APPENDIX C. INSTALLATION COST MODEL

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX C. INSTALLATION COST MODEL

C.1 INTRODUCTION

The Department of Energy (DOE) created a complex installation cost model called the "Installation Model" based on RS Means, a well-known and respected construction cost estimation method.[a] The model encompasses a broad array of product classes, installation sizes, and venting configurations:

- Non-weatherized gas furnaces, oil furnaces, gas boilers, oil boilers
- New and replacement markets
- Single and multi-family dwellings
- Venting Category: I (non-condensing), III (stainless vents), and IV (condensing)
- Vents: Masonry chimneys, lined and un-lined, type B metal, or plastic PVC
- Vent Connectors: Single wall and double wall
- Water Heater Options: Gas (vented in common w/furnace) and electric (isolated)
- Special situations: Chimney relining, and orphaned water heaters

The model establishes installation costs for all trial standard levels under consideration for the primary non-weatherized gas furnace class. Secondary classes—oil furnaces, oil boilers, and gas boilers— with appreciable vents are also included; weatherized gas furnaces and mobile home furnaces do not have appreciable vents exterior to the appliance, and therefore were not included. This appendix serves to document the model and its results, and compares it to other known installation cost data sets and assumptions. The model can be downloaded from the DOE website, www.eere.energy.gov/building.html.

Applying the RS Means methodology to a furnace or boiler installation requires its detailed description, including knowledge of vent length, venting material, vent type, diameter, number of elbows, etc. To estimate these quantities, DOE reviewed relevant literature, data, and installation manuals. Each assumption was distribution of values derived from available data, and a Crystal Ball Monte Carlo simulation[b] was used to model the resultant costs[c].

A glossary of venting terminology is provided in section C.10 of this appendix for reference.

---

[a] All cost figures for this chapter are in 2004$.
[b] See Chapter 8 for a description of the Monte Carlo simulation methodology.
[c] The model presents costs in year 2004 dollars.

C.2 DESCRIPTION OF VENTING OPTIONS AND CONFIGURATIONS

Venting costs are complex because there are a large variety of installation scenarios possible. Figure 3.2 from the 1994 GRI report[1] *Assessment of Technology of Improving the Efficiency of Residential Gas Furnaces and Boilers, Volume I* describes a decision tree for assessing installation specifics. Figure C.2.1 below recasts the GRI decision tree, and adds estimated installation frequency to the picture (the dotted and dashed box borders).

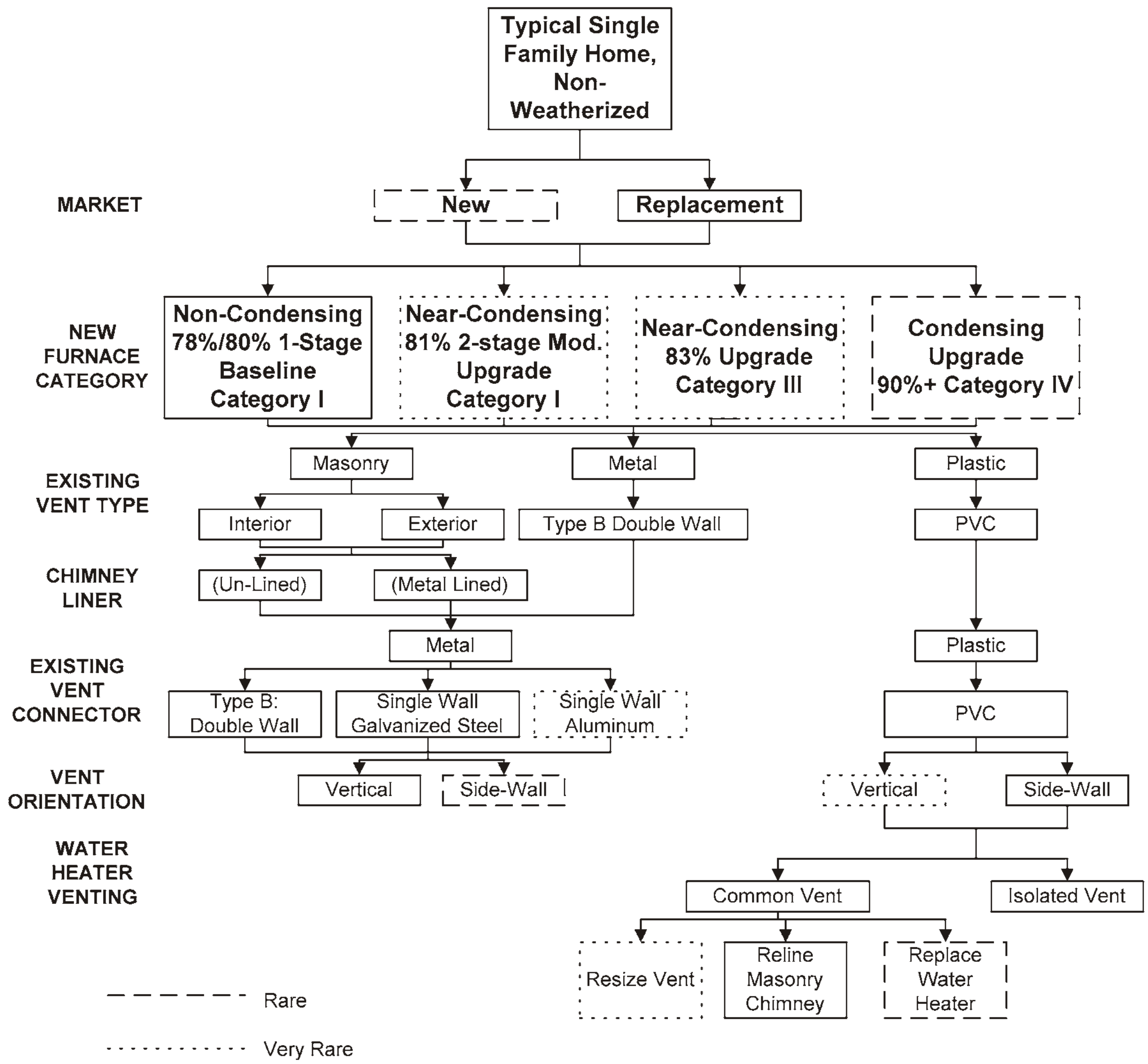


Figure C.2.1 Common Venting Options for a Typical U.S. Single Family Home

To reduce the options modeled to a manageable set, installation scenarios estimated to occur less than 5 percent of the time were not modeled (shown as very rare in Figure C.2.1). One exception is two-stage modulating 81 percent AFUE furnaces (see below).

For each appropriate combination of options above, a separate physical bill of materials was created and costed. The total cost for each trial standard level was then obtained by weight averaging the cost estimates of as many as twenty four separate bills of material. The weight averaging used depends on how often each combination occurs in the field, as documented in the 1994 GRI venting survey[1]. The following subsections describe in greater detail the installation variables and their frequency of occurrence in the field that must be considered to calculate furnace installation costs for baseline and trial standard cases.

The remainder of section 6.2.2 and section 6.2.3 of this appendix describe the Installation Model methodology using non-weatherized gas furnaces, the primary class, as an example. In sections 6.2.4 and 6.2.5 of this appendix, assumptions and results are presented for the four product classes that the Installation Model covers: non-weatherized gas furnaces, oil furnaces, gas boilers, and oil boilers.

C.2.1 Market

For non-weatherized gas furnaces, approximately 25 percent of the market is for new construction, and 75 percent is replacement (see Chapter 3, Market & Technology Assessment, of this TSD). Costs for new construction installations and replacement installations are weighted 25 percent:75 percent to obtain final costs for each trial standard level.

C.2.2 Furnace Category

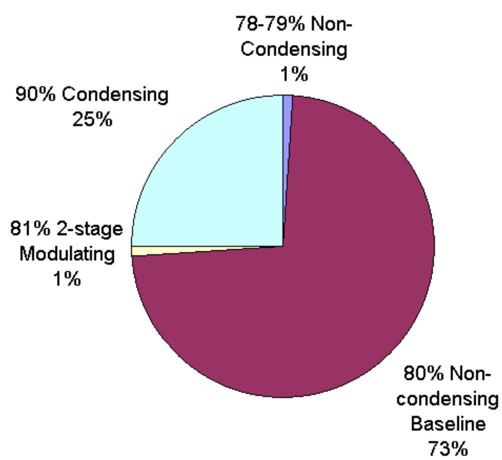


Figure C.2.2 Year 2003 Furnace Category Distribution

Figure C.2.2 is a breakdown of 2003 furnace sales volumes, showing three main furnace venting types: non-condensing, near-condensing, and condensing. These are defined by the presence or absence of acidic condensate in the vent, which has the potential to corrode the vent. If this occurs, carbon monoxide may enter the living space, presenting a safety hazard.

Non-Condensing. The NAECA baseline is 78 percent AFUE, but this represents only 1-2 percent of the current market. These "chimney friendly" furnaces are used primarily with exterior masonry chimneys. The "market majority" baseline is 80 percent non-condensing, with a 73 percent market share.

Near-Condensing. In the special case of 81 percent AFUE *two-stage* modulating furnaces, an insulating Type B vent connector is required for all installations above and beyond National Fuel Gas Code requirements (condensation of exhaust gas water vapor is less likely to occur with this added insulation). This is referred to as level 81 percent A, and has an approximate 1 percent market share. There are no appreciable *single-stage* 81 percent AFUE furnaces sales in 2004; further, no energy savings is available for this design option. It remains in the model as illustrative of the costs of using double wall vent connectors.

At the DOE Venting workshop in May 2002, the differences between steady state efficiency and AFUE were discussed in detail. It was determined for the ANOPR that if a minimum standard was set to 81 percent, 82 percent, and 83 percent AFUE respectively, 8 percent, 35 percent, and 100 percent of units in the current *single-stage* furnace population could be above 83 percent steady state efficiency. This condition is likely to cause vent corrosion and carbon monoxide leaks into the living space. It was therefore assumed that at these trial standard levels, 8 percent, 35 percent, or 100 percent of installations would shift to using a more expensive category III stainless steel vent to allow safe operation at these levels. No market sales exist at these levels; they are illustrative of the costs associated with venting near-condensing furnaces only. This is because consumers are more likely to install a condensing furnace rather than pay for an expensive (~$700) stainless steel vent.

For the NOPR, taking into account ANOPR public meeting and subsequent feedback, DOE decided not to pursue 81%, 82%, or 83% AFUE minimum efficiency standards for non-weatherized gas furnaces because the safety risks are too great. In addition, Category III venting of non-weatherized furnaces does not apply.

Condensing. All furnaces with a 90 percent AFUE or greater are aggregated together as condensing, because they all have similar installation characteristics.

In summary, three original trial standard levels were evaluated for non-weatherized gas furnaces:

C.1) 80 percent AFUE market baseline[a] non-condensing
C.2) 81 percent AFUE 2-stage modulating near-condensing
C.3) 90 percent AFUE condensing

---

[a] For the purpose of this appendix, the term "baseline" is defined as the market baseline of 80 percent AFUE. In the life-cycle cost analysis, the baseline may occur at higher AFUE levels.

C.2.3 Existing Vent Type

From Figure C.2.1, the three most common types of exhaust vents are: ~50 percent market share[1] masonry chimney (non-condensing, Figure C.2.3), ~30 percent market share Type B double wall (non-condensing, more insulating, more expensive, Figure C.2.4), and ~10-20 percent market share plastic side wall (condensing, less expensive, Figure C.2.5). Typical components are identified in the figures[2]. The purpose of the exhaust vent is to allow gas appliance combustion by-products to safely exit the domicile.

Less-efficient high temperature non-condensing furnaces use a high flue gas temperature to heat the insides of the vent above the dew point to ensure that water vapor in the flue gas does not condense; if it does not re-evaporate quickly during the furnace firing cycle, it is likely that it will corrode the vent and/or furnace, reducing vent system and/or appliance lifetime sharply (typically a small amount of condensate at cold startup is acceptable as long as it dries out quickly). More-efficient low temperature condensing furnaces purposefully condense the water vapor in a secondary heat exchanger within the furnace, increasing efficiency by reducing latent heat loss. Acidic condensate is fed to a drain, and the flue gas temperature is very low, allowing the use of less expensive plastic piping (PVC). Thus vent costs and configuration assumptions strongly affect the installation cost versus efficiency curve for residential furnaces and boilers.

Masonry Chimney. Figure C.2.3 shows a non-condensing lined-masonry chimney, venting a furnace in common with a water heater. For unlined chimneys, the flexible liner shown is not present, and a clay tile liner is used. Since the 1970s, chimney construction techniques have changed. For newer chimneys, the chimney and clay tile liner as shown is usually replaced by a masonry facade on the exterior, and a flexible metal liner inside a wooden chase on the interior (these are faster to build compared to brick by brick). If the water heater is electric (isolated)[a], the common water heater vent shown is not present.

---

[a] There are a number of water heater types that are not a gas water heater vented in common with a furnace. These include electric, gas direct side-vented, and gas power vented water heaters. In this appendix, the term "isolated" water heater is defined to include all of these possibilities, but only the most prevalent (>90 percent) option – electric water heaters – is modeled.

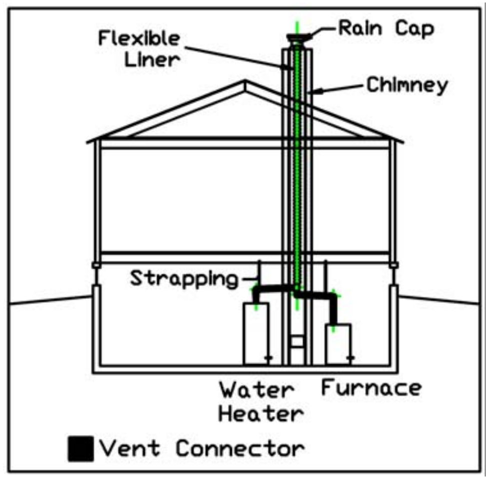


Figure C.2.3 Illustration of Lined Masonry Chimney Vented Installations

Type B Double Wall Metal. Figure C.2.4 shows a Type B double wall metal vent. The addition of wall thimbles, storm collar, and flashing replace the chimney. The jog shown for illustrative purposes is possible, but not typical; most vents go straight through the roof. If the water heater is electric (isolated), the common water heater vent shown will not be present.

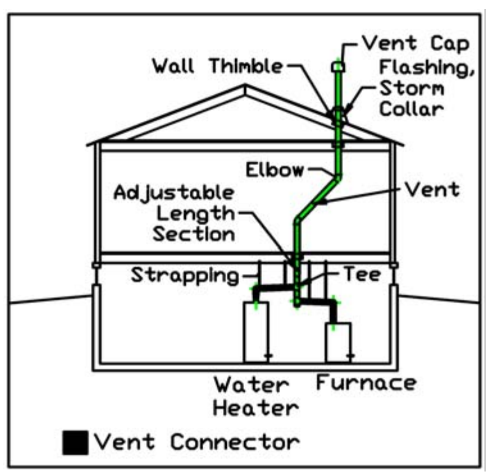


Figure C.2.4 Illustration of Type B Double Wall Metal Vented Installations

Plastic PVC. Figure C.2.5 shows a horizontal side wall plastic vent, used for Category IV condensing furnaces. For each furnace, two plastic pipes are used. One brings combustion air from the outside to the furnace, and the other vents the combustion exhaust. Exhaust piping is sloped downward toward the furnace so that condensate drips back into the furnace for collection and drainage. A companion gas water heater is shown (analogous to the common vented scenario above); only a single plastic exhaust vent is required in this case, as combustion air for the water heater is drawn from the interior of the home. If the water heater is electric (isolated), this exhaust vent will not be present.

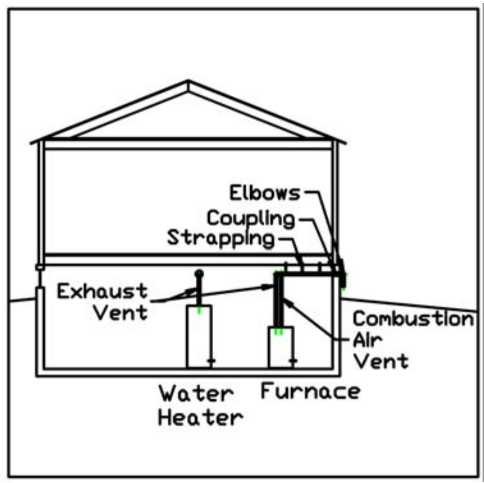


Figure C.2.5 Illustration of Horizontal Side Wall Plastic Vented Installations

C.2.4 Chimney Liner

See the above section for an illustration of a typical two-ply aluminum chimney liner, which is considered equivalent to a Type B double wall metal vent with regards to its diameter and insulating properties[a]. There are two types of masonry chimneys—interior and exterior. Exterior chimneys are exposed on three sides; because they are less insulated by the structure, the internal temperature is lower and exhaust gases are more likely to condense. Interior chimneys are surrounded by the heated building (except when the building is cold after power outages or construction first-starts); the internal temperature is higher and exhaust gases are less likely to condense. Because of these different insulating properties, the National Fuel Gas Code (NFGC)[3] has different lining requirements. These are important because the cost of chimney relining is a major component of furnace installation cost.

Exterior Chimneys. In Table 13.11 of the National Fuel Gas Code,[3] the minimum allowable input rating of appliances vented in exterior masonry chimneys is above 150 kBTU/hour, the upper limit for commonly sold residential furnaces, except for the following situations:

---

[a] In the National Fuel Gas Code[3], a two-ply aluminum liner is equivalent to a Type B double wall, except that the flexible ripples reduce the pipe's capacity by 20 percent, so sometimes larger liners are required for equivalent vent capacity as compared to Type B. For this analysis these differences are not considered material to the overall results.

- Southern Florida, 10’ or less vent height, chimney area 12-113 in^2
- Southern Florida, 15’ or less vent height, chimney area 19-28 in^2
- Southern Florida, 20’ or less vent height, chimney area 28 in^2
- Northern Florida, Southern Texas, 6-10’ or less vent height, chimney area 12-38 in^2

This is so restrictive that it is assumed that all exterior lined chimneys will require a re-lining upon replacement.

Interior Chimneys. In the electric (isolated) water heater case—furnace alone 50 percent of the time—Tables 13.3 and 13.4 of the NFGC mandate that an interior chimney be re-lined. The other 50 percent of the time—furnaces vented in common with a water heater—the vertical vent upsizing / 7X rule applies. This rule specifies that the flow area of the vertical vent shall not exceed seven times (7X) the flow area of the smallest vent connector, i.e. the water heater. Water heater vents are typically 3 inches in diameter, so an interior masonry chimney cannot exceed 49 square inches, corresponding to a 8 x 8 nominal chimney liner size. Figure C.2.6 shows a distribution of chimney liner sizes sold by a leading clay tile liner manufacturer. The most popular size is near the cut-off, and a wide variety of sizes are sold. As shown, it is assumed that the 7X upsizing rule will be violated ~70 percent of the time for the “interior chimney vented in common” case[a]. Finally, combining the “venting in common with a water heater” and the “isolated from a water heater” cases yields the result that 85 percent[b] the time, an interior chimney is required to be relined. Discussions with a few contractors indicated that this percentage is 50 percent rather than 85 percent; therefore a broad band in the sensitivity was applied.[c]

Using the 1994 GRI survey[1] for the ratio of exterior to interior masonry chimneys, it is estimated that 91 percent of the time[d] masonry chimneys will need to be re-lined in the baseline case to comply with the National Fuel Gas Code. Note also that in the NAECA baseline case, 78 percent AFUE “chimney friendly” furnaces are usually connected to exterior masonry chimneys. These will be relined 100 percent of the time when replaced with a 80 percent AFUE furnace or higher, or use the adapter offered by one manufacturer. Because the current market share of 78 percent furnaces is <1 percent, the 78 percent NAECA baseline case is therefore subsumed in the 80 percent Baseline case.

In 1994[1], 2 percent of masonry chimney furnace vents were lined. It is estimated that since then, 13 percent of chimneys have been relined in 2002, and 27 percent will be relined by 2015, the

---

[a] Current sales distribution will only approximate the existing housing stock chimney size distribution, so a relatively wide band was set on this input in the sensitivity analysis.
[b] (100%*50% + 70%*50%) = 85%
[c] Possible factors for this discrepancy include (a) consumer reluctance to pay high relining costs (b) installers are not educated on NFGC requirements and (c) the chimney size distribution assumed was too broad
[d] (Exterior + 85% Interior)/(Exterior + Interior) = (19% + (85%*29%)/(29%+19%)) = 91%

date of possible standard introduction (see section C.8 of this appendix). These weighting assumptions are reflected in the absolute installation costs of the baseline (as the percentage of existing relinings goes up, a smaller relining cost is assumed). They are important to compare to other data sources, but have a reduced impact on the incremental costs because relining costs are netted out.

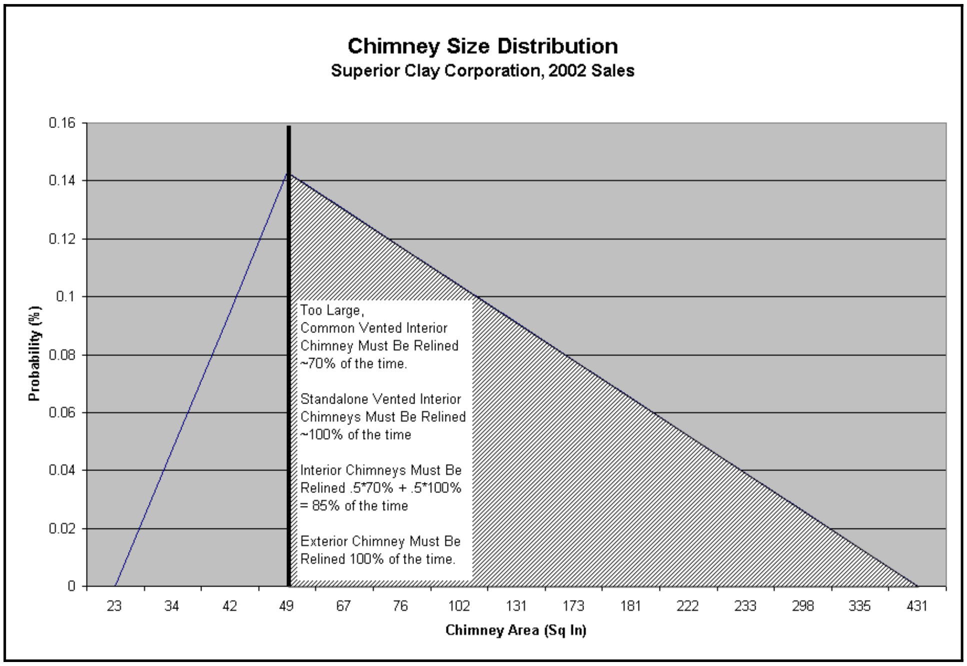


Figure C.2.6 Approximate Chimney Size Distribution: Existing Housing Stock

C.2.5 Existing Vent Connector

As indicated in Figure C.2.1, there are three main types of vent connectors possible: Type B double wall, single wall galvanized steel, and single wall Aluminum. A double wall vent is a vent that uses a galvanized steel outer tube to surround an aluminum inner tube and is sold in multiple section lengths; the air gap in-between provides insulation. This more expensive insulation reduces the likelihood of condensation in the vent connector. Single wall galvanized steel vent is simply a zinc coated steel tube vent. Aluminum single wall vent connectors are found in some regions, and are assumed to be equivalent to galvanized steel single wall vent. For condensing furnaces, the vent connector does not exist.

The vent connector portion of the vent is shown as the shaded region in Figure C.2.3 and Figure C.2.4. In each figure there are two vent connectors shown: one for the water heater, and one for the furnace. As water heater capacity is typically less than furnace capacity, it is possible that the water heater vent connector diameter will be less that the furnace vent connector diameter.

In 1994[1], single wall vent connectors were dominant (73 percent of the market), followed by double wall (16 percent) and plastic (7 percent). Since 1992, more condensing furnaces have been installed, and chimney relinings done. Assuming 2-ply chimney liners are connected to Type B vent connectors, it is estimated in section 6.2.8 that vent connector proportions will shift to 53 percent (single wall) and 36 percent(double wall) by 2015.

C.2.6 Venting Option Conclusion

In section 6.2.2.3, three common vents have been introduced—masonry chimneys, Type B metal, and plastic vents. Section 6.2.2.4 differentiates between lined and unlined masonry chimneys. For the purpose of determining incremental installation costs, baseline existing configurations are not plastic, leaving three common existing vent configurations of interest for non-codensing furnaces—unlined masonry, lined masonry, and Type B. From section C.2.5, each of these vents can be used with either a single wall or double wall vent connector, doubling the number of considered configurations. These six combinations are shown in row 3 of Table C.2.1, labeled bill of materials 1 through bill of materials 6.

Table C.2.1 Six Common Vent and Vent Connector Configurations for Non-Condensing Furnaces

Vent	**Masonry Unlined (23%)**		**Masonry Lined (27%)**		**Type B Double Wall (32%)**		**Plastic (6%)**	**Other (11%)**
Vent Connector	**Single Wall (53%)**	**Double Wall (36%)**	**Single Wall (53%)**	**Double Wall (36%)**	**Single Wall (53%)**	**Double Wall (36%)**	**Plastic (6%)**	**Other (5%)**
	BOM 1	**BOM 2**	**BOM 3**	**BOM 4**	**BOM 5**	**BOM 6**		
Configuration Weight	17%	11%	20%	13%	23%	16%		

Rows 1 and 2 of Table C.2.1 show the frequency of occurrence of each type of vent and vent connector for non-condensing furnace. To create a weighted average cost estimate, the costs for each type of vent and vent connector for non-condensing furnace are evaluated, and the weighting factors (normalized from rows 1 and 2)[a] shown in row 4 are applied using the following sumproduct formula:

$$Weighted\ Average = Row\,3(BOM\ Costs) \times Row\,4\ (WeightedFactors)$$
$$= BOM1*17\% + BOM2*11\% + BOM3*20\% +$$
$$BOM4*13\% + BOM5*23\% + BOM6*16\%$$

C.2.7 Vent Orientation

In the case of category I non-condensing metal vents, all vents are oriented vertically. Category III power vented furnaces use special stainless steel side-wall concentric vent, but these occur rarely in the case of non-weatherized gas furnaces, so they are not shown (but would look like the water heater vent shown in Figure C.2.5). For category IV condensing plastic vents, most (>95 percent) installations are sidewall. Some condensing installations use vertical vents when local or national vent codes may be otherwise violated (for instance, exhaust vents may not be near windows or an intake, or closer than 10' from the property line, etc.) This rare circumstance is not considered.

In conclusion, the most common vent orientations shown in Figure C.2.1 are therefore implicit in the three Trial Standard Levels designated in section C.2.2–80 percent Baseline (vertical), 81 percent (vertical), and 90 percent (horizontal).

C.2.8 Water Heater Venting

In the 1994 GRI report[1] field survey, Appendix G reports that approximately 50 percent of residential furnaces are commonly vented with a gas water heater, as shown in Figure C.2.3 and Figure C.2.4; this is almost equivalent to the proportion of electric:gas water heaters used in the recent water heater rulemaking.[4] The six venting configurations in section C.2.6 of this appendix

---

[a] To normalize the total weighting for each column, the following procedure was used:

(1) Exclude the Plastic and Other existing vent cases because they are not relevant to the incremental installation cost. This transforms the year 2015 estimated 23%/27%/32% Unlined Masonry / Lined Masonry / Type B percentages to 28%/33%/39% by dividing each by .83 (= 1—.06 plastic - .11 (Other)).

(2) From section C.8, the 2015 estimated single wall : double wall vent connector ratio is .53: .36. Again, the other case (Other 2.2%, Plastic 7.24%, No Data 1.7%) is excluded: Single Wall Percentage = .53 / (.89) = .62**.**, and Double Wall Percentage = .24 / (.89) = .38**.**

(3) Finally, the percentages in steps 1 and 2 above are multiplied to determine column weighting. These final column weighting results are shown in row 6. For example, 28% unlined masonry * 62% single wall = 17%. weighting for the combined option unlined masonry, single wall vent connector.

have therefore been doubled to twelve to take into account these two possibilities: (a) electric water heater (isolated) and (b) gas water heater (common vented); with a 50:50 weighting used. In addition, the special situation of orphaned water heaters can impact vent costs, so these are discussed in the next section.

Orphaned Water Heaters. Sometimes, in the case of a 90 percent+ AFUE condensing furnace replacing a (78–80 percent) non-condensing gas furnace, the existing vent will be too large for the water heater that is now the only appliance attached to it. When this happens, the water heater is stranded or orphaned. Three existing vent configurations lead to the following options:

Unlined Masonry Chimney Vents. The relining considerations outlined in section C.2.4 still apply—91 percent of the time an un-lined chimney will need to be relined. Discussions with a few installation contractors indicate that this percentage is 100 percent— contractors tend to be slightly more conservative in the case of an orphaned water heater. These relining costs are reflected in Table C.2.2, a list of orphaned water heater consumer options and predicted costs.

If the gas water heater is near the end of its useful lifetime, the consumer may elect to spend money on the purchase of a new side-wall direct vented water heater rather than a re-lining. Contractor discussions produced estimates that this occurs ~10 percent of the time; this was nominally adopted, with a broad range in the sensitivity analysis. In this case, the cost of a new concentric water heater vent is included, plus the cost difference between a direct vent and a standard vent water heater. The total cost of this option is almost the same as the purchase of a new standard water heater plus relining (see Table C.2.2). In installations where the water heater location is restricted (can't be located on a side wall due to local code or other issues), a more expensive power vented water heater is purchased with the new plastic vent. This occurs rarely (~5 percent of 10 percent), and has been discounted.

The consumer may also elect to replace the gas water heater with an electric water heater to avoid the cost of relining. Estimates of [electric water heater installation cost + electrical service installation + five year energy extra cost] costs indicate that the total is higher than the cost of relining, as shown in Table C.2.2, so this possibility has been discounted; contractor discussions are in agreement that gas to electric conversions occur very rarely.

Table C.2.2 *Orphaned Water Heater* Consumer Options (*Unlined Masonry Vents*)

Orphaned Water Heater Consumer Options	5-yr Energy Delta*	Water Heater Cost**	Water Heater Installation **	Other Costs: (Installation Model)	Other Cost Description	Total
Reline				$355	Reline	$355
New Gas + Reline		$181	$159	$355	Reline	$695
New Electric + Service	$295	$202	$159	$112	Electric Service	$768
New Gas Direct Side-wall Vented		$383	$159	$168	Concentric Direct Vent	$710
New Gas Side-wall Power Vented		$408	$159	$410	Power Vent	$978

* EIA[5]
** Water Heater Rule[6]

Type B Double Wall Metal Vent. When a common vent is initially installed, it must conform to the 7X rule (section C.2.4) so that the water heater can vent properly when it is on and the furnace is off. When the furnace vent connector is abandoned, the Type B double wall vent + water heater vent connector still conforms to the 7X rule, so no additional installation cost is necessary. Contractor discussions indicate that sometimes the double wall vent was sized incorrectly in the first place, and is re-sized to correct tthe problem. But this circumstance is rare, and is present for the baseline case also. As such, it does not affect the incremental costs and has been discounted.

Lined Masonry Chimney Vents. This is equivalent to the section on Type B double wall metal vents.

Orphaned Water Heater Summary. To summarize, for the orphaned water heater configuration, the added costs assumed are:

Table C.2.3 Orphaned Water Heater Cost Adder Summary

Existing Vent	Option	Frequency	Nominal Added Cost
Unlined Masonry	Chimney is re-lined	25%	$355
Unlined Masonry	New Direct Vent Water Heater (Vent Only)	3%	$370
Lined Masonry	No added cost	33%	$0
Type B Vent	No added cost	39%	$0

Note that in Table C.2.3, costs are nominal outputs calculated by the installation model and will vary with installation size (relining costs vary with building height).

C.2.9 Venting Configurations Summary

The preceding sections describe a large number of commonly found venting scenarios:

4 Trial Standard Levels

x 2 Markets

x 12 Vent / Vent Connector / Water Heater Configurations

96 Possible Combinations

Each possible combination corresponds to a single physical bill of materials. Because many combinations are equivalent to others, the actual number of bills of materials evaluated in the cost model is 58 rather than 96. These equivalences are discussed in the next section.

Table C.2.4 Results Table Format (Baseline Example)

Baseline Non-Condensing 80% AFUE Trial Standard Level												
Market	Vent / Vent Conn / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
		Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Plastic (6%)	Other (5%)			
Replacement (75%)	Water Heater Isolated (50%)	BOM 1 ($)	BOM 2 ($)	BOM 3 ($)	BOM 4 ($)	BOM 5 ($)	BOM 6 ($)			Sum Product	50% Baseline	75%
	Water Heater Isolated (50%)	BOM 7 ($)	BOM 8 ($)	BOM 9 ($)	BOM 10 ($)	BOM 11 ($)	BOM 12 ($)			Sum Product	50% Replace-ments	80% Baseline
New (25%)	Water Heater Isolated (50%)	BOM 13 ($)	BOM 14 ($)	BOM 15 ($)	BOM 16 ($)	BOM 17 ($)	BOM 18 ($)			Sum Product	50% Baseline	25%
	Water Heater Isolated (50%)	BOM 19 ($)	BOM 20 ($)	BOM 21 ($)	BOM 22 ($)	BOM 23 ($)	BOM 24 ($)			Sum Product	50% New	
Weighting		18%	11%	20%	12%	24%	15%					

Table C.2.4 illustrates the cost summary format and weighting procedure of the 24 bills of materials evaluated for the 80 AFUE percent baseline trial standard as an example. The weighting factors in the bottom row and two left columns are applied to calculate the weighted averages in the right three columns, progressively building up to the trial standard level weighted average at the far right as shown by the arrows.

By virtue of the above procedure, these weighting factors are important in calculating the incremental installation costs. The general approach was to start with the 1994 GRI survey[1], update the proportions from estimates of trends over the last decade, apply the same weighting factors to all trial standard levels, and run sensitivity studies on the results to study how changes in the weighting assumptions affect the results. The 1994 regional breakdown of the weighting factors also show that the weights applied vary dramatically from region to region; additional sensitivities of these variations were conducted, and are discussed in a later section.

C.3 MODEL APPROACH

For the furnace and boiler rulemaking, the focus of the installation model is to predict the absolute and incremental installation costs for a variety of trial standard levels. These costs are added to the equipment costs for further analysis of paybacks and energy savings in the LCC and NES analyses. Summary calculations of the absolute and incremental costs are illustrated in Table C.3.1 for the three original trial standard levels under consideration.

Table C.3.1 Original Results Summary

Non-Weatherized Gas Furnace **Installation Cost Summary**	**Trial Standard Level Weighted Average (WA)**	**Incremental Installation Cost ($)**
80% AFUE Baseline	80% WA	--
81%A AFUE 2-stage Modulation	81%A WA	81%A WA - 80% WA
90%+ AFUE Condensing	90%+ WA	90%+ WA - 80% WA

Figure C.3.1 (on the next page) shows the connections between the various elements of the cost model computations. First, size-related calculations are done to estimate quantities for the individual bills of materials based on installation size. The total cost for each trial standard level is obtained by weight averaging cost estimates for as many as 24 separate bills of materials. Finally, the incremental costs only used in engineering analysis are calculated by subtracting the trial standard level installation costs from the 80 percent baseline installation costs on the summary table.

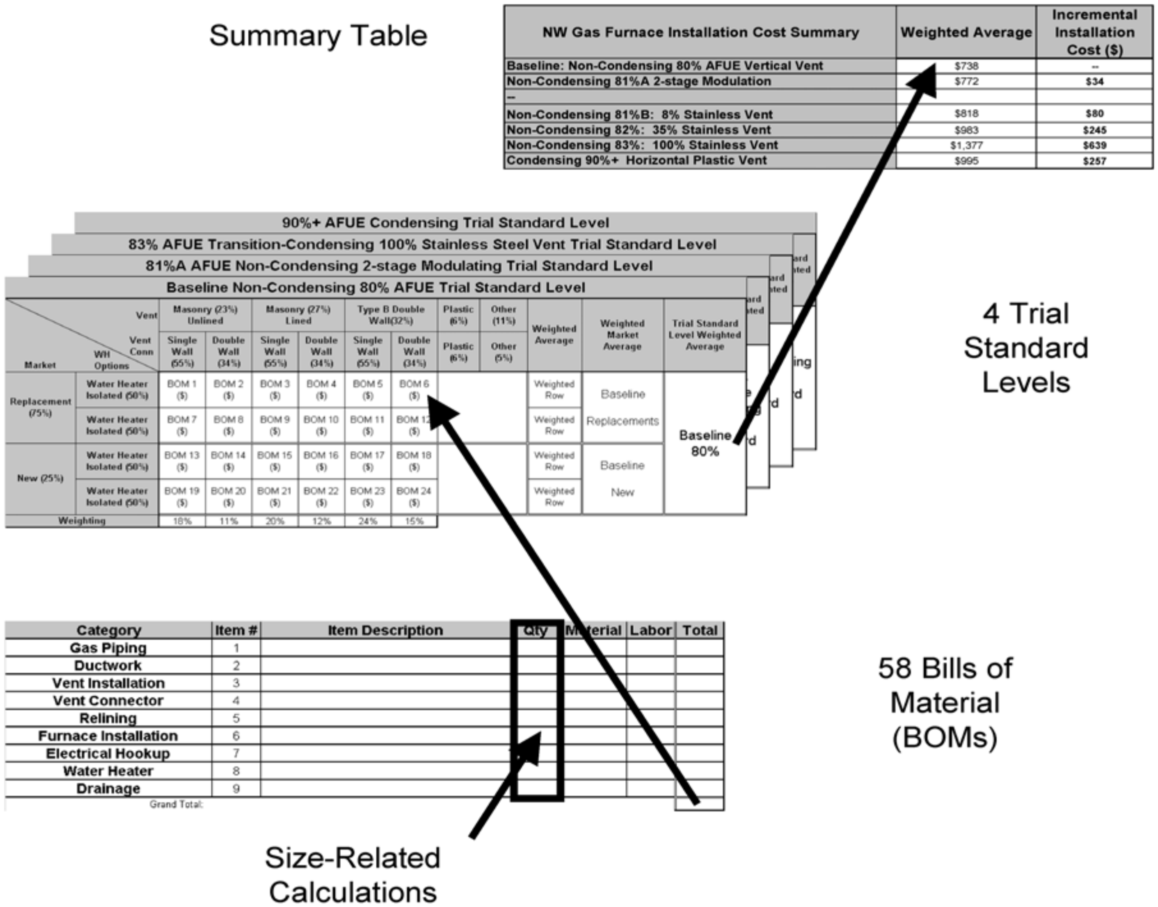


Figure C.3.1 Model Structure Overview (Illustration Only)

C.3.1 Candidate Standard Levels

In the rest of this section, the format for the four original trial standard level summary tables are described and discussed, showing the reduction in the number of bills of materials evaluated.

80 percent AFUE Baseline Non-Condensing Trial Standard Level. Table C.3.2 shows Bills of Materials 1 through 24, as previously described in an example. For new 80 percent AFUE installations, it is assumed that an unlined masonry chimney will not be built, but instead a metal-lined wooden chase and façade will be built according to current construction practice. Therefore the unlined masonry and lined masonry columns are equivalent (BOM 13=15, 14=16, 19=21, and 20=22). Also, for new installations, furnace removal labor is omitted.

Table C.3.2 Format of 80 percent AFUE Baseline Trial Standard Level Results

Baseline Non-Condensing 80% AFUE Trial Standard Level												
Market	Vent / Vent Conn / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
		Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Plastic (6%)	Other (5%)			
Replacement (75%)	Water Heater Isolated (50%)	BOM 1 ($)	BOM 2 ($)	BOM 3 ($)	BOM 4 ($)	BOM 5 ($)	BOM 6 ($)			Weighted Row	Baseline Replacements	80% Baseline
	Water Heater Isolated (50%)	BOM 7 ($)	BOM 8 ($)	BOM 9 ($)	BOM 10 ($)	BOM 11 ($)	BOM 12 ($)			Weighted Row		
New (25%)	Water Heater Isolated (50%)	BOM 13 ($)	BOM 14 ($)	BOM 15 ($)	BOM 16 ($)	BOM 17 ($)	BOM 18 ($)			Weighted Row	Baseline New	
	Water Heater Isolated (50%)	BOM 19 ($)	BOM 20 ($)	BOM 21 ($)	BOM 22 ($)	BOM 23 ($)	BOM 24 ($)			Weighted Row		
Weighting		18%	11%	20%	12%	24%	15%					

81 percent AFUE Two-Stage Modulation Near-Condensing Trial Standard Level. Table C.3.3 delineates Bills of Materials 25 through 47 for the 81 percent AFUE two-stage Modulation Near-Condensing Trial Standard Level (TSL). It is equivalent to the Baseline TSL, except for three outlined possibilities: masonry unlined w/ single wall vent connector, masonry lined w/single wall vent connector, and Type B double wall w/ single wall vent connector. In these columns the existing single wall vent connector will not be used; it will be upgraded to double wall vent connector 100 percent of the time. For new installations, labor for furnace replacement is omitted.

Table C.3.3 Format of 81 percent AFUE Two-stage Modulating Trial Standard Level Results

81%A AFUE Non-Condensing 2-stage Modulating Trial Standard Level												
Market	Vent / Vent Conn / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
		Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Plastic (6%)	Other (5%)			
Replacement (75%)	Water Heater Isolated (50%)	BOM 24 ($)	BOM 25 ($)	BOM 26 ($)	BOM 27 ($)	BOM 28 ($)	BOM 29 ($)			Weighted Row	81%A Replacements	81%A 2-stage Modulating
	Water Heater Isolated (50%)	BOM 30 ($)	BOM 31 ($)	BOM 32 ($)	BOM 33 ($)	BOM 34 ($)	BOM 35 ($)			Weighted Row		
New (25%)	Water Heater Isolated (50%)	BOM 36 ($)	BOM 37 ($)	BOM 38 ($)	BOM 39 ($)	BOM 40 ($)	BOM 41 ($)			Weighted Row	81%A New	
	Water Heater Isolated (50%)	BOM 42 ($)	BOM 43 ($)	BOM 44 ($)	BOM 45 ($)	BOM 46 ($)	BOM 47 ($)			Weighted Row		
Weighting		18%	11%	20%	12%	24%	15%					

81 percent B, 82 percent AFUE Near-Condensing Trial Standard Levels. These are 92 percent:8 percent and 60 percent:40 percent weighted averages of the 81 percent A and 83 percent (100 percent stainless steel vent) Trial Standard Levels, respectively, as described in section 6.2.2.2.

90 percent+ Condensing Trial Standard Level. Table C.3.4 illustrates the condensing trial standard level. Furnace replacements with an electric water heater (isolated) is Bill of Materials 49; the three existing furnace vents – unlined masonry, lined masonry, and type B double wall – are all equivalently abandoned in place, and a new plastic sidewall vent is installed.

The new plastic side wall vent consists of two pipes—one combustion air and the other exhaust, an estimated 90% of the time. In addition, some of the time a pump is installed in the case where a drain is not convenient to the furnace. The 1994 GRI study[1] cites 20 percent as the probability for this occurrence, but the basis is three phone calls to California contractors in 1994. Therefore 20 percent was nominally assigned, with a broad range in the sensitivity analysis.

Table C.3.4 Format of 90%+ Condensing Trial Standard Level Results

90%+ AFUE Condensing Trial Standard Level													
	Vent	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
Market	WH Options / Vent Conn	Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Single Wall (55%)	Double Wall (34%)	Plastic (6%)	Other (5%)			
Replacement (75%)	Water Heater Isolated (50%)	BOM 49 ($)								Weighted Row	90% Replacements	90% Condensing
	Water Heater Isolated (50%)	BOM 51 ($)		BOM 52 ($)						Weighted Row		
New (25%)	Water Heater Isolated (50%)	BOM 53 ($)						BOM 50 ($)		BOM 53 ($)	90% New	
	Water Heater Isolated (50%)	BOM 54 ($)								BOM 54 ($)		
Weighting		18%	11%	20%	12%	24%	15%					

Bill of Materials 50, a new condensing furnace with an electric (isolated) water heater, was calculated using Canadian assumptions for comparison purposes with the Canadian installation data. Because its weighting factor is zero, it does not factor directly into the analysis.

The orphaned water heater costs outlined in section C.2.8 are added to Bills of Materials 51 and 52. In Bill of Materials 51, masonry unlined chimneys, the water heater is orphaned 100 percent of the time; and the costs in section C.2.8 are applied: relining 90 percent of the time, and a new direct vent water heater 10 percent of the time. In Bill of Materials 52, lined chimneys or Type B vents, there are no added water heater costs– it is equivalent to Bill of Material 49.

Bill of Materials 53, new condensing furnace with an electric (isolated) water heater, is equivalent to Bills of Materials 49 and 52 above, except that the additional labor to remove the old furnace is omitted. Bill of Materials 54, the new condensing furnace installed with a common (gas) water heater, is the same as Bill of Materials 53, except it includes the vent portion of a side-wall direct vented water heater (shown in Figure C.2.5). In this case, the material cost of the new water heater vent is part of the purchase cost of the direct vent water heater. Therefore the cost differential between a direct vent and standard water heater is included[a], plus a labor cost estimate[b] of installation of the concentric side-wall vent. These costs are included to be on the same basis as the baseline, where the cost of the common water heater vent has also been included.

C.3.2 Bill of Materials Calculations

The overall results table has inputs from the results tables for each Trial Standard Level described in section C.2.1. These in turn are fed by BOM calculations 1 through 58. This section discusses how each of these BOM calculations is done. A summary of the model assumptions is given in section C.2.4 if the reader desires to skip over these finer details.

There are three steps associated with calculating a bill of material; each is considered in turn:

A) Calculate Size-Related Parameters to Determine Bill of Materials Quantities
B) Create Bill of Materials
C) Determine labor and Material Costs for each Bill of Materials line item

Size-Related Parameter Calculation. There are a number of installation specific parameters that must be estimated to determine quantities for individual bill of material line items, in order to determine costs using RS Means. These are:

Vent Connector Diameter. A literature search of most commonly sold residential (40-150 kBTU input) furnace installation manuals produced the conclusion that most residential non-condensing models are sold with a 3” diameter outlet; condensing furnaces use two 2” diameter outlets. For larger furnaces, this can increase to 4” and 3” respectively; 3” and 2” are chosen as nominal vent connector diameter assumptions.

Vent Diameter. A matrix of most commonly sold residential gas furnaces (40-150 kBTU input) combined with the most common sizes of water heaters (30-50 gallon) was developed. For each point in the matrix, and bracketing maximum and minimum typical vent heights, the National Fuel Gas Code (NFGC) was used to calculate minimum vent diameter. It is assumed that contractors will use the smallest size possible to minimize installation cost. As the most common furnace size assumed below is 80 kBTU input, 4” is selected as the nominal vent diameter size. See Table C.3.5.

---

[a] Estimates were obtained by averaging quotes from distributors for three largest water heater manufacturers
[b] Calculated by the Installation Model.

Table C.3.5 Common Vent Diameters Calculated Using the NFGC

Type B Vent Diameter			No Water Heater	Water Heater Size (kBTU)	
				30	50
Furnace Size (kBTU)	40	10' H	3"	4"	4"
		50' H	3"/NA	4"	4"
	80	10' H	4"	5"	5"
		50' H	3"/4"	4"	4"
	150	10' H	4"/5"	6"	7"
		50' H	4"/5"	5"	5"

Number of Tees and Elbows. The number of tees and elbows assumed is shown in Figure C.2.3 through Figure C.2.5. These are summarized in Table C.3.7. Not seen in Figure C.2.5, the combustion air and exhaust vents must be greater than one foot away from each other at the building exit to satisfy the NFGC. Thus the three elbows shown in are actually six. In the sensitivity analysis, pairs of two and four elbows are added to the nominal numbers shown in Table C.3.7 to account for possible jogs and obstructions (see Figure C.2.4 for an example). The NFGC requires that the installer attempt to minimize unnecessary bends (and thus elbows) in the vent system.

Table C.3.6 Nominal Tees and Elbows

Nominal Number of Tees/Elbows	Masonry Lined	Masonry Lined	Type B Metal Vent	Plastic PVC Vent
Electric Water Heater (Isolated)	0/1	0/1	1/1	0/6
Gas Water Heater (Common)	0/2	1/3	2/2	0/8

Furnace Size. In the LCC, RECS 2001 house-by-house data are used to derive the capacity of heating appliances in an existing home. From the output of LCC Monte Carlo simulations, the furnace size distribution is indicated by Figure C.3.2. The 80,000 kBTU input average is very close to the baseline capacity of 75,000 kBTU input, as recommended by GAMA.

Water Heater Vent Diameter. A review of manufacturer specification sheets of common 30-50 gallon water heaters produced the conclusion that 3" is appropriate for the nominal size of the water heater vent connector.

Distance Between Supports. The number of feet between supporting brackets for pipe runs. For plastic piping runs, RS Means specifies 3 supports per 10 feet.[7] For Type B vent or single wall connector metal pipe runs, 1 support per 10 feet was estimated.

Vent Length. To estimate vertical vent length, the following formula is used:

$$Vertical\ Vent\ Length\ (feet)$$

$$= Average Ceiling\ Height * \left((Number\ of\ Floors) + \begin{Bmatrix} 1/2\ if\ basement \\ 1/4\ if\ crawlspace \\ -1/2\ if\ slab\ on\ grade \end{Bmatrix} + \frac{1}{2} \right) + 3$$

Each of the variables in this formula and their sources are explained below.

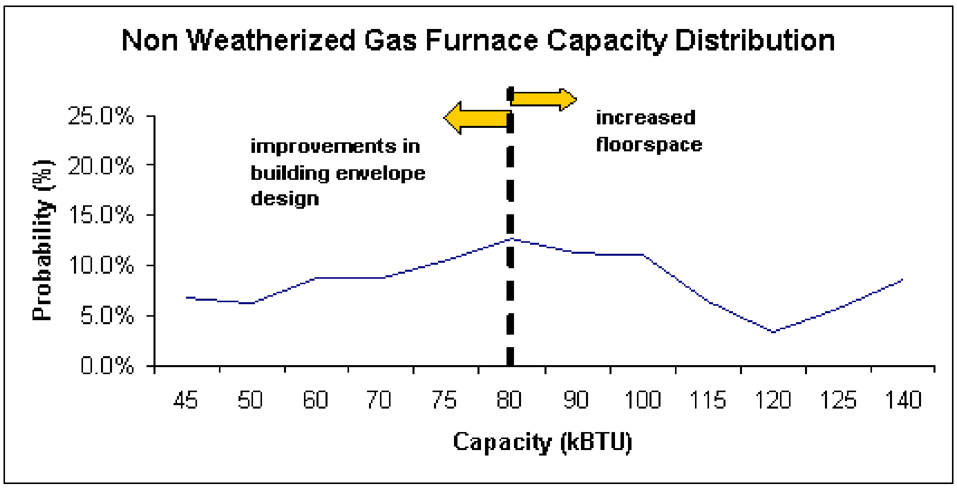


Figure C.3.2 Furnace Size Distribution

Average ceiling height: Taken from a National Association of Home Builders (NAHB), Builders Economic Council (BEC) Survey, 2001. Eight feet is the nominal value in Figure C.3.3.

Number of Floors: In the LCC, RECS 2001 house-by-house data are used to derive the number of floors, using a subset of RECS houses for non-weatherized gas furnaces (see Chapter 8). From the output of LCC Monte Carlo simulations, the number of floors is indicated by Figure C.3.4. The weighted average of this distribution is 1.6.

For the relatively rare case of multifamily dwellings greater than three floors, it is assumed that each floor will have its own furnace; thus each furnace will cost-share the multi-story vent, and a vent length of one floor is assigned to the furnace. See Figure G.1(n) of the National Fuel Gas Code.[3]

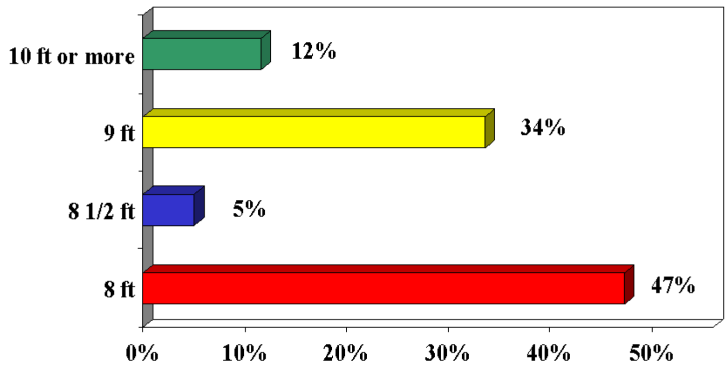


Figure C.3.3 Average Ceiling Height

Basement Distribution: U.S. Census housing statistical abstracts provide current basement configuration information, shown in Figure C.3.5. Presence of a full basement is chosen as the nominal value, with a broad distribution.

The *(½ if basement, ¼ if crawlspace, -½ if slab on grade)* factor estimates the vent length in the basement, as shown in Figure C.2.5.

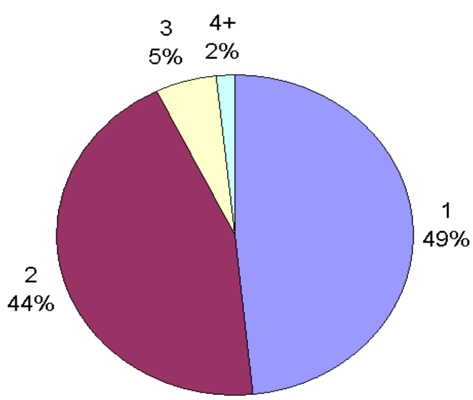


Figure C.3.4 Number of Floors in a Dwelling

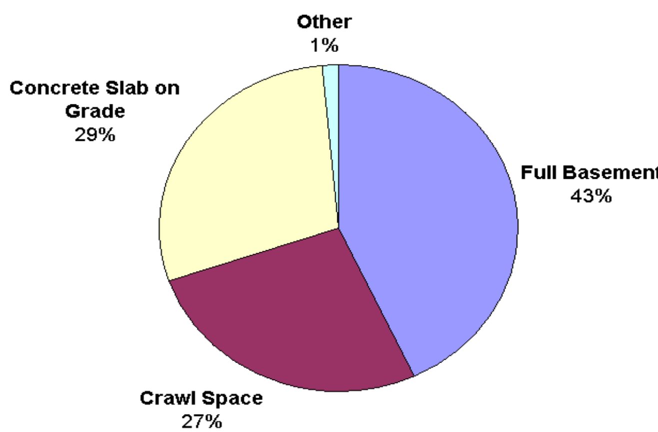


Figure C.3.5 Basement Types

The *½ factor* at the right of the equation estimates the height of the attic, and the *+3* represents a nominal estimate of the extension of the vent over the roof line. These last two factors will vary with roof pitch and vent location (whether the vent is at the center of the domicile or on the edge).

Thus the minimum vertical vent length is for a single story, slab on grade, 8' ceiling house: 8*(1-1/2+1/2)+3 = 11 feet. The maximum vertical vent is for a 3 story w/basement, 10' ceiling house: 10*(3+1/2+1/2)+3 = 43 feet. The nominal average vertical vent height is for 1.6-story w/basement, 8’ ceilings: 8*(1.6 + 1/2 + 1/2)+3 = 24'.

For horizontal side wall venting, it is more difficult to estimate appropriate lengths. The average minimum length is 1/2*average ceiling height + 3' (to exterior wall) + 2'(L on exterior) + 1’(pipe jog to meet code), or ~ 10 feet. The average and average maximum length is estimated by using a series of nested assumptions. These are:

a) Calculate typical house cross sectional area from RECS data on living area combined with the number of floors.
b) Calculate the maximum corner to corner diagonal length by assuming a 1:1 to 3:1 house length : width ratio.
c) Assume the horizontal maximum will be 1/2 the maximum diagonal wall length, and the nominal average horizontal will be approximately 3/4 this length (with a broad distribution).
d) Add 1/2*average floor height (to ceiling) + 2’ (L on exterior) + 1’(pipe jog).

Assumption (a). 2001 RECS LCC data are available for the # of floors, as shown in Table C.3.7. An example of the RECS living area distributions is shown in Figure C.3.6; all others are similar, approximately uniform, distributions. These uniform distribution size ranges are shown in Table C.3.7 as a function of the # of floors for the non-weatherized gas furnace (NWGF) class.

Table C.3.7 Assumed Living Area Square Feet Ranges (NWGF)

# of Floors	**Minimum square feet**	**Maximum square feet**
1	531	3,918
2	520	5,110
3	367	5,264
4+	894	1,602

To calculate cross sectional area, we use the following formula:

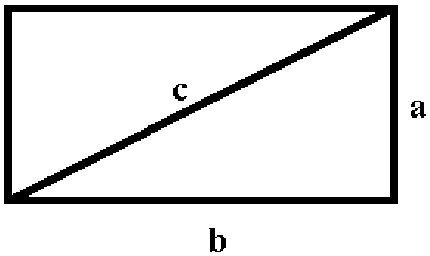
$$Cross\ Sectional\ Area = \frac{Living\ Area}{Number\, of\ Floors} = \frac{1659}{1.6} = 1036\ sf\ (\text{nominal})$$

Nominal cross sectional area is 1036 sf, based on the median value of 1.6 floors.

Assumption (b). A top view cross section of a building, and the formula for the maximum possible diagonal, is:

Assumption (c) and (d). Finally, the following formula is used to calculate the average horizontal vent length:

$$\textit{Avg Horizontal Vent Length (feet)} = .75\ \textit{nominal}(0 -> 1\ \textit{range}) * \textit{Max Diagonal} + \frac{\textit{Avg Ceiling Height}}{2} + 2' + 1'$$



$$\textit{Maximum Possible Diagonal} = \frac{c}{2} = \frac{\sqrt{\left(\frac{\sqrt{Area}}{L/W}\right)^2 + \left(L/W * \sqrt{Area}\right)^2}}{2}$$

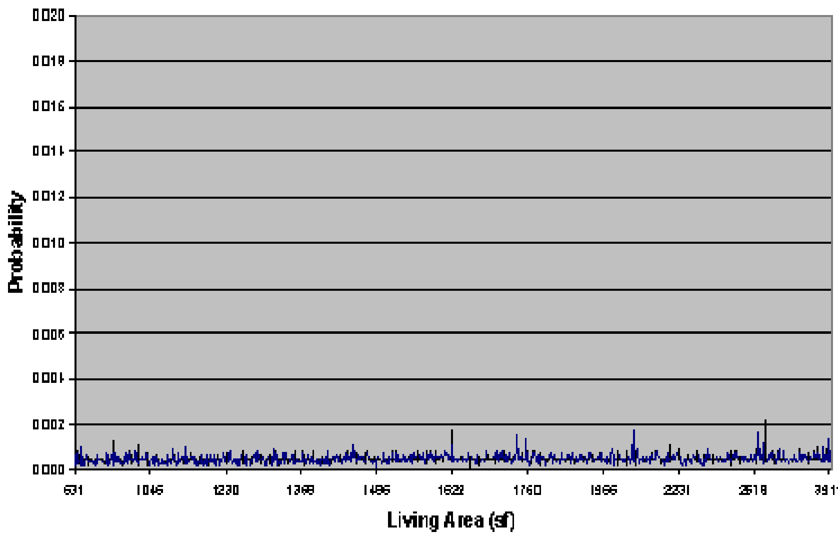


Figure C.3.6 NWGF, 1-Floor Living Area (LCC 2001 RECS)

For the most common living area of 1659 sq ft (median value from Table C.3.8), 1.6-floors, 1:1 L/W, 8' ceilings, the above formula calculates the nominal average horizontal vent length as 22'. This confirms contractor estimates that the average horizontal run length is approximately equal to the average vertical run length (A 1.6 story nominal vertical vent is 24').

Vent Connector Length. For vertical venting, the vent connector rise is already included in the vent length. A minimum run is 1', or a single pipe section. The NFGC specifies a maximum run of 100 percent of the vertical vent length. For the average horizontal length of the vent connector, the following industry rule-of-thumb[2] was used:

*Horizontal Vent Connector Length (feet) = 1.5 Feet * Vent Connector Diameter (inches)*

From the 3" nominal assumption in (1) above, the nominal horizontal vent connector length is 4.5 feet.

Create Bill of Materials (BOM). Once the above parameters and quantities are known, the components shown in Figure C.2.3, Figure C.2.4, and Figure C.2.5 can be compiled to create a bill of materials for a particular installation scenario. The "master" bill of material shown in Table C.3.8 lists what is included in the cost estimates for *all* installation configurations, i.e. items are turned on or off depending on configuration. The bill of materials is a composite based on relevant trade literature, installation manuals, and furnace-installation-related line items found in RS Means (2003 Residential & Mechanical Cost Data).

Table C.3.8 Master BOM: Includes All Installation Configurations

Category	Item #	Item Description
Gas Piping	1	1/2" dia gas pipe
	2	Ground-joint union (gas pipe)
Ductwork	3	Return & Supply Ductwork -- furnace transitions, galv steel
Vent Installation	4	Vent chimney, double wall, type B, 4 inch Diameter, Liner, or PVC pipe
	5	Type B or PVC, Elbows, 4 inch Diameter
	6	Type B Adjustable Length piece to 12in, 4 inch Diameter, or PVC couplings
	7	Wall Thimble, 4-7in Adjustable, 4 inch Diameter
	8	Roof Flashing, 4 inch Diameter
	9	Tee & Tee Cap, 4 Inch Diameter
	10	Top, 4 Inch Diameter
	11	Chimney Chase Structure
Vent Connector	12	Chimney vent, type B, 3 inch Diameter
	13	Type B, Elbows, 3 inch Diameter
	14	1/2 in wide galv steel strapping
Relining	15	Flexible 2 ply Al Liner w/flash, cap, mortar collar 4 in Dia"
	16	Connector
Furnace Installation	17	75 MBH furnace-- site & connect
Electrical Hookup	18	Thermostat hookup, low voltage wire, heat + cool
Water Heater	19	Orphaned:Replacement Water Heater Vent Adder
	20	Chimney vent, type B, 3 inch Diameter, or PVC pipe
	21	Type B or PVC, Elbows, 3 inch Diameter
	22	1/2 in wide galv steel strapping
Drainage	23	Condensate hose-- SDR15, 3/4 inch diameter
	24	Condensate Pump

Gas Piping: a union and single pipe section needed to attach the furnace to an existing (replacement) or assumed-to-be-part-of-construction (new) gas supply.

Ductwork: It is assumed for all installations that the return and supply air ducting costs are part of new construction or previously existing installations and are therefore not included. One return and one supply duct transition piece is included in the estimates to connect the furnace to the ducts.

Vent: A double wall type B vent, a liner vent in a wooden chase, or a plastic vent.

Vent connector: Furnace vent connector for Type B and masonry lined installations.

Relining: For cases where a masonry chimney is relined with a flexible liner.

Furnace Installation: Installation and hookup labor, including testing and adjustments. Also includes the cost of removing an old furnace in replacement installations.

Electrical Hookup: It is assumed that a thermostat is included in the installation of a new furnace, and will be replaced for a replacement installation. The labor to run the thermostat wiring is also included in all cases.

Water Heater: For common-vented water heaters, the water heater vent connector cost is included here. If the water heater is orphaned, and replaced rather than relined, the new replacement vent is in the "Orphaned: Replacement Water Heater Vent Adder" line item.

Drainage: For condensing furnaces, excess condensate must be deposited in a drain. In some cases, a drain does not exist close to the furnace and must be pumped through a hose to a remote drain. An additional outlet wired to the furnace junction box will be necessary to connect the pump. In some installation, the pump, outlet, and condensate drain hose. Contractor discussions indicate that condensate neutralizers do not need to be included because most local codes do not require neutralization of the weakly acidic condensate[a]. Drip pans are required by code an estimated 40% of the time.

Auxiliary Indirect Materials: sealants, duct tape, PVC adhesive, fasteners, etc. These minor cost components are assumed to be part of overhead and are therefore not listed in Table C.3.8.

Labor and Material Costs for Each BOM Line Item. For each of the line items shown in Table C.3.8, an estimate of labor and material costs was made to find the total installation cost for a particular installation scenario. From past experience, RS Means material cost estimates tend to be high, so for each of the above line items, material costs were found by getting quotes from two national distributors—Grainger and McMaster—and specialty supply houses (for Type B vent, etc.) In most cases, list prices were found; typical contractor discounts range from 25 percent—35 percent off of list price (most installers are relatively low volume operations). The contractor usually marks up purchased materials before selling them to their customer. We assumed a 10 percent markup, yielding a 15 percent-25 percent discount off of list prices for component costs.

It is expected that the quantity of necessary gas piping (or flexible connector in Earthquake-prone localities), duct transitions, thermostat wiring, auxiliary indirect materials, inclusion or exclusion of a new thermostat, etc., will vary among installations. Because these do not necessarily vary with efficiency, a nominal estimate of the cost of these quantities is held constant across all installations cost modeled. Therefore they will not affect the output incremental installation costs.

---

[a] See also "Condensing Furnaces: Lessons from a Utility" by Jonathan Beers, Home Energy Magazine Online Nov/Dec '94.

RS Means provides labor hour estimates on a per piece or per linear foot basis for each of the line items shown in Table C.3.8. Line items are assigned a labor crew, and (labor + overhead) $/hour rates are given in Table C.3.9. Note that the labor hours used in RS Means are crew hours, and the labor rates are crew rates; to calculate hourly labor rates it is necessary to divide by the number in the crew.

Table C.3.9 2003 RS Means Crew Labor Rates

Crew	**Crew Labor Rate ($/Hour) incl. O&P**
1 Electrician	$47-$52
1 Plumber	
Q-1 Plumber + Helper	
Q-9 Sheet metal worker + Helper	
Q-10 Pair of Sheet-metal Workers + Helper	

The total line item costs were calculated using the following formula:

$$\begin{aligned} Total\ Line\ Item\ Cost &= List\ Price * (1 - Contractor\ Discount + Contractor\ Markup) + \\ &Qty\begin{bmatrix} \#\ feet \\ or \\ \#units \end{bmatrix} * Crew\ Hours \begin{bmatrix} per\ feet \\ or \\ per\ unit \end{bmatrix} * Crew\ Labor\ Rate(\$/\ Hour\ incl.\ O\ \&\ P) \end{aligned}$$

In some cases, RS Means did not contain a one to one match for the needed line item, and a proxy was substituted. For instance, chimney flexible liner is not found in section 15500, “Breechings, Chimneys, & Stacks”; flexible aluminum duct from section 15810 was substituted. These substitutions are listed in Table C.3.10.

Table C.3.10 RS Means Substitutions

Substitution	**For**	**Comment**
U-hook support (15060 300 4720), .083 hours each	Strapping support labor for metal vents	Strapping not listed
Submersible pump (15418 940 7100), 1.3 hours	Condensate pump installation labor: Simplex condensate return system 3/4hp 15 GPM (15180 300 2020), 8.9 hours	Condensate pump system listed too large and complex; labor times unrealistic
Assumed 1' foot each for supply and return, 16"x20" duct, 26 Ga steel, 15% waste. From RS Means technical note R15810-050, this is 5 lbs/linear foot, or 5*2*1.15 =11.5 pounds of steel	Duct material quantity	Proxy for necessary modifications to the existing/new ductwork needed to connect the supply and air return ducts to the furnace.
Flexible Aluminum Duct, Non-insulated, (15810 600 2830)	2-ply Aluminum Chimney liner labor	Chimney liners are installed from the roof: 15810 600 0052, added labor for elevated installation was included.
Type B Elbow, (15550 440 0950)	Liner/Type B Adapter labor	Adapter not listed
Simulated brick chimney top, 4' high, 16"x16", (10305 100 1100)	Construction of wood chimney chase for new masonry installations	Needed for apples to apples comparison of new masonry versus Type B vent
Substitution	**For**	**Comment**
Concrete Hole Drilling (16132 260 0160), 8" wall	*40% to obtain wood wall penetration + sealing labor time for plastic vents	Wall thimble time for metal vents include penetration
Oil Boiler Installation Labor Time Proxy (15500 500 7xxx)	Gas Boiler Installation Labor Time (15500 400 3xxx) Listed installation times are too high for residential applications.	Per conversations with Mel Marsden, RS Means Co., 6/11/03. RS Means is reviewing the numbers and will issue a correction in the distant future.

C.4 MODEL ASSUMPTIONS SUMMARY

In the previous sections, a large number of assumptions were detailed that apply to furnace installations inside a typical U.S. home. These are summarized for non-weatherized gas furnaces below:

C.4.1 Venting Options

- Category I vertical vents, and Category IV sidewall vents
- Aluminum single wall vent connectors – assumed equivalent to steel single wall

- Vertical Category IV condensing plastic vents – occurs rarely, not modeled

C.4.2 Weighting

- New/Replacement: 25 percent/75 percent—Residential Furnace & Boiler Marketing Analysis[8]

- Water Heater Common: 50 percent—1994 GRI survey[1] confirmed by the 2001 water heater rule.[4]

- Vent Distribution in 2015: 9 percent Exterior Masonry, 14 percent Interior Masonry, 27 percent Lined Masonry, 32 percent Type B, 18 percent Other [1994 GRI survey modified to take into account relinings between 1992 and 2015, see section 6.2.8]

- Vent Connector Distribution in 2015: 53 percent/36 percent/11 percent Single Wall/Double Wall/Other [see section 6.2.8]

C.4.3 Probabilities

- Masonry Chimneys will need relining 90 percent of the time in all cases to comply with the NFGC.

- Condensate pumps will be required 20 percent of the time when condensing furnaces are installed. Drip pans will be required an estimated 40% of the time.

- Orphaned Water Heater: If a furnace + water heater are vented commonly in a masonry chimney, the water heater will be orphaned 100 percent of the time; in this case the chimney will be relined 90 percent of the time, and the water heater replaced (with a new direct vent water heater) 10 percent of the time. Otherwise, there are no added orphaned water heater costs.

- Additional jogs (see Figure C.2.4) are estimated to be required 15 percent of the time to circumvent obstructions – Two extra elbows 10 percent of the time, and 4 extra elbows 5 percent of the time.

- 10% of the time, a combustion air pipe will be omitted for a condensing installation.

C.4.4 Size-Related Parameters

- Vent Connector Diameter: 3” Non-condensing, 2” Condensing

- Vent Diameter: 3-5”, nominal 4” for non-condensing; 2” for condensing.

- Number of Elbows: 1-3 Non-condensing, 6-8 Condensing, see Table C.3.6.

- Furnace Size: 40-150 kBTU input, 80 kBTU nominal. See Figure C.3.2 (LCC 1997 RECS data).

- Number of stories: 1-4, 1.6 nominal

- Water Heater Vent Diameter: 3”

- Number of feet between supporting brackets: 3 or 1 per 10’, plastic or metal pipe runs respectively.

- Vent Length + Vent Connector Rise: 27’ nominal if vertical vented, 20’ nominal if side wall vented.

- Vent Connector Run: 4.5 feet

C.4.5 Material

- 1’ each of return and supply ducting are included

- Thermostat replacement included

- 1’ of supply gas piping + union included

- Indirect materials --- sealants, fasteners, etc. are excluded (part of overhead)

- Current quotes on all materials

- When a vent connector is re-used, 2’ of pipe is added as a proxy for the appliance connector

- All material components are CPI adjusted from 2003 to 2004 dollars.

C.4.6 Financial

- Contractor Discount: 25 percent

- Contractor Material Markup: 10 percent

- Crew Rates: Average 49 $/Hour in 2003 including overhead and profit, CPI adjusted from 2003 to 2004 dollars.

- Labor Times: RS Means, including substitutions delineated in Table C.3.11

C.4.7 Gas Boiler Assumptions

The assumptions above are used for the gas boiler class, with the following exceptions:

1) Regional weighting was changed for vent connector type, vent type, and percentage of water heaters vented in common from a national 2015 projection to a 15 percent Midwest/15 percent Northwest/70 percent Northeast 2015 projection.
2) New/Replacement market weighting was changed from 25 percent/75 percent to 5 percent/95 percent.
3) Vent and vent connector diameters were increased by 1" to allow for larger capacity flows (based on installation manual reviews).
4) Appliance capacity was shifted to reflect 2001 RECS data and larger size equipment.
5) Labor times for gas boilers, as listed in RS Means, are too high when compared to oil boilers and oil furnaces, per conversations with Mel Marsden, RS Means Co., 6/11/03. As a proxy, oil boiler installation times are used. RS Means is reviewing the numbers and will issue a correction in the distant future.

C.4.8 Oil Furnace Assumptions

For the oil-fired furnace class, the non-weatherized gas furnace assumptions were modified to include the following changes:

1) Regional weighting was changed for vent connector type, vent type, and percentage of water heaters vented in common from a national 2015 projection to a Northeast 2012 projection.
2) New/Replacement market weighting was changed from 25 percent/75 percent to 5 percent/95 percent.
3) Vent and vent connector diameters were increased by 1" to allow for larger capacity flows (based on installation manual reviews).
4) Appliance capacity was shifted to reflect 2001 RECS data and larger size equipment.
5) Type L stainless steel relinings must be applied an estimated 10 percent of the time
6) Type L vents must be used rather than Type B.

Note that the model assumes that at progressively higher AFUE levels, up to 85 percent AFUE when the probability is 100 percent, that the consumer will have to replace the existing lining system (type L 300 or 400 series stainless) with a more corrosion resistant AL29-4C stainless steel Type L vent. At these near condensing levels – that partially condense and dry out – AL29-4C is able to better withstand the effects of extremely corrosive sulfuric acid.

C.4.9 Oil Boiler Assumptions

The Installation Model was modified to estimate venting costs for oil-fired boilers. These modifications include:

1) Regional weighting was changed for vent connector type, vent type, and percentage of water heaters vented in common from a national 2015 projection to a Northeast 2015 projection.
2) New/Replacement market weighting was changed from 25 percent/75 percent to 5 percent/95 percent.
3) Vent and vent connector diameters were increased by 1" to allow for larger capacity flows (based on installation manual reviews).
4) Appliance capacity was shifted to reflect 2001 RECS data and larger size equipment.
5) Type L stainless steel relinings must be applied an estimated 10 percent of the time
6) Type L vents must be used rather than Type B.

Similar to oil fired furnaces, it is conservatively assumed that at 87 percent AFUE all installations will need to be upgraded to AL29-4C stainless.

C.5 MODEL RESULTS

The total cost for each trial standard level is obtained by weight averaging cost estimates for as many as twenty four separate bills of material. For the three original standard levels-- 80 percent, 81 percent, and 90 percent-- the total possible number of bills of materials is seventy two. Because some venting configurations are equivalent to others, a total of fifty eight separate bills of material are costed in the model to account for all common venting configuration combinations. In an average US home, the final results of these combinations for non-weatherized gas furnaces are shown in Table C.5.1:

Table C.5.1 Overall Results for Non-Weatherized Gas Furnaces

Non-Weatherized Gas Furnace Installation Cost Summary	Weighted Average	Incremental Installation Cost ($)
78% NAECA Baseline*	$760	---
80% Market Baseline	$764	$4
81% 2-stage Modulation	$799	$35
90%+ Condensing	$999	$235

* The Installation Model was created using common venting scenarios, including the prevalent 80 percent market baseline. It was subsequently realized that the 1 percent of the population now using "chimney friendly" 78 percent AFUE furnaces would need to pay ~$380 to reline their chimneys to conform with an 80 percent minimum efficiency standard. This is a .075 (replacement market) X 1% x $380 = $4 difference. Alternatively, one manufacturer sells an adapter kit for these furnaces to avoid relining. Otherwise, the NAECA and market baseline are identical and are used interchangeably.

Detailed absolute cost breakdowns of these results are contained in section 6.2.9.

For each "Market x Water Heater Option x Vent x Vent Connector" combination shown in section C.9, the difference between the 81 percent, and 90 percent AFUE trial standard level installation cost and the 80 percent AFUE baseline can be calculated. These relative installation costs are discussed below. An incremental (as opposed to absolute) view of the results allows a better understanding of how the incremental costs are affected by the weighting factors applied, and reduces the effect of baseline cost assumptions.

C.5.1 81 percent AFUE Two-stage Modulation Relative Cost Breakdown

Figure C.5.1 shows a breakdown of the incremental costs for the 81 percent trial standard level. The $22 at the upper left was calculated by subtracting the costs of the Baseline "Replacements electric (isolated) water heater unlined masonry single wall vent connector" scenario ($824 in Table C.9.1) from the 81 percent "Replacements electric (isolated) water heater unlined masonry single wall vent connector" scenario ($846 in Table C.9.2). All other cells were calculated similarly, and the weighting factors were applied to result in a final delta of $34, matching the result in Table C.5.1.

In Figure C.5.1, the double wall vent connector columns are not affected by the requirement to upgrade to Type B double wall vent connector, resulting in zero deltas for columns 4, 6, and 8. There are three relevant clusters. In cluster 1 – masonry lined or Type B single wall vent connector replacements – the single wall vent connector must be upgraded to type B double wall, so the cost incremental is the cost of a full length double wall vent connector minus the cost of an appliance connector in the baseline. In cluster 2 – masonry unlined single wall vent connector replacements – the chimney is relined 91 percent of the time for both the baseline and 81 percent case. The baseline costs reflect a full single wall vent connector (+water heater vent connector if present); the 81 percent case reflects a full double wall vent connector (+water heater vent connector if present). For the 10 percent of the time the vent is not relined, cluster (1) costs apply. Finally, in cluster 3 – single wall vent connector new installations – the difference between a full double wall vent connector and a full single wall vent connector are applied. With the impact of weighting, a total incremental cost of $35 results.

(2) 100% full DW vent connector minus 91% full SW vent connector

(1) full DW vent connector minus 2' of SW; water heater vent connector is re-used

	Existing Vent --->	Masonry (23%) Unlined; 9% won't need relining		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average
	Existing Vent Connector --->	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)	
Non-Condensing 81%A 2-stage Modulation Replacement Delta										
Replacement	Water Heater Isolated (50%)	$23	$0	$88	$0	$88	$0	X		$42
	Water Heater Common (50%)	$41	$0	$88	$0	$88	$0			$45
Weighting		17%	11%	20%	13.2%	23%	16%			$43
Non-Condensing 81%A 2-stage Modulation New Delta										
New	Water Heater Isolated (50%)	$20	$0	$20	$0	$20	$0	X		$12
	Water Heater Common (50%)	$20	$0	$20	$0	$20	$0			$12
										$12
									81%A Incremental Cost, Weighted 75%/25% :	$35

(3) 100% * [full DW vent connector minus full SW vent connector]

Figure C.5.1 81 percent: Breakdown of Installation Cost Deltas (81 percent-80 percent)

C.5.2 90 percent+ AFUE Condensing Relative Cost Breakdown

Figure C.5.2 shows a breakdown of the incremental costs for the 90 percent trial standard level, and five relevant clusters. In cluster 1—masonry lined or Type B double wall replacements—an additional plastic vent and condensate pump is added to vent and drain the new condensing furnace. In cluster 2—masonry unlined replacements with an orphaned water heater—the costs in cluster (1) are added to the cost of relining the flue for the orphaned water heater; 10 percent of the time, the consumer will replace the water heater instead of relining at similar costs. In cluster 3—electric (isolated) water heater masonry unlined replacements—the costs of cluster 1 are offset by the relining that is required in the baseline. In cluster 4—electric (isolated) water heater new installations – the plastic vent is less expensive than a metal vent. Finally, in cluster 5—gas (common) water heater new installations—these savings are mitigated by the cost of a new direct vent for the gas water heater. With the impact of weighting, a total incremental cost of $235 results.

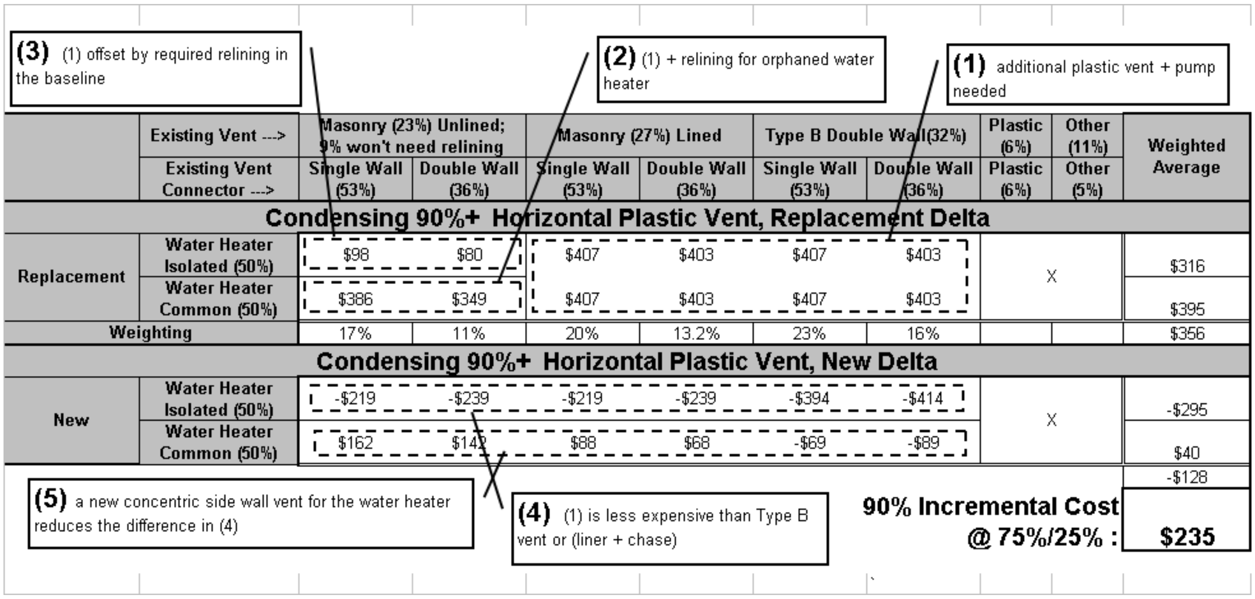


Figure C.5.2 90 percent: Breakdown of Installation Cost Deltas (90 percent - 80 percent)

C.5.3 Gas Boiler Model Results

The results for the Gas Boiler class are shown in Table C.5.2:

Table C.5.2 Overall Results for the Gas Boiler Class

Gas Boiler Installation Cost Summary	Trial Standard Level Weighted Average	Incremental Installation Cost ($)
Baseline: Non-Condensing 80% AFUE Vertical Vent	$1,520	--
Non-Condensing 83%: 26% Stainless Vent	$1,834	**$314**
Non-Condensing 84%: 24% Stainless Vent	$1,809	**$290**
Non-Condensing 85%: 55% Stainless Vent	$2,184	**$664**
Non-Condensing 86%: 100% Stainless Vent	$2,727	**$1,208**
Condensing 90%+	$2,149	**$629**

C.5.4 Oil Furnace Model Results

The results for the Oil Furnace class are shown in Table C.5.3:

Table C.5.3 Overall Results for the Oil Furnace Class

Oil Furnace Installation Cost Summary	Trial Standard Level Weighted Average	Incremental Installation Cost ($)
Baseline: Non-Condensing 80% AFUE Vertical Vent	$539	**--**
Non-Condensing 83%: 25% Stainless Vent	$835	**$296**
Non-Condensing 84%: 50% Stainless Vent	$1130	**$591**
Non-Condensing 85%: 75% Stainless Vent	$1,426	**$887**
Non-Condensing 86%: 100% Stainless Vent	$1,721	**$1,182**

C.5.5 Oil Boiler Model Results

The results for the Oil Boiler class are shown in Table C.5.4:

Table C.5.4 Overall Results for the Oil Boiler Class

Oil Boiler Installation Cost Summary	Trial Standard Level Weighted Average	Incremental Installation Cost ($)
Baseline: Non-Condensing 80% AFUE Vertical Vent	$1,450	**--**
Non-Condensing 84%: 25% Stainless Vent	$1,757	**$308**
Non-Condensing 85%: 50% Stainless Vent	$2,065	**$615**
Non-Condensing 86%: 75% Stainless Vent	$2,372	**$923**
Non-Condensing 87%: 100% Stainless Vent	$2,680	**$1,230**

C.6 SENSITIVITY ANALYSIS

In the installation model, there are a large number of variables that are not well known. To capture the impact of these variations on the installation costs, a Monte Carlo simulation was run (using Crystal Ball™ software).

C.6.1 Sensitivity Analysis Assumptions

Nominal variable assumptions were detailed in the previous sections, and the ranges are summarized in Table C.6.1.

Table C.6.1 Sensitivity Analysis Assumption Ranges

Variable Name	**Min**	**Nominal**	**Max**	**Source**
Total Living Area (sf)	520	2,176	4450	Derived from subset of 1997 RECS data used in LCC
Total Furnace Size (Input kBTU)	45	80	140	Derived from subset of 1997 RECS data used in LCC
Single Wall Vent Connector Probability	25%	53%	88%	88% = highest in 1992 GRI survey; 53% = 2015 projection; 25% = lowest in 1992
Horizontal Run Multiplier	0	.75	1	Assumption in text, Section 6.2.3.2.1
RSMeans Labor Factor	90%	100%	110%	Estimated local labor rate fluctuations.
Relined Masonry Vent Probability	2%	27%	48%	2% = 1994 GRI survey[1]; 27% = 2015 projection (section 6.2.8)
Percentage single pipe condensing	5%	10%	50%	Estimated market prevalence
Percentage of New Installations	20%	25%	30%	Chapter 3, Market & Technology Analysis, of this TSD
New Vent Diameter (In)	3”	4”	5”	Residential model literature search
New Condensing Vent Diameter (In)	2”	2”	3”	Residential model literature search
Materials Markup	10%	10%	15%	RS Means Residential[7], p. vii
Building Length / Width Ratio	1:1	1:1	3:1	Assumption of typical building shape
Elbow Adder (Units)	85% = 0, 10%= 2, 5% = 4			Assume added elbows needed for some installations for jogs around obstructions
Chimney Size Cutoff	50%	85%	100%	Chimney size distribution; approximation from 2002 major supplier sales
Chimney Chase Material Cost ($)	$175	$175	$325	RS Means Residential[7], p 461. Small to large chimney chase size.
Chimney Chase Crew Labor Hours (Hours)	0.8	0.8	1.14	RS Means Residential[7], p 461. Small to large chimney chase size
List Price Markup	20%	25%	40%	Estimate based on experience for low volume contractors
Basement Configuration Index	Basement, Crawlspace, or Slab on Grade			US Census 2001 Statistical Abstracts[9]
Avg Floor Height (feet)	8’	8’	10’	NAHB, BEC Survey, 2001
% Retrofits w/ Condensate Pump	0%	20%	40%	Broad distribution; 20% = 1992 GRI survey; only 3 data points

In the absence of known distributions, a triangular min-mean-max distribution was used.

C.6.2 Incremental Cost Result Ranges

The non-weatherized gas furnace results for the incremental costs show a broad distribution, as one would expect:

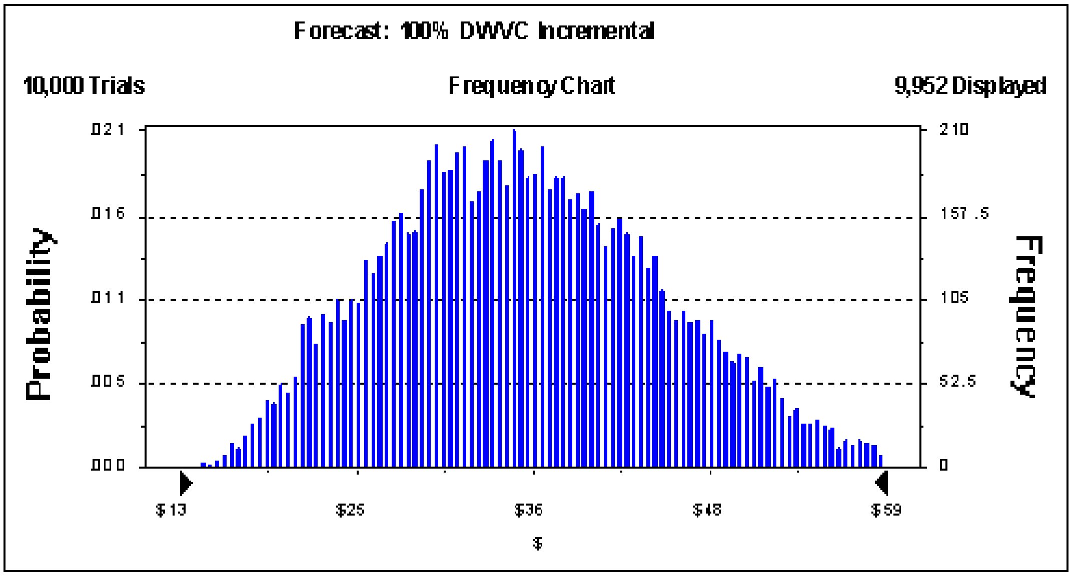


Figure C.6.1 81% AFUE Two-stage Modulation Incremental Cost Distribution Results

Incremental installation costs for the 81 percent A two-stage modulation trial standard level range from $13 to $65.

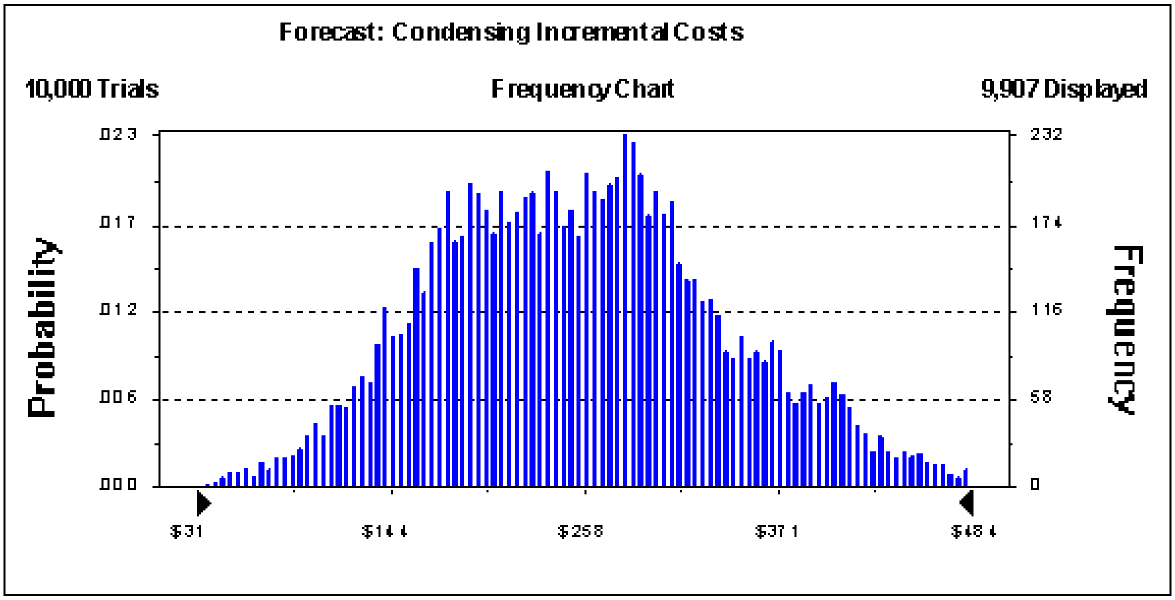


Figure C.6.2 90%+ AFUE Condensing Incremental Cost Distribution Results

Incremental installation costs for the 90 percent condensing trial standard level range from -$5 to $605. This broad spread results from the uncertainty associated with estimating horizontal vent length.

C.6.3 Cost Result Sensitivity

Tornado sensitivity charts are shown in Figure C.6.3. They show that four factors are the primary sources of uncertainty and variability in the installation model:

- Weighting factors (relined masonry vent probability, single wall vent connector probability, percentage new installations, chimney size cutoff);
- Vent length – and therefore cost – drivers (total living area, basement configuration index, average height per floor);
- Material cost factors (catalog house markup); and,
- Labor cost factors (total furnace size (directly affects installation labor time), RS Means labor factor).

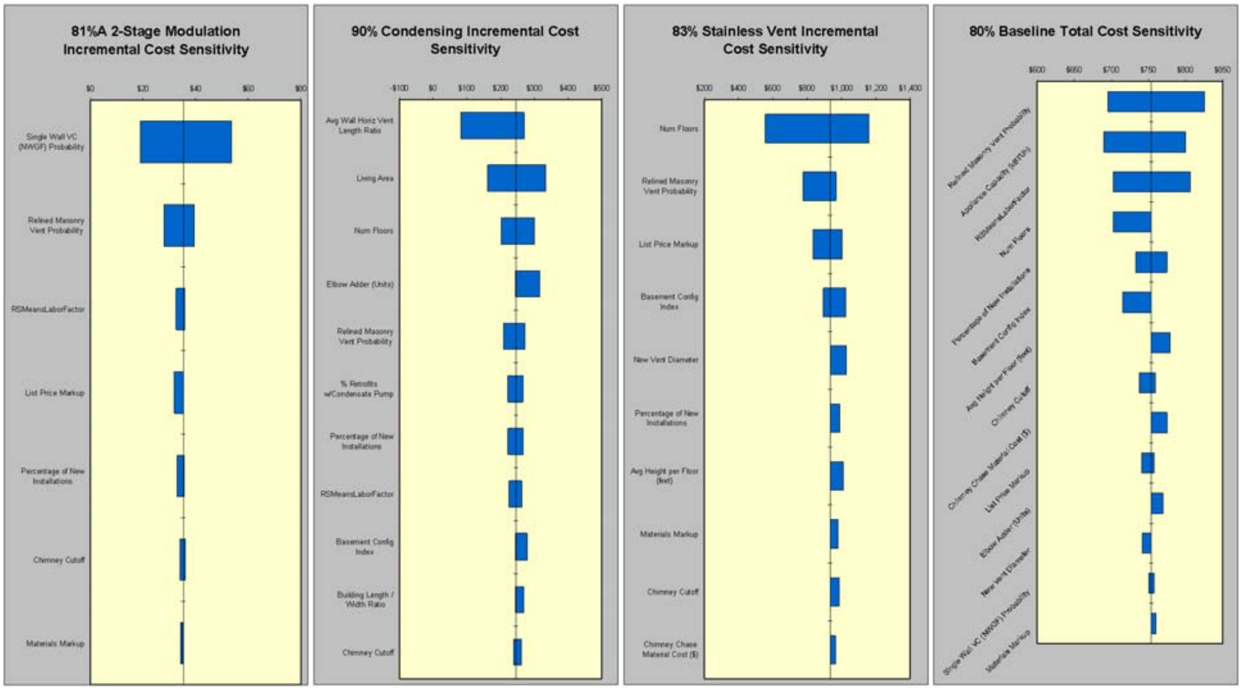


Figure C.6.3 Baseline, 81 percent A, 83 percent, and 90 percent AFUE Tornado Charts

C.6.4 Weighting Sensitivity

In this section, the effects on the results of two types of weighting variations are evaluated: regional differences and 2015 projected relining trends.

Regional Differences. In the 1992 GRI FN, large regional variations in the incidence of electric to gas water heaters, vent types, and type of vent connectors are detailed. In Figure C.6.4, the effects of these variations on the three original trial standard level incremental costs are shown.

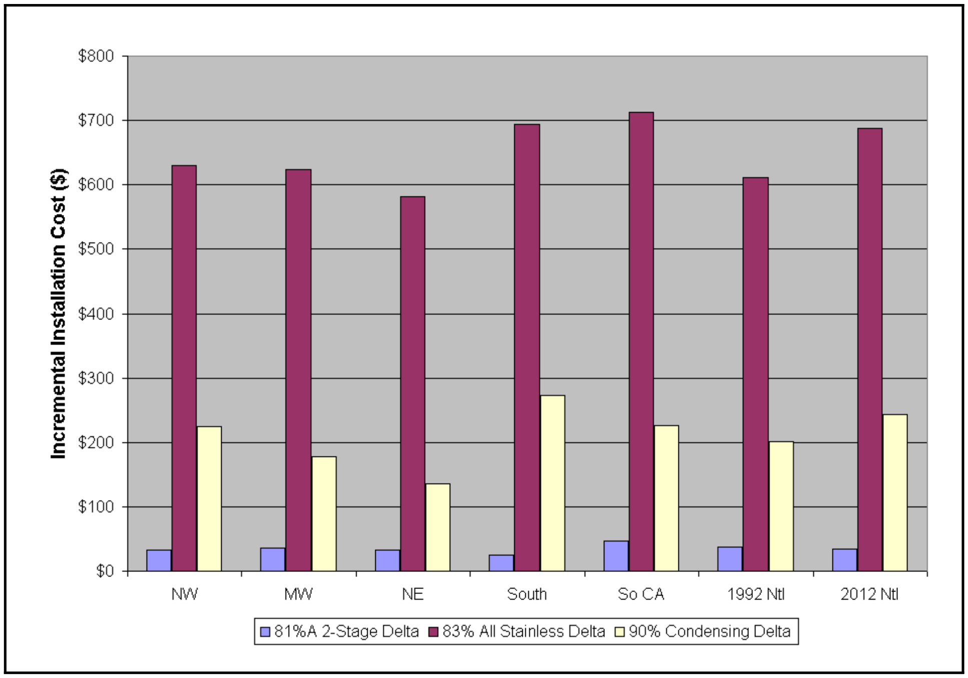


Figure C.6.4 Regional Variation Effects on Incremental Costs

These variations are mostly dependent on the gas:electric water heater ratio, which varies in 1992 from 27 percent:73 percent in the Northeast to 82 percent:18 percent in the South; the difference between these extremes is $34, and $181 for the 81 percent, and 90 percent trial standard levels respectively.

Recent Trends. From an analysis of shipment data and NFGC chimney relining assumptions, vent weighting is assumed to shift from 48/2/32/18 percent masonry unlined/masonry lined/Type B double wall/Other in 1994[1] to 23/27/32/18 percent in 2015, as the existing masonry chimney population is relined. Furthermore, it is assumed that the single wall vent connector/double wall vent connector/other ratio shifts from 74/16/11 percent in 1992 to 53/36/11 percent in 2015, as these masonry chimneys are relined with presumably double wall vent connectors. Figure C.6.5 shows the sensitivity of the 81 percent AFUE A and 90 percent AFUE incremental results to these assumptions. As the percentage of lined masonry chimneys increases, baseline costs decrease because less relining is needed. This magnifies the differences the condensing case and the baseline, so the incremental costs increase linearly.

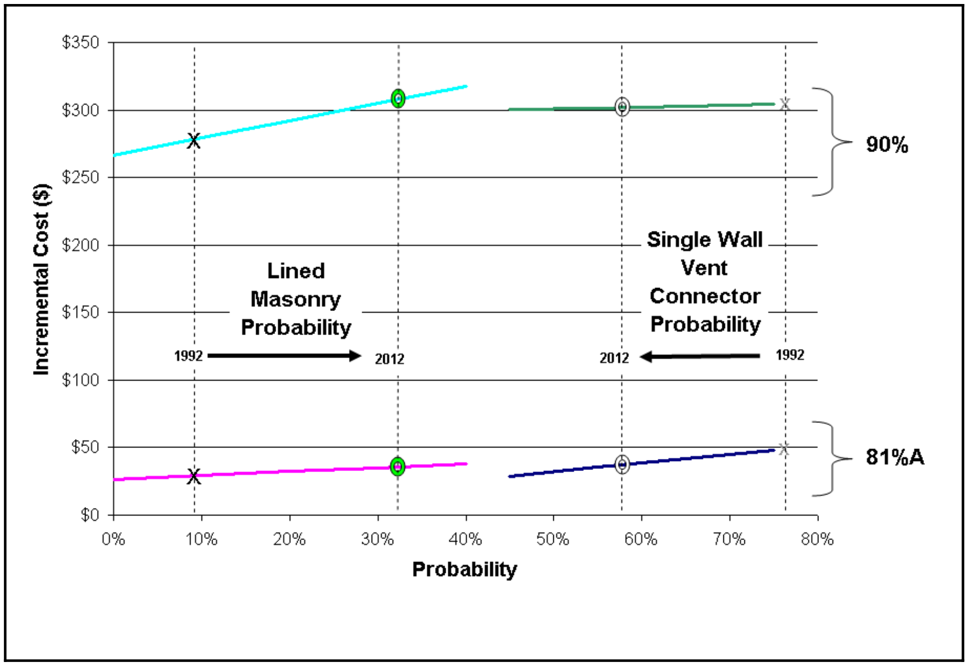


Figure C.6.5 Masonry Relining Effects on Incremental Costs

In the 81 percentA case, weighting assumption impacts are +/- 10 percent; likewise, for 90 percent, the impact range is +/- 5 percent. This weighting error is much smaller than the variations due installation size and unknown parameters shown in the sensitivity analysis (section C.6).

C.7 INSTALLATION MODEL RESULTS COMPARED TO OTHER DATA

It is possible to compare installation cost estimates for several efficiency levels but not for others. No comparison data are available for 81 percent AFUE two-stage modulating products (Level 81 percent). For condensing products (90+ percent), a detailed comparison of the installation model results to the GRI[a], Canadian, and installation cost data sets is shown in Table C.7.1.

---

[a] GTI has published a 2003 update to the 1994 GRI report, based on using the Bureau of Labor Statistics Index of Hourly Earnings (IHE) as an inflation factor. In this document, the CPI index is used instead to maintain consistency with all other analyses. The IHE results are approximately 10 percent higher than the CPI index results.

Table C.7.1 Installation Data Comparison: GRI, Canadian, and WI

Non-weatherized Gas Furnaces Data Set Comparison	2002 Installation Model*			1994 GRI** Replace-ment	1999 Canadian** Avg_{Wtd}	1996 WI** Avg_{wtd}
	Replace-ment	New	Avg_{wtd}			
80% Baseline	$739	$1,105	$831	$965	$371	$668
90%+ Condensing	$1,053	$967	$1,032	$1,239	$401	$908

* 1994 GRI weighting used for comparison. This lowers the incremental cost from $244 to $201
** CPI Index adjusted to 2001 $ for comparison

As can be observed, installation cost estimates vary significantly. For instance, the 80 percent AFUE installation model replacement installation cost differs from the 1994 GRI replacement baseline by $226 ($739 versus $965). We would expect that installation cost estimate differences can be explained by differences in methodology, sampling error, and assumptions. In particular, baseline (80 percent AFUE) assumptions can differ depending on what is, or is not included, in the installation. The following sections explore and attempt to reconcile these differences.

C.7.1 Comparison of the Installation Model to 1994 GRI Data

There are a number of explanations, and possible reasons, for the observed differences in baseline installation costs. These include:

- Furnace relining and vent connector costs are weighted differently for the 80 percent AFUE baseline case. GRI applies [relining plus Type B vent connector] costs 15 percent of the time, while the Installation Model applies [relining plus existing (single wall or Type B) vent connector] costs 23 percent of the time.

- Non-efficiency related costs may differ – i.e., the GRI survey may include more ductwork or plumbing labor than is assumed in the Installation Model.

- The GTI 2003 update report uses a higher index for inflation than the CPI Index based numbers shown. An inflation factor also may not take into account improvements in labor savings over the last ten years.

Focusing on incremental costs instead of total installation costs will mitigate the impact of the factors described above. Table C.7.2 shows a comparison of incremental costs for a 90 percent trial standard level.

Table C.7.2 Incremental Installation Cost Data Comparison

90% Condensing Data Comparison		**Incremental Cost ($)**
Installation Model*	Replacement	$314
	New	-$138
	Avg_{wtd}	$201
1994 GRI**	Replacement	$274
1996 WI**	Avg_{Wtd}	$239
1999 Canadian**	Avg_{Wtd}	$30

* 1992 GRI weighting used for comparison. This lowers the incremental cost from $244 to $201

** CPI Index adjusted to 2001 $ for comparison

For the replacement market, the installation model and GRI agree to within 13 percent—$274 versus $314. However, for the new construction market, there is a sharp difference. The installation model predicts that the installation cost of a new 90 percent AFUE condensing furnace will be less than that of an 80 percent AFUE non-condensing unit. (Note that when the cost of the furnace is included, the total installed cost of the condensing furnace is higher). This is because the plastic pipe vent of the condensing furnace costs less than a Type B metal chimney. Once the proportion of new and replacement installations is considered, the installation model's overall incremental cost decreases from $314 to $201. In contrast, GRI assumes in its "New House Usage Analysis" that new construction furnace installation costs are equivalent to replacement installation costs, where a vent already exists.

C.7.2 Comparison of the Installation Model to 1999 Canadian Data

From discussions with Helyar & Associates, who conducted the Canadian cost survey, it is our understanding that the 1999 Canadian data is valid only for the case of a new condensing unit being installed into new construction. The Canadian estimates do not include gas piping, electrical hookup, or removal of an old furnace. The 80 percent AFUE baseline Canadian estimates also do not include relining or vent connector costs for replacement installations, or the cost of a new metal vent for new installations (a power vented plastic vent for 80 percent AFUE is assumed). For the 90 percent condensing trial standard level, Canadian estimates do not include provision for a condensate pump (a drain will be available in new constructions).

With the above assumptions, using the installation model to estimate the cost of a new condensing furnace into new construction yields results that are reasonable when compared with the Canadian data. For this situation – BOM 50—the venting cost model estimates costs of $463, compared to $401 for the Canadian data. This is agreement within 15 percent.

C.7.3 Comparison of the Installation Model to the 1996 Wisconsin Data

The Wisconsin installation data consists of a sample of 10 condensing furnace installations performed in Wisconsin. The installation cost data shows absolute cost's of $831 (Installation Model) versus $668 (Wisconsin) [baseline 80 percent AFUE], and $1,032 versus $908 [90 percent condensing]. The explanations for these absolute cost differences discussed in section C.7.1 apply; in addition, the Wisconsin data implicitly assumes regional weightings of vent connector type, vent type, and gas:electric (isolated) water heater ratio. The venting cost model uses national averages that may be different from local Wisconsin custom, with as large as a +/- $75 cost impact.[a]

Despite these absolute cost differences, the incremental cost difference is $201 (Installation Model) versus $239 (Wisconsin), agreement within 15 percent.

C.7.4 Comparison Summary

In summary, DOE found that available data sources were in reasonable agreement with the installation model when the installation costs are compared using similar assumptions. For the 90 percent Condensing standard level, the installation model incremental costs match GRI costs within 13 percent for replacement markets, and match Wisconsin costs within 15 percent for all markets. The Canadian data does not directly apply to the Unites States, but when similar assumptions are used, the RS Means model agrees with Canadian installation costs within 15 percent.

Overall, the Installation Model incremental costs agree with all known data for the 90 percent Condensing standard level.

C.8 WEIGHTING ESTIMATIONS FOR YEAR 2015

The purpose of this section is to provide an estimate of the average probability in year 2015 for a home to either having a single or double wall vent connector, and to estimate how many masonry chimneys will be lined by 2015.

C.8.1 Single : Double Wall Vent Connector Ratio

The National Fuel Gas Code (NFGC) venting tables have not changed between 1992, the year of the GRI venting survey, and 2003. It is therefore likely that the proportion of single wall: double wall vent connectors is similar to 1992 (73 percent : 16 percent). However, conversations with a few contractors imply that a recent trend has been increasing use of double wall vent connectors despite their higher costs, to be more conservative regarding vent condensation. If it is assumed that 50 percent

[a] Source: Installation Model sensitivity analysis. The Northeast and Southern regions are at the extremes, with the Midwest region close to the center. See section C.6

of all installations since 1992 until 2015 have single wall vent connectors (SWVC), the following equations result:[a]

$$\frac{New\ Growth + Installed\ SWVCs}{Total\ Households} = \frac{.73*(53-45)+.5*45}{53} = 53\%\ SWVC$$

$$\frac{New\ Growth + Installed\ DWVCs}{Total\ Households} = \frac{.16*(53-45)+.39*45}{53} = 36\%\ DWVC$$

The proportion of "Other" was kept constant, at 11 percent.

C.8.2 Masonry Chimney Linings

From the National Fuel Gas Code, it is assumed in section C.2.4 that exterior masonry chimneys will be re-lined 100 percent of the time, and interior masonry chimneys will be relined 85 percent of the time. This implies a shift in the proportion of lined masonry chimneys over time. In particular, we project the following changes in these proportions from 1992 to 2015:

- Exterior Unlined – 19 percent to 9 percent
- Interior Unlined – 29 percent to 14 percent
- Unlined to Lined – 2 percent to 27 percent

Table C.8.1 shows the details of this projection.

Historical GAMA shipment data, including replacements, were used for the years 1992—2000. Shipment forecasts were used from 2001 to 2012; the replacement market was estimated as 75 percent of the total. There data are contained in columns one through four.

For each year, it is assumed that 19 percent and 29 percent, respectively, of the replacements are exterior masonry and interior masonry. These are columns five and six. To calculate column seven, lined masonry chimneys, DOE used use the following formula:

*# Lined Chimneys = Exterior * 100% + Interior * 85%*

[a] The American Housing Survey (AHS) 1999 reported a total of 45 million. households (1999) with central furnaces (or approx. 46.3 million in year 2000). The same source reports a total of 40 million. households in 1992. During the last 8 years (1993-2000) approx. 18 million. units were shipped (or 39 percent of the stock was updated). Shipment projections are that 27+ million furnaces will be purchased between 2001 and 2015. A linear projection of the above household totals yields 52.6 mln households.

Table C.8.1 Year 2012 Chimney Relining Projections

(millions)	Year	Historical Shipments NWGF	Replace-ments	Masonry Chimney		
				Exterior	**Interior**	**Already Relined**
Total Households	1992	40.0		7.56	11.76	0.85
				19%	29%	2%
GAMA shipment data	1993	2.12	1.49	0.28	0.44	0.65
	1994	2.16	1.41	0.27	0.41	0.62
	1995	2.00	1.36	0.26	0.40	0.59
	1996	2.27	1.46	0.28	0.43	0.64
	1997	2.23	1.46	0.28	0.43	0.64
	1998	2.38	1.52	0.29	0.45	0.67
	1999	2.53	1.65	0.31	0.48	0.72
	2000	2.56	1.80	0.34	0.53	0.79
Shipment forecast	2001	1.85	1.39	0.26	0.41	0.61
	2002	2.11	1.58	0.30	0.47	0.69
	2003	2.08	1.56	0.29	0.46	0.68
	2004	2.11	1.58	0.30	0.47	0.69
	2005	2.15	1.61	0.30	0.47	0.71
	2006	2.2	1.65	0.31	0.49	0.72
	2007	2.26	1.70	0.32	0.50	0.74
	2008	2.32	1.74	0.33	0.51	0.76
	2009	2.4	1.80	0.34	0.53	0.79
	2010	2.48	1.86	0.35	0.55	0.82
	2011	2.56	1.92	0.36	0.56	0.84
	2012	2.61	1.96	0.37	0.58	0.86
Totals		45.4	32.5			14.3
Total Households	**2012**	**52.6**		**9%**	**14%**	**27%**

These proportions are discussed in section C.2.4. Finally, the total number of lined chimneys between 1992 and 2012 was summed, and this was divided by the total number of households to yield a total of 27 percent. Unlined chimneys are then (50 percent-27 percent) = 23 percent, and the interior and exterior proportions were calculated using a constant 29 percent:19 percent ratio (from the 1992 data). Thus interior chimneys are 29 percent/(29 percent+19 percent) * 23 percent = 14 percent, and exterior chimneys are 19 percent/(29 percent+19 percent) * 23 percent = 9 percent.

Projections for 2012 are assumed to be valid for 2015, with wide bands adopted in the sensitivity.

C.9 ABSOLUTE COST BREAKDOWN

The total result tables for each trial standard level are shown below (2003$).

C.9.1 Non-Weatherized Gas Furnace

Baseline: Non-Condensing 80% AFUE Vertical Vent												
Market	Vent / Vent Conn / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
		Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$853	$871	$544	$549	$544	$549			$635	$648	$694
	Water Heater Common (50%)	$941	$977	$544	$549	$544	$549			$661		
New (10%)	Water Heater Isolated (50%)	$1,014	$1,034	$1,014	$1,034	$1,189	$1,209			$1,090	$1,113	
	Water Heater Common (50%)	$1,014	$1,034	$1,087	$1,107	$1,244	$1,264			$1,136		
Weighting		17%	11%	20%	13%	23%	16%					

Figure C.9.1 80 percent AFUE Baseline Installation Cost (NWGF)

Non-Condensing 81%A 2-stage Modulation												
Market	Vent / Vent Conn / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
		Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$875	$871	$632	$549	$632	$549			$676	$691	$734
	Water Heater Common (50%)	$982	$977	$632	$549	$632	$549			$706		
New (10%)	Water Heater Isolated (50%)	$1,034	$1,034	$1,034	$1,034	$1,209	$1,209			$1,102	$1,125	
	Water Heater Common (50%)	$1,034	$1,034	$1,107	$1,107	$1,264	$1,264			$1,148		
Weighting		17%	11%	20%	13%	23%	16%					

Figure C.9.2 81 percent AFUE 2-Stage Modulation Installation Cost (NWGF)

Condensing 90%+ Horizontal Plastic Vent												
Market	Vent / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
	Vent Conn	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$951						$522		$951	$1,004	$1,002
	Water Heater Common (50%)	$1,326		$951						$1,057		
New (10%)	Water Heater Isolated (50%)	$795						$481		$795	$985	
	Water Heater Common (50%)	$1,175								$1,175		
Weighting		17%	11%	20%	13%	23%	16%					

Figure C.9.3 90 percent AFUE Condensing Installation Cost (NWGF)

C.9.2 Gas Boilers

Baseline: Non-Condensing 80% AFUE Vertical Vent												
Market	Vent / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
	Vent Conn	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$1,757	$1,790	$1,369	$1,377	$1,369	$1,377			$1,485	$1,501	$1,538
	Water Heater Common (50%)	$1,863	$1,930	$1,369	$1,377	$1,369	$1,377			$1,518		
New (10%)	Water Heater Isolated (50%)	$1,790	$1,827	$1,790	$1,827	$1,866	$1,903			$1,834	$1,865	
	Water Heater Common (50%)	$1,790	$1,827	$1,909	$1,945	$1,923	$1,960			$1,895		
Weighting		17%	11%	20%	13%	23%	16%					

Figure C.9.4 80 percent AFUE Baseline Installation Cost (Gas Boiler)

Non-Condensing 86%: 100% Stainless Vent												
Market	WH Options \ Vent	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
	Vent Conn	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$2,777								$2,777	$2,777	$2,678
	Water Heater Common (50%)	$2,777								$2,777		
New (10%)	Water Heater Isolated (50%)	$1,782								$1,782	$1,782	
	Water Heater Common (50%)	$1,782								$1,782		
Weighting		100%										

Figure C.9.5 86 percent AFUE All Stainless Vent Installation Cost (Gas Boiler)

Condensing 90%+												
Market	WH Options \ Vent	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
	Vent Conn	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$2,106						$1,490		$2,106	$2,168	$2,130
	Water Heater Common (50%)	$2,546		$2,106						$2,229		
New (10%)	Water Heater Isolated (50%)	$1,604						$1,288		$1,604	$1,794	
	Water Heater Common (50%)	$1,984								$1,984		
Weighting		17%	11%	20%	13%	23%	16%					

Figure C.9.6 90 percent AFUE Condensing Installation Cost (Gas Boiler)

C.9.3 Oil Furnaces

Baseline: Non-Condensing 80% AFUE Vertical Vent												
Market	Vent / Vent Conn / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
		Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$532	$532	$488	$488	$488	$488			$500	$503	$575
	Water Heater Common (50%)	$547	$551	$488	$488	$488	$488			$505		
New (10%)	Water Heater Isolated (50%)	$1,216	$1,216	$1,216	$1,216	$1,216	$1,216			$1,216	$1,231	
	Water Heater Common (50%)	$1,216	$1,216	$1,307	$1,307	$1,216	$1,216			$1,246		
Weighting		17%	11%	20%	13%	23%	16%					

Figure C.9.7 80 percent AFUE Baseline Installation Cost (Oil Furnace)

Non-Condensing 86%: 100% Stainless Vent												
Market	Vent / Vent Conn / WH Options	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
		Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$1,753								$1,753	$1,753	$1,690
	Water Heater Common (50%)	$1,753								$1,753		
New (10%)	Water Heater Isolated (50%)	$1,124								$1,124	$1,124	
	Water Heater Common (50%)	$1,124								$1,124		
Weighting		100%										

Figure C.9.8 86 percent AFUE All Stainless Vent Installation Cost (Oil Furnace)

C.9.4 Oil Boilers

Baseline: Non-Condensing 80% AFUE Vertical Vent												
	Vent	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
Market	WH Options / Vent Conn	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$1,460	$1,460	$1,411	$1,411	$1,411	$1,411			$1,425	$1,427	$1,472
	Water Heater Common (50%)	$1,475	$1,479	$1,411	$1,411	$1,411	$1,411			$1,430		
New (10%)	Water Heater Isolated (50%)	$1,859	$1,859	$1,859	$1,859	$1,859	$1,859			$1,858	$1,873	
	Water Heater Common (50%)	$1,859	$1,859	$1,950	$1,950	$1,859	$1,859			$1,888		
Weighting		17%	11%	20%	13%	23%	16%					

Figure C.9.9 80 percent AFUE Baseline Installation Cost (Oil Boiler)

Non-Condensing 87%: 100% Stainless Vent												
	Vent	Masonry (23%) Unlined		Masonry (27%) Lined		Type B Double Wall(32%)		Plastic (6%)	Other (11%)	Weighted Average	Weighted Market Average	Trial Standard Level Weighted Average
Market	WH Options / Vent Conn	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Single Wall (53%)	Double Wall (36%)	Plastic (6%)	Other (5%)			
Replacements (90%)	Water Heater Isolated (50%)	$2,728								$2,728	$2,728	$2,632
	Water Heater Common (50%)	$2,728								$2,728		
New (10%)	Water Heater Isolated (50%)	$1,767								$1,767	$1,767	
	Water Heater Common (50%)	$1,767								$1,767		
Weighting		100%										

Figure C.9.10 87 percent AFUE All Stainless Vent Installation Cost (Oil Boiler)

C.10 VENTING GLOSSARY

7X Rule – A "maximum size limit" rule in the NFGC that specifies that the flow area of the vertical vent shall not exceed seven times (7X) the flow area of the smallest vent connector.

AFUE – Annual Fuel Utilization Efficiency.

Baseline – 80 percent AFUE, the maximum market sales baseline. Other sections in this document – i.e. the LCC – may define the baseline differently.

BOM – Bill of Material. A list of all components of an installation, including quantities.
Common vented water heater – a gas water heater that is vented using the same vent as a furnace.

Condensate – Water vapor that condenses in a vent (or inside a furnace) because the flue gas temperature is lower than the dew point. It is usually acidic due to the presence of carbon dioxide and carbon monoxide in the flue exhaust, which form carboxylic acid. If chloride or other ions are present (from salt spray, laundry detergents, etc.), the condensate can be more corrosive. A high number of wet / dry cycles can also concentrate the condensate, increasing the risk of pitting corrosion.

Condensing – a furnace that is designed to purposefully collect condensate, including condensate that forms in its vent.

Contractor Discount – the discount applied to list prices that reflect what a contractor pays for an item.

Contractor Markup – the markup a contractor applies to a material item before selling it to a customer.

Crew Hours – How long it takes a crew to execute a particular task. Because crews can be more than one person, this differs from labor hours.

Double Wall – a vent or vent connector that is formed from a pipe within a pipe, held concentric by standoffs. The gap is filled with air, providing insulation. The inside pipe is usually aluminum, while the outside pipe is usually galvanized steel.

Exterior Chimney – a chimney running along an exterior wall; the outside is exposed to the elements for its entire length.

GAMA – Gas Appliance Manufacturers Association.

GRI – Gas Research Institute (now called GTI-Gas Technology Institute).

Installation Model – a complex installation cost model created for the DOE to simulate venting and other installation costs nationwide.

Interior Chimney – a chimney that originates in the interior of the home.

Isolated water heater – a water heater that is not a gas water heater vented in common with a furnace. Possibilities include an electric water heater, or a gas water heater with either a direct side-wall vent or a power vent.

kBTU – thousands of British Thermal Units, a measure of furnace capacity.

LCC – Lifecycle Cost Analysis.

Liner – Typically a flexible 2-ply aluminum corrugated "pipe within a pipe" vent that is inserted into a masonry chimney. Use of a flexible pipe avoids section-connecting labor.

Monte Carlo simulation – a system which uses random numbers to measure the effects of uncertainty in a spreadsheet model.

NAECA – National Appliance Energy Conservation Act.

NAHB – National Association of Home Builders.

Near-condensing – a furnace that is close (or over) the 83 percent steady-state efficiency limit; condensation in the vent is likely.

NES – National Energy Savings analysis.

NFGC – National Fuel Gas Code. Code sponsored by the National Fire Protection Agency that governs venting practices nationally. Other local codes also apply.

Non-condensing – a furnace that is designed so that there is minimal condensation in its exhaust vent.

NWGF—Non-weatherized gas furnace; intended for indoor use.

Orphaned Water Heater—When a 90 percent+ AFUE condensing furnace replaces a (78-80 percent) non-condensing gas furnace, the existing vent may be too large for the water heater that is now the only appliance attached to it.

PVC – Polyvinyl chloride, an inexpensive plastic pipe.

Relining – The practice of inserting a liner down a masonry chimney to provide insulation.

RS Means—A well-known methodology of estimating construction costs created by RS Means, Inc., based in Kingston, MA.

Single Wall – a vent connector that is formed from a pipe with walls using a single sheet of thin metal. Usually made of galvanized steel or aluminum.

Stranded Water Heater – see Orphaned Water Heater.

TSL – Trial Standard Level. Designation for a specific efficiency level that would be more stringent than currently enacted.

Type B Vent – a double wall vent.

Vent – Vertical exhaust pipe that carries flue gases from a furnace to outside a home. Section extends from the outside (the cap), down to the floor where the furnace is located.

Vent Connector – Exhaust pipe section that runs horizontally from the vent, and then down to the furnace.

REFERENCES

1. Battelle, Jakob, Crisafulli, Menkedick, Fischer, Phillips, Osborne, Cross, Whitacre, Murray, & Sheppard, AGA Laboratories, DeWerth, and Thrasher., *Topical Report Assessment of Technology for Improving the Efficiency of Residential Gas Furnaces and Boilers Volumes I&II*, 1994. Gas Research Institute. Chicago, IL. Report No. GRI-94/0039. Interim Topical Report.

2. Cooper, Lee, Quinlan, Sirowatka, and Featherstone, *Warm Air Heating for Climate Control, 4th Edition*. 2000.: Upper Saddle River, New Jersey.

3. National Fire Protection Association, *National Fuel Gas Code -2002 Edition*, 2002. 1 Batterymarch Park, P.O. Box 9101, Quincy MA.

4. U.S. Department of Energy-Office of Building Research and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Water Heaters*, 2000. U.S. Department of Energy. Washington, DC. Report No. LBNL-47419. <http://www.eren.doe.gov/buildings/codes_standards/reports/waterheater/index.html>

5. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: Household Energy Consumption and Expenditures 2001,* 2001. (Last accessed May 18, 2005.) <http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html>

6. U.S. Department of Energy-Office of Energy Efficiency and Renewable Energy, Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters; Final Rule. *Federal Register*, 2001. 66(11): pp. 4474-4497.

7. RS Means Company Inc., *2003 Residential Cost Data - 22nd Annual Edition*. 2002. ed. M. Mossman.: Kingston, MA.

8. RS Means, *Facilities Mainteance & Repair Cost Data 2002*. 2001, RS Means Company, Inc.: Kingston, MA.

9. U.S. Department of Commerce - Bureau of the Census, *Statistical Abstract of the United States*, 2001. Washington, DC.