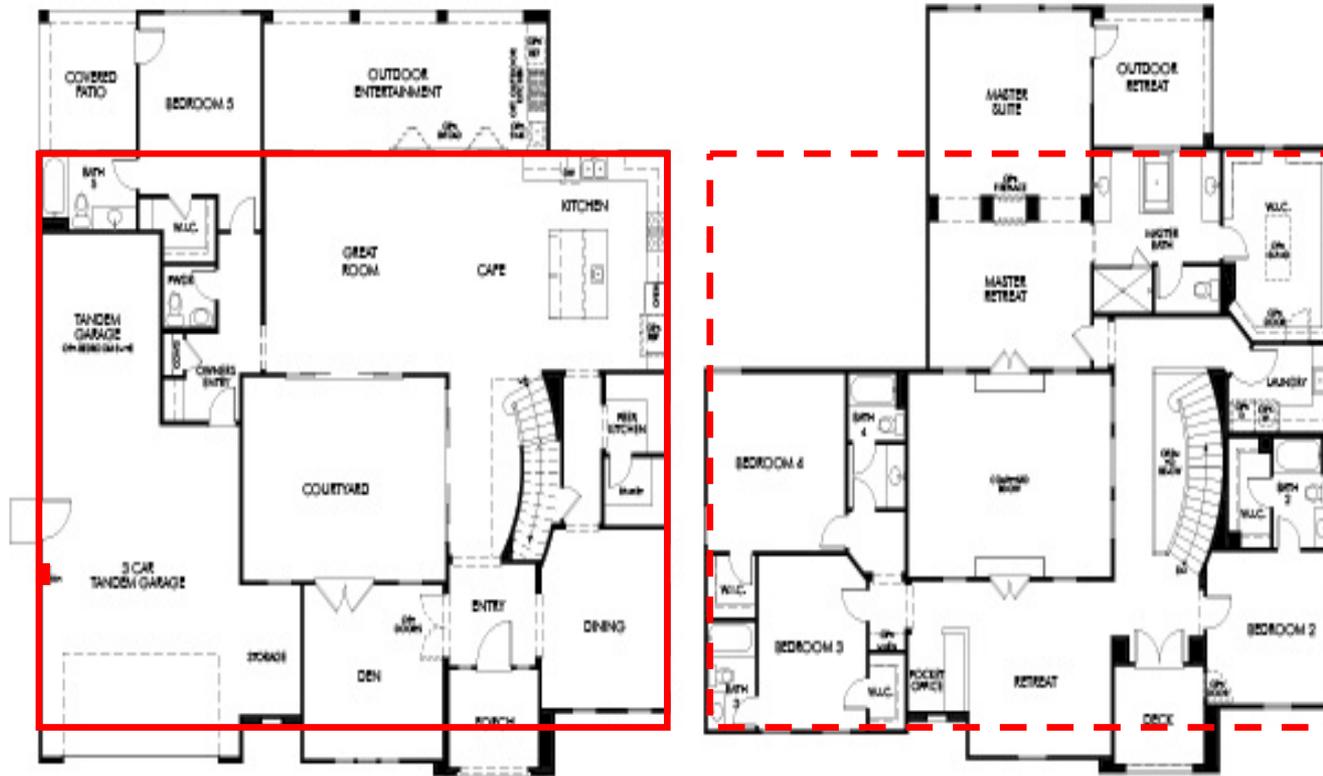


2 Story  
4 Br/3.5 Ba  
3,853 sq ft  
Lincoln, CA

~71 %  
(2,026 sq ft)

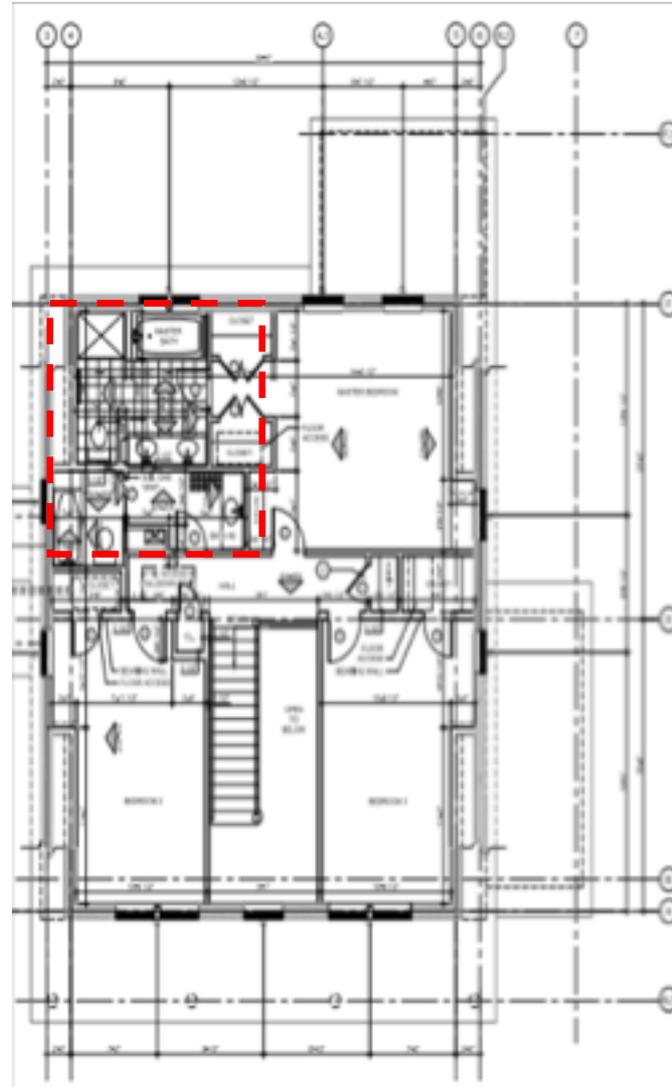
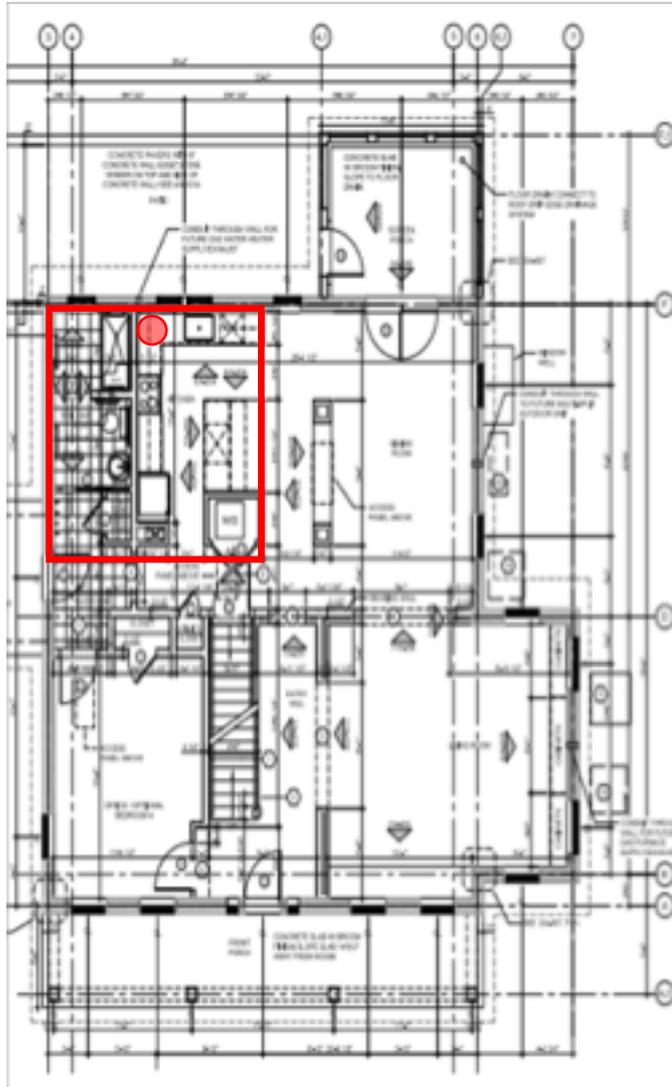


2 Story, 5 Br/5.5 Ba, 4,269 sq ft  
La Verne, CA ~72% (3,074 sq ft)



**Best 2-Story So Far...**

# 2 Story, 4Br / 3Ba, 2,709 sq ft Gaithersburg, MD ~12% (325 sq ft)



# Multi-Family Unit Floor Plans

The wet room rectangle has the same area as the hot water system rectangle for all of the 2-story homes in this sample.

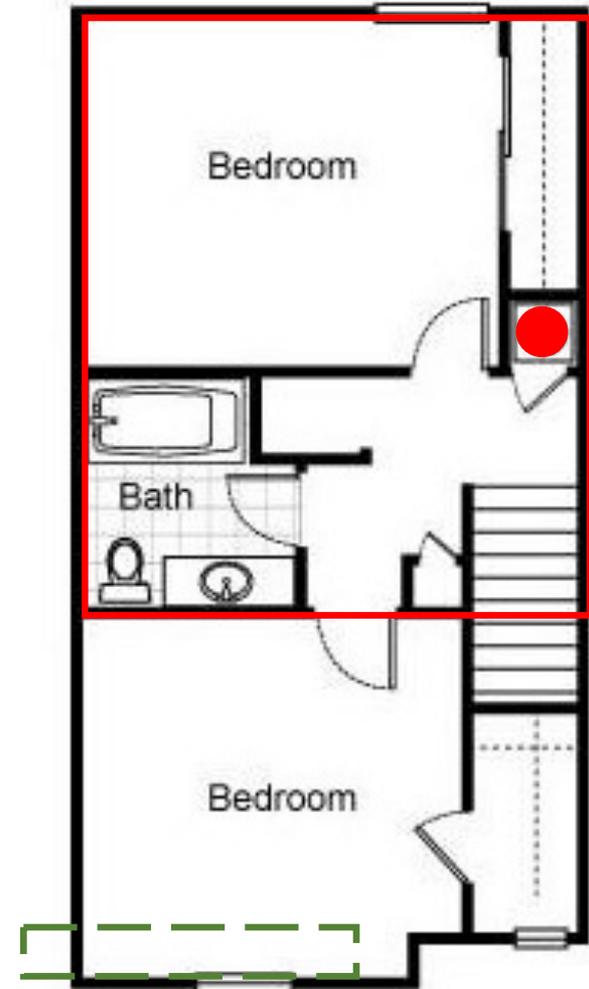
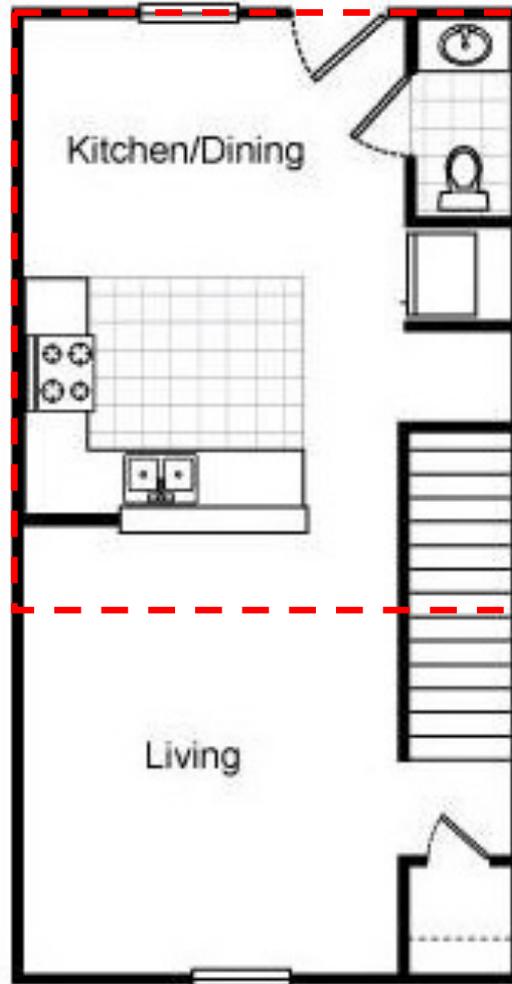
1 Story  
1Br/1Ba  
720 sq ft  
Chula Vista, CA

~29%  
(209 sq ft)



2 Story  
2Br/2Ba  
908 sq ft  
Richmond, CA

~33%  
(300 sq ft)



# 2 Story, 2 Br/2.5 Ba, 1275 sq ft Ventura, CA ~34% (434 sq ft)



1 Story  
1Br/1Ba  
665 sq ft  
Newark, CA

~50%  
(333 sq ft)



1 Story, 3 Br/2 Ba, 1136 sq ft  
Bakersfield, CA ~62% (699 sq ft)

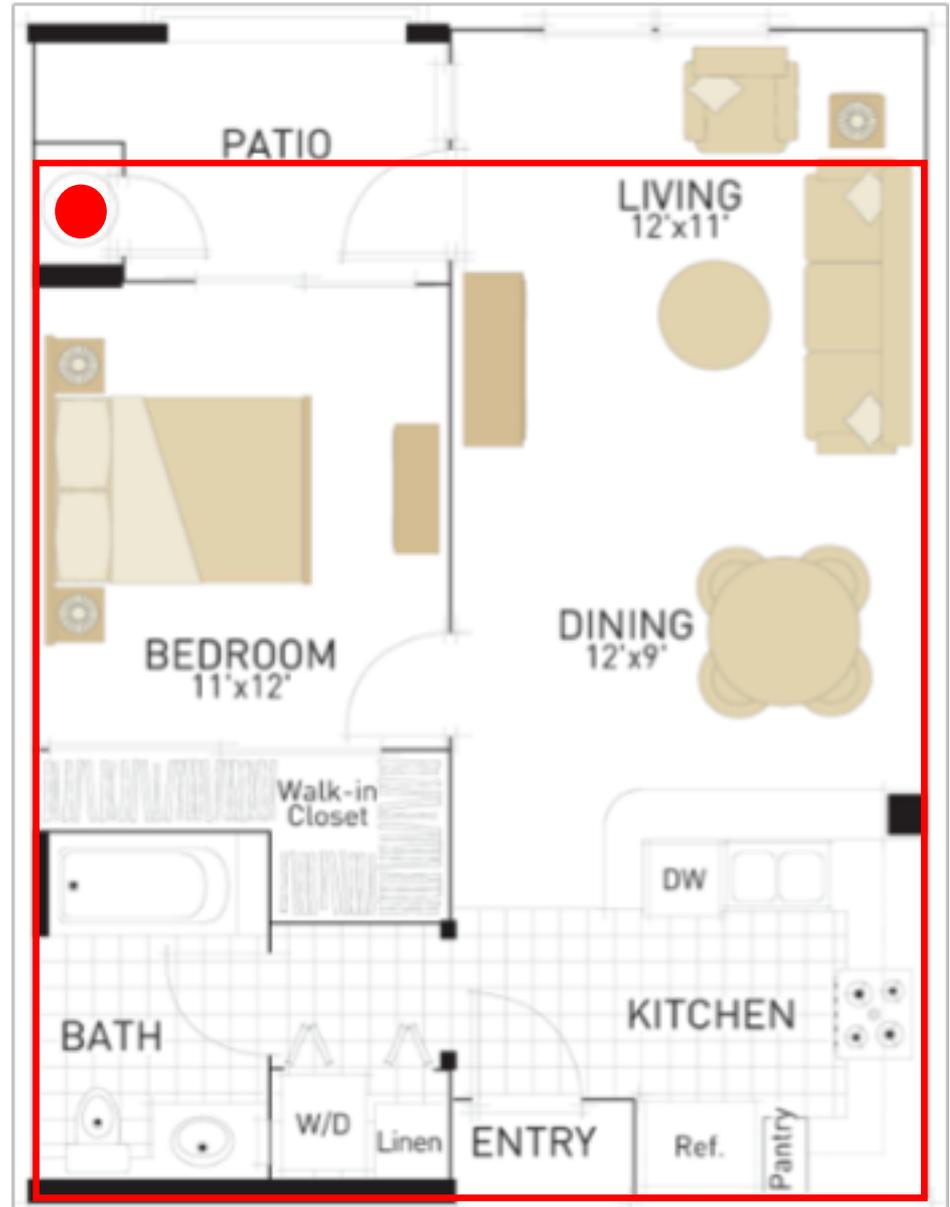


1 Story, 4Br/2Ba, 1217 sq ft  
Banning, CA ~67% (815 sq ft)



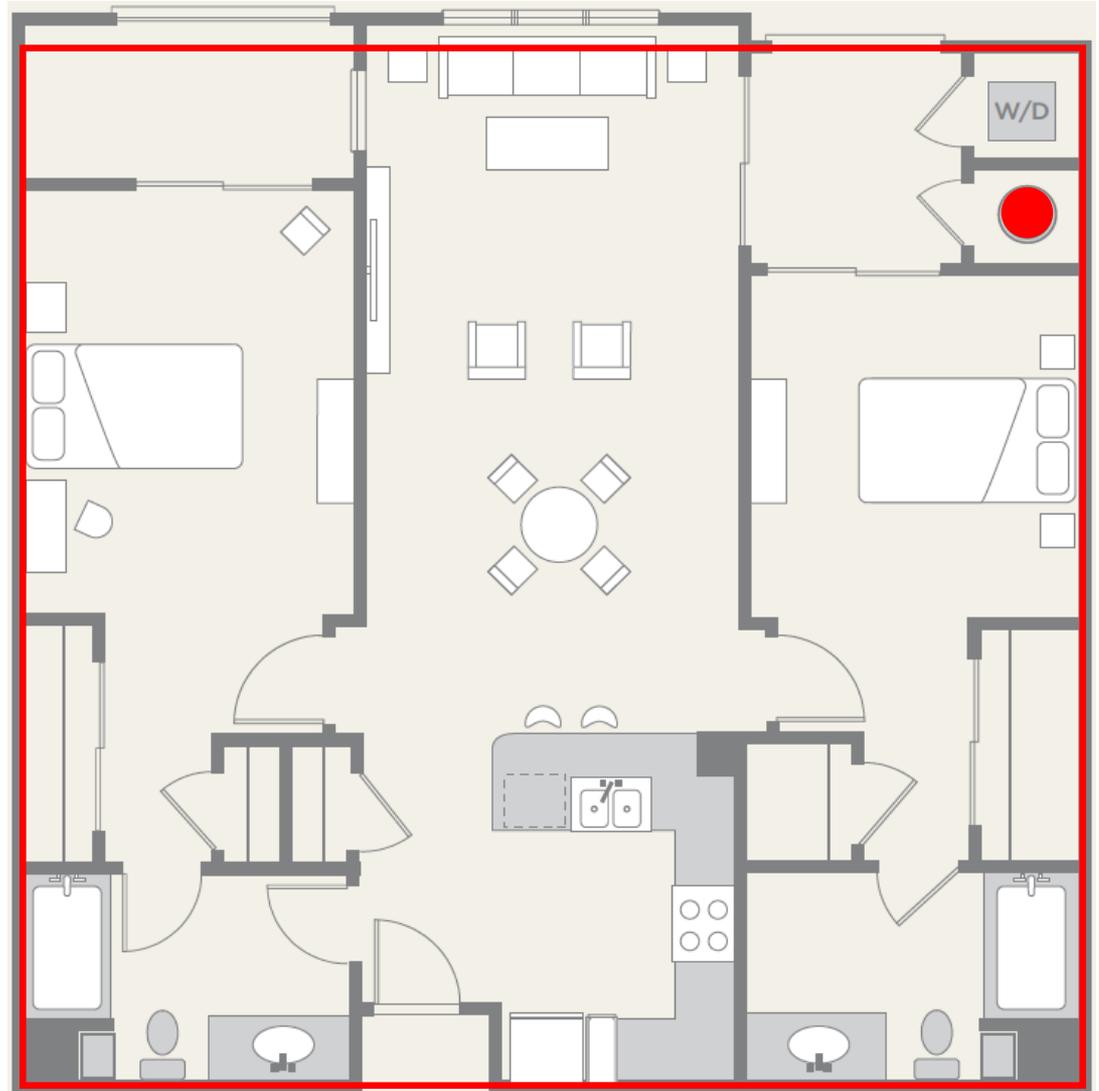
1 Story  
1Br/1Ba  
670 sq ft  
San Jose, CA

~90%  
(603 sq ft)

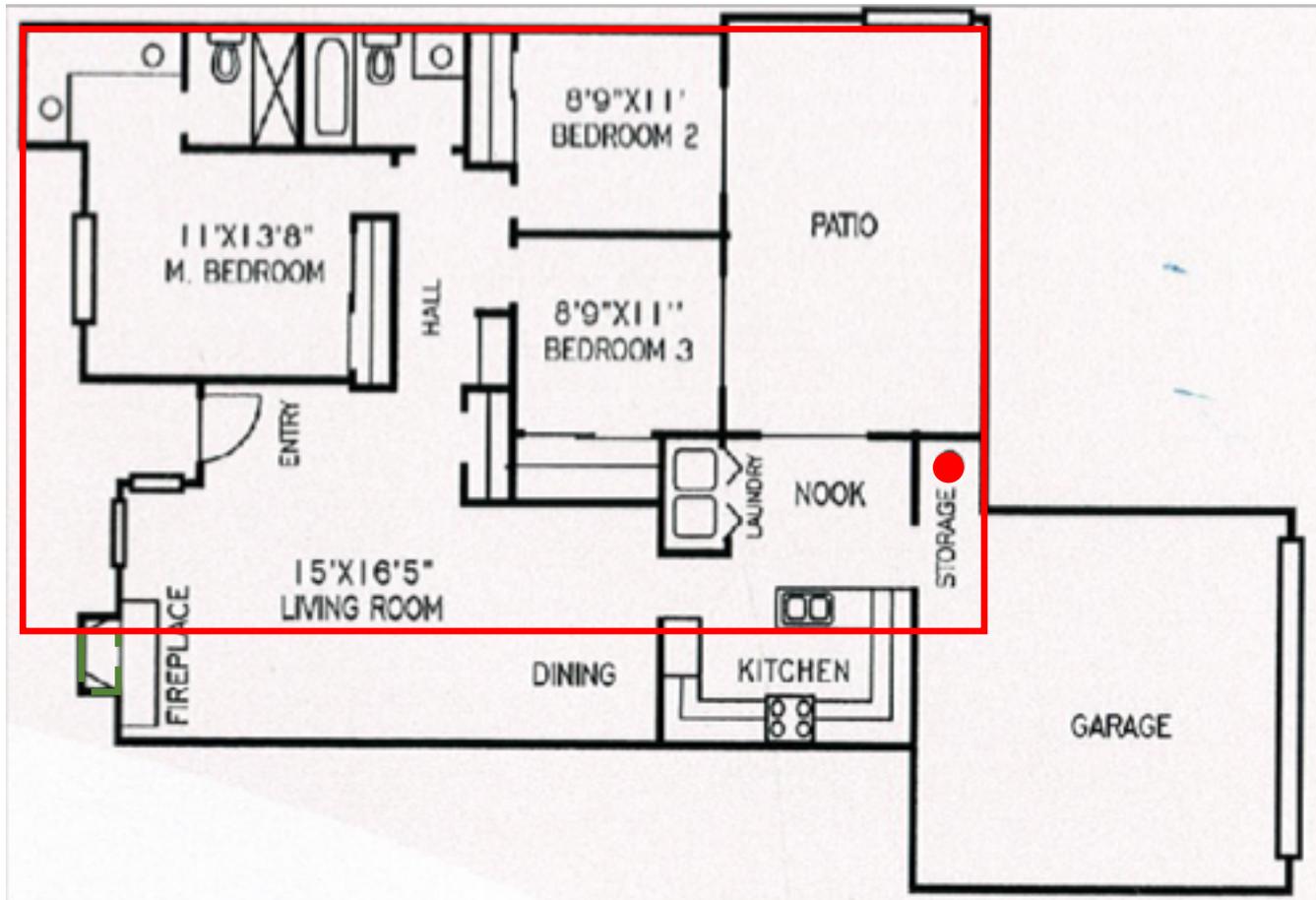


1 Story  
2Br/2Ba  
1232 sq ft  
San Diego, CA

~99%  
(1220 sq ft)



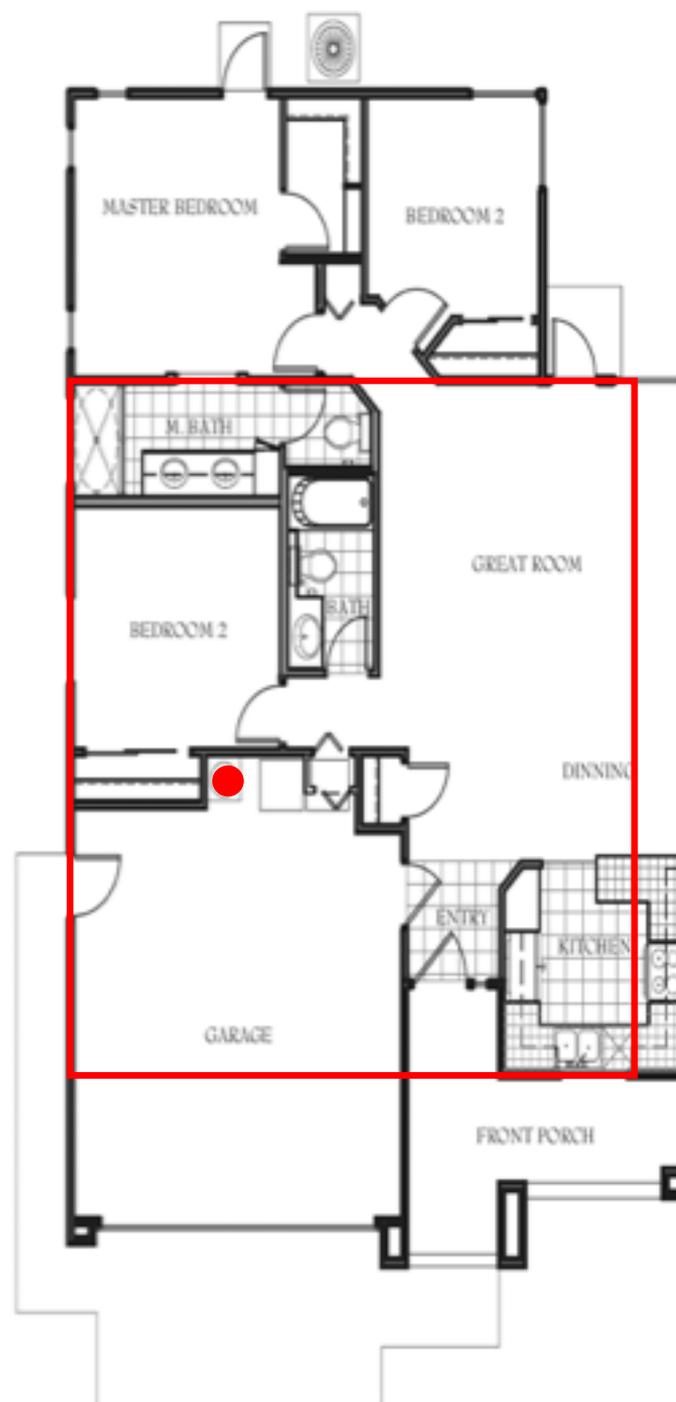
1 Story, 3Br/2Ba, 1360 sq ft  
Fresno, CA ~115% (1564 sq ft)



Locating water heaters  
nearer to the fixtures...

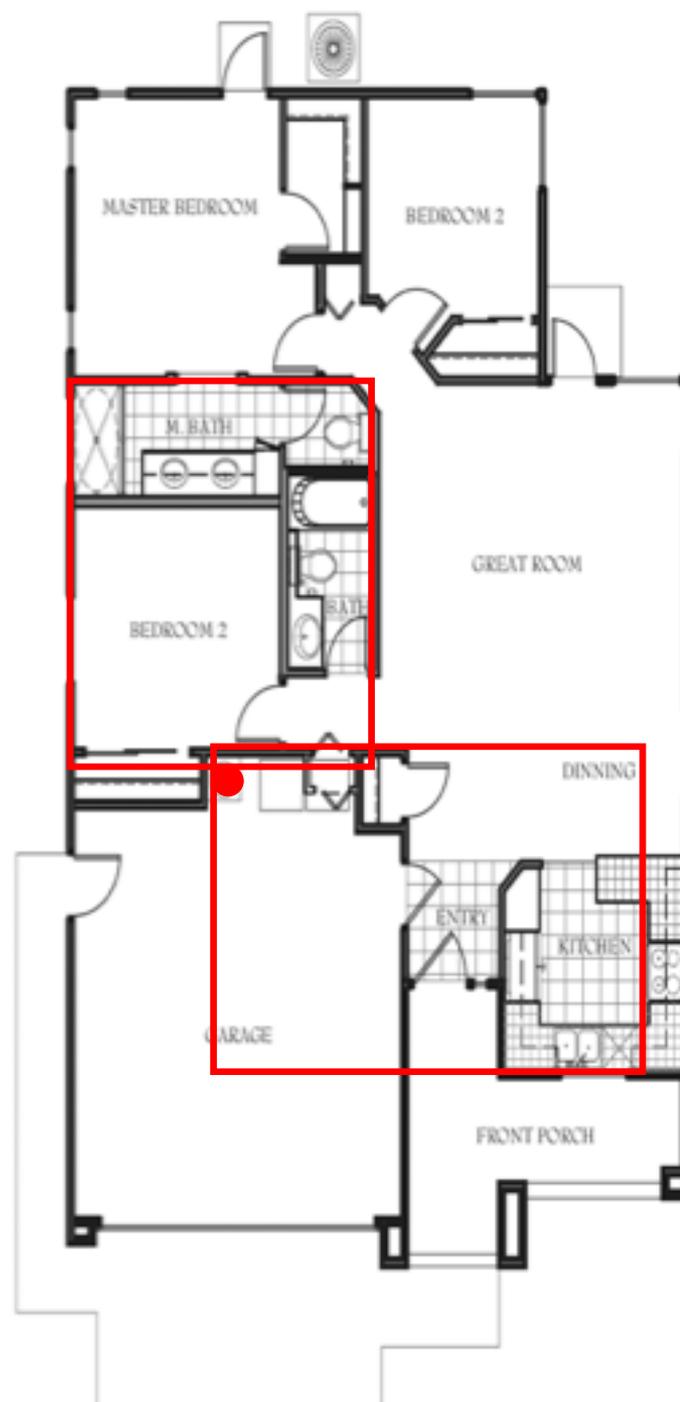
1 Story  
2 Br/2 Ba  
1,224 sq ft  
Chico, CA

~88%  
(1,077 sq ft)



1 Story  
2 Br/2 Ba  
1,224 sq ft  
Chico, CA

~58%  
(710 sq ft)



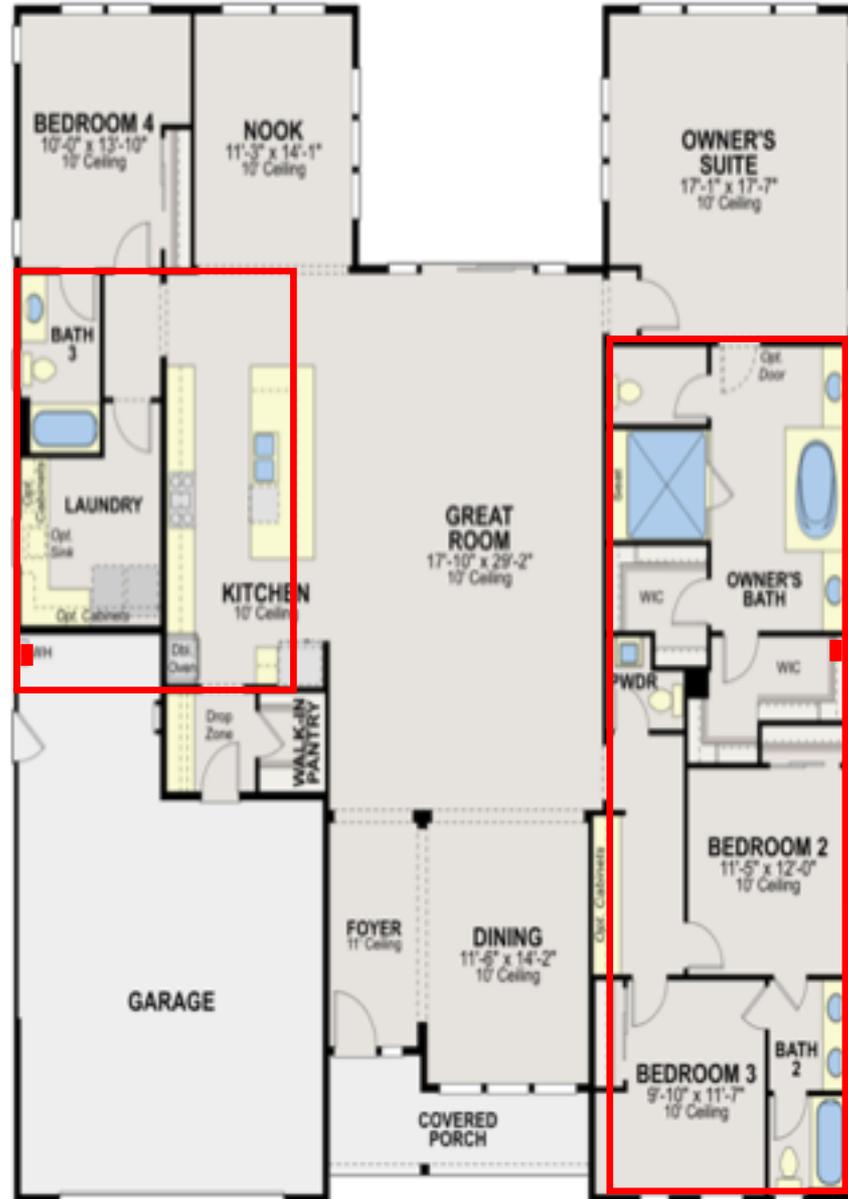
1 Story  
4Br/3.5Ba  
2,952 sq ft  
Morgan Hill, CA

~105%  
(3,100 sq ft)



1 Story  
4Br/3.5Ba  
2,952 sq ft  
Morgan Hill, CA

~43%  
(1,269 sq ft)

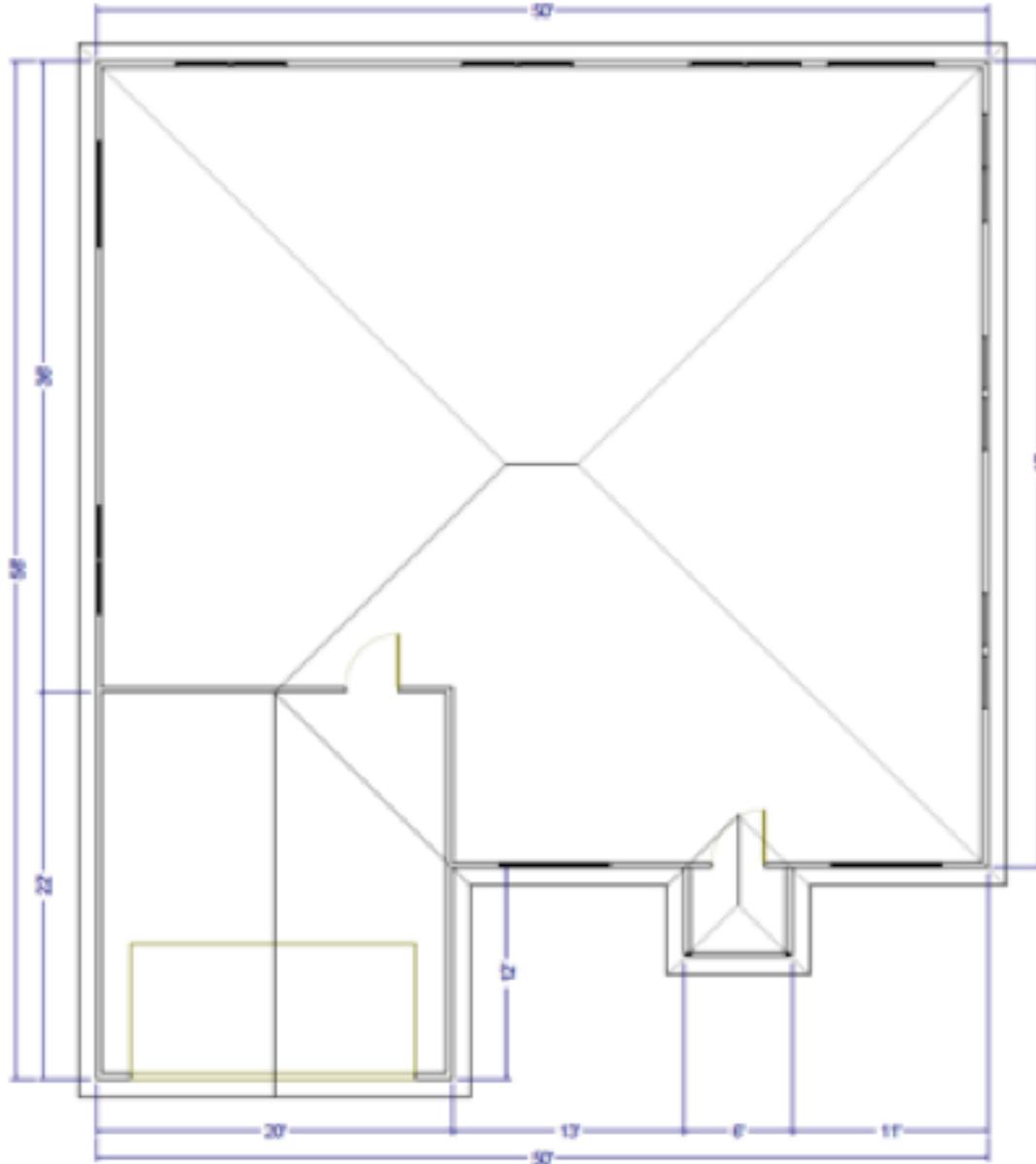




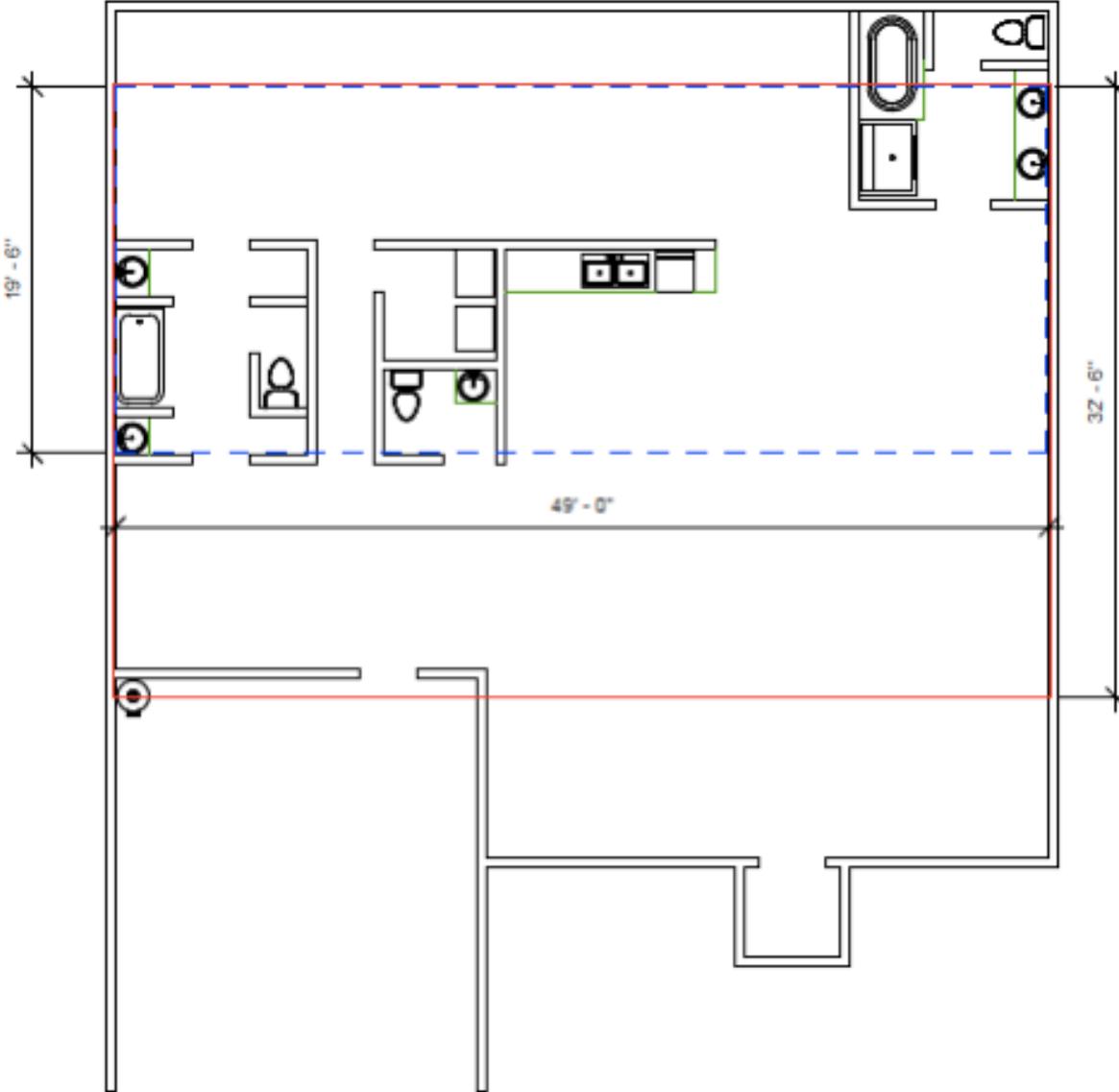




# Prototype Floor Plan – 1-story, 2,100 SF



# Reference Case



## **Wet Room Rectangle**

19.5 feet X 49 feet

956 square feet

**45.5% of floor area**

## **Hot Water System Rectangle**

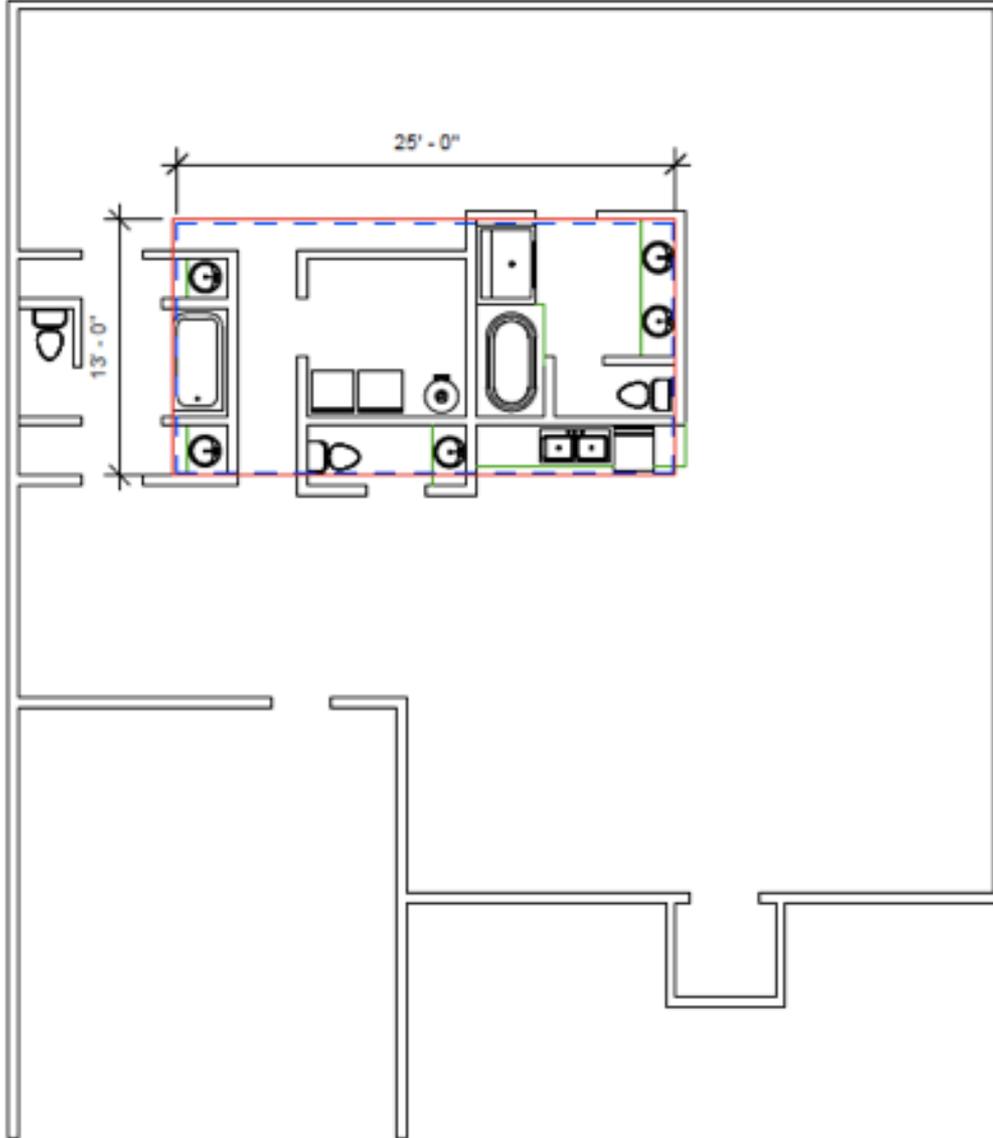
32.5 feet X 49 feet

1592 square feet

**76% of floor area**



# Compact Plumbing Core



## Wet Room Rectangle

13 feet X 25 feet

325 square feet

**15.5% of floor area**

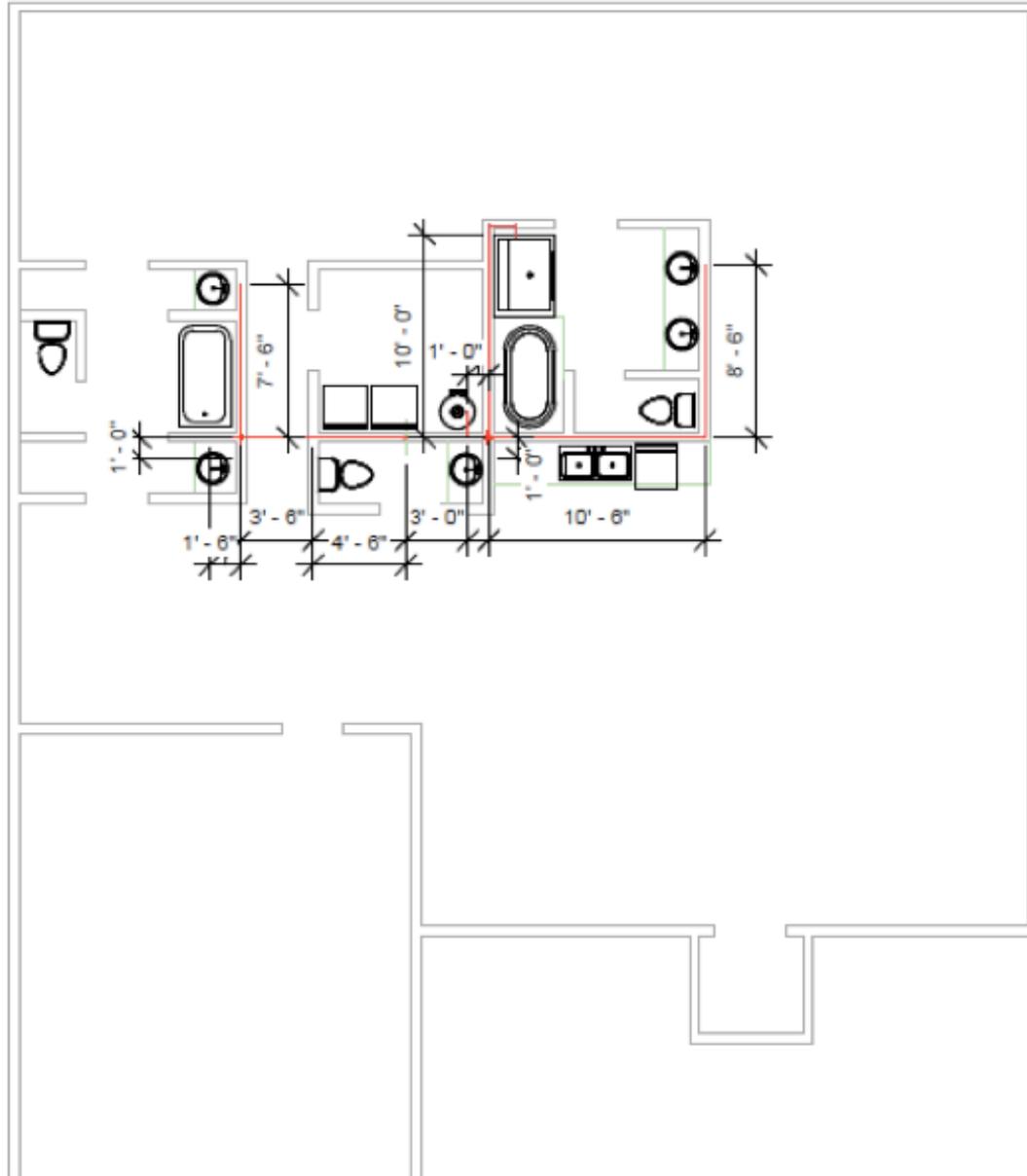
## Hot Water System Rectangle

13 feet X 25 feet

325 square feet

**15.5% of floor area**

# Compact Plumbing Core



# Benefits of a Compact Core

- Reductions in first costs
- Additional savings over time
  - Reductions in energy, water and emissions
  - Reductions on energy and water costs

# Reductions in First Costs

- \$1,000 - \$2,000 per dwelling unit based on labor costs ranging from \$30-50 per hour
  - Lower for smaller dwellings, greater for larger dwellings
  - Applicable to multi-family dwelling units
  - Most of the savings comes from reduced labor costs.

# Scatter Plot of the Relationship between the Hot Water System and the Floor Area



Source: <http://kiddywampus.blogspot.com>

*How Low Can We Go?*

# Variables to Account For:

- Time-to-Tap
- Volume-until-Hot
- Flow rates and fill volumes of plumbing fixtures and appliances
- Patterns of hot water use, now and over time
- Longevity of the hot water system infrastructure
- Potential for pathogen growth and harm
- Anything else?

# There is a Limit to How Low We Can Go.

- Unless the heater is in the fixture or appliance, there will always be some volume in the pipe between the source and the use.
- It takes roughly twice the volume in the pipe for hot water to come out the other end.
- We need to decide what is an “acceptable” time-to-tap or volume-until-hot and work backwards to determine the maximum allowable in the pipe between the source and the use.
  - Plumbing up from below needs about 5 feet of pipe.
  - Plumbing down from above needs about 10 feet of pipe

# Time-to-Tap, Volume-until-Hot – 5 ft. of Pipe

Pipe Material	Pipe Diameter (nominal, inches)				
	0.25	0.375	0.5	0.75	1
<b>Gallons to Hot: 5 Feet of Pipe</b>					
Copper-Type L	0.04	0.08	0.12	0.25	0.43
CPVC	NA	NA	0.10	0.21	0.35
PEX	0.03	0.05	0.09	0.18	0.31
<b>Time to Hot @ 0.5.gpm: 5 Feet of Pipe (seconds)</b>					
Copper-Type L	5	9	15	30	51
CPVC	NA	NA	12	25	42
PEX	3	6	11	22	37
<b>Time to Hot @ 1.0 gpm: 5 Feet of Pipe (seconds)</b>					
Copper-Type L	2	5	7	15	26
CPVC	NA	NA	6	13	21
PEX	2	3	6	11	18

# Time-to-Tap, Volume-until-Hot – 10 ft. of Pipe

Pipe Material	Pipe Diameter (nominal, inches)				
	0.25	0.375	0.5	0.75	1
<b>Gallons to Hot: 10 Feet of Pipe</b>					
Copper-Type L	0.08	0.15	0.24	0.50	0.86
CPVC	NA	NA	0.20	0.42	0.69
PEX	0.05	0.10	0.18	0.37	0.61
<b>Time to Hot @ 0.5.gpm: 10 Feet of Pipe (seconds)</b>					
Copper-Type L	10	18	29	60	103
CPVC	NA	NA	23	50	83
PEX	6	12	22	44	73
<b>Time to Hot @ 1.0 gpm: 10 Feet of Pipe (seconds)</b>					
Copper-Type L	5	9	15	30	51
CPVC	NA	NA	12	25	42
PEX	3	6	11	22	37

# How Low Can We Go? How Close Can We Get?

- The shorter the pipe, the less time it takes.
- The lower the flow rate, the longer it takes.
- How long is too long?
  - 5 seconds?
  - 10 seconds?
  - Longer?

**Water, energy and time efficient hot water systems start with deciding how long we want people to wait.**

# So What Can We Do?

1. Decide how long we want people to wait for hot water to arrive.
2. Account for the fact that it takes approximately twice as much water as in in the pipe for hot water to arrive at the other end of the pipe.
3. Select pipe diameters based on the pressure drop due to flow rates. Minimize the number of fittings, particularly 90° elbows.
4. Work backwards to get the distance from the source of hot water to the uses.
5. Cluster the uses of hot water close to each other and to the source of hot water that serves them. There can be more than one cluster in each dwelling.
6. Locate these clusters such that the wet rooms are surrounded by dry rooms.

# So What Can We Do? (continued)

## **Result:**

- >75% reduction in hot water distribution length (similar savings in cold water piping, drain lines and vent stacks)
- >75% reduction in hot water distribution pipe volume
- Time-to-tap less than 15 seconds at all fixtures and appliances
- Volume-until-hot less than 2 cups
- Reduced construction costs (\$2-3,000 for plumbing, \$5-10,000 for all mechanical)

# So What Can We Do? (continued)

## Bring back the Core!

- Compact wet room core
- Compact mechanical room core
  - Drop ceilings, closets with removable panels, serviceable mechanical equipment, including filters without the need for a ladder

## Right-size the Supply Piping

- 2018 IAPMO Uniform Plumbing Code (UPC)
  - Appendix M, Peak Water Demand Calculator
  - Single- and multi-family homes with water-conserving plumbing fixtures, fixture fittings and appliances
  - In general, can expect reduction of one nominal diameter.
    - Going smaller than 0.5 inch nominal?
    - Pay attention to velocity and residual pressure
  - <http://www.iapmo.org/water-demand-calculator/>

# When you have been asked to “make it so!”

Options for existing buildings where it is not possible to optimize the layout of the wet rooms

## New Construction

- Follow the principles of Structured Plumbing
- Consider having more than one plumbing zone

## Retrofit

- Evaluate the layout of the hot water distribution system
- Determine best options based on this analysis

Please send email to request literature on both of these.

# Preliminary Conclusions

1. Design and build dwellings with floor plans that allow for efficient mechanical infrastructure
2. Reduce the UA of the hot water distribution system (reduce the length, optimize the diameter, insulate like crazy)
3. Reduce hot water system complexity
4. Reduce the amount of time the hot water distribution system spends in the pathogen high growth temperature zone
5. Utilize waste energy where practical
6. Select efficient water heaters that match the system parameters

Questions?