APPENDIX 8.5. ANALYSIS OF ELECTRICITY EFFICIENCY DESIGN OPTIONS FOR FURNACES AND BOILERS

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8.5.1 INTRODUCTION

Residential furnaces and boilers use electricity for the circulating-air fan or circulating-water pump as well as for other electrical components (see section 3.2 in Chapter 3 for further discussion). In many applications, the furnace fan is also the air handler for the air conditioner.

As discussed in Chapter 1, the Department has determined that it does not have the authority to regulate electricity consumption in residential furnaces and boilers. While it was considering this issue, the Department analyzed all design options that met the screening criteria, including design options specific to saving electricity. The Department presents the analysis of these design options in this appendix only for the purposes of (a) full reporting to the public of that complete analysis, and (b) making the information available for possible use in voluntary or other non-regulatory efforts by manufacturers, utilities and other interested parties. This appendix is provided for information only.

To develop more information, DOE tested various circulating-air blowers in a common-size furnace using the Air Movement and Control Association test standard 210 (AMCA 210) as a method of determining the airflow capacity of a furnace circulating-air blower. Appendix 8.6 describes this testing.

8.5.2 ELECTRICITY EFFICIENCY OPTIONS THAT PASSED SCREENING

As described in Chapter 4, several design options specific to saving electricity in furnaces and boilers passed the screening. These are:

- Increased motor efficiency: applies to furnace blowers and hot-water boiler pumps. DOE considered (1) an improved permanent split-capacitor (PSC) motor, which uses improved materials and design and is slightly more efficient, (2) an electronically-commutated motor (ECM), and (3) a switched-reluctance motor.

- Increased blower impeller efficiency: substitutes a backward-inclined blade blower for a forward-inclined blade design, increasing furnace volume and shipping weight.

- Improved circulating pump (boilers only): uses an ECM for the circulating pump.

- Electronic (interrupted) ignition: applies to oil-fired equipment.

8.5.3 MANUFACTURING COST

Through discussion with component suppliers and consultants, and review of available literature, the Department estimated production costs for each of the electricity efficiency options assuming high-volume production (Tables 8.5.3.1 and 8.5.3.2). For the ECM, the cost could decrease to the $80 range after 2012, due to increased competition and incremental technology improvements. The switched-reluctance motor has the potential to be a lower cost option, but within the time span of this rulemaking, the technology is assumed to have the same cost as an ECM.

Table 8.5.3.1 Incremental Manufacturing Cost of Electricity-Efficiency Design Options for Furnaces*

Design Option	$
More-efficient PSC motor	5
Electronically-commutated motor	103
Switched-reluctance motor	103
Improved blower impeller	68 **

* Relative to baseline equipment.
** $49 additional production cost + $19 additional transportation cost due to larger size of the furnace cabinet

Table 8.5.3.2 Incremental Manufacturing Cost of Electricity-Efficiency Design Options for Hot-Water Boilers and Oil Equipment*

Design Option	$
Boilers: Improved circulating pump (using an ECM)	103
Oil Equipment: Interrupted ignition	17

* Relative to baseline equipment.

8.5.4 CALCULATION OF FURNACE OR BOILER ELECTRICITY CONSUMPTION WITH DESIGN OPTIONS, USING DOE TEST PROCEDURE

The electricity consumption of residential furnaces and boilers is represented by the Annual Auxiliary Electrical Energy (E_{AE}) parameter, which DOE calculated and reported in kWh/yr in accordance with the DOE test procedure, section 10.2.3. The details of the approach to calculate electricity consumption are reported in Appendix 6.3.

E_{AE} does not include blower operation for the air conditioner during the cooling season. In fact, the circulating-air blower (which is part of the furnace) is also the air handler for the air conditioner, and any efficiency improvement on the circulating-air blower will also provide electricity savings during the cooling season. The Department accounted for this in the LCC analysis to accurately show the effect of improving furnace electricity efficiency.

For each AFUE level above the baseline, DOE considered several electricity-efficiency design options. The selected design options for the different product classes are shown in the tables below.

Table 8.5.4.1 Electricity-Efficiency Design Options for Gas Furnaces

Product Class	Improved Blower Motor (PSC+)	Improved Blower Motor (ECM)	Improved Blower Motor (SR)	Improved Blower Impeller
Non-Weatherized Gas Furnaces	X	X	X	X
Weatherized Gas Furnaces		X		
Mobile Home Gas Furnaces		X		

Table 8.5.4.2 Electricity-Efficiency Design Options for Oil-Fired Furnaces and Hot-Water Boilers

Product Class	Improved Blower/Pump Motor (ECM)	Interrupted Ignition
Oil-Fired Furnaces	X	X
Hot-Water Gas Boilers	X	
Hot-Water Oil-Fired Boilers		X

The calculation of electricity consumption starts with the calculation of E_{AE} in accordance with the DOE test procedure. At each AFUE level, the analysis yields a percentage reduction in electricity consumption associated with each electricity-efficiency design option. When an electricity-efficiency design option is introduced, there is usually a small increase in fuel consumption because a more efficient motor generates less heat, which otherwise would contribute to the heating requirements. To develop a better understanding of the performance of more efficient blower/motor combinations, DOE conducted testing. Appendix 6.6 presents a summary of the testing results.

Generally, inclusion of electricity-efficiency design options slightly increases the payback period for a given AFUE level relative to use of baseline electricity features, since more efficient electrical components generate less waste heat.

8.5.5 ELECTRICITY-EFFICIENCY DESIGN OPTIONS CONSIDERED IN THE LCC ANALYSIS FOR FURNACES

The baseline design for the furnace circulating-air blower is a forward-curved centrifugal blower powered by a PSC induction motor. In the LCC Analysis, DOE considered three design options to improve blower efficiency: 1) an improved PSC motor (PSC+); 2) an ECM; and 3) a backward-curved blower impeller with a different ECM motor (BC/ECM+). DOE did not conduct any LCC analysis for the switched reluctance motor because it may be less efficient than the ECM motor and may be more costly.

The PSC+ is a motor with a dedicated lamination design using higher-grade electrical steel and tighter windings, with proportionately more copper to limit winding losses. ECM motors have permanent magnets on the rotor. By changing the frequency and voltage on the stator coils, the speed and torque of the motor can be adjusted. The BC/ECM+ motor operates at a higher speed, has a smaller diameter, and has improved magnets and electronics.

Furnaces with ECM or BC/ECM+ blower motors are programmed to take advantage of the adjustable speed and torque of ECM motors to provide constant airflow, regardless of the static pressure. This is the equivalent of a vertical fan curve at the nominal airflow of the furnace.

Chapter 7 describes the general approach for calculating furnace blower electricity consumption. A full accounting of the impact of electricity-efficiency design options requires consideration of blower electricity consumption in the heating season and in the cooling season when an air conditioner may be in use.

Section 7.5.4 in Chapter 7 describes the approach for calculating blower electricity consumption (BE) for baseline furnaces. Although the approach generally applies to the blower efficiency design options, the calculation of BE varies somewhat with each design option.

For the PSC+ design option,

$$BE = \frac{AHP}{\eta_{overall} \times scalar}$$

where:

AHP = air horsepower (W),
$\eta_{overall}$ = overall efficiency, and
$scalar$ = the incremental motor efficiency gain from the PSC+ design option.

AHP and $\eta_{overall}$ depend on static pressure and airflow, as described in section 7.5.3. on Overall Air-Moving Efficiency.

For the ECM design option, the Department developed a series of equations to calculate the blower speed and shaft power from the furnace static pressure, the blower-motor efficiency from the shaft power and speed, and the blower-motor power consumption from the efficiency and shaft power. The Department developed these equations for ECM motors from the product literature of a motor manufacturer.[1] See Appendix 8.7, Power Consumption of ECM Blower-Motors.

For the BC/ECM+ design option, the Department developed an equation for BE as a function of static pressure and airflow from a prototype backward-inclined blower developed by General Electric.[2] The static pressure and airflow is determined from the intersection of the duct system curve and the vertical fan curve of a furnace, as with an ECM motor. This is explained further in Appendix 8.8, Power Consumption of BC/ECM+ Blower-Motors.

Section 7.6.2 of Chapter 7 describes the calculation of furnace electricity consumption during the summer when the blower moves the air cooled by the air conditioner. More-efficient blower design options will reduce the amount of heat from the blower and blower motor added to the cooled airstream. However, the annual household cooling load does not change. The cooling provided by the air-conditioning system, including the furnace blower, must remain the same, so the air-conditioner operating hours are reduced. See Appendix 8.9, Air Conditioner Operating Hours, for the derivation of these calculations. The Department calculated the new air-conditioner operating hours as:

$$ACOHnew = \frac{ACOHexist}{1 + 3.412 \times \left(\dfrac{BEexist - BEnew}{ACcapacity} \right)}$$

where:

BE	=	blower motor power (W), and
$AC_{capacity}$	=	cooling capacity of the air conditioner (Btu/h).

8.5.6 ELECTRICITY-EFFICIENCY DESIGN OPTIONS CONSIDERED IN THE LCC ANALYSIS FOR BOILERS AND OIL-FIRED EQUIPMENT

The power consumption of the circulating pump motor for hot-water boilers is fixed at 62 watts for the baseline design. The improved circulating pump with ECM would reduce pump power by 32 percent[3] or from 62 to 42 watts.

For oil-fired furnaces and boilers, the LCC analysis considered interrupted ignition. DOE estimated the electricity savings from interrupted ignition based on a reduction of the on-time of the burner interrupted ignition device from 3.87 min/cycle (for intermittent ignition) to 0.75 min/cycle.

8.5.7 RESULTS OF ENERGY CONSUMPTION CALCULATIONS

The average energy use for each design option for non-weatherized gas furnaces is shown in Table 8.5.7.1. The range of annual gas use for non-weatherized gas furnaces for all design options is shown in Figure 8.5.7.1. Figures 8.5.7.2 and 8.5.7.3 show the range of winter and summer electricity consumption, respectively.

Table 8.5.7.1 Non-Weatherized Gas Furnace Energy Use

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
78% Baseline	66.4	488.0	156.7
80%	64.8	476.2	156.7
80% PSC+	64.8	459.1	148.9
80% ECM	65.5	299.8	117.9
80% BC/ECM+	65.8	239.8	77.3
80% 2-stage Mod.	63.4	475.4	156.7
80% 2-stage Mod. ECM	64.8	246.1	117.9
80% 2-stage Mod. BC/ECM+	65.3	200.6	77.3
81% 8% Cat. III	64.1	469.8	153.9
81% PSC+	64.1	453.6	148.9
81% ECM	64.7	296.2	117.9
81% BC/ECM+	65.0	236.9	77.3
81% 2-stage Mod, no Cat. III	62.7	469.8	156.7
81% 2-stage Mod ECM	64.0	243.2	117.9
81% 2-stage Mod BC/ECM+	64.5	198.2	77.3
82%	63.2	464.9	156.7
82% PSC+	63.3	448.2	148.9
82% ECM	63.9	292.6	117.9
82% BC/ECM+	64.2	234.0	77.3
82% 2-stage Mod	62.0	464.4	156.7
82% 2-stage Mod ECM	63.3	240.3	117.9
82% 2-stage Mod BC/ECM+	63.7	195.8	77.3
83%	62.5	459.4	156.7

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
90% Baseline Cond.	57.8	421.1	156.7
90% PSC+	57.9	406.6	148.9
90% ECM	58.3	277.6	117.9
90% BC/ECM+	58.5	224.1	77.3
91% 2-stage Mod ECM	57.2	238.5	117.9
91% 2-stage Mod BC/ECM+	57.5	197.4	77.3
91% Step Mod ECM	56.8	236.9	117.9
91% Step Mod BC/ECM+	57.3	196.4	77.3
92%Incr. HX Area	56.6	412.2	156.7
92% PSC+	56.6	397.9	148.9
92% ECM	57.1	271.7	117.9
92% BC/ECM+	57.3	219.2	77.3
93% 2-stage Mod ECM	56.0	233.5	117.9
93% 2-stage Mod BC/ECM+	56.3	193.2	77.3
93% Step Mod ECM	55.6	231.9	117.9
93% Step Mod BC/ECM+	56.1	192.3	77.3
96% Step Mod ECM	53.9	224.9	117.9
96% Step Mod BC/ECM+	54.3	186.4	77.3

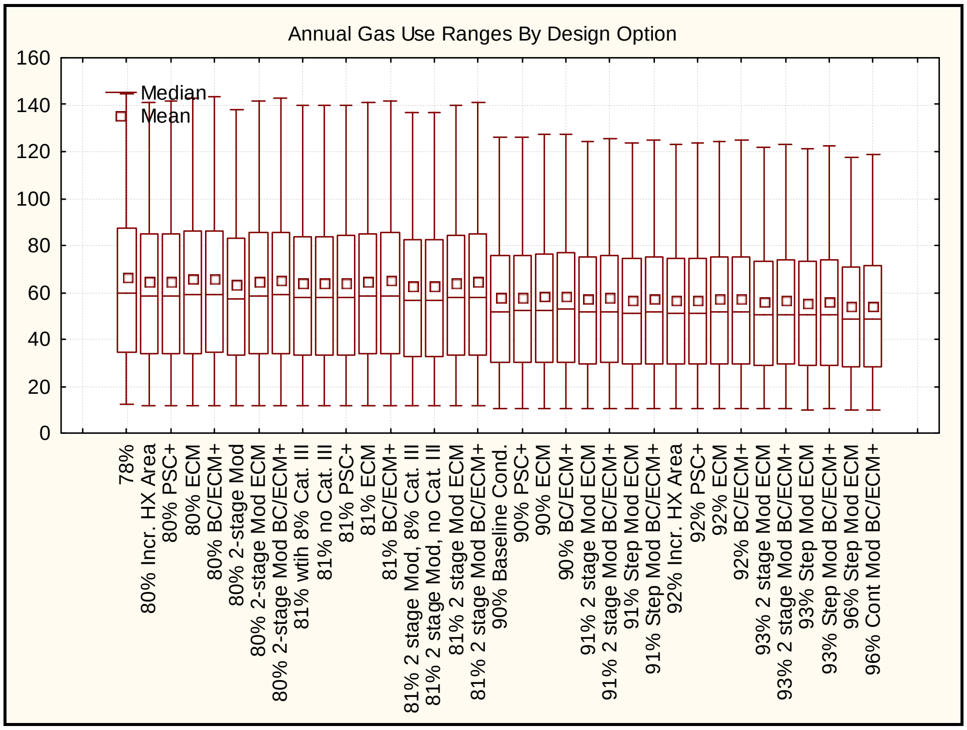

Figure 8.5.7.1 Range of Annual Gas Use, Non-Weatherized Gas Furnaces

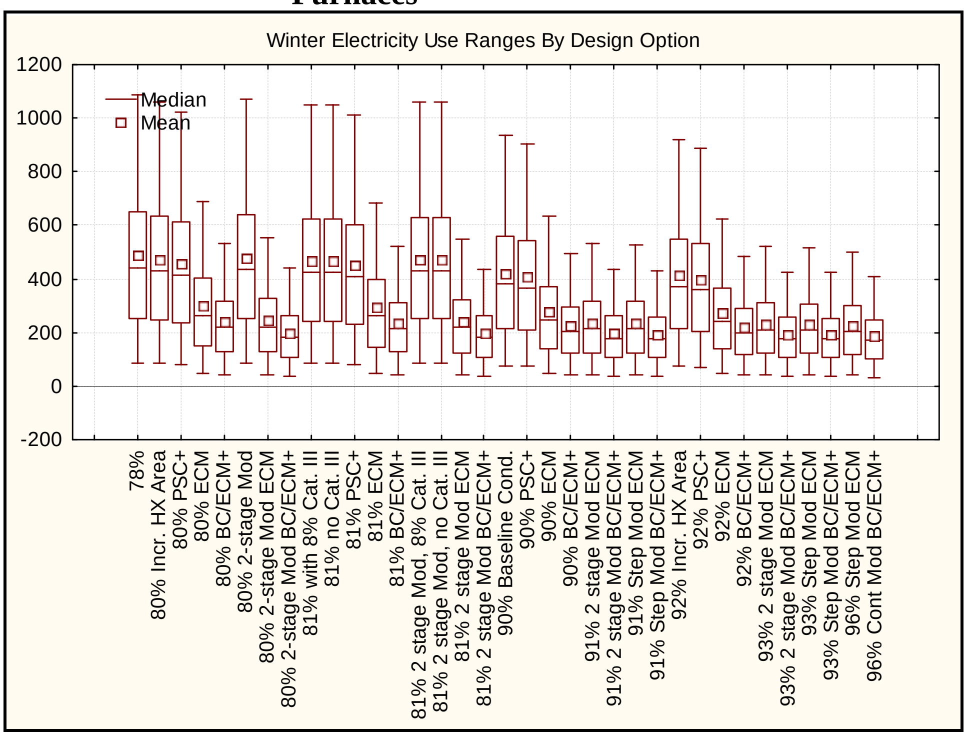

Figure 8.5.7.2 Range of Winter Electricity Use, Non-Weatherized Gas Furnaces

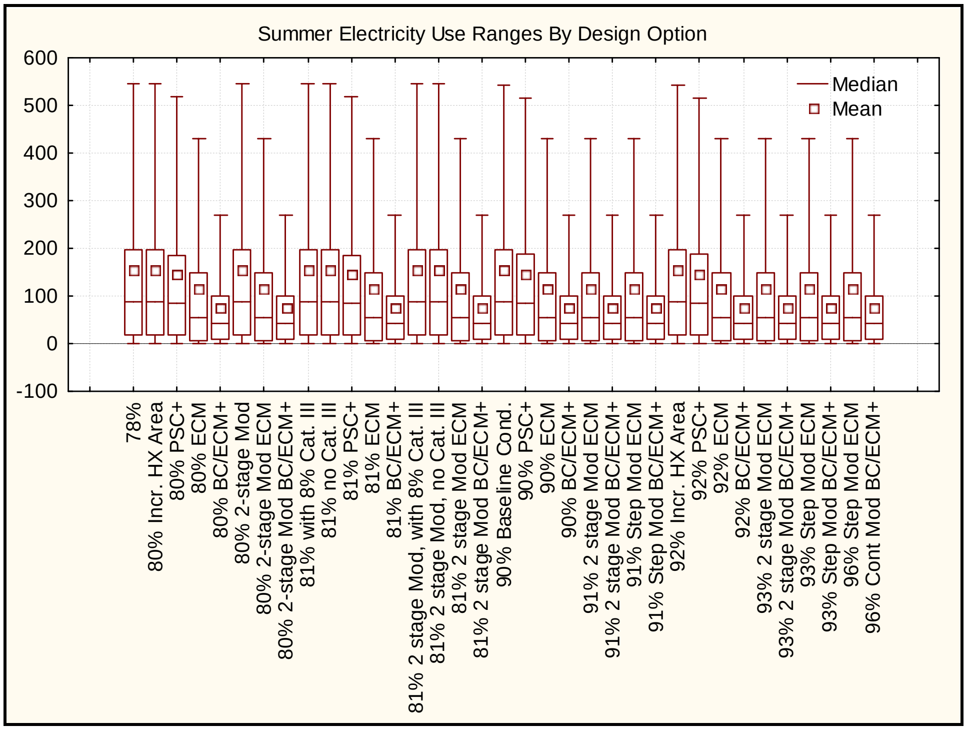

Figure 8.5.7.3 Range of Summer Electricity Use, Non-Weatherized Gas Furnaces

The average energy use for each design option for mobile home furnaces is shown in Table 8.5.7.2. The range of annual gas use for mobile home furnaces for all design options is shown in Figure 8.5.7.4. Figures 8.5.7.5 and 8.5.7.6 show the range of winter and summer electricity consumption respectively.

Table 8.5.7.2 Mobile Home Furnace Energy Use

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
75% Baseline	50.8	374.0	228.7
80%	45.0	404.5	228.7
80% ECM	45.8	220.8	126.4
80% 2-stage Mod	43.9	397.9	228.7
81%	44.5	399.7	228.7
81% ECM	45.3	218.2	126.4
81% 2-stage Mod	43.4	393.3	228.7
82%	44.0	395.0	228.7
82% ECM	44.7	215.5	126.4
82% 2-stage Mod	42.9	388.8	228.7
90%	40.2	359.2	232.7

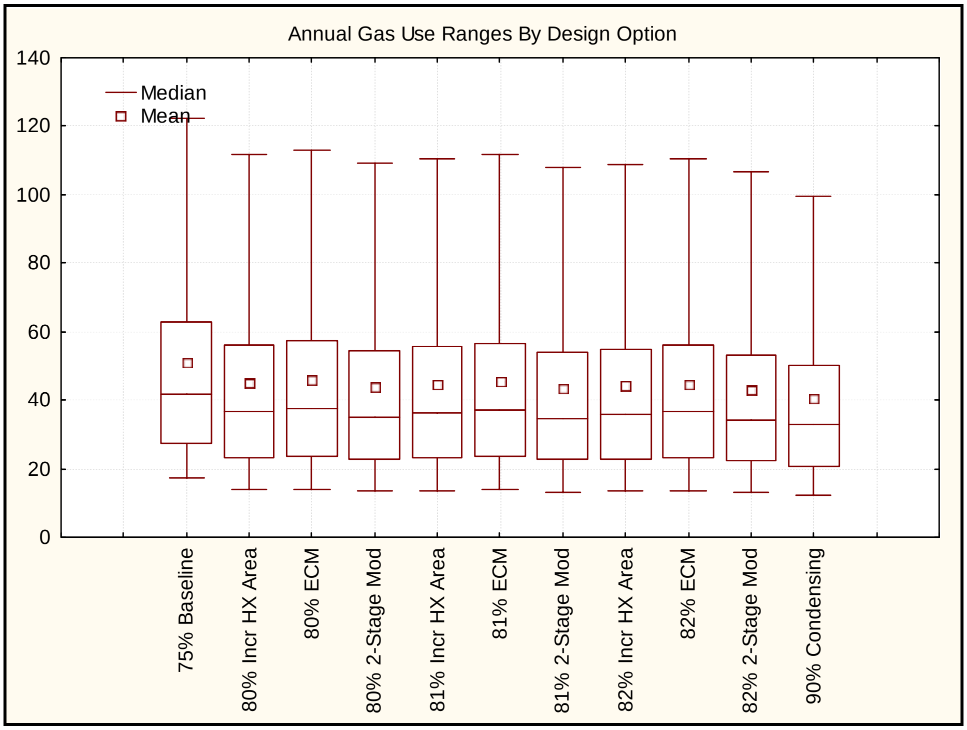

Figure 8.5.7.4 Range of Annual Gas Use, Mobile Home Furnaces

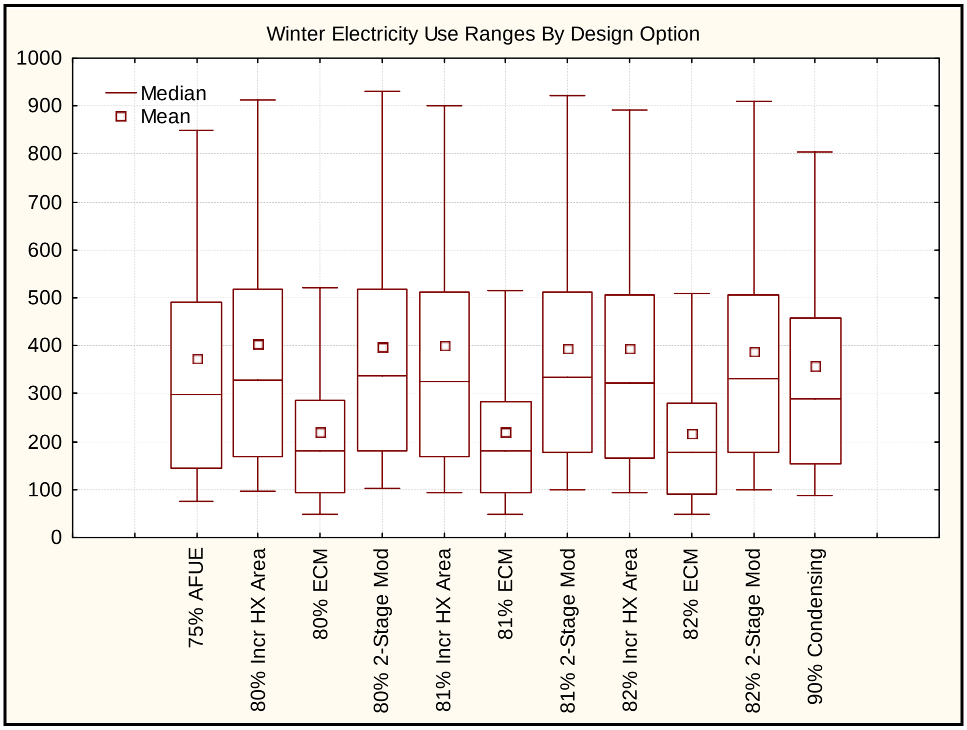

Figure 8.5.7.5 Range of Winter Electricity Use, Mobile Home Furnaces

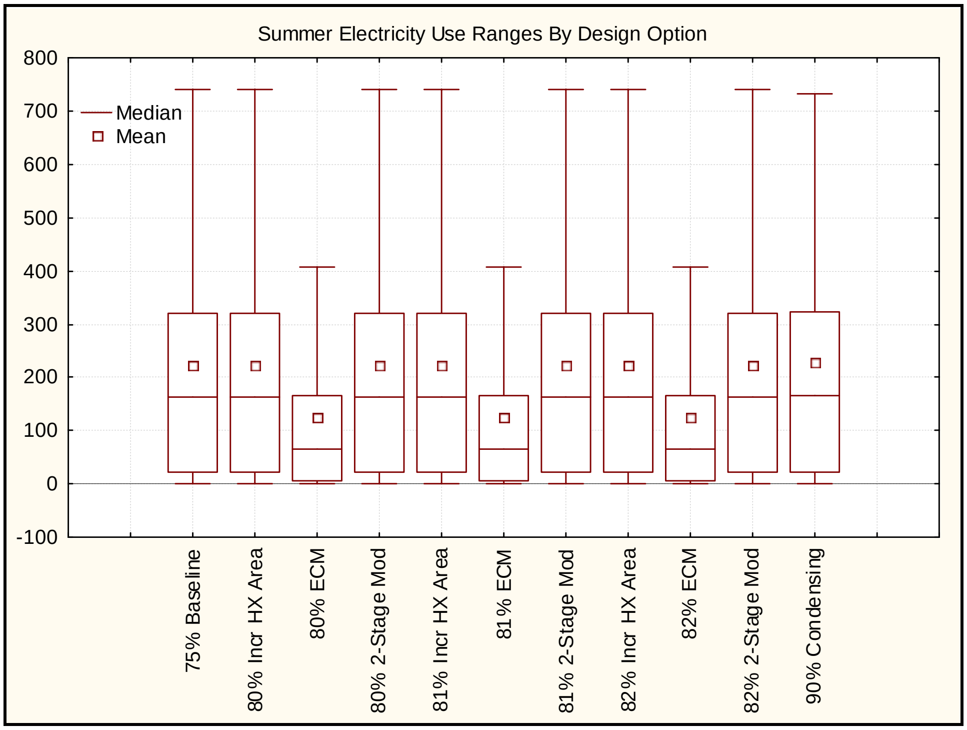

Figure 8.5.7.6 Range of Summer Electricity Use, Mobile Home Furnaces

The average energy use for each design option for weatherized furnaces is shown in Table 8.5.7.3. The range of annual gas use for weatherized furnaces for all design options is shown in Figure 8.5.7.7. Figures 8.5.7.8 and 8.5.7.9 show the range of winter and summer electricity consumption respectively.

Table 8.5.7.3 Weatherized Furnaces Energy Use

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
78% Baseline	40.3	298.2	372.2
80% Incr. HX Area	39.3	291.0	372.2
80% Improved Insulation	39.1	289.9	372.2
80% PSC+	39.3	280.7	353.7
80% ECM	39.7	182.2	281.2
80% Improved Heat Xfer	39.3	291.0	372.2
81% Incr. HX Area	38.8	287.5	372.2
81% Improved Insulation	38.7	286.4	372.2
81% PSC+	38.9	277.4	353.7
81% ECM	39.3	180.0	281.2
81% Improved Heat Xfer	38.8	287.5	372.2
82% Incr. HX Area	38.3	284.1	372.2
82% Improved Insulation	38.2	283.0	372.2
82% PSC+	38.4	274.1	353.7
82% ECM	38.8	177.9	281.2
82% Improved Heat Xfer	38.3	284.1	372.2
83% Incr. HX Area	37.9	280.7	372.2
83% Improved Insulation	37.8	279.7	372.2
83% PSC+	37.9	270.8	353.7
83% ECM	38.3	175.7	281.2
83% Improved Heat Xfer	37.9	280.7	372.2

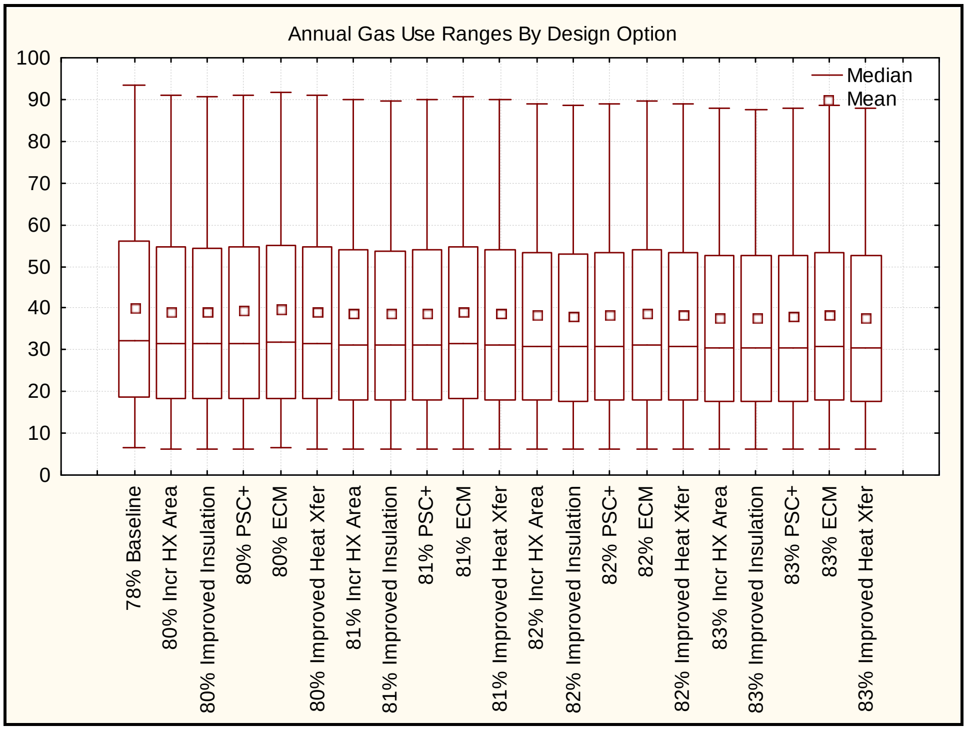

Figure 8.5.7.7 Range of Gas Use, Weatherized Gas Furnaces

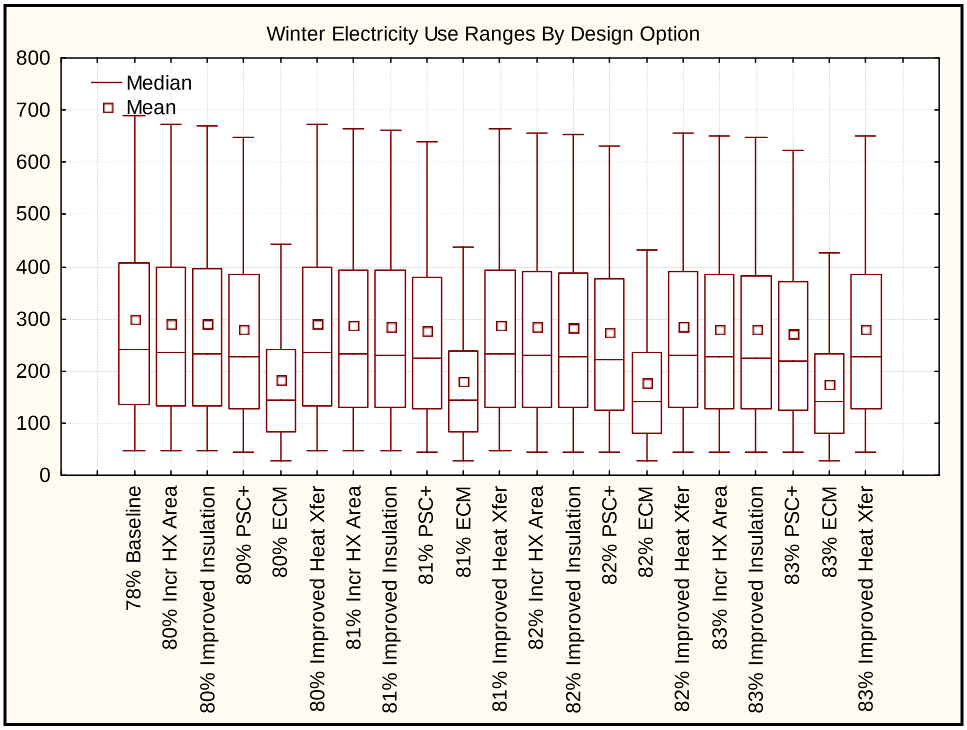

Figure 8.5.7.8 Range of Winter Electricity Use, Weatherized Gas Furnaces

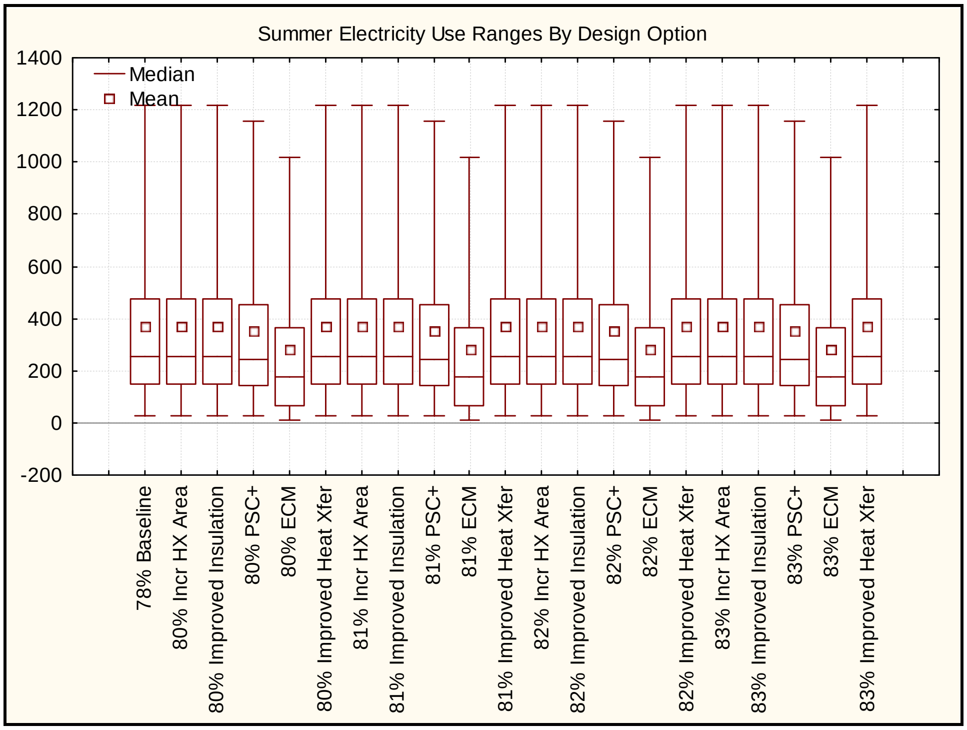

Figure 8.5.7.9 Range of Summer Electricity Use, Weatherized Furnaces

The average energy use for each design option for oil-fired furnaces is shown in Table 8.5.7.4. The range of annual oil use for all design options is shown in Figure 8.5.7.10. Figures 8.5.7.11 and 8.5.7.12 show the range of winter and summer electricity consumption respectively.

Table 8.5.7.4 Oil-Furnace Energy Use

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
78% Baseline	87.8	787.3	71.3
80%	85.7	768.1	71.3
81% Incr. HX Area	84.7	758.9	71.3
81% Atom Burner 2-stage Mod.	82.6	845.3	71.3
81% Interrupted Ignition	84.8	727.2	71.3
81%ImprovedSupplyFanMotor(ECM)	85.6	533.6	57.3
82%	83.7	749.9	71.3
82% Atom Burner 2-stage Mod.	81.6	835.6	71.3
82% Interrupted Ignition	83.8	718.6	71.3
82%ImprovedSupplyFanMotor(ECM)	84.6	527.2	57.3
83%	82.7	741.1	71.3
83% Atom Burner 2-stage Mod.	80.7	826.0	71.3
83% Interrupted Ignition	82.8	710.1	71.3
83%ImprovedSupplyFanMotor(ECM)	83.6	520.9	57.3
84%	81.7	732.5	71.3
84% Atom Burner 2-stage Mod.	79.8	816.7	71.3
84% Interrupted Ignition	81.8	701.9	71.3
84%ImprovedSupplyFanMotor(ECM)	82.6	514.8	57.3
85%	80.8	724.1	71.3
85% Atom Burner 2-stage Mod.	78.9	807.1	71.3
85% Interrupted Ignition	80.9	693.8	71.3
85%ImprovedSupplyFanMotor(ECM)	81.6	508.9	57.3

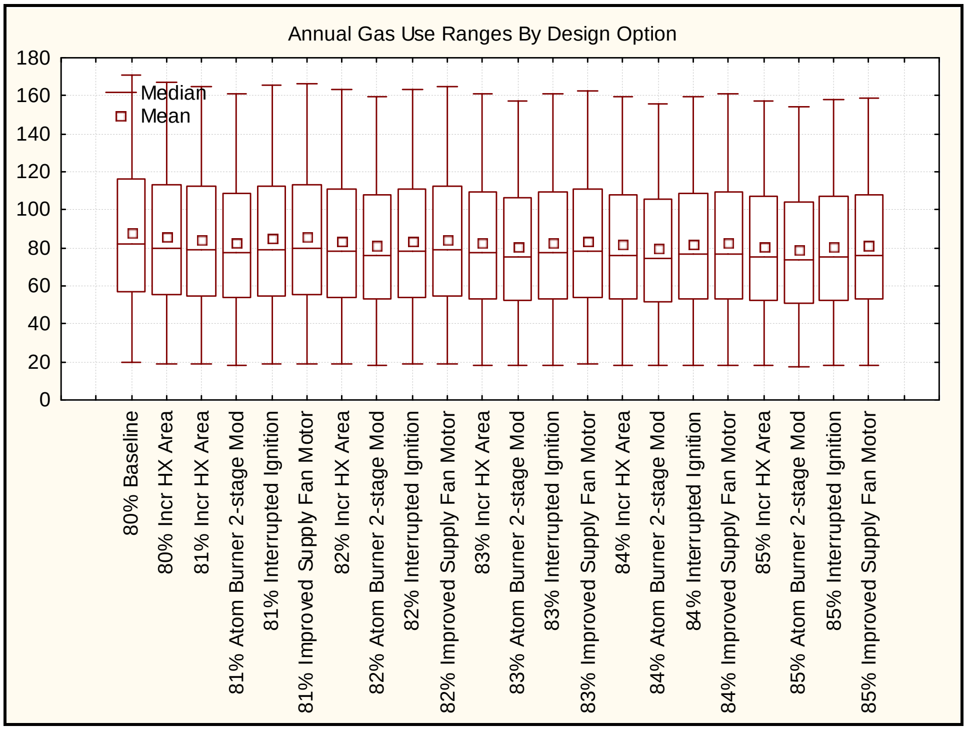

Figure 8.5.7.10 Range of Oil Use, Oil-Fired Furnaces

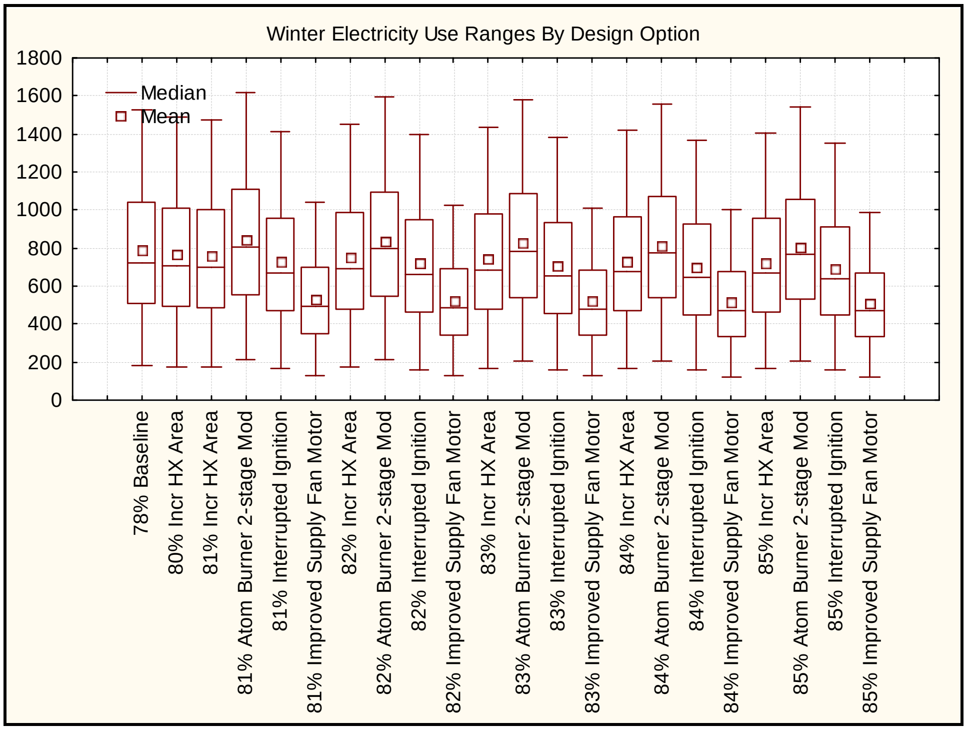

Figure 8.5.7.11 Range of Winter Electricity Use, Oil-Fired Furnaces

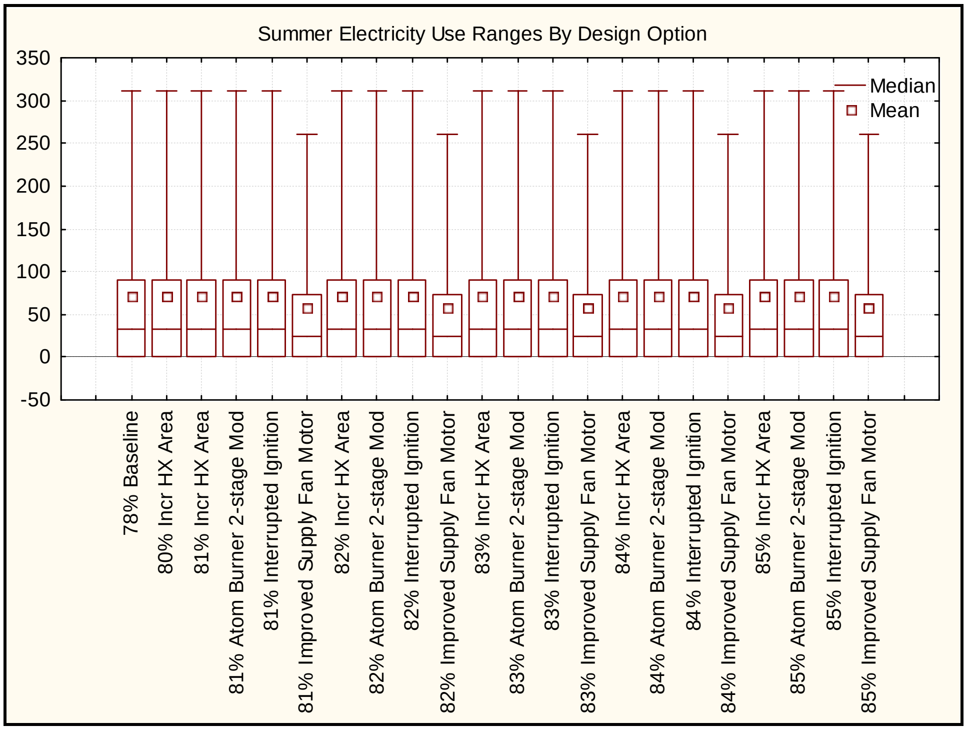

Figure 8.5.7.12 Range of Summer Electricity Use, Oil-Fired Furnaces

The average energy use for each design option for hot-water gas boilers is shown in Table 8.5.7.5. The range of annual gas use for all design options is shown in Figure 8.5.7.13. Figure 8.5.7.14 shows the range of winter electricity consumption.

Table 8.5.7.5 Gas Boiler Energy Use

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)
80% Baseline	93.5	378.9
81%	88.8	379.8
81% 2-stage mod. + Indc Draft	87.4	561.7
81% Imp Circ Pump	89.0	337.6
82%	87.7	375.2
82% 2-stage mod. + Indc Draft	86.4	555.1
82% Imp Circ Pump	87.9	333.5
83% Imp Ht Xfer / Elec. Ign	86.7	370.8
83% 2-stage mod. + Indc Draft	85.4	548.6
83% Imp Circ Pump	86.9	329.6
84%	85.7	366.5
84% 2-stage mod. + Indc Draft	84.4	542.3
84% Imp Circ Pump	85.8	325.7
88%	81.8	350.0
91%	79.3	301.0
99%	73.0	276.9

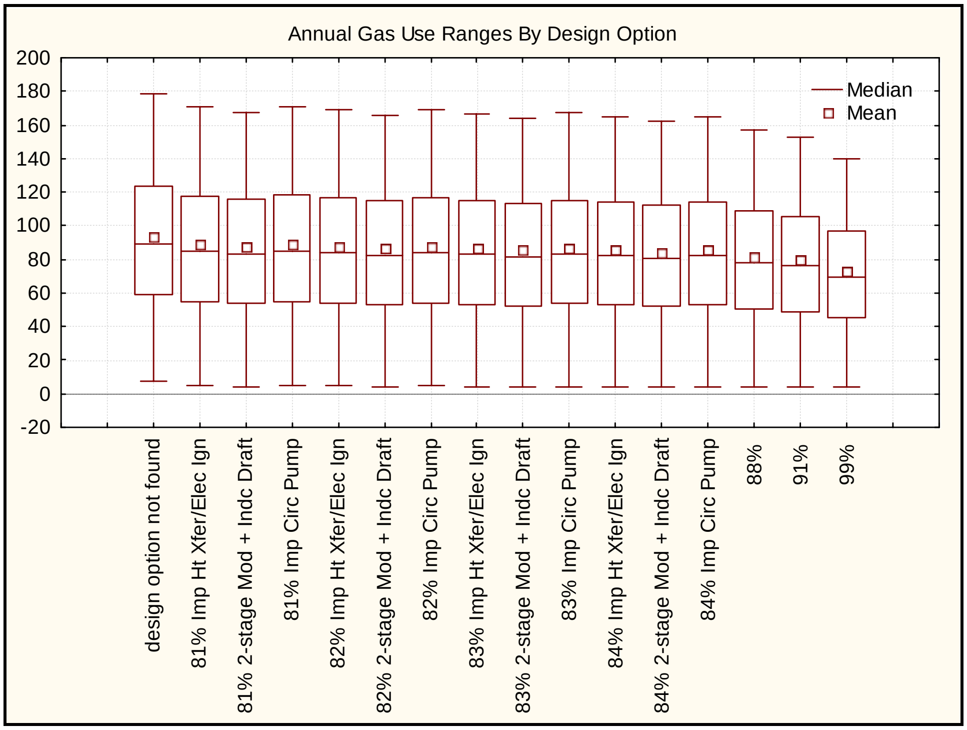

Figure 8.5.7.13 Range of Gas Use, Hot Water Gas Boilers

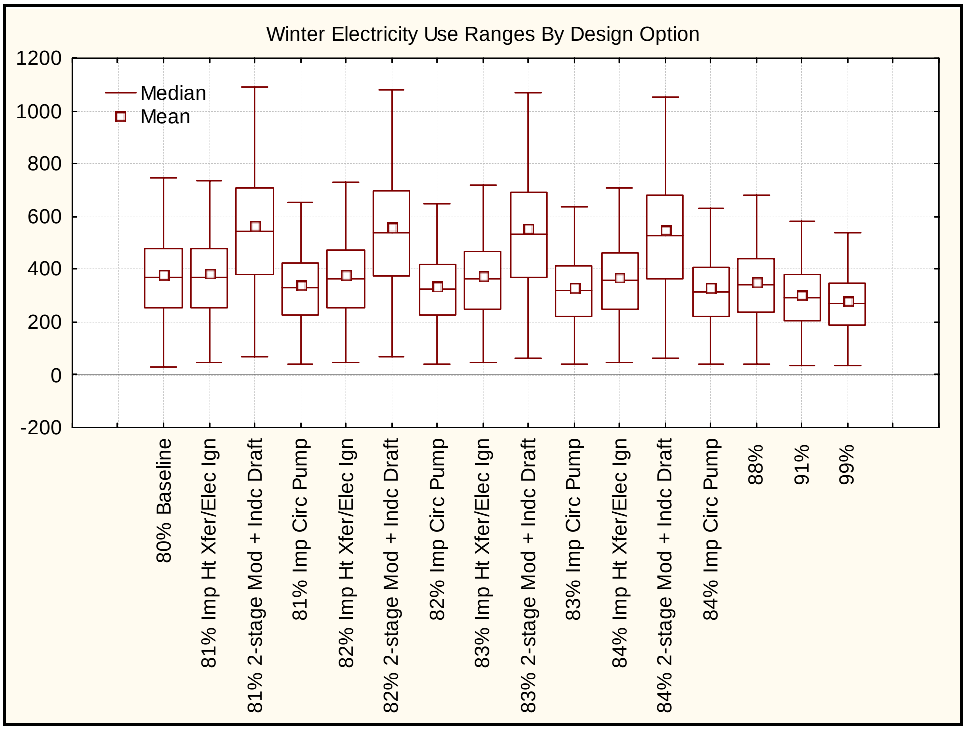

Figure 8.5.7.14 Range of Winter Electricity Use, Hot Water Gas Boilers

The average energy use for each design option for hot-water oil-fired boilers is shown in Table 8.5.7.6. The range of annual oil use for oil boilers for all design options is shown in Figure 8.5.7.15. Figure 8.5.7.16 shows the range of winter electricity consumption.

Table 8.5.7.6 Oil Boiler Energy Use

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)
80% Baseline	108.7	381.3
81%	107.4	376.7
81% Atom Burner 2-stage Mod.	105.9	566.9
81% Interrupted Ign	107.5	345.3
81% Imp Circ Pump	107.5	338.3
82%	106.1	372.2
82% Atom Burner 2-stage Mod.	104.6	560.1
82% Interrupted Ign	106.2	341.1
82% Imp Circ Pump	106.2	334.2
83%	104.8	367.7
83% Atom Burner 2-stage Mod.	103.4	553.6
83% Interrupted Ign	104.9	337.1
83% Imp Circ Pump	105.0	330.3
84%	103.6	363.4
84% Atom Burner 2-stage Mod.	102.2	547.1
84% Interrupted Ign	103.7	333.1
84% Imp Circ Pump	103.7	326.4
86%	101.2	355.1
86% Atom Burner 2-stage Mod.	99.9	534.7
86% Interrupted Ign	101.3	325.4
86% Imp Circ Pump	101.3	318.9
90%	97.0	276.4
95%	91.9	262.0

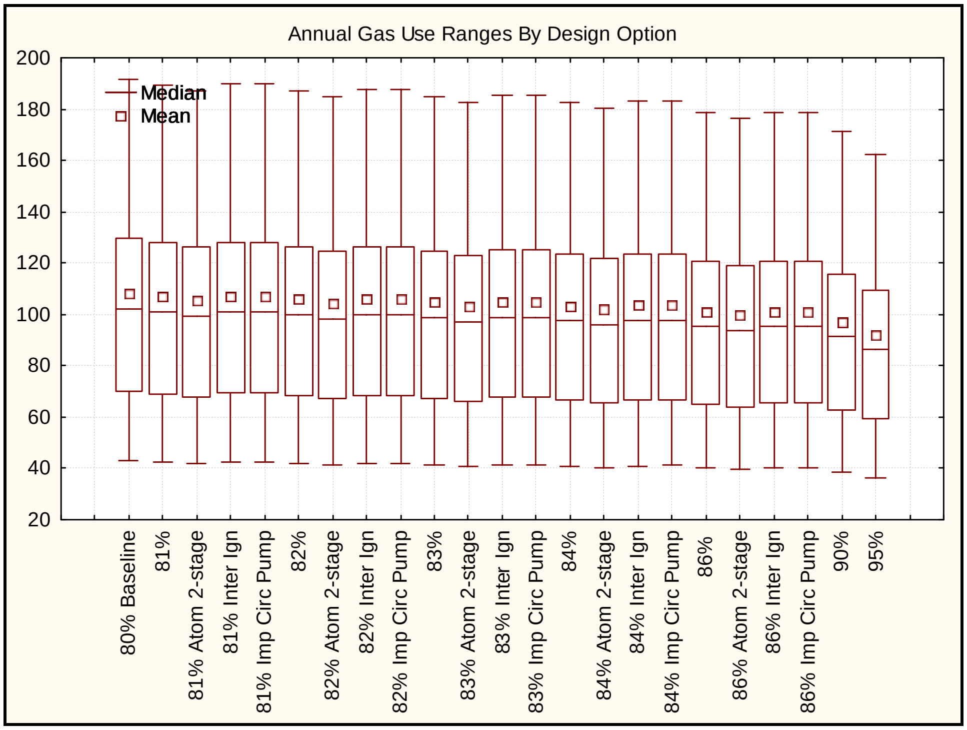

Figure 8.5.7.15 Range of Annual Oil Use, Hot-Water Oil Boilers

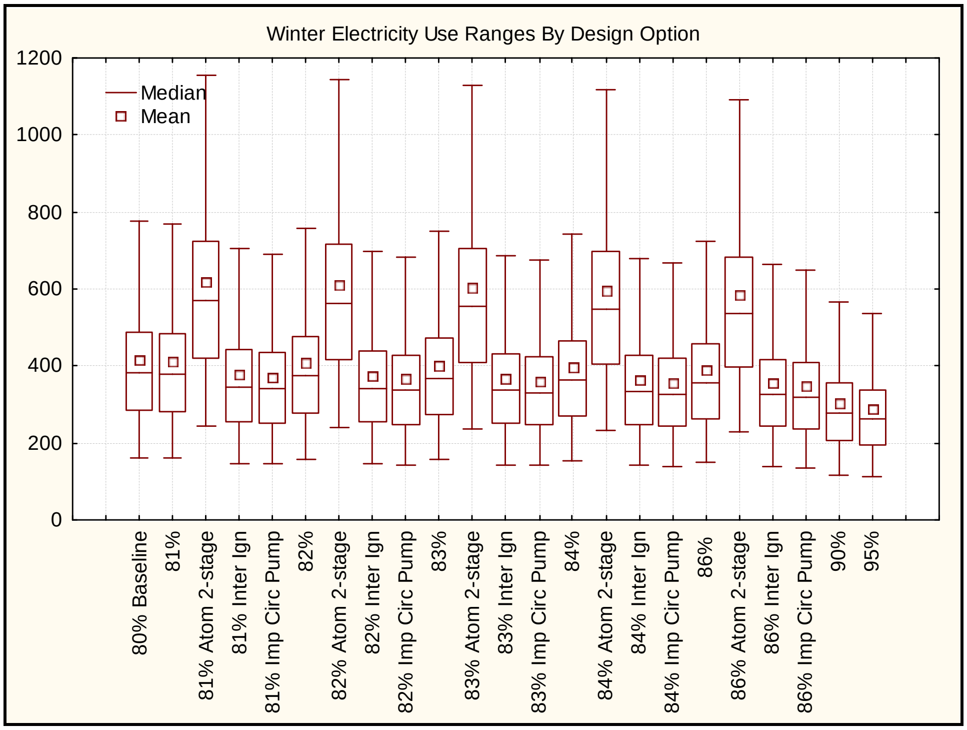

Figure 8.5.7.16 Range of Winter Electricity Use, Hot-Water Oil Boilers

8.5.8 LCC RESULTS INCLUDING ELECTRICITY-EFFICIENCY DESIGN OPTIONS

The calculation of LCC and PBP for equipment with the electricity-efficiency design options followed the approach described in Chapter 8. For these options, summer electricity prices were used for calculating the energy cost of summer electricity consumption.

Table 8.5.8.1 shows the LCC and payback results for all design options for non-weatherized gas furnaces. At 80 percent and 81 percent AFUE levels, the improved PSC motor increases the LCC savings relative to designs with a baseline blower. The ECM and BC/ECM+ options have a negative effect on LCC.

Table 8.5.8.1 LCC and PBP Results for Non-Weatherized Gas Furnaces, Including Electricity-Efficiency Design Options

	LCC					Payback	
Design Option (AFUE and technology description)	**Average**	**Average Savings**	**Net Cost**	**No Impact***	**Net Benefit**	**Median**	**Average ****
	$	$	%	%	%	years	years
78% Baseline	$9,966						
80%	$9,795	$0	0%	99%	1%	2.1	37.8
80% PSC+	$9,784	$7	17%	27%	56%	5.4	5.3
80% ECM	$9,873	-$59	60%	27%	14%	23.0	33.7
80% BC/ECM+	$9,822	-$21	51%	27%	23%	17.2	26.3
80% 2-stage mod.	$9,718	$41	33%	27%	40%	8.6	13.5
80% 2-mod. ECM	$9,795	-$13	48%	27%	26%	15.4	21.1
80% 2-stage mod. BC/ECM+	$9,782	$1	45%	27%	28%	14.3	20.9
81%, 8% Cat. III	$9,789	-$3	32%	27%	41%	8.8	27.8
81% PSC+	$9,779	$5	30%	26%	44%	8.1	21.3
81% ECM	$9,868	-$62	51%	26%	23%	17.8	26.2
81% BC/ECM+	$9,816	-$24	45%	26%	29%	14.8	22.9
81% 2-stage Mod, no Cat. III	$9,680	$63	29%	26%	45%	7.6	17.0
81% 2-stage Mod ECM	$9,796	-$20	44%	26%	29%	14.4	21.1
81% 2-stage Mod BC/ECM+	$9,782	-$5	43%	26%	31%	13.7	20.5
82%	$10,170	-$292	70%	26%	4%	28.7	84.6
82% PSC+	$10,159	-$284	69%	26%	5%	29.2	80.6
82% ECM	$10,249	-$351	71%	26%	3%	48.4	102.4
82% BC/ECM+	$10,197	-$312	68%	26%	6%	34.8	80.3

	LCC					Payback	
Design Option **(AFUE and technology description)**	**Average**	**Average Savings**	**Net Cost**	**No Impact***	**Net Benefit**	**Median**	**Average ****
82% 2-stage Mod	$10,103	-$256	65%	26%	9%	18.5	60.2
82% 2-stage Mod ECM	$10,179	-$310	67%	26%	7%	34.6	82.1
82% 2-stage Mod BC/ECM+	$10,164	-$295	65%	26%	9%	30.9	70.4
83%	$10,400	-$468	73%	26%	1%	63.3	121.3
90% Baseline Cond.	$9,917	-$154	56%	26%	18%	17.9	42.5
90% PSC+	$9,907	-$145	57%	15%	27%	14.3	37.9
90% ECM	$10,007	-$226	66%	15%	19%	21.5	47.0
90% BC/ECM+	$9,957	-$180	63%	15%	22%	19.1	42.0
91% 2-stage Mod ECM	$9,898	-$141	58%	15%	26%	16.5	40.6
91% 2-stage BC/ECM+	$9,878	-$118	58%	15%	27%	16.2	37.8
91% Step Mod ECM	$10,119	-$328	67%	15%	18%	22.2	54.2
91% Step Mod BC/ECM+	$10,110	-$315	66%	15%	18%	21.6	49.2
92%Incr. HX Area	$9,924	-$166	60%	15%	25%	16.1	41.7
92% PSC+	$9,914	-$156	63%	2%	35%	13.2	35.8
92% ECM	$10,015	-$255	76%	2%	22%	21.3	45.0
92% BC/ECM+	$9,965	-$205	73%	2%	25%	19.2	39.7
93% 2-stage Mod ECM	$9,912	-$154	67%	2%	32%	15.7	39.1
93% 2-stage Mod BC/ECM+	$9,891	-$133	66%	2%	32%	15.7	35.7
93% Step Mod ECM	$10,134	-$373	78%	2%	21%	21.6	50.4
93% Step Mod BC/ECM+	$10,124	-$362	77%	2%	21%	21.4	45.1
96% Step Mod ECM	$10,724	-$954	89%	2%	9%	32.3	88.9
96% Step Mod BC/ECM+	$10,738	-$967	91%	0%	9%	32.8	83.6

* “No impact” means that the base case furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

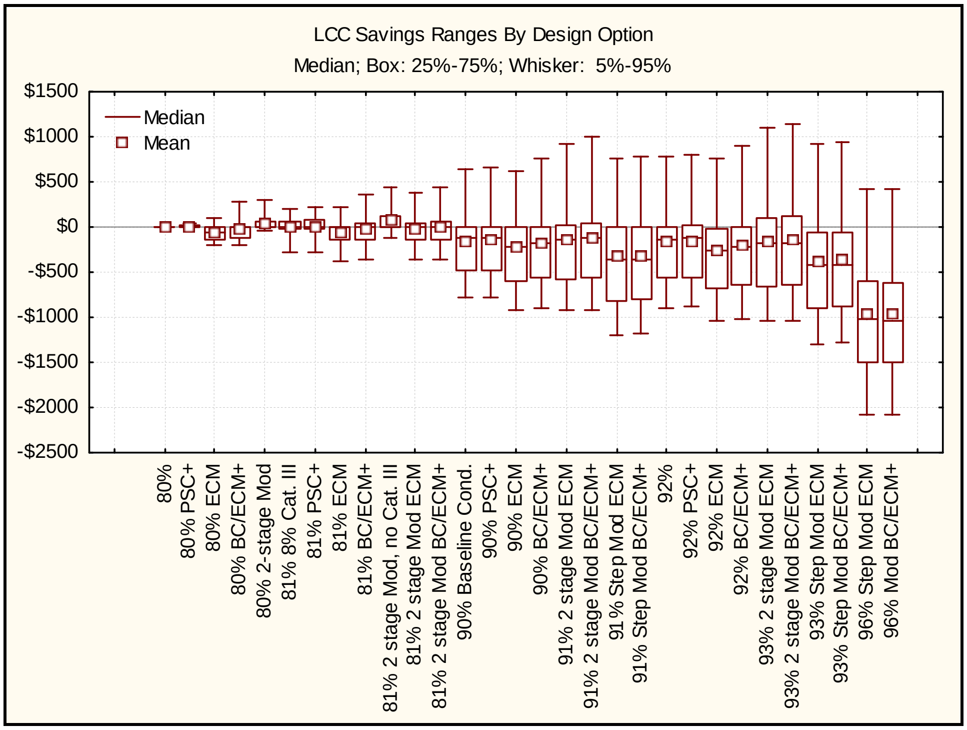

Figure 8.5.8.1 Range of LCC Savings by Design Option for Non-Weatherized Gas Furnaces

Figure 8.5.8.1 shows the range of LCC savings for all design options for non-weatherized gas furnaces. For each design option, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have LCC savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each design option.

Table 8.5.8.2 shows the results for weatherized gas furnaces. For all considered AFUE levels, the improved PSC motor increases the LCC savings relative to designs with a baseline blower. The ECM option has a negative effect on LCC. Figure 8.5.8.2 shows the range of LCC savings by design option for weatherized gas furnaces.

Table 8.5.8.2 LCC and PBP Results for Weatherized Gas Furnaces, Including Electricity-Efficiency Design Options

Design Option (AFUE and technology description)	LCC					Payback	
	Average	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average **
78% Baseline	$8,545						
80% Incr. HX Area	$8,457	$2	0%	98%	2%	1.1	1.5
80% Improved Insulation	$8,454	$4	26%	46%	28%	9.0	8.2
80% PSC+	$8,441	$10	6%	46%	48%	3.4	4.0
80% ECM	$8,529	-$37	43%	46%	11%	19.3	26.7
80% Improved Heat Xfer	$8,467	-$4	52%	46%	2%	2.8	3.7
81% Incr. HX Area	$8,418	$23	2%	46%	52%	2.0	2.6
81% Improved Insulation	$8,415	$25	20%	20%	60%	5.2	6.4
81% PSC+	$8,402	$36	4%	20%	76%	2.8	3.4
81% ECM	$8,490	-$35	58%	20%	22%	16.0	21.2
81% Improved Heat Xfer	$8,424	$18	32%	20%	48%	3.8	5.1
82% Incr. HX Area	$8,380	$53	3%	20%	77%	2.1	2.9
82% Improved Insulation	$8,377	$56	18%	0%	82%	4.3	5.6
82% PSC+	$8,364	$69	4%	0%	96%	2.6	3.2
82% ECM	$8,452	-$19	65%	0%	35%	14.1	18.3
82% Improved Heat Xfer	$8,382	$51	24%	0%	76%	2.5	3.4
83% Incr. HX Area	$8,347	$86	6%	0%	94%	2.9	3.9
83% Improved Insulation	$8,345	$88	11%	0%	89%	3.9	5.5
83% PSC+	$8,331	$102	3%	0%	97%	3.0	3.6
83% ECM	$8,420	$13	58%	0%	43%	12.2	15.0
83% Improved Heat Xfer	$8,345	$89	4%	0%	96%	2.4	3.3

* "No impact" means that the base case furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

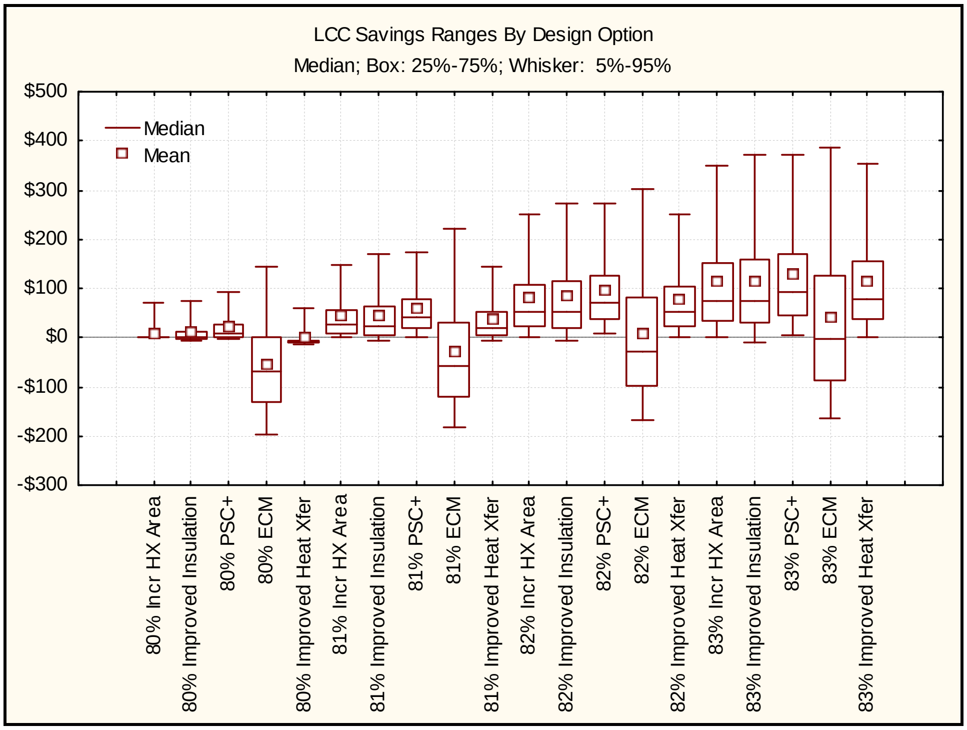

Figure 8.5.8.2 Range of LCC Savings by Design Option for Weatherized Gas Furnaces

Table 8.5.8.3 shows the results for mobile home gas furnaces. The ECM option has a negative effect on LCC. Figure 8.5.8.3 shows the range of LCC savings by design option for mobile home gas furnaces.

Table 8.5.8.3 LCC and PBP Results for Mobile Home Gas Furnaces, Including Electricity-Efficiency Design Options

Design Option (AFUE and technology description)	LCC					Payback	
	Average LCC	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average **
75% Baseline	$7,904						
80%	$7,480	$64	1%	85%	14%	2.4	4.7
80% ECM	$7,568	-$21	67%	5%	28%	20.0	36.1
80% 2-stage modulation	$7,718	-$163	80%	5%	15%	26.0	60.5
81%	$7,428	$112	10%	5%	85%	4.4	6.3
81% ECM	$7,517	$28	57%	5%	38%	15.6	21.1
81% 2-stage modulation	$7,670	-$117	75%	5%	20%	24.9	60.3
82%	$7,385	$153	14%	5%	81%	5.1	7.5
82% ECM	$7,473	$69	49%	5%	46%	13.3	17.4
82% 2-stage modulation	$7,630	-$80	70%	5%	25%	22.9	56.3
90%	$7,352	$184	46%	5%	49%	12.5	22.7

* "No impact" means that the base case furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

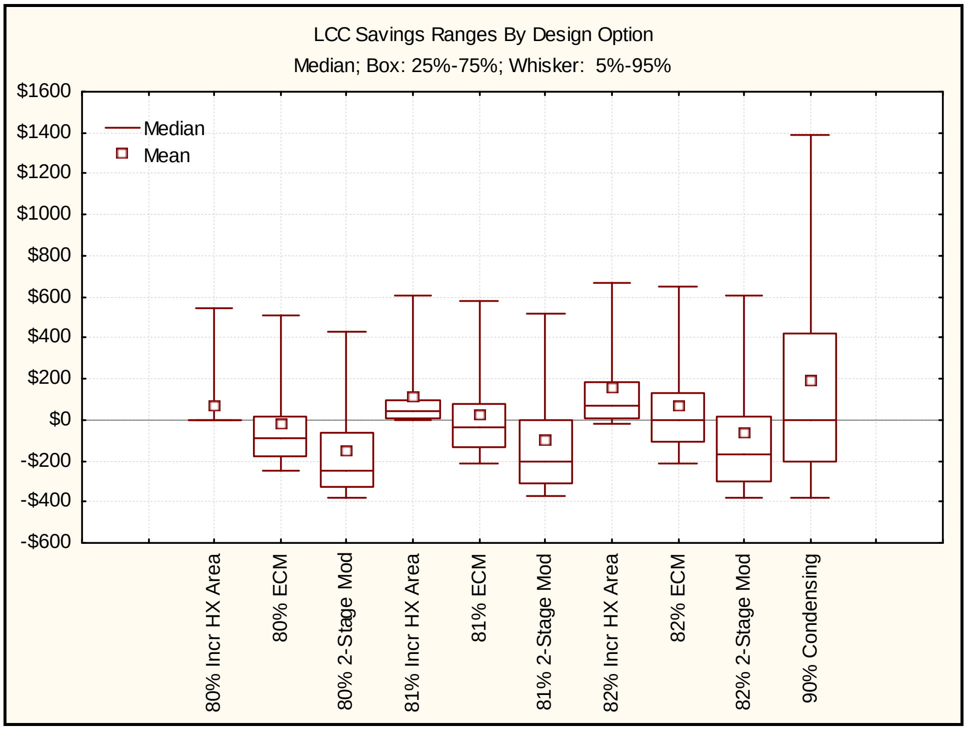

Figure 8.5.8.3 Range of LCC Savings by Design Option for Mobile Home Gas Furnaces

Table 8.5.8.4 shows the results for oil-fired furnaces. Interrupted ignition shows LCC savings at the 81–83 percent AFUE levels, though slightly less than the designs with baseline features. The other electricity-efficiency design options also show positive LCC savings in some cases, but have lower LCC savings than designs with baseline features. Figure 8.5.8.4 shows the range of LCC savings by design option for oil-fired furnaces.

Table 8.5.8.4 LCC and PBP Results for Oil-Fired Furnaces, Including Electricity-Efficiency Design Options

Design Option (AFUE and technology description)	LCC					Payback	
	Average	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average **
78% Baseline	$16,194						
80% Incr. HX Area	$15,900	$11	0%	96%	4%	0.2	0.2
81%	$15,762	$95	2%	39%	59%	0.4	0.5
81% Atom Burner 2-stage Mod.	$15,885	$8	42%	30%	28%	11.7	19.4
81% Interrupted Ignition	$15,785	$79	13%	30%	57%	2.8	4.9
81% ECM	$15,945	-$33	50%	30%	20%	14.4	22.8
82%	$15,625	$190	2%	30%	68%	0.3	0.4
82% Atom Burner 2-stage Mod.	$15,753	$89	35%	22%	42%	8.5	13.8
82% Interrupted Ignition	$15,648	$173	10%	22%	68%	1.7	3.5
82% ECM	$15,807	$49	39%	22%	38%	9.2	16.8
83%	$15,492	$293	3%	22%	75%	0.3	0.4
83% Atom Burner 2-stage Mod.	$15,626	$178	31%	15%	54%	6.8	11.2
83% Interrupted Ignition	$15,515	$273	10%	15%	75%	1.3	2.9
83% ECM	$15,674	$138	32%	15%	53%	7.1	14.7
84%	$15,967	-$111	58%	15%	27%	13.7	20.8
84% Atom Burner 2-stage Mod.	$16,106	-$240	71%	7%	22%	16.3	25.1
84% Interrupted Ignition	$15,990	-$133	66%	7%	26%	14.4	21.2
84% ECM	$16,148	-$279	74%	7%	18%	17.6	32.8
85%	$15,845	$1	49%	7%	44%	10.0	13.8
85% Atom Burner 2-stage Mod.	$15,989	-$143	69%	0%	31%	13.7	20.1
85% Interrupted Ignition	$15,868	-$22	58%	0%	42%	10.8	14.9
85% ECM	$16,026	-$180	72%	0%	28%	14.6	27.3

* "No impact" means that the base case furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

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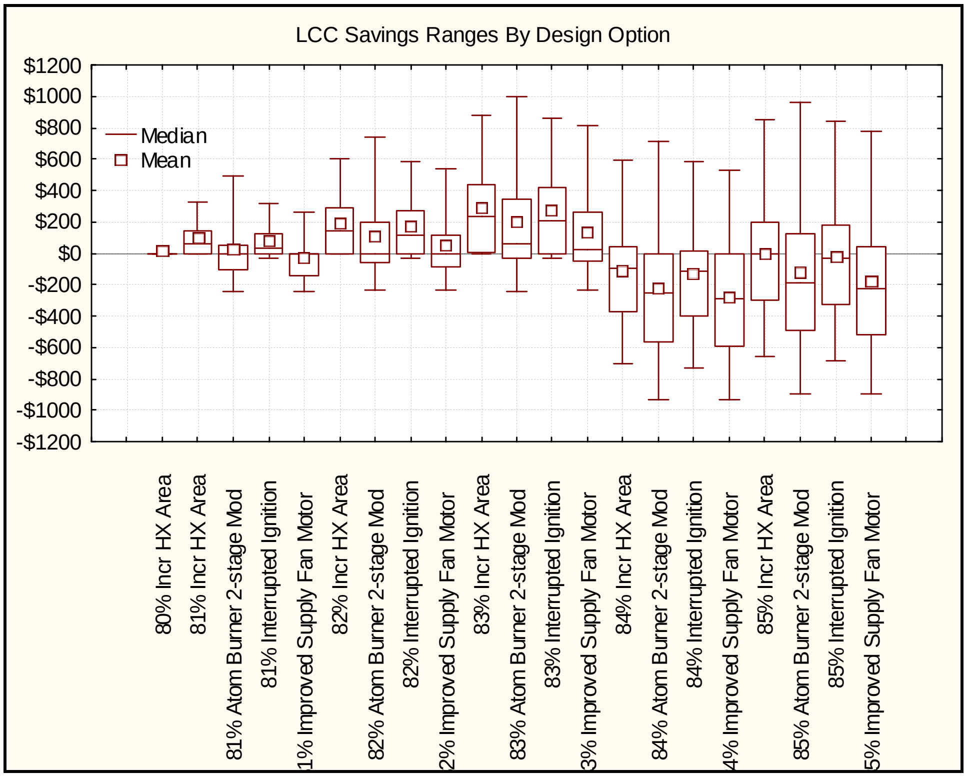

Figure 8.5.8.4 Range of LCC Savings by Design Option for Oil-Fired Furnaces

Table 8.5.8.5 shows the results for hot-water gas boilers. The improved circulation pump (with ECM) has a negative effect on LCC. Figure 8.5.8.5 shows the range of LCC savings by design option for hot-water gas boilers.

Table 8.5.8.5 LCC and PBP Results for Hot-Water Gas Boilers, Including Electricity-Efficiency Design Options

Design Option (AFUE and technology description)	LCC					Payback	
	Average LCC	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average **
80% Baseline	$10,635						
81%	$10,371	$93	0%	65%	35%	2.1	2.4
81% 2-stage modulation	$10,599	-$36	38%	44%	18%	9.9	14.8
81% Imp Circ Pump	$10,620	-$48	41%	44%	16%	15.1	55.9
82%	$10,314	$125	3%	44%	53%	2.5	3.3
82% 2-stage modulation	$10,542	-$36	48%	30%	22%	9.3	19.6
82% Imp Circ Pump	$10,564	-$51	51%	30%	19%	19.1	42.9
83%	$10,256	$166	5%	30%	66%	2.5	3.3
83% 2-stage modulation	$10,483	-$29	59%	15%	27%	9.9	23.3
83% Imp Circ Pump	$10,505	-$46	61%	15%	24%	17.8	39.6
84%	$10,199	$215	6%	15%	79%	2.5	3.4
84% 2-stage modulation	$10,426	$0	62%	6%	32%	10.5	22.7
84% Imp Circ Pump	$10,448	-$20	63%	6%	31%	15.1	31.4
88%	$10,741	-$294	67%	6%	27%	17.5	29.8
91%	$10,823	-$372	75%	3%	22%	19.3	43.0
99%	$11,304	-$853	85%	0%	15%	21.7	46.1

* "No impact" means that the base case furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

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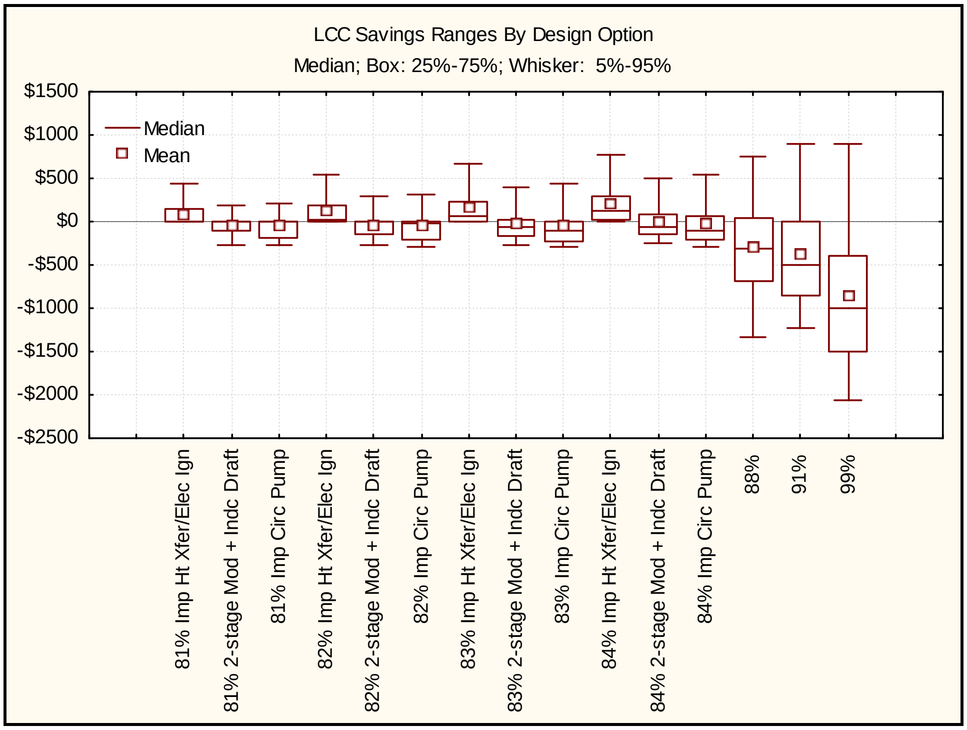

Figure 8.5.8.5 Range of LCC Savings by Design Option for Hot-Water Gas Boilers

Table 8.5.8.6 shows the results for hot-water oil-fired boilers. Interrupted ignition shows LCC savings at the 81–83 percent AFUE levels that are about the same as the designs with baseline features. The other electricity-efficiency design options have lower LCC savings than designs with baseline features. Figure 8.5.8.6 shows the range of LCC savings by design option for hot-water oil-fired boilers.

Table 8.5.8.6 LCC and PBP Results for Hot-Water Oil-fired Boilers, Including Electricity-Efficiency Design Options

Design Option (AFUE and technology description)	Average	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average **
80% Baseline	$14,890						
81%	$14,772	$6	0%	95%	5%	0.6	0.8
81% Atomized Burner	$15,166	-$36	11%	89%	0%	70.4	104.9
81% Inter Ign	$14,776	$6	4%	89%	7%	6.0	9.4
81% Imp Circ Pump	$14,995	-$17	10%	89%	1%	39.5	64.0
82%	$14,657	$18	0%	89%	11%	0.7	0.8
82% Atomized Burner	$15,051	-$45	16%	84%	0%	35.0	64.3
82% Inter Ign	$14,661	$18	4%	84%	12%	3.4	6.7
82% Imp Circ Pump	$14,880	-$17	13%	84%	3%	21.1	44.5
83%	$14,545	$36	0%	84%	16%	0.7	0.8
83% Atomized Burner	$14,939	-$119	37%	61%	2%	23.0	45.0
83% Inter Ign	$14,549	$35	16%	61%	23%	7.8	10.1
83% Imp Circ Pump	$14,768	-$52	33%	61%	6%	52.8	67.8
84%	$14,435	$79	0%	61%	39%	0.7	0.8
84% Atomized Burner	$14,830	-$169	58%	37%	5%	26.7	57.6
84% Inter Ign	$14,439	$77	17%	37%	46%	3.8	7.4
84% Imp Circ Pump	$14,659	-$61	51%	37%	11%	24.1	49.8
86%	$14,943	-$234	52%	37%	11%	23.0	31.6
86% Atomized Burner	$15,338	-$602	91%	7%	2%	53.0	98.1
86% Inter Ign	$14,947	-$238	73%	7%	20%	17.4	24.9
86% Imp Circ Pump	$15,167	-$442	88%	7%	5%	41.3	59.3
90%	$15,260	-$527	81%	7%	12%	19.6	23.8
95%	$15,561	-$829	88%	0%	12%	19.1	23.0

* "No impact" means that the base case furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

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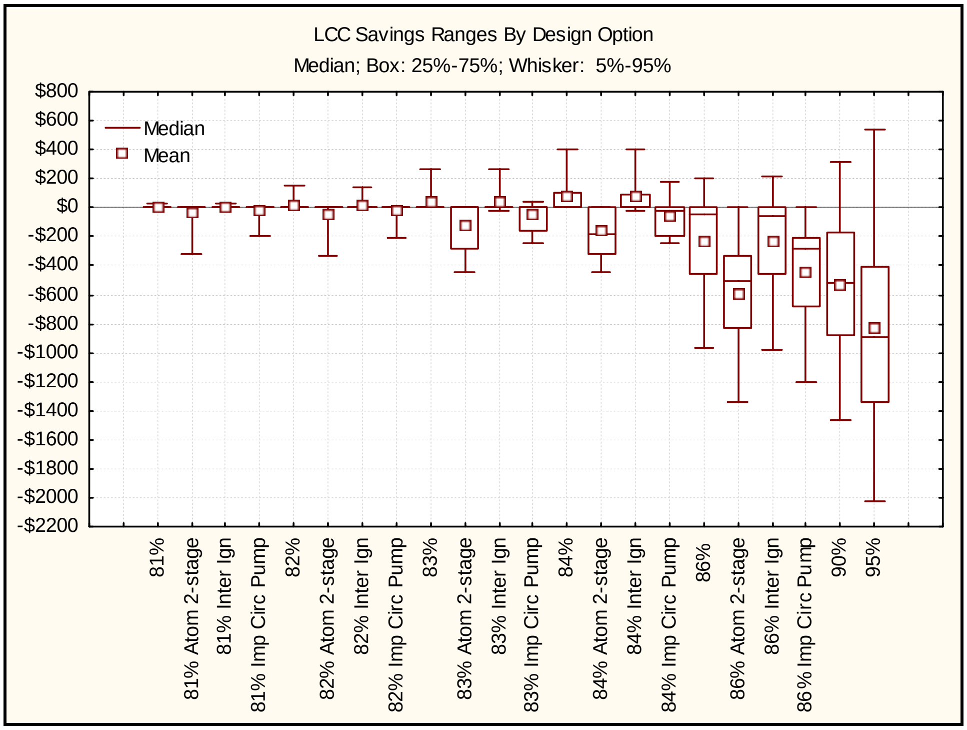

Figure 8.5.8.6 Range of LCC Savings by Design Option for Hot-Water Oil-Fired Boilers