BACKGROUND DOCUMENTATION ON COMPACT HOT WATER DISTRIBUTION ACM DEVELOPMENT

1.1 Background

The 2016 Title 24, Part 6 Residential Alternative Calculation Method (ACM) provides for a compliance option credit for compact hot water distribution systems. The fundamental goal of the compact credit is to reward building designs that bring the water heater close to the hot water use points. To qualify for the credit, the builder must have a HERS inspector verify that the total length of plumbing between the water heater and furthest hot water use point is shorter than a threshold value as shown in Table 1. If compliance is demonstrated, the distribution system multiplier (DSM) used in residential compliance software calculations is set at 0.7[1].

Table 1: Threshold Pipe Lengths in Current 2016 HERS-Verified Compact Hot Water Distribution

Floor Area Served (ft^2)	Maximum Measured Water Heater to Use Point Distance (ft)
< 1000	28’
1001-1600	43’
1601-2200	53’
2201-2800	62’
> 2800	68’

Under the 2016 Title 24, Part 6 code we expect to see a very high saturation of gas tankless water heaters with typical locations on exterior garage walls, resulting in greater plumbing distances between the water heater and hot water use points. This, combined with tankless cold start delays exacerbate water waste and homeowner wait times.

To address concerns with the current compact criteria and to bolster industry uptake of the measure, the Statewide CASE Team has developed a simplified 2019 draft proposal. The credit aims to motivate builders to locate the water heater in a central location, thereby reducing occupant wait time for hot water, and associated energy use and water waste. The credit could be achieved through locating the water heater on the exterior wall of the house (close to key use points), centrally in the attic, or in a garage location in closer proximity to the fixtures. While these possibilities are available, builders have expressed a strong preference to locate the water heater in the garage. The following analysis generically uses the term “centrally located in the garage” to describe the basic approach of bringing the water heater in close proximity to use points.

The proposal is based on two levels of credit: Basic and Expanded. The Basic Credit would consist of a plan view check without any HERS verification, significantly reducing the effort required to demonstrate compliance. Alternatively, builders can earn an Expanded Credit by meeting more rigorous criteria, including simple HERS verification steps. The magnitude of the Expanded Credit increases

[1] The DSM compares the proposed distribution system to a “standard” trunk and branch distribution system which has a nominal DSM of 1.0. Better performing distribution systems have DSMs below 1.0 and worse performing would have a DSM greater than 1.0.

savings, depending upon the level of compactness of the plumbing design. The following sections describe the method for determining compliance with the Basic and Expanded Credit and background information used to develop the approach.

1.2 Basic Compact Credit

To apply for the Basic Compact credit, plan takeoff calculations must be completed that demonstrate that the plumbing design (water heater to fixture proximity) is more compact than a threshold criterion that is defined based on floor area and number of stories. Compactness is characterized by calculating the "Weighted Distance" from the water heater to the fixtures, and the threshold is identified by the "Qualification Distance". Details on the calculations are presented in the following sections.

1.3 Weighted Distance

The proposal is based on three different Weighted Distance calculation methods:

- for standard non-recirculating distribution systems,
- for recirculation systems, and
- for houses with multiple water heaters (either recirculation or non-recirculation).

Calculation of the Weighted Distance varies depending on the type of system being installed. The calculation is based on a single, standard equation with modifications for each of the three options. In each case the basis of the calculation is the plan-view, straight line distance from the water heater to the fixtures in three rooms of the house. It is calculated using the following equation.

Weighted_Distance = x * d_MasterBath + y * d_Kitchen + z * d_FurthestFixture

where,

- x, y, and z = Weighted Distance coefficients (unitless), see Table 2.
- d_MasterBath = The plan view, straight line distance from the water heater to the furthest fixture in the master bathroom (ft).
- d_Kitchen = The plan view, straight line distance from the water heater to the furthest fixture in the kitchen (ft).
- d_FurthestThird = The plan view, straight line distance from the water heater to the furthest fixture in the furthest room[2] in the house (ft).

Table 2 shows the values for the coefficients depending on the type of distribution system.

Table 2: Weighted Distance Coefficients

Distribution System	x	y	z
Non-Recirculating	0.4	0.4	0.2
Recirculating	0	0	1

The rationale behind the weighting factors is as follows. For non-recirculating systems, the master bath and kitchen represent the two use points found in all homes which include high hot water usage and are also most prone to customer satisfaction concerns on long wait times. For this reason, a higher weighting factor of 0.4 was applied. At the same time, the furthest remaining fixture also should be factored in to the compactness assessment, and is therefore assigned a factor of 0.2. For recirculating

[2] Because the Master Bath and Kitchen have separate terms, the FurthestThird fixture must not be in either of these rooms.

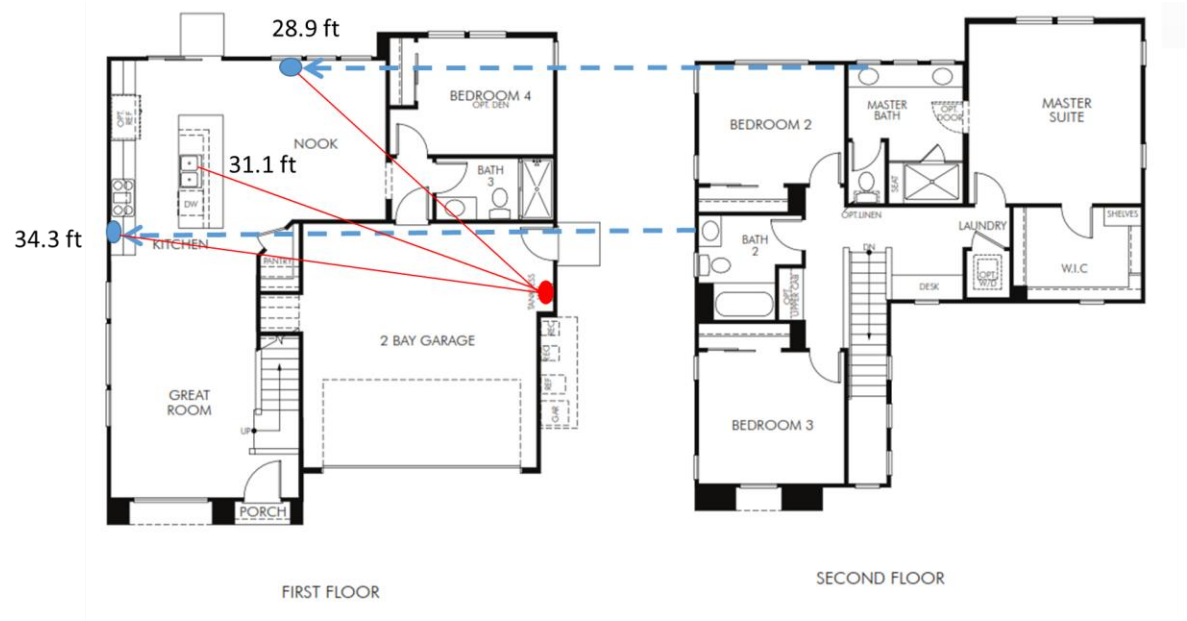
systems, the size of the recirculation loop is dictated by how far the loop has to be extended to serve that fixture (with prompt hot water delivery), hence full weighting is applied only to the furthest fixture.

Note that the calculations are only based on horizontal plan view distance measurements. Vertical length (for example, the vertical distance from the first to second floor) is neglected in the calculations. Use points that are located on floors different than the water heater would have their location translated to the appropriate floor.

In houses with multiple water heaters, the Weighted Distance calculation is performed for each water heater. The master bath and kitchen are only included in the calculations for the water heater serving those use points. For example, one water heater may serve both the Master bathroom and the kitchen, and therefore the calculation for that water heater would include all three terms; the second water heater in that house would just include the d_FurthestFixture term. If various water heaters have different types of distribution system, one would use the appropriate form of the equation for each water heater. The Weighted Distance for the building is the sum of the Weighted Distance calculations for each individual water heater[3].

Figure shows an example weighted distance calculation for an 1,814 ft^2 2-story house with a standard non-recirculating distribution system. The design locates the water heater on the exterior wall, as shown by the red oval. The dotted blue lines and ovals represent translating the fixtures on the second floor to the first floor, neglecting the vertical distance. The red lines and listed distances represent the distance from the water heater to each fixture used in the calculation. The Weighted Distance calculation for this example is shown below Figure 1.

[3] Because the d_FurthestFixture term is included for each water heater the sum of the weighting factors will increase above 1.0 as additional water heaters are added (each water heater would add 0.2). A well designed system with multiple water heaters will be able to achieve a significantly better Weighted Distance, so this is not considered an issue.



Weighted Distance = 0.4 * 28.9 ft + 0.4 * 31.1 ft + 0.2 * 34.3 ft = 30.9 ft

Figure 1: Example Weighted Distance Calculation

1.4 Qualification Distance

To qualify for the Basic Credit, the Weighted Distance must be less than the Qualification Distance. The qualification distance is a function of conditioned floor area (CFA) and number of stories. It was developed based on a review of 60 production builder floor plans from 16 different builders. The Qualification Distance is the defined threshold for rewarding builders for placing the water heater in a central location and/or architectural designs with use points considerably closer to the water heater than standard. The proposed criterion was developed based on ~25% of the 60 floor plans with water heaters located on the external wall of the garage meeting the credit, while 75% of floor plans with a centrally (optimally) located water heater in the garage achieving the credit. The Qualification Distance calculation changes based on the type of distribution system (recirculation, non-recirculation, or multiple water heaters). The following sections document the Qualification Distance equations for each distribution system type with more detailed information on the plan evaluation results located in the Additional Information on Qualification Distance Calculations section at the end of this document.

The Qualification Distance for systems with multiple water heaters is identified by using the equation for the appropriate distribution system (recirculation or non-recirculation), and dividing by the number of water heaters installed. To comply each water heater must meet the criteria individually.

The generic form of the Qualification Distance formula is shown below, and the coefficients are included in Table.

Qualification_Distance = (a + b * CFA) / n

where

a, b = Qualification distance coefficients (unitless), see Table,

CFA = Conditioned floor area of the building (ft^2), and

n = Number of water heaters in the building (unitless).

Table 3 presents the values of the coefficients depending on the number of stories and type of distribution system.

Table 3: Coefficients for the Qualification Distance Calculation

	Non-Recirculating Distribution		Recirculating Distribution	
Number of Stories	a	b	a	b
1	10	0.0095	22.7	0.0099
2	15	0.0048	11.5	0.0095
3	10	0.003	0.5	0.0014

The Qualification Distance calculation for the example 1,814 ft^2, 2-story house in the Weighted Distance example is shown below.

Qualification Distance = 15 + 0.0048 * 1814 ft^2 = 23.2 ft.

1.5 Application of Credit in the ACM

2016 Title 24, Part 6 ACM Appendix B uses an equation based on the size of the building and type of distribution system to estimate the energy lost in the pipes. It is currently calculated using the following equation.

$$DLM_k = 1 + (SDLM_k - 1) * DSM_k$$

where

DLM_k = Distribution loss multiplier (unitless),

$SDLM_k$ = Standard distribution loss multiplier (unitless), and

DSM_k = Distribution system multiplier (unitless).

$SDLM_k$ is a function of the size of the building, and DSM_k is determined by the type of distribution system. The Title 24 ACM Manual contains a table specifying the DSM_k for each type of distribution system. The 2019 code change proposal adds a term, the Compactness Factor (CF), to that equation. The proposed form is shown below.

$$DLM_k = 1 + (SDLM_k - 1) * DSM_k * \mathrm{CF}$$

The CF is a multiplier that reduces the distribution loss multiplier in compact distribution systems. Plans that are not compliant with the Basic Credit calculation will use a CF of 1. Plans that earn the Basic Credit will receive a CF of 0.7.

The 1,814 ft^2 floor plan used in the example thus far has a 30.9 ft Weighted Distance and a 23.2 ft Qualification Distance (as shown in Figure). As currently designed, it does not qualify for the Basic Credit and would receive a CF of 1.0. However, relocating the water heater as shown in Figure 2 below results in a significantly reduced Weighted Distance.

Weighted Distance = 0.4 * 12.9 ft + 0.4 * 11.8 ft + 0.2 * 16.1 ft = 13.1 ft

Figure 2: Example Weighted Distance Calculation with a Central Water Heater

With a centrally located water heater, the 13.1 ft Weighted Distance is less than the 23.2 ft Qualification Distance, and the home would receive the Basic Credit. The CF-1R would report that the plan meets the Compact Basic Credit.

1.6 Expanded Credit

The Expanded Credit is more difficult to achieve, but rewards the builder with a larger compliance credit, and allows the magnitude of the credit to scale with increasing level of plumbing compactness. In order to earn the Expanded Credit, the plan must first meet the Basic Credit criteria. In addition, there is a HERS verification requirement demonstrating that the following eligibility criteria have been met.

- No hot water piping >1" piping is allowed,
- Length of 1" limited to 8 ft or less,
- Two and three story buildings cannot have hot water distribution piping in the attic, unless the water heater is also located in the attic. (For most 2 and 3 story buildings, the piping must be run between the floors.), and
- Eligible recirculating systems must be HERS-Verified Demand Recirculation: Manual Control conforming to RA4.4.17.

By meeting these criteria, the builder will earn a credit larger than the Basic Credit that scales with the level of compactness. The scaling factor is based on the ratio of the Weighted Distance to the Qualification Distance. The credit will scale from a minimum of 0.3 (the existing 2016 ACM point of use distribution system credit) to a maximum equal to the Basic Credit (0.7), as shown below:

CF = 0.3 + 0.4 * (Weighted_Distance) / (Qualification_Distance)

Since a Weighted Distance of zero feet in length cannot be achieved, a CF of 0.3 is not physically possible, but only defines the lower bounds of the equation.

Returning to the 1,814 ft^2 example shown in Figure 2, the centrally located water heater had a Weighted Distance of 13.1 ft and a Qualification Distance of 23.2 ft. The following equation shows the CF this house would receive under the Expanded Credit.

$$CF = 0.3 + 0.4 * (13.1/23.2) = 0.52$$

The CF-1R would report that the plan meets the Compact Expanded Credit. The CF-2R Form CF2R-PLB-22-H would specify the required eligibility criteria for the installer and the CF-3R Form CF3R-PLB-22-H would represent the HERS verification component.

Additional Information on Qualification Distance Calculations

The Qualification Distance equations were created based on a review of 60 production builder floor plans currently available in California (from 16 builders). To create the Qualification Distance, the following steps were taken:

1. Calculate the Weighted Distance for each floorplan using the water heater location as listed on the plans.
2. Repeat the calculations, assuming a water heater optimally (i.e. central to the use points for that plan) located in the garage.
3. Create a Qualification Distance formula which passes 25% of floorplans with the externally located water heater[4], and 75% of floor plans with the relocated, central water heater.

The following three plots show the data used to create the Qualification Distance equations for 1, 2, and 3 story buildings for both standard distribution systems and recirculation loops. In each case the yellow data points represent the Weighted Distance results for the externally located water heater, the blue points for the centrally located water heater, and the red line represents the proposed Qualification Distance line. The tables after each plot show the percentage of floorplans which qualify in both the external location and central water heater locations.

[4] These 25% of plans would be considered to have plan designs with use points located closer to the water heater.

Qualification Distance for Non-Recirculating Distribution Systems

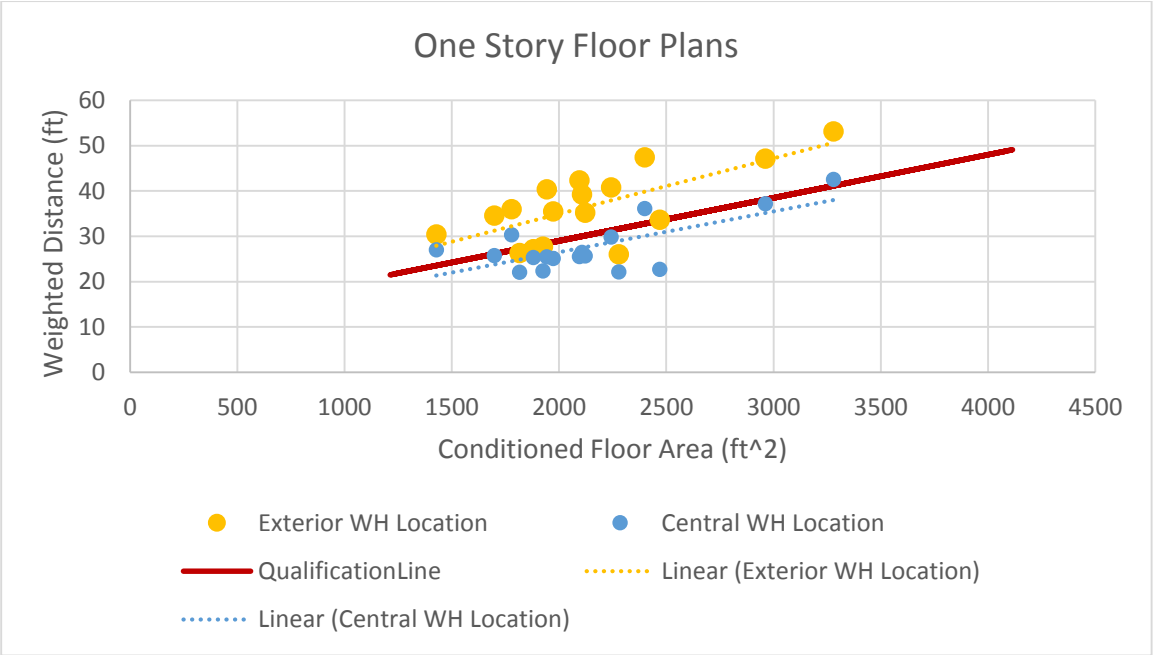


Figure 3: Weighted Distance Calculations and Qualification Distance for 1-story Homes (Non-recirculating)

Table 4: Percentage of 1-story Floor Plans that Meet the Criterion (Non-recirculating)

Water Heater Location	Passing Floor Plans (%)
External Wall in Garage	24
Central in Garage	76

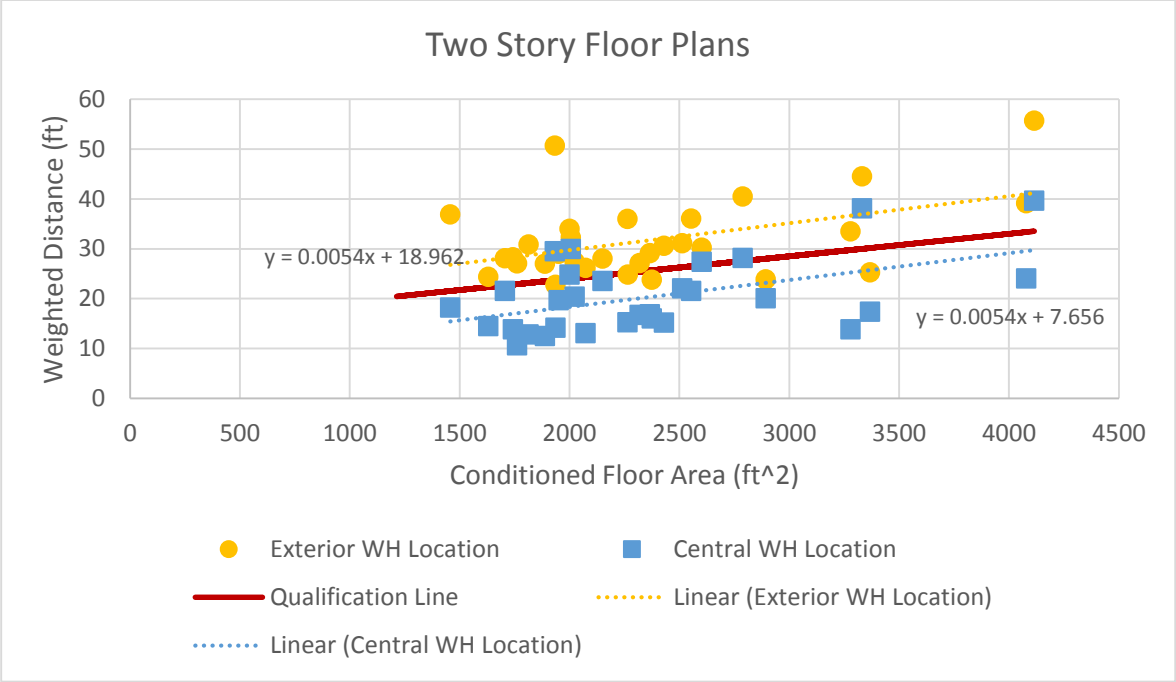


Figure 4: Weighted Distance Calculations and Qualification Distance for 2-story Homes (Non-recirculating)

Table 5: Percentage of 2-story Floor Plans that Meet the Criterion (Non-recirculating)

Water Heater Location	Passing Floor Plans (%)
External Wall in Garage	16
Central in Garage	77

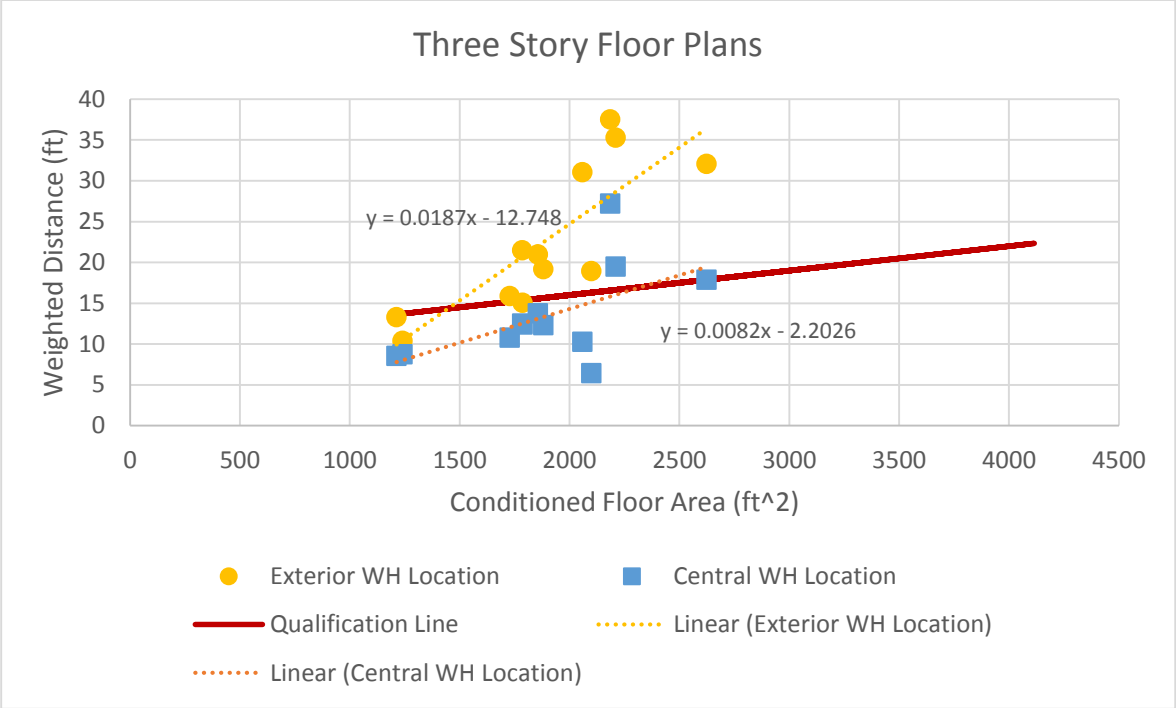


Figure 5: Weighted Distance Calculations and Qualification Distance for 3-story Homes (Non-recirculating)

Table 6: Percentage of 3-story Floor Plans that Meet the Criterion (Non-recirculating)

Water Heater Location	Passing Floor Plans (%)
External Wall in Garage	25
Central in Garage	75

Qualification Distance for Recirculation Loops

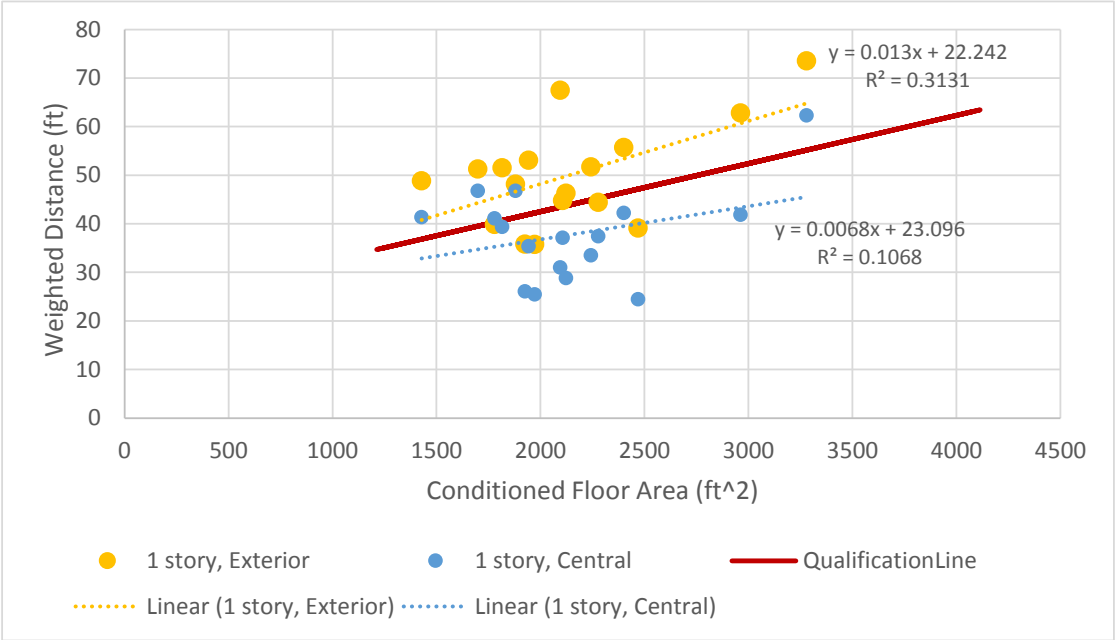


Figure 6: Weighted Distance Calculations and Qualification Distance for 1-story Homes (Recirculation)

Table 7: Percentage of 1-story Floor Plans that Meet the Criterion (Recirculation)

Water Heater Location	Passing Floor Plans (%)
External Wall in Garage	29
Central in Garage	71

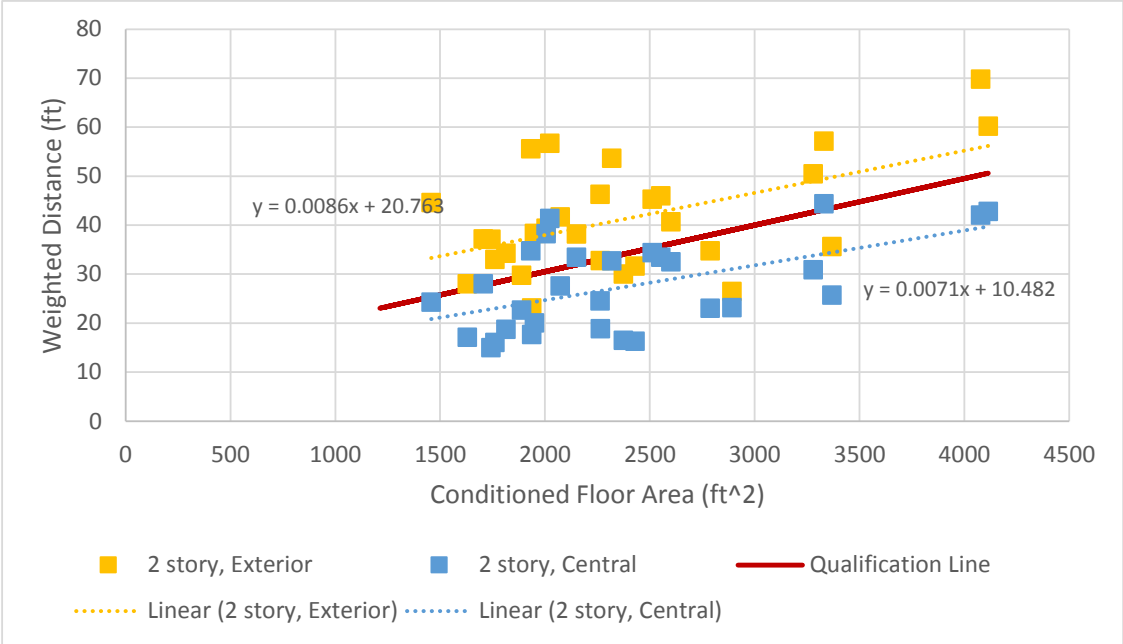


Figure 7: Weighted Distance Calculations and Qualification Distance for 2-story Homes (Recirculation)

Table 8: Percentage of 2-story Floor Plans that Meet the Criterion (Recirculation)

Water Heater Location	Passing Floor Plans (%)
External Wall in Garage	24
Central in Garage	79

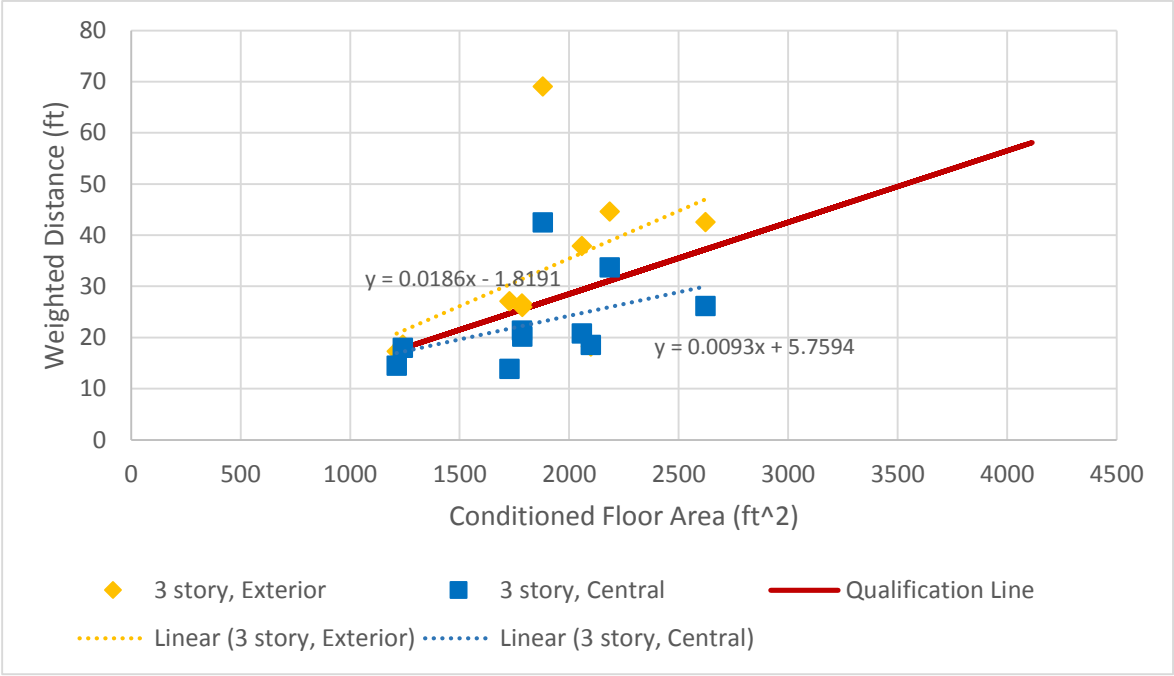


Figure 1: Weighted Distance Calculations and Qualification Distance for 3-story Homes (Recirculation)

Table 1: Percentage of 3-story Floor Plans that Meet the Criterion (Recirculation)

Water Heater Location	Passing Floor Plans (%)
External Wall in Garage	20
Central in Garage	70