Economics of Condensing Gas Furnaces and Water Heaters Potential in Residential Single Family Homes

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ABSTRACT

Residential space and water heating accounts for over 90% of total residential primary gas consumption in the United States. Condensing space and water heating equipment are 10-30% more energy-efficient than conventional space and water heating. Currently, condensing gas furnaces represent 40 percent of shipments and are common in the Northern U.S. market. Meanwhile, manufacturers are planning to develop condensing gas storage water heaters to qualify for Energy Star® certification. Consumers, installers, and builders who make decisions about installing space and water heating equipment generally do not perform an analysis to assess the economic impacts of different combinations and efficiencies of space and water heating equipment. Thus, equipment is often installed without taking into consideration the potential life-cycle economic and energy savings of installing space and water heating equipment combinations. Drawing on previous and current analysis conducted for the United States Department of Energy rulemaking on amended standards for furnaces and water heaters, this paper evaluates the extent to which condensing equipment can provide life-cycle cost-effectiveness in a representative sample of single family American homes. The economic analyses indicate that significant energy savings and consumer benefits may result from large-scale introduction of condensing water heaters combined with condensing furnaces in U.S. residential single-family housing, particularly in the Northern region. The analyses also shows that important benefits may be overlooked when policy analysts evaluate the impact of space and water heating equipment separately.

Introduction

Residential space and water heating accounts for 39% of total residential primary energy consumption and 94% of all residential gas[1] consumption in the United States (4.6 quads in 2009). (USDOE 2010a) A gas furnace and a gas water heater is the most common combination of space and water heating equipment in existing single-family homes and on average about half of all new single-family homes are installed with this combination (USDOC BOC 2010a; USDOC-BOC 2010b).

In the replacement market for single-family homes, the homeowner and contractor are primarily responsible for the selection of space and water heating equipment. Yet a large fraction of furnace and water heater replacements are done on an emergency basis. In new single-family construction, the builder is primarily responsible for the selection of space and water heating equipment (Ashdown et al. 2004).

This study applies a life-cycle cost (LCC) analysis[2] to calculate the economic advantages and disadvantages to consumers of several alternative gas furnace and water heater combinations installed in single-family homes. In the past, the U.S. Department of Energy (DOE) has

[1] Includes both natural gas and liquid petroleum gas (LPG).
[2] An LCC analysis is a cost/benefit analysis over the lifetime of the equipment from a consumer perspective.

performed separate LCC analysis on residential furnaces and on water heaters (Lekov et al. 2006; Lekov 2000). This paper expands on a gas furnace and water heater study (Lekov et al. 2009) that assessed the economics of gas space and water heating equipment combinations in the new single-family construction market to look at the replacement market in single-family homes. It updates the new construction results with updated data using the recently published USDOE 2010 water heating rulemaking. (USDOE 2010b)

U.S. Gas Space and Water Heating Market and Technology Characterization

Central heating systems (air distribution and hydronics) in the United States account for 82% of residential heating equipment stock in 2005 (USDOE 2005) and 98% of all single family new construction built from 1997-2008 (USDOC-BOC 2010b). The U.S. central space heating market is dominated by forced air furnaces which account for 85% of the stock and 97% of all single family new constructions built during 1997-2008. The current stock of residential water heating equipment is predominantly storage water heaters. Regionally, gas-fired water heating is dominant in all regions except in the South.

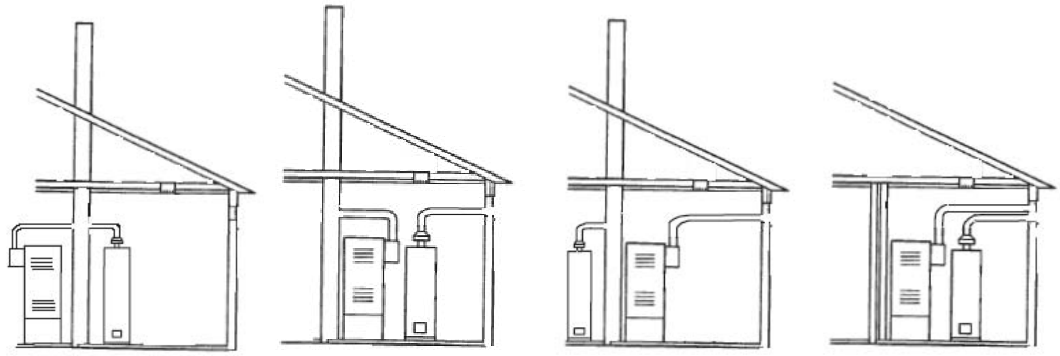
Gas furnaces and water heaters are often distinguished by whether they use condensing or non-condensing technology. A typical non-condensing gas furnace (NCGF) has an efficiency rating of about 80 percent annual fuel utilization efficiency (AFUE), while a condensing gas furnace (CGF) has an efficiency rating at or above 90-percent AFUE. In 2008, the most common furnace installed for replacement and in new construction was a non-condensing gas furnace (approximately 56%) (AHRI 2010a).

The efficiency of water heaters, depending on the rated volume and other design considerations, ranges from 0.50 to 0.63 energy factor (EF) for Non-Condensing Water Heaters (NCWH). Currently, nearly all gas water heaters installed are non-condensing. There are currently no shipments of residential condensing water heaters (CWH)[3], but there are prototype models available and condensing water heaters are included in the current Energy Star® water heater program (USEPA 2008).

The venting installation requirements are different for the various furnace and water heater designs. Figure 1 illustrates typical venting configurations. Identifying venting configurations is important because the venting system represents a significant fraction of the total installed cost and differs significantly for different furnace and water heater combinations. For new construction, configuration (d) is the least expensive, since it uses plastic venting materials and shorter vent lengths. Configuration (a) uses a single vent system for both appliances and is the most common venting configuration. Configurations (b) and (c) are the most expensive because of the need to apply two different venting types.

[3] There are some "non-residential" condensing models that are being used in residential applications (e.g., A.O. Smith's Vertex models)

Figure 1. Four Gas Furnace and Gas Water Heater Venting Configurations



(a) gas furnace and water heater vented through the roof; (b) gas furnace vented through the roof and gas water heater vented through the sidewall; (c) gas furnace vented through the sidewall and gas water heater vented through the roof; and (d) gas furnace and gas water heater vented through the sidewall

Methodology

This study assessed the energy savings and economics of the selected water heater and furnace configurations when they are installed single family homes. The LCC analysis addressed both the cost of buying and installing a furnace or water heater, and the operating costs summed over the lifetime of the equipment, discounted to the present.

To account for the uncertainty and variability of the inputs to the LCC analysis, Monte Carlo[4] simulations were applied, with many of the variables used in the calculations (e.g., discount rate, energy prices, equipment lifetime) represented as distributions of values and with probabilities (weighting) attached to each value (Lutz et al. 2000). The LCC analysis estimated furnace and water heater energy consumption under field conditions for a sample of households selected from the 2005 Residential Energy Consumption Survey (RECS 2005) (USDOE 2005). The sample was derived from single-family households in RECS 2005 that had both a gas furnace and gas storage water heater. This study focuses on non-weatherized gas furnaces, but since RECS does not specify the type of gas furnace, the sample weighting was adjusted. Since weatherized gas furnaces[5] are installed mostly in the South, the RECS weight was decreased for all households in the South by 25%.[6] For new construction, the sample was derived by selecting only single-family households built after 1980[7] and adjusting the regional weights by the using the most current new housing characteristics data from the U.S. Census. (USDOC-BOC 2010b)

Table 1 shows the four gas furnace and water heating options considered in this analysis. The efficiency values used in the calculations were based on commonly available models (USDOE 2007; USDOE 2010b). Option 1 (NCGF/NCWH) represents the least efficient furnace and water heater combination and Option 4 (CGF/CWH) represents the most efficient

[4] The Monte Carlo method uses computational algorithms that rely on repeated random sampling to compute results. In this study, the Monte Carlo analysis is performed using Crystal Ball, add-on software to MS Excel. The results are based on 10,000 samples per Monte Carlo simulation run.

[5] Also known as gas package heating/cooling units

[6] Weatherized gas furnaces account for approximately 11% of gas furnace shipments. These furnaces are all assumed to be in the south, so the 11% share of gas furnace implies that 25% of homes with gas furnace in the South have a weatherized gas furnace. The weight of all RECS households in the South are decreased to approximate the effect of removing households from the sample.

[7] Households built after 1980 was selected in order to have a large enough sample size.

combination. The fact that Option 4 (CGF/CWH) uses venting configuration (d) is significant, since this configuration is the least expensive one for new construction and could be beneficial in some replacement installations.

For the replacements, several scenarios are possible: furnace and water heater are replaced at the same time, furnace is replaced first, or water heater is replaced first. For simplicity and because the condensing furnace market is increasing and holds a significant market share, for this study the furnace is assumed to be replaced first. In **Table 1**, Options 1 and 3 represent the cases where the homeowner replaces the furnace, but the water heater is replaced once it fails in the future). The failure year of the water heater after the furnace is replaced is calculated by taking into account the existing equipment age from RECS 2005 of the water heater and the lifetime distribution. For Options 2 and 4, which include a condensing water heater, both pieces of equipment are replaced at the same time (either because they failed at same time or early replacement of water heater is chosen). The remaining value of the existing water heater is accounted for by annualizing the total installed cost of the existing water heater and applying this cost for the remaining useful lifetime. This cost varies among the sample households depending on the age of the water heater.

Table 1. Gas Furnace and Gas Water Heater Options

Option		Furnace Type	Gas Water Heater Type[a]	Venting Configuration
1	NCGF/NCWH	Non-condensing (80% AFUE)	Non-Condensing (0.59 EF)	Configuration (a)
2	NCGF/CWH		Condensing (0.78 EF)	Configuration (b)
3	CGF/NCWH	Condensing (90%AFUE)	Non-Condensing (0.59 EF)	Configuration (c)
4	CGF/CWH		Condensing (0.78 EF)	Configuration (d)

[a] Water heater efficiency at 40 gallon rated volume. Condensing water heater efficiency is based on manufacturer measurements of a prototype model. The current Energy Star® efficiency requirement for condensing water heaters is 0.80 EF.

To calculate the relative advantages and disadvantages of an option, the life-cycle cost savings and the pay-back period (PBP) are assessed by comparing Option 1, which is the most common, to higher efficiency options (2-4).

In addition to a national LCC analysis, a regional LCC analysis is performed for Northern states (above 5000 HDD) and Southern states (below 5000 HDD) (USDOC-BOC 2009). The regional analysis accounts for significant energy use variations due to climate conditions (particularly for furnaces) as well as for regional differences in household characteristics, energy prices, and other parameters.

The analysis considered the period from initial furnace and water heater installation to the end of the lifetime of the furnace. Given the lifetime distributions for the water heater and the furnace, most of the time one or more additional water heater(s) would be installed during the lifetime of the furnace. In these cases, the total installed cost of the replacement water heater was added to the operating cost as an annualized expense from the time of the replacement to the end of the furnace lifetime.

LCC and PBP Analysis

The total installed cost includes the consumer cost and the installation cost, which includes labor, overhead, and any miscellaneous materials and parts. The operating cost includes the energy expenditures and the repair and maintenance costs as well as the annualized cost of a replacement water heater. Each of these inputs is discussed below.

Consumer product cost. Consumer product costs are based on U.S. DOE research that derived the consumer cost based on manufacturer cost and contractor/builder and distributor markups for gas furnaces (USDOE 2007) and the gas water heaters (USDOE 2010b).[8] Manufacturer costs of a condensing furnace include the additional secondary heat exchanger cost. The manufacturer cost of a condensing water heater includes the cost of changes to the heat exchanger and the tank. The analysis applies markups to transform the manufacturer costs into a consumer cost.[9]

Table 2 shows the average consumer costs for the furnaces and water heaters used in the LCC analysis. The prices are higher for new construction because DOE applies a builder markup. The given prices are based on manufacturer costs that assume a high level of production of these products and reflect economies of scale in production that are not yet being captured in the current condensing water heater market. For comparison, the current retail price for a commercial condensing water heater which has characteristics similar to the residential water heater is $1,600.[10] Based on this model (which has a higher input capacity than an equivalent residential model), the cost for a comparable residential model should be lower due to the smaller burner required for residential designs. Tax credits that are available for gas condensing furnaces and water heaters purchased by Dec. 31, 2010 or state and utility rebates are not included.

Table 2. Average Consumer Product Cost for Gas Furnace and Gas Water Heater Options

Options	**Gas Furnace (2009$)**		**Gas Water Heater (2009$)**		**Total (2009$)**	
	New Home	**Replacement**	**New Home**	**Replacement**	**New Home**	**Replacement**
NCGF/NCWH	$1,481	$1,182	$515	$448	$1,997	$1,629
NCGF/CWH	$1,481	$1,182	$1,126	$1,052	$2,608	$2,234
CGF/NCWH	$1,956	$1,599	$515	$448	$2,472	$2,046
CGF/CWH	$1,956	$1,599	$1,126	$1,052	$3,083	$2,651

Installation cost. The installation costs for each of the options shown in **Table 3** come from US DOE research based on RSMeans cost estimates (USDOE 2010b). The installation cost includes labor and materials for the gas furnace and water heater. The basic installation includes adding a gas line branch, water piping, and condensate drain for water heaters and air-distribution connections and electrical components for furnaces, as well as the cost of locating and setting up the units. The main difference in installation cost between condensing and non-condensing equipment is the difference in cost of exhausting the condensate flue gases via a horizontal plastic vent compared to exhausting them via a vertical metal vent. Three different vent systems are considered: Option 1 uses a common vent through the roof; Options 2 and 3 use a combination of vertical metal vent and horizontal plastic vent; and Option 4 uses plastic vent. (See Figure 1).

[8] DOE research used a reverse-engineering approach to obtain manufacturers' costs.
[9] The overall markup approach is explained in US DOE Heating Products Rulemaking TSD (USDOE 2010b).
[10] Based on AO Smiths Vertex condensing water heater at 76 kBtu/h (http://www.pexsupply.com/AO-Smith-GPHE-50-50-Gallon-76000-BTU-Vertex-Power-Vent-Residential-Gas-Water-Heater)

Table 3. Installation Costs for Furnace and Water Heater Options (2009$)

Option	Venting Installation Configuration	New Construction			Replacement		
		Furnace	Water Heater	Total	Furnace	Water Heater	Total
NCGF/NCWH	Configuration A	$992	$945	$1,936	$784	$583	$1,246
NCGF/CWH	Configuration B	$1,281	$658	$1,939	$784	$1,036	$1,820
CGF/NCWH	Configuration C	$685	$1,234	$1,918	$942	$583	$1,425
CGF/CWH	Configuration D	$500	$623	$1,123	$778	$1,001	$1,780

Heating load and hot water use. Energy consumption for both the furnace and the water heater is based on calculations that use DOE test procedures while varying certain input parameters (Lutz et al. 1999; Lutz et al. 2004). The house heating load (for furnaces) and the hot water use (for water heaters) used in the calculations vary for each sample household. **Table 4** shows the house heating load and hot water use average and median values for the household sample by region. The national average hot water use (45.7 gal) is lower than the average value for gas water heaters (64.2 gal) in the DOE test procedure for water heaters.

Table 4. Average House Heating Load and Hot Water Use by Region

	Units	Northern Region				Southern Region	National
		Northeast	Midwest	Northwest	Total		
House Heating Load	MMBtu/y	49.0	48.1	39.5	48.1	28.8	39.4
Hot Water Use	gal/day	46.6	42.6	46.4	43.9	48.8	45.7

Operating costs. The operating costs represent the costs paid by the consumer to operate and maintain or repair the furnace and the water heater over the lifetime of the equipment. The operating cost uses energy consumption and energy prices as inputs. Average monthly energy prices are determined separately for the nine Census divisions and four large states based on 2008 EIA data, historical monthly EIA data, and 2008 U.S. Census Bureau population estimates (USDOE 2010c; USDOE 2010d; USDOE 2010e; USDOC-BOC 2010c). The derived energy prices are matched to each individual household depending on its location. To arrive at prices in future years, 2008 average prices are multiplied by the forecast of annual average price changes in AEO2010 (Early Release) (USDOE 2010a).

The furnace maintenance cost accounts for regular maintenance every five years, while the maintenance cost for water heaters includes maintenance for draining the tank and checking the flammable vapor ignition resistant (FVIR) system. The analysis assumes that certain components of both furnaces and water heaters might be repaired during the lifetime of the equipment (e.g. ignition device, blower motor, and power vent) (USDOE 2010b).[11] **Table 5** lists the repair cost of key components as used in the analysis.

[11] In the LCC analysis both the lifetime of the equipment and the component lifetime are presented as distributions. Therefore only households that have relatively longer equipment lifetime encounter repair costs.

Table 5. Gas Furnace and Gas Water Heater Component Repair Cost and Lifetime

	Component	Lifetime	Repair Cost (2009$)	Applied to Option
Gas Furnace	Electronic Ignition	10	$204	1,2,3,4
	Blower Motor	12	$297	1,2,3,4
	Inducer Motor	15	$297	1,2,3,4
Gas Water Heater	Pilot Light Ignition	10	$162	1,3
	Electronic Ignition	15	$204	2,4
	Power Vent	15	$297	2,4

Discount rate. The LCC analysis discounted future operating costs to 2010 and summed them over the lifetime of the furnace. For new construction, the discount rate used reflects after-tax real mortgage rates and on average equals 3.0%, while for the replacement market, the discount rate averages 5.1% (USDOE 2010b).

Lifetime. Lifetime estimates for furnaces and water heaters are shown in Table 6 (USDOE 2007; USDOE 2010b). In the analysis, lifetime is represented as a Weibull distribution. The analysis uses the same lifetime for all furnace and water heater designs.

Table 6. Furnace and Water Heater Lifetime

Product Class	Minimum	Average	Maximum
Gas Water Heater	6	13	30
Gas Furnace	10	20	30

Results

The life-cycle cost savings for the national sample compared to purchase and use of the baseline non-condensing furnace and water heater and the pay-back period of each considered option in the case of replacement and new construction are shown in **Table 7**. The share of households with net LCC benefit and with net LCC cost is also shown in **Table 7**. (Note: 15-20% of furnace and water heater shipments are for new construction.) In replacement cases, the condensing gas furnace provides positive LCC savings and a reasonable PBP when paired with a non-condensing water heater, but on average the condensing water heater does not provide savings in either of the considered combinations. In new construction, combining a condensing gas furnace with a condensing water heater is the most attractive option, providing a net benefit to three-fourths of the households in the new construction sample.

Results for the North and South household samples are shown in **Tables 8** and **9**, respectively. In the North, the pattern of results is roughly the same as with the national sample for new construction. However, in this region the condensing gas furnace plus condensing water heater option has a slightly positive LCC savings for replacement situations. Over half of the sample households have a net cost. In the South, the condensing gas furnace plus condensing water heater option are attractive in new construction, but none of the options have a positive average LCC savings in the replacement sample. Regional results are shown in **Figure 2**.

Results for the condensing gas furnace plus condensing water heater option vary among parts of the North region as shown in **Table 10**. The differences are due mostly to variation in energy prices and energy use.

Table 7. National LCC and PBP Results for Replacement and New Construction Cases

Option	Life-Cycle Cost *(2009$)*			Life-Cycle Cost Savings			Payback Period[12]	
	Average Installed Price	Average Lifetime Operating Cost*	Average LCC	Average Savings *(2009$)*	Households with Net Cost	Households with Net Benefit	Mean *(years)*	Average *(years)*
REPLACEMENT								
NCGF/NCWH	$2,875	$14,164	$17,038					
NCGF/CWH	$4,054	$13,799	$17,853	-$815	94%	6%	35	55
CGF/NCWH	$3,471	$13,179	$16,650	$389	42%	59%	9.7	17
CGF/CWH	$4,431	$12,814	$17,245	-$206	66%	34%	15.8	22.2
NEW CONSTRUCTION								
NCGF/NCWH	$3,933	$16,226	$20,159					
NCGF/CWH	$4,546	$15,859	$20,406	-$247	69%	31%	21	34
CGF/NCWH	$4,390	$15,111	$19,501	$658	26%	74%	8.1	12
CGF/CWH	$4,206	$14,745	$18,951	$1,208	14%	86%	3.5	5.9

* Discounted

Table 8. LCC and PBP Results for Replacement and New Construction Cases (NORTH)

Option	Life-Cycle Cost *(2009$)*			Life-Cycle Cost Savings			Payback Period	
	Average Installed Price	Average Lifetime Operating Cost*	Average LCC	Average Savings *(2009$)*	Households with Net Cost	Households with Net Benefit	Mean *(years)*	Average *(years)*
REPLACEMENT								
NCGF/NCWH	$3,027	$16,549	$19,576					
NCGF/CWH	$4,271	$16,169	$20,440	-$864	94%	6%	35	54
CGF/NCWH	$3,584	$15,311	$18,896	$680	23%	77%	6.6	8.2
CGF/CWH	$4,565	$14,931	$19,496	$80	56%	44%	12.8	14.3
NEW CONSTRUCTION								
NCGF/NCWH	$4,060	$18,988	$23,046					
NCGF/CWH	$4,730	$18,601	$23,329	-$283	71%	29%	22	35
CGF/NCWH	$4,575	$17,584	$22,157	$889	16%	84%	7.6	7.9
CGF/CWH	$4,321	$17,197	$21,518	$1,530	5%	95%	3.0	3.7

* Discounted

[12] Large differences in the average and median values for PBP are due to outliers in the distribution of results. A limited number of excessively long PBPs produce an average PBP that is very long. Therefore, the median PBP usually is a more representative value to gauge the length of the PBP.

Table 9. LCC and PBP Results for Replacement and New Construction Cases (SOUTH)

Option	Life-Cycle Cost *(2009$)*			Life-Cycle Cost Savings			Payback Period	
					Households with			
	Average Installed Price	Average Lifetime Operating Cost*	Average LCC	Average Savings *(2009$)*	Net Cost	Net Benefit	Mean *(years)*	Average *(years)*
REPLACEMENT								
NCGF/NCWH	$2,608	$9,989	$12,597					
NCGF/CWH	$3,675	$9,651	$13,326	-$729	93%	7%	34	56
CGF/NCWH	$3,273	$9,446	$12,719	-$121	73%	27%	23	32
CGF/CWH	$4,196	$9,108	$13,304	-$707	84%	16%	25	36
NEW CONSTRUCTION								
NCGF/NCWH	$3,709	$11,398	$15,109					
NCGF/CWH	$4,225	$11,067	$15,294	-$185	65%	35%	18.1	33.1
CGF/NCWH	$4,066	$10,789	$14,857	$252	44%	56%	11.9	20.2
CGF/CWH	$4,005	$10,458	$14,464	$644	28%	72%	5.6	9.7

* Discounted

Figure 2: Option with the Lowest LCC (Fraction of Households)

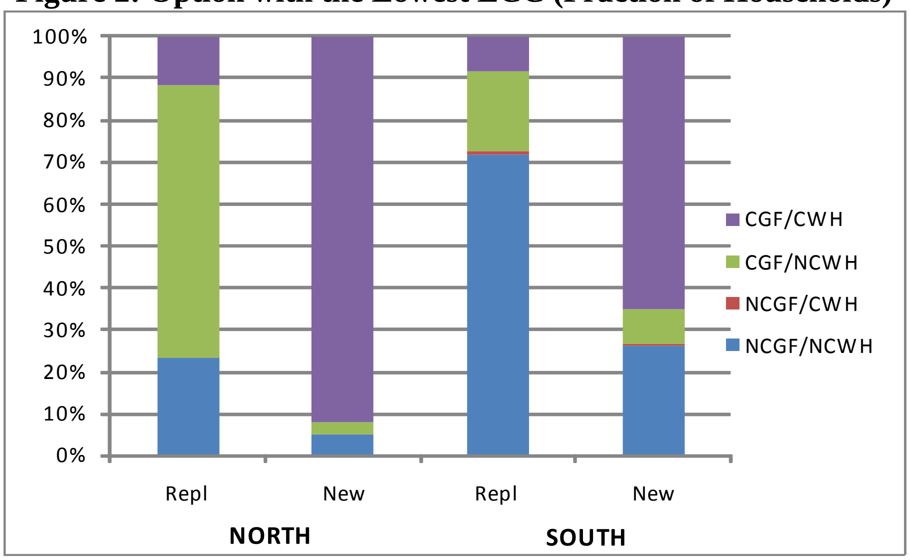


Table 10. Option 4 results for Replacement Cases in North Subregions

	Average LCC Savings	% Households with Net Benefit	Average Payback Period (years)	Fraction of National Sample
Northeast	$159	48%	13.5	12.6%
Midwest	$83	44%	14.4	42.3%
Northwest	-$53	38%	15.4	8.8%
Total North	$80	44%	14.3	63.6%

Discussion

The results assume that the consumer product cost for a condensing water heater falls to levels that are well below the prices that are likely in the near term. The assumed prices could come about if production rises to a significant level, or if subsidies lower the cost to consumers. The recently established Federal standards for large-volume gas water heaters, which will take effect in 2015, require condensing technology, and thus will increase production. To some degree, economies of scale in production of large-volume gas water heaters could spill over into the more common tank sizes.

This study did not consider all possible options for space heating and water heating combinations. Other options that could be attractive for some consumers include: gas tankless water heaters, heat pump water heaters, heat pump space heaters, and solar water heaters, as well as other combination space heating/water heating equipment types.

Conclusion

For the U.S. single family housing market the most common combination of water heating and space heating is a gas furnace with a gas water heater. This study found that at a national level, using a condensing furnace and a condensing water heater would show economic benefit for close to one third of household replacement installations and for a large majority of new construction if they are installed at the same time.

The economics of installing condensing furnaces and condensing water heaters are most favorable in the North. In this region the CGF plus CWH option has a positive LCC savings for replacement situations, mostly due to avoiding chimney relining costs when installing condensing equipment. Still, less than half of the sample households have a net benefit. In the South, the CGF plus CWH option is still quite attractive in new construction, but none of the options has positive average LCC savings in the replacement sample.

The economic results for the CGF plus CWH option vary among parts of the North due mostly to variation in energy prices and energy use. The economics are most favorable in the Northeast and Midwest, which account for more than 80 percent of the gas furnace and water heater households in the North.

The economic results indicate that significant energy savings and consumer benefits may result from large-scale introduction of condensing water heaters combined with condensing furnaces in U.S. residential single-family housing, particularly in the North. It also shows that important benefits may be overlooked when policy analysts evaluate the impact of space and water heating equipment separately.

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