COMMONWEALTH OF KENTUCKY
BEFORE THE PUBLIC SERVICE COMMISSION

In the matter of:	)	
	)	
ELECTRONIC INVESTIGATION OF THE REASONABLENESS OF THE ENERGY EFFICIENCY AND CONSERVATION RIDER OF COLUMBIA GAS OF KENTUCKY, INC.	)))	Case No. 2018-00044

PREPARED DIRECT TESTIMONY OF WILLIAM STEVEN SEELYE ON BEHALF OF COLUMBIA GAS OF KENTUCKY, INC.

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COLUMBIA GAS OF KENTUCKY, INC.

July 16, 2018

PREPARED DIRECT TESTIMONY OF WILLIAM STEVEN SEELYE

Q: Please state you name and business address.

A: My name is William Steven Seelye, and my business address is The Prime Group, LLC, 6435 West Highway 146, Crestwood, Kentucky, 40014.

Q: By whom and in what capacity are you employed?

A: I am the managing partner for The Prime Group, LLC, a firm located in Crestwood, Kentucky, providing consulting and educational services in the areas of utility regulatory analysis, revenue requirement support, cost of service, rate design and economic analysis.

Q: On whose behalf are you testify in this proceeding?

A: I am testifying for Columbia Gas of Kentucky, Inc. ("Columbia Gas" or "Company"), which provides natural gas sales and transportation services in Kentucky.

Q: Please describe your educational and professional background.

A: I received a Bachelor of Science degree in Mathematics from the University of Louisville in 1979. I have also completed 54 hours of graduate level course work in Industrial Engineering and Physics. From May 1979 until July 1996, I was employed by Louisville Gas and Electric Company ("LG&E"). From May 1979 until December, 1990, I held various positions within the Rate Department of LG&E. In December 1990, I became Manager of Rates and Regulatory Analysis. In May 1994, I was given additional responsibilities in the marketing area and was promoted to Manager of Market Management and Rates. I left LG&E in July 1996 to form The Prime Group, LLC, with two other former employees of LG&E. Since leaving LG&E, I have performed or supervised the preparation of cost of service and rate studies for over 150 investor-owned utilities, rural electric distribution cooperatives, generation and transmission cooperatives, and municipal utilities. A more detailed description of my qualifications is included in Exhibit Seelye-1.

Q. Have you ever testified before any state or federal regulatory commissions?

A. Yes. I have testified in over 75 regulatory proceedings in 11 different jurisdictions including the Kentucky Public Service Commission ("Commission"). A listing of my testimony in other proceedings is included in Exhibit Seelye-1.

Q: Please describe your experience with demand side management (DSM) programs and cost recovery mechanisms.

A: In Kentucky, I have assisted the following utilities with the development of DSM cost recovery mechanisms: Louisville Gas and Electric Company, Kentucky Utilities, Delta Natural Gas Company, and Columbia Gas. I have also developed a DSM cost recovery mechanism for Nova Scotia Power Company. I have assisted numerous utilities in the economic evaluation of their DSM, energy efficiency, and demand-response programs and have worked with utilities in maximizing the benefit derived from their existing demand side management programs. I have also developed time-of-use, interruptible, real-time pricing, cogeneration, and other rates designed to encourage customers to modify their demand and usage patterns.

Q: Did you submit testimony in support of Columbia Gas's current Energy Efficiency and Conservation Rider (EECR).

A: Yes. Columbia Gas proposed its current EECR rate schedule in Case No. 2009-00141, which was a general rate case. I submitted testimony in support of the EECR in that proceeding. I also submitted testimony in Case No. 2016-00107 in connection with the five-year review and renewal of Columbia's programs. In its Order in that proceeding dated October 11, 2016, the Commission approved Columbia's programs through June 30, 2021.

Q: What is the purpose of your testimony in this proceeding?

A: The purpose of my testimony is to provide a general assessment of the effectiveness of the EECR rate schedule and to recommend that the rider continue to remain in effect in its current form. I will provide a general assessment of the effectiveness of the current level of funding for DSM and energy efficiency programs and of the effectiveness of the programs that have been developed through collaborative processes. I will also comment on the adequacy of the programs on a going forward basis. I will also explain the importance of Columbia Gas's DSM and energy efficiency programs both to Columbia Gas and to its customers. I testify that Columbia Gas's current level of funding for DSM and energy efficiency is reasonable and that the current programs being offered are also reasonable.

Q: Please describe Columbia Gas's EECR rate schedule.

A: Columbia Gas's EECR is applicable to residential customers served under Rate Schedule GSR and commercial customers service under Rate Schedule GSO. It is designed to provide for the recovery of DSM program costs, to provide for the recovery of net revenues from lost sales due to the implementation of DSM programs, and to provide a small incentive for Columbia Gas to implement DSM programs. While the EECR rate schedule is applicable to both residential and commercial rate schedules, Columbia Gas currently offers no Energy Efficiency/Conservation Programs for commercial customers and therefore the applicable EECR charge for commercial rate schedules is zero. Columbia Gas's current EECR schedule is included as Exhibit Seelye-2.

Columbia Gas's EECR provides a dollar-for-dollar recovery of costs incurred by the Company to implement and operate DSM programs that have been approved by the Commission. Because DSM and energy efficiency programs by design result in a reduction in sales to customers, the EECR rate schedule provides for the recovery of revenues from lost sales due to the implementation of those programs. The EECR also provides a small incentive designed to encourage the Company to develop and implement DSM programs and includes a reconciliation adjustment to ensure that there will not be any over- or under-recovery of either DSM program costs or revenues from lost sales under the mechanism.

Columbia Gas's EECR thus consists of the following four components: (1) a Energy Efficiency/Conservation Program Cost Recovery (EECPCR) component that provides for the recovery of DSM program costs, (2) an EECP Revenue from Lost Sales (EECPLS) component that provides for the recovery of revenues from lost sales, (3) an EECP Incentive (EECPI) component that is designed to encourage Columbia Gas to develop and implement DSM programs, and (4) an EECP Balance

Adjustment (EECPBA) that reconciles for any over- or under-recovery of program costs, revenues from lost sales, and incentives.

Q: Is Columbia Gas's EECR rate schedule consistent with the DSM mechanism described in KRS 278.285?

A: Yes. Utilities in Kentucky can propose a DSM cost recovery mechanism pursuant to KRS 278.285. Subsection 2 of KRS 278.285, of states as follows:

> A proposed demand-side management mechanism including:
>
> (a) Recover the full costs of commission-approved demand-side management programs and revenues lost by implementing these programs;
> (b) Obtain incentives designed to provide financial rewards to the utility for implementing cost-effective demand-side management programs; or
> (c) Both of the actions specified
>
> may be reviewed and approved by the commission as part of a proceeding for approval of new rate schedules initiated pursuant to KRS 278.190 or in a separate proceeding initiated pursuant to this section which shall be limited to a review of demand-side management issues and related rate-recovery issues as set forth in subsection (1) of this section and in this subsection.

In accordance with KRS 278.285, Columbia Gas's EECR provides for recovery of the full cost of commission-approved demand-side management programs, provides for recovery of revenue lost by implementing these programs, and allows the Company to obtain incentives designed to financial rewards for implementing cost-effective demand-side management programs. Also, consistent with the practice for most cost recovery mechanisms that have been approved by the Commission over the years, the EECR rider includes an over- and under-recovery mechanism that ensures that the Company doesn't collect more or less than the amounts determined by the other components of the EECR.

Q: Without a DSM cost recovery mechanism, do utilities have an incentive to pursue demand-side management strategies that would reduce sales and encourage customer conservation?

A: No. In traditional regulation, utilities have an incentive to increase retail sales relative to historical test-year levels that were used for calculating their base rates. The incentive for utilities to maximize the "throughput" of gas sales and transportation volumes in an attempt to increase net margins is referred to as a "throughput incentive". Utility profits are reduced when demand side management and energy efficiency programs reduce sales and transportation volumes from levels that would have been obtained without these programs. Under traditional regulation, there is an incentive for utilities to avoid programs aimed at reducing sales. It is critical to address this throughput incentive and to provide for DSM program cost recovery if the utility is to be actively involved in demand side management and energy efficiency programs that encourage customers to conserve energy, utilize the most efficient appliances and manage their bill

Q: Is Columbia Gas's EECR rate schedule still adequate?

A: Yes. The EECR rate schedule still reflects sound ratemaking principles for encouraging Columbia to promote DSM and energy conservation programs; it is fully consistent with provisions set forth in Section 2 of KRS 278.285; and it is consistent with DSM and energy conservation cost recovery mechanisms that have been approved for other gas and electric utilities that pass the Total Resource Cost Test.

Q: Do you recommend any changes to the EECR rate schedule?

A: No.

Q: Please describe Columbia Gas's current DSM and energy efficiency programs.

A: Columbia Gas offers three programs targeted to residential customers taking service under Rate Schedule GSR -- (i) High-Efficiency Appliance Rebates, (ii) a Home Energy Audit program, and (iii) a Low-Income High Efficiency Furnace Replacement program. The Energy Audit and the High-Efficiency Furnace Rebate programs are generally available to all customers taking service under Rate

Schedule GSR. The Low-Income High Efficiency Furnace Replacement program is only available to residential customers that receive Low Income Home Energy Assistance Program (LIHEAP) funding.

Q: Please describe the High-Efficiency Appliance Rebates offered by Columbia Gas.

A: Under the High-Efficiency Appliance Rebate Program, Columbia Gas currently provides the following rebates for the installation of high-efficiency appliances:

Appliance	Efficiency Level	Size	Rebate
Forced Air Furnace	≥ 90%	≥ 30,000 Btu	$400
Dual Fuel Furnace	≥ 90%	≥ 30,000 Btu	$300
Space Heater	99%	≥ 10,000 Btu	$100
Gas Logs	99%	≥ 18,000 Btu	$100
Gas Fireplace	≥ 90%	≥ 18,000 Btu	$100
Tank Hot Water Heater	0.62 Energy Factor	≥ 40 gallons	$200
Power Vent Hot Water Heater	0.62 Energy Factor	≥ 40 gallons	$250
On Demand Hot Water Heater	0.67 Energy Factor	N/A	$300

Table 1

These rebates incentivize customers to install appliances that are more efficient yet more costly to install than standard appliances. These rebates help off-set the higher installation cost of higher-efficiency alternatives.

Q: Are appliance rebates developed as part of a collaborative process?

A: Yes. Columbia Gas formed a DSM collaborative group to discuss new programs and the modification of existing programs. The implementation of any new rebate would be discussed at a collaborative meeting consisting of community action councils, gas marketers, the Office of the Attorney General, or other interested parties.

Q: How much did Columbia Gas spend on High-Efficiency Appliance rebates during the most recent program year?

A: For the 12-month period ended December 31, 2017, Columbia Gas spent $396,224 on High-Efficiency Appliance rebates.

Q: Do you recommend that Columbia Gas continue to offer these High Efficiency Appliance Rebates?

A: Yes.

Q: Please describe the Columbia Gas's Energy Audit program.

A: Under the Energy Audit Program, Columbia Gas funds free walk-through energy audits (now also referred to as "check-ups) to residential customers. The audits are performed by a qualified outside contractor selected by the Company. These audits encompass the following services:

- An analysis of the dwelling's usage history and the detection of any abnormalities or trends relative to the square footage, load and surrounding dwelling usage trends;
- Checking for proper changes of the heating system filtering devices and clearance from obstructions of all return air registers;
- Inspection of outer wall switch plates and outlets for insulation protection or gasket installation;
- Checking of ceiling insulation levels;
- Inspection of duct systems;
- Checking of exterior windows and doors for unwanted leakage and heat loss;
- Identification of areas of high energy loss through thermal imaging;
- Providing options and recommendations to the occupant;
- Providing the occupant with an audit kit consisting of caulk, switch plate and outlet gaskets, electric outlet plugs and weather stripping.

Q: How does Columbia Gas inform residential customer about the existence and benefits of the program?

A: Columbia Gas uses a number of communication channels to inform residential customers about the program, including commercial and public radio notices, online advertisement (e.g. the Weather Channel), Public Television notices, customer in-bill newsletters, the Company's website, magnets on service vehicles, and direct mail. These channels are similar to those used by other utilities in Kentucky.

Q: Do you recommend that Columbia Gas continue to offer its Energy Audit Program?

A: Yes. Energy audits are important tools for helping customers to conserve energy and customers provide favorable feedback in response to the audits or "Home Energy Check-ups".

Q: Please describe the Low-Income High Efficiency Furnace Replacement Program.

A: Under the Low-Income High Efficiency Furnace Replacement Program, Columbia Gas currently provides up to $2,800 toward the cost of installing a high efficiency forced air furnace of 90 percent efficiency or higher for a qualifying low-income customer. Columbia Gas partners with the Community Action Council for Lexington-Fayette, Bourbon, Harrison and Nicholas Counties, Inc ("CAC") to provide this service. The CAC identifies potential customers, qualifies the customers, and works with its contractors to replace existing furnaces with high efficiency forced air furnaces of 90 percent efficiency or higher.

Q: Why is the Low-Income High Efficiency Furnace Replacement Program important part of Columbia Gas's DSM and energy efficiency program?

A: Low-income customers often live in older homes with older, less efficient furnaces. I have conducted study after study for utilities across the U.S. and have found that customers receiving LIHEAP funding use more gas and electric energy than the average residential usage. One of the reasons for this is that LIHEAP customers often have inefficient appliance stocks. Because people receiving LIHEAP funding are the customers who are typically the least able financially to replace inefficient furnaces, this program fulfills an important need in Columbia Gas's service territory for improving energy efficiency and thus reducing the customer's bill. While the High-Efficiency Appliance Rebate program will incentivize customers who have sufficient financial resources to install more efficient appliances, for low-income customers rebates are simply not enough to encourage the efficient replacement of aging, inefficient furnaces.

Q: How much did Columbia Gas spend on its Low-Income Furnace Replacement program during the most recent program year?

A: For the 12-month period ended October 31, 2017, Columbia Gas spent $200,845 on its Low-Income Furnace Replacement program.

Q: Do you recommend that Columbia Gas continue to offer its Low-Income Furnace Replacement program?

A: Yes.

Q: How much is Columbia Gas's total annual budget for its Energy Efficiency/Conservation Program?

A: Columbia Gas's total annual budget for all three programs is $908,000. This annual budget has not changed since the EECR rate schedule was first introduced in November 2009.

Q: Have you prepared an exhibit showing the annual expenditures for each program since the inception of the Energy Efficiency/Conservation Program?

A: Yes. Exhibit Seelye-3 shows the annual expenditures for each program along with administrative costs. The following table shows the average annual direct cost for each program.

Program	Average Annual Direct Expenditure For Program
High-Efficiency Appliance Rebates	$ 86,659
Home Energy Audit program	$ 415,436
Low-Income High Efficiency Furnace Replacement	$ 298,854
Total Direct Expenditures	$ 800,948

Table 2

Q: Is the overall level spent by Columbia Gas on conservation and energy efficiency programs reasonable?

A: Yes, I would characterize Columbia Gas's DSM and energy efficiency program as modest yet reasonable. Without introducing programs that provide greater benefits toward reducing the rates of all customers on Columbia Gas's system, I would not recommend expanding the program.

Q: Have you prepared an exhibit showing the number of participants for each program since the inception of the Energy Efficiency/Conservation Program?

A: Yes. Exhibit Seelye-4 shows the number of participants for each program along with administrative costs. The following table shows the total participants for each program since the EECR rate schedule was implemented in 2009:

Program	Total Participants
High-Efficiency Appliance Rebates	8,336
Home Energy Audit program	2,580
Low-Income High Efficiency Furnace Replacement	970
Total Participants	11,886

Table 3

Q: Are the program participants widely dispersed throughout Columbia Gas's service territory?

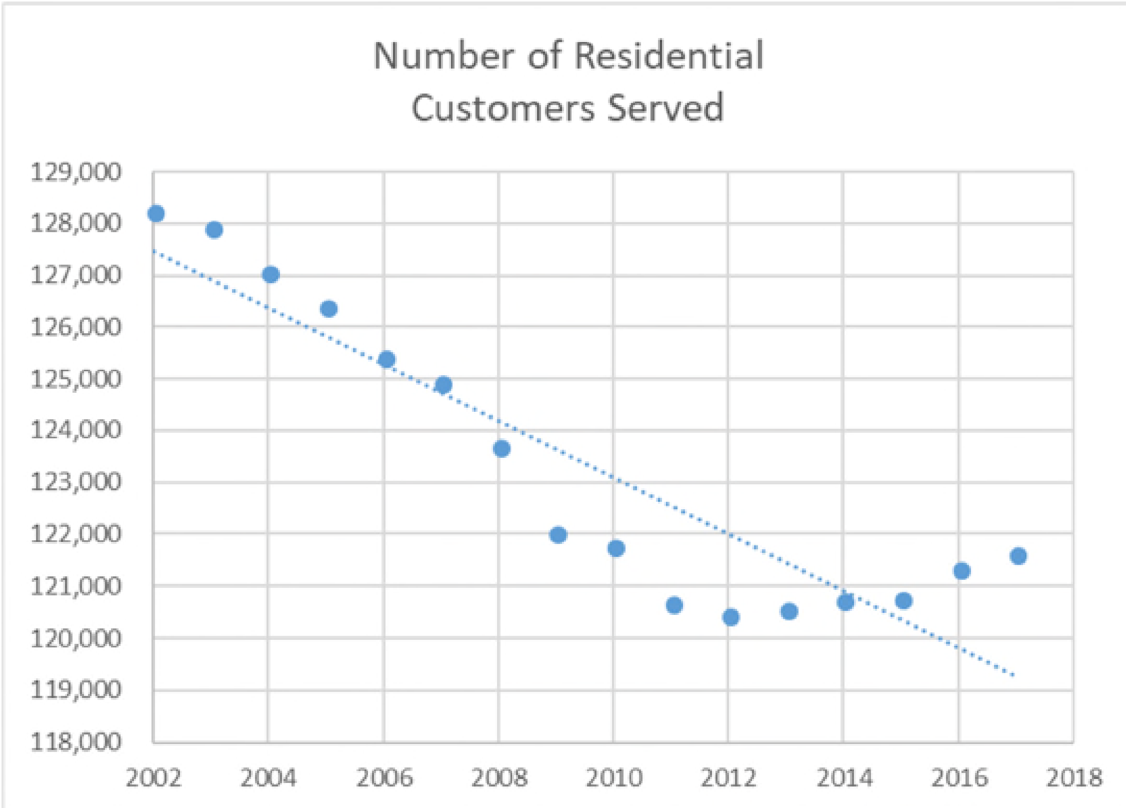
A: Yes. Residential customers in all of Columbia's service area participated in Columbia Gas's Energy Efficiency/Conservation Program. Participants by county are shown in Exhibit Seelye-5.

Q: Why are Columbia's DSM and energy conservation programs important to the Company and its customers?

A: As previously discussed, Columbia provides three DSM and energy conservation programs: (i) High-Efficiency Appliance Rebates, (ii) a Home Energy Audit program, and (iii) a Low-Income High Efficiency Furnace Replacement program. The High-Efficiency Appliance Rebates and the Low-Income High Efficiency Furnace Replacement program are particularly important to help ensure that Columbia continues to provide gas service for major appliances. The harsh reality for gas utilities is that it has become increasingly more difficult to retain existing customers and to pipe out service to new homes. In September 25, 2014, the U.S. Energy Information Administration (EIA) published a report titled "Everywhere but the Northeast, Fewer Homes Choose Natural Gas as Heating Fuel" which indicated that new customers were showing a preference for electric service over natural gas service. See Exhibit Seelye-6. The report stated that "[p]art of the national change in heating fuel choice can be attributed to population migration farther west and south. But even within Census regions, electricity has been gaining market share at the expense of natural gas." Columbia is no different from other gas utilities in finding it difficult to encourage builders to install gas appliances and encouraging existing customers to replace old or failing natural gas appliances with *natural gas appliances* rather than with *electric appliances*. For this reason, the rebates provided by the High-Efficiency Appliance Rebates and the Low-Income High Efficiency Furnace Replacement program to install natural gas appliances are of significant strategic importance to Columbia. These incentive programs also benefit participants by encouraging them to install high efficiency appliances and they benefit non-participants by helping to ensure that the utility's fixed costs are not spread over a smaller and smaller sales volumes because of customers abandoning natural gas in favor of electric service.

Q: Please explain how a gas utility's rates are affected when they lose appliances to electric utilities?

A: A gas utility must install fixed assets to provide service to its customers. Specifically, the utility must install distribution mains, services, and meters to connect new customers. When an existing customer switches its gas water heater or furnace to an electric water heater or furnace, or when a customer leaves Columbia's system by disconnecting gas service altogether, the fixed costs of the facilities installed to provide service to the customer do not automatically disappear. These fixed costs must be spread to the utility's other customers, thereby putting upward pressure on the utility's rates. Therefore, in terms of the distribution delivery rates that customers pay for gas service, the utility and its customers are better off if the utility can continue to serve gas appliances. Similarly, a utility's fixed costs are spread over a larger customer base (i.e., over more MCF or over more customer-months to which the customer charge is applied) when new customers are added to the system. This is particularly true when customers are added to an existing line extension. During the past couple of decades, Columbia's residential customer base has decreased from 128,241 customers as of December 31, 2002 to 121,630 as of December 31, 2017. (Columbia served 119,997 residential customers as of June 30, 2018, but the dip from December 2017 to June 2018 would in part be related to seasonal reductions in customers during the summer months.) The decline in residential customers from 2002 to 2017 is demonstrated in the following graph (Graph 1):



Graph 1

This graph illustrates the difficulty that Columbia has faced in retaining existing residential customers and attracting new residential customers. The graph also strongly suggests that Columbia's appliance rebates, which were first implemented in 2009, may have helped quell the steep decline in the number of residential customers that Columbia has seen during the last couple of decades. Columbia firmly believes that its appliance rebate and replacement programs have been key reasons that the decline in residential customers has abated since the implementation of the rebate and replacement programs. Columbia is now experiencing an increase in the number of residential customers that it serves, in large part, Columbia strongly believes, because its rebate and replacement programs place gas appliances on a more favorable footing in comparison to electric appliances.

Obviously, retaining existing customers, retaining gas appliances, and attracting new customers are critically important to a stand-alone gas utility. It is Columbia's position that offering appliance rebates and incentives is important to all three of these objectives. Rebates and replacement programs encourage existing customers to replace their current *gas* appliances with new *gas* appliances rather than with new *electric* appliances when their appliances fail. Incentives encourage customers and contractors building new homes to install *gas* appliances rather than electric appliances that generally have lower up-front installed costs. As mentioned earlier, an impediment to gas appliances being installed in new residential construction is the relatively higher up-front cost of gas appliances in comparison to electric appliances. Ultimately, Columbia and its existing customer base are better off if the Company can retain existing customers and add new customers.

Q: Could you provide an example illustrating how offering incentives can benefit non-participants by ensuring that lost fixed cost recovery is not spread to other customers?

A: Yes. Columbia competes with some East Kentucky Power Cooperative's ("EKPC's") member systems to serve space heating and water heating appliances in critical growth areas outside of the municipal regions served by Kentucky Utilities Company and Kentucky Power Company. (Columbia's service territory overlaps with some EKPC member systems, Kentucky Utilities and Kentucky Power, but the suburban and rural areas served by EKPC represent significant growth areas for Columbia.) When Columbia loses a gas appliance to one of its electric competitors, the fixed cost of Columbia's backbone delivery system must be spread to Columbia's other customers. Columbia believes that its appliance rebate programs have been instrumental in preventing the loss of current and prospective customers. During 2017, Columbia residential customers used on average 62 Mcf of natural gas. If Columbia loses a customer using 62 Mcf to one of EKPC's member systems, then the fixed costs recovered from the customer must be spread to the Columbia's other customers. Specifically, Columbia recovers approximately $628.48 in fixed annual costs from a residential customer that uses 62 Mcf, as shown below:

Customer Charge	12 Cust-Months @$16/Mo	= $192.00
Delivery Charge	62 Mcf @ $7.04	= $436.48
Total Fixed Cost Recovery		**= $628.48**

Therefore, if Columbia were to lose 5,000 customers, as it did from 2002 through 2009 prior to the implementation of its rebate programs (see above), then Columbia would need to collect approximately $3.1 million in annual revenues from other customers. This corresponds to an annual increase in rates of $25.31 for each of Columbia's remaining customers ($3.1 million ÷ 122,500 customers = $25.31 per customer.) In contrast, Columbia's residential customers are currently charged $0.55 per customer per month for its energy efficiency and conservation programs. This equates to $6.60 per year. If Columbia's rebate programs can prevent the loss of customers that it experienced during the 2002 to 2009 timeframe, then Columbia's existing customers would realize a net annual savings of $18.71 per customer from the rebate programs.

Q: What are some of the reasons that customers would choose electric appliances over gas appliances even though gas appliances might be less costly in the long run?

A: The up-front cost of electric appliances is often lower than for gas appliances, even though high-efficiency gas appliances often perform as well or better than electric appliances. The lower up-front cost of electric appliances provides a strong inducement for builders to install electric appliances over gas appliances. In general, builders will often install lower efficiency appliances instead of high efficiency appliances because of the lower up-front costs. See Lekov et al., "Economics of Residential Gas Furnaces and Water Heaters in US New Construction Market", *Energy Efficiency* (2010) 3:203-222. See Exhibit Seelye-7. Also, residential customers will often opt for lower up-front-cost electric appliances when replacing existing gas appliances. Furthermore, when servicing a water heater that needs replacing, plumbers are more likely to carry electric water heaters in their service trucks than gas water heaters. Rebates will often allow customers to choose what is more cost effective than what is simply more convenient.

Q: Are the impacts of the cost to participants and non-participants captured in any of the California Tests?

A: The Total Resource Cost ("TRC") Test evaluates the overall cost impact to participants and non-participants.

Q: What is the result of the TRC Test for Columbia Gas' programs?

A: As provided in its response to Item 3 of the Commission Staff's Third Request for Information, Columbia Gas' programs pass the TRC Test and show the value to all customers, both participants and non-participants of Columbia Gas' programs.

Q: Does this complete your prepared direct testimony?

A: Yes

WILLIAM STEVEN SEELYE

Summary of Qualifications

Provides consulting services to numerous investor-owned utilities, rural electric cooperatives, and municipal utilities regarding utility rate and regulatory filings, cost of service and wholesale and retail rate designs; and develops revenue requirements for utilities in general rate cases, including the preparation of analyses supporting pro-forma adjustments and the development of rate base.

Employment

Principal and Managing Partner
The Prime Group, LLC
(1996 to 2012) (2015-Present)
(Associate Member 2012-2015)

Provides consulting services in the areas of tariff development, regulatory analysis, revenue requirements, cost of service studies, rate design, fuel and power procurement, depreciation studies, lead-lag studies, and mathematical modeling.

Assists utilities with developing strategic resource and marketing plans. Assist with resource planning and cost benefit analyses for generation investment projects. Performs economic analyses evaluating the costs and benefits of an electric generation projects; performs business practice audits for electric utilities, gas utilities, and independent transmission organizations, including audits of production cost modeling, fuel procurement practices and controls, and wholesale marketing procedures. Assists investor-owned utilities in the development of testimony regarding the prudence of power supply decisions and of investments in specific generation and distribution assets.

Provides utility clients assistance regarding regulatory policy and strategy; project management support for utilities involved in complex regulatory proceedings; process audits; state and federal regulatory filing development; cost of service development and support; the development of innovative rates to achieve strategic objectives; unbundling of rates and the development of menus of rate alternatives for use with customers; performance-based rate development.

Prepared retail and wholesale rate schedules and filings submitted to the Federal Energy Regulatory Commission (FERC) and state regulatory commissions for numerous of electric and gas utilities. Performed cost of service or rate studies for over 150 utilities throughout North America. Prepared market power analyses in support of market-based rate filings submitted to the FERC for utilities and their marketing affiliates. Performed business practice audits for electric utilities, gas utilities, and independent transmission organizations (ISOs), including audits of production cost modeling, retail utility tariffs, retail utility billing practices, and ISO billing processes and procedures.

Instructor in Mathematics
Walden School and Private Instruction
(2012-2015)

Taught advanced placement calculus, linear algebra, pre-calculus, college algebra and differential equations.

Manager of Rates and Other Positions
Louisville Gas & Electric Co.
(May 1979 to July 1996)

Held various positions in the Rate Department of LG&E. In December 1990, promoted to Manager of Rates and Regulatory Analysis. In May 1994, given additional responsibilities in the marketing area and promoted to Manager of Market Management and Rates.

Education

Bachelor of Science Degree in Mathematics, University of Louisville, 1979
66 Hours of Graduate Level Course Work in Electrical and Industrial Engineering and Physics.

Associations

Member of the Society for Industrial and Applied Mathematics

Expert Witness Testimony

Alabama: Testified in Docket 28101 on behalf of Mobile Gas Service Corporation concerning rate design and pro-forma revenue adjustments.

Colorado: Testified in Consolidated Docket Nos. 01F-530E and 01A-531E on behalf of Intermountain Rural Electric Association in a territory dispute case.

Submitted expert report in No. 14-CV-30031 before District Court, Prowers County, State of Colorado, on behalf of Arkansas River Power Authority in the *City of Lamar et al v. Arkansas River Power Authority regarding* power planning and operations.

FERC: Submitted direct and rebuttal testimony in Docket No. EL02-25-000 et al. concerning Public Service of Colorado's fuel cost adjustment.

Submitted direct and responsive testimony in Docket No. ER05-522-001 concerning a rate filing by Bluegrass Generation Company, LLC to charge reactive power service to LG&E Energy, LLC.

Submitted testimony in Docket Nos. ER07-1383-000 and ER08-05-000 concerning Duke Energy Shared Services, Inc.'s charges for reactive power service.

Submitted testimony in Docket No. ER08-1468-000 concerning changes to Vectren Energy's transmission formula rate.

Submitted testimony in Docket No. ER08-1588-000 concerning a generation formula rate for Kentucky Utilities Company.

Submitted testimony in Docket No. ER09-180-000 concerning changes to Vectren Energy's transmission formula rate.

Submitted testimony in Docket No. ER11-2127-000 concerning transmission rates proposed by Terra-Gen Dixie Valley, LLC.

Submitted testimony in Docket No. ER11-2779 on behalf of Southern Illinois Power Cooperative concerning wholesale distribution service charges proposed by Ameren Services Company.

Submitted testimony in Docket No. ER11-2786 on behalf of Norris Electric Cooperative concerning wholesale distribution service charges proposed by Ameren Services Company.

Florida: Testified in Docket No. 981827 on behalf of Lee County Electric Cooperative, Inc. concerning Seminole Electric Cooperative Inc.'s wholesale rates and cost of service.

Illinois: Submitted direct, rebuttal, and surrebuttal testimony in Docket No. 01-0637 on behalf of Central Illinois Light Company ("CILCO") concerning the modification of interim supply service and the implementation of black start service in connection with providing unbundled electric service.

Indiana: Submitted direct testimony and testimony in support of a settlement agreement in Cause No. 42713 on behalf of Richmond Power & Light regarding revenue requirements, class cost of service studies, fuel adjustment clause and rate design.

Submitted direct and rebuttal testimony in Cause No. 43111 on behalf of Vectren Energy in support of a transmission cost recovery adjustment.

Submitted direct testimony in Cause No. 43773 on behalf of Crawfordsville Electric Light & Power regarding revenue requirements, class cost of service studies, fuel adjustment clause and rate design.

Kansas: Submitted direct and rebuttal testimony in Docket No. 05-WSEE-981-RTS on behalf of Westar Energy, Inc. and Kansas Gas and Electric Company regarding transmission delivery revenue requirements, energy cost adjustment clauses, fuel normalization, and class cost of service studies.

Kentucky: Testified in Administrative Case No. 244 regarding rates for cogenerators and small power producers, Case No. 8924 regarding marginal cost of service, and in numerous 6-month and 2-year fuel adjustment clause proceedings.

Submitted direct and rebuttal testimony in Case No. 96-161 and Case No. 96-362 regarding Prestonsburg Utilities' rates.

Submitted direct and rebuttal testimony in Case No. 99-046 on behalf of Delta Natural Gas Company, Inc. concerning its rate stabilization plan.

Submitted direct and rebuttal testimony in Case No. 99-176 on behalf of Delta Natural Gas Company, Inc. concerning cost of service, rate design and expense adjustments in connection with Delta's rate case.

Submitted direct and rebuttal testimony in Case No. 2000-080, testified on behalf of Louisville Gas and Electric Company concerning cost of service, rate design, and pro-forma adjustments to revenues and expenses.

Submitted rebuttal testimony in Case No. 2000-548 on behalf of Louisville Gas and Electric Company regarding the company's prepaid metering program.

Testified on behalf of Louisville Gas and Electric Company in Case No. 2002-00430 and on behalf of Kentucky Utilities Company in Case No. 2002-00429 regarding the calculation of merger savings.

Submitted direct and rebuttal testimony in Case No. 2003-00433 on behalf of Louisville Gas and Electric Company and in Case No. 2003-00434 on behalf of Kentucky Utilities Company regarding pro-forma revenue, expense and plant adjustments, class cost of service studies, and rate design.

Submitted direct and rebuttal testimony in Case No. 2004-00067 on behalf of Delta Natural Gas Company regarding pro-forma adjustments, depreciation rates, class cost of service studies, and rate design.

Testified on behalf of Kentucky Utilities Company in Case No. 2006-00129 and on behalf of Louisville Gas and electric Company in Case No. 2006-00130 concerning methodologies for recovering environmental costs through base electric rates.

Testified on behalf of Delta Natural Gas Company in Case No. 2007-00089 concerning cost of service, temperature normalization, year-end normalization, depreciation expenses, allocation of the rate increase, and rate design.

Submitted testimony on behalf of Big Rivers Electric Corporation and E.ON U.S. LLC in Case No 2007-00455 and Case No. 2007-00460 regarding the design and implementation of a Fuel Adjustment Clause, Environmental Surcharge, Unwind Surcredit, Rebate Adjustment, and Member Rate Stability Mechanism for Big Rivers Electric Corporation in connection with the unwind of a lease and purchase power transaction with E.ON U.S. LLC.

Submitted testimony in Case No. 2008-00251 on behalf of Kentucky Utilities Company and in Case No. 2008-00252 on behalf of Louisville Gas and Electric Company regarding pro-forma revenue and expense adjustments, electric and gas temperature normalization, jurisdictional separation, class cost of service studies, and rate design.

Submitted testimony in Case No. 2008-00409 on behalf of East Kentucky Power Cooperative, Inc., concerning revenue requirements, pro-forma adjustments, cost of service, and rate design.

Submitted testimony in Case No. 2009-00040 on behalf of Big Rivers Electric Corporation regarding revenue requirements and rate design.

Submitted testimony on behalf of Columbia Gas Company of Kentucky in Case No. 2009-00141 regarding the demand side management program costs and cost recovery mechanism.

Submitted testimony in Case No. 2009-00548 on behalf of Kentucky Utilities Company and in Case No. 2009-00549 on behalf of Louisville Gas and Electric

Company regarding pro-forma revenue and expense adjustments, electric and gas temperature normalization, jurisdictional separation, class cost of service studies, and rate design.

Submitted testimony in Case No. 2010-00116 on behalf of Delta Natural Gas Company concerning cost of service, temperature normalization, year-end normalization, depreciation expenses, allocation of the rate increase, and rate design.

Submitted testimony in Case No. 2011-00036 on behalf of Big Rivers Electric Cooperative concerning cost of service, rate design, pro-forma TIER adjustments, temperature normalization, and support of MISO Attachment O.

Submitted testimony in Case No. 2016-00107 on behalf of Columbia Gas Company of Kentucky regarding a tariff application to the continue its energy efficiency and conservation rider and programs.

Submitted testimony in Case No. 2016-00274 on behalf of Kentucky Utilities Company and Louisville Gas and Electric Company in support of community solar rates.

Submitted testimony in Case No. 2016-00370 on behalf of Kentucky Utilities Company and in Case No. 2016-00371 on behalf of Louisville Gas and Electric Company regarding electric and gas class cost of service studies and proposed rates.

Submitted rebuttal testimony in Case No. 2018-00050 on behalf of South Kentucky Rural Electric Cooperative Corporation regarding the regulatory application of the filed rate doctrine and cost shifts to other electric cooperatives related to a proposed purchased power agreement.

Maryland — Submitted direct testimony in PSC Case No. 9234 on behalf of Southern Maryland Electric Cooperative regarding a class cost of service study.

Nevada: — Submitted direct and rebuttal testimony in Case No. 03-10001 on behalf of Nevada Power Company regarding cash working capital and rate base adjustments.

Submitted direct and rebuttal testimony in Case No. 03-12002 on behalf of Sierra Pacific Power Company regarding cash working capital.

Submitted direct and rebuttal testimony in Case No. 05-10003 on behalf of Nevada Power Company regarding cash working capital for an electric general rate case.

Submitted direct and rebuttal testimony in Case No. 05-10005 on behalf of Sierra Pacific Power Company regarding cash working capital for a gas general rate case.

Submitted direct and rebuttal testimony in Case Nos. 06-11022 and 06-11023 on behalf of Nevada Power Company regarding cash working capital for a gas general rate case.

Submitted direct and rebuttal testimony in Case No. 07-12001 on behalf of Sierra Pacific Power Company regarding cash working capital for an electric general rate case.

Submitted direct testimony in Case No. Docket No. 08-12002 on behalf of Nevada Power Company regarding cash working capital for an electric general rate case.

Submitted direct testimony in Case No. Docket No. 10-06001 on behalf of Sierra Pacific Power Company regarding cash working capital for an electric general rate cases.

Submitted direct testimony in Case No. Docket No. 11-06006 on behalf of Nevada Power Company regarding cash working capital for an electric general rate case.

New Mexico Submitted testimony in support of filing of Advice Notice No. 60 on behalf of Kit Carson Electric Cooperative, Inc.

Submitted direct testimony in Case No. 15-00375-UT on behalf of Kit Carson Electric Cooperative, Inc. regarding revenue requirements, the need for a rate increase, class cost of service study, apportionment of the revenue increase to the classes of service, and rate design.

Submitted testimony in Advice Notices in Case No. 15-00087-UT on behalf of Jemez Mountain Electric Cooperative in support of tribal right of way cost recovery surcharge mechanisms.

Submitted direct testimony in Case. No. 16-00065-UT on behalf of Kit Carson Electric Cooperative in support of an application for continuation of its fuel and purchased power cost adjustment clause.

Nova Scotia: Testified on behalf of Nova Scotia Power Company in NSUARB – NSPI – P-887 regarding the development and implementation of a fuel adjustment mechanism.

Submitted testimony in NSUARB – NSPI – P-884 regarding Nova Scotia Power Company's application to approve a demand-side management plan and cost recovery mechanism.

Submitted testimony in NSUARB – NSPI – P-888 regarding a general rate application filed by Nova Scotia Power Company.

Submitted testimony on behalf of Nova Scotia Power Company in the matter of the approval of backup, top-up and spill service for use in the Wholesale Open Access Market in Nova Scotia.

Submitted testimony in NSUARB – NSPI – P-884 (2) on behalf of Nova Scotia Power Company's regarding a demand-side management cost recovery mechanism.

Virginia: Submitted testimony in Case No. PUE-2008-00076 on behalf of Northern Neck Electric Cooperative regarding revenue requirements, class cost of service, jurisdictional separation and an excess facilities charge rider.

Submitted testimony in Case No. PUE-2009-00029 on behalf of Old Dominion Power Company regarding class cost of service, jurisdictional separation, allocation of the revenue increase, general rate design, time of use rates, and excess facilities charge rider.

Submitted testimony in Case No. PUE-2009-00065 on behalf of Craig-Botetourt Electric Cooperative regarding revenue requirements, class cost of service, jurisdictional separation and an excess facilities charge rider.

Submitted testimony in Case No. PUE-2011-00013 on behalf of Old Dominion Power Company regarding class cost of service, jurisdictional separation, allocation of the revenue increase, and rate design.

ENERGY EFFICIENCY AND CONSERVATION RIDER
ENERGY EFFICIENCY/CONSERVATION PROGRAM COST RECOVERY
(Continued)

MODIFICATIONS TO EECPRC (continued)

Each change in the EECPRC shall be placed into effect with meter readings on and after the effective date of such change.

Adjustment Factors: Per Meter per Billing Period

Residential:

EECPCR	$0.61	
EECPLS	$0.03	
EECPI	$0.12	
EECPBA	($0.21)	R
Total EECPRC for Residential Customers	$0.55	R

Commercial:

EECPCR	$0.00
EECPLS	$0.00
EECPI	$0.00
EECPBA	$0.00
Total EECPRC for Commercial Customers	$0.00

DATE OF ISSUE January 20, 2017

DATE EFFECTIVE January 31, 2017

ISSUED BY /s/ Herbert A. Miller, Jr.
TITLE President

KENTUCKY
PUBLIC SERVICE COMMISSION
Talina R. Mathews
EXECUTIVE DIRECTOR
Talina R. Mathews

EFFECTIVE
1/31/2017
PURSUANT TO 807 KAR 5:011 SECTION 9 (1)

Exhibit Seelye-3

Columbia Gas of Kentucky, Inc.
Energy Efficiency/Conservation Program Costs

Program Period Year End	Energy Audit Program	High-Efficiency Appliance Rebate Program	Furnace Replacement Program	Direct Program Cost	CKY Program Administration	Total Program Cost
Oct-10	$ 53,189	$ 189	$ 58,246	$ 111,624	$ -	$ 111,624
Oct-11	171,252	616,153	195,801	983,206	2,500	985,706
Oct-12	29,949	442,839	296,421	769,209	27,694	796,903
Oct-13	302,235	443,083	704,940	1,450,258	20,325	1,470,583
Oct-14	40,257	498,650	531,170	1,070,077	73,170	1,143,247
Oct-15	32,189	451,731	252,645	736,565	18,397	754,962
Oct-16	45,940	474,616	150,760	671,316	37,807	709,123
Oct-17	18,262	396,224	200,845	615,331	68,168	683,499
Total	$ 693,273	$ 3,323,485	$ 2,390,828	$ 6,407,586	$ 248,061	$ 6,655,647
Average Annual	$ 86,659	$ 415,436	$ 298,854	$ 800,948	$ 31,008	$ 831,956

Exhibit Seelye-4

Columbia Gas of Kentucky, Inc.
Energy Efficiency/Conservation Program Participants

Program Period Year End	Energy Audit Program	High-Efficiency Appliance Rebate Program	Furnace Replacement Program	Total Program Participants
Oct-10	183	-	24	207
Oct-11	277	1,429	91	1,797
Oct-12	158	1,138	160	1,456
Oct-13	1,399	1,194	264	2,857
Oct-14	252	1,248	198	1,698
Oct-15	116	1,179	98	1,393
Oct-16	76	1,131	59	1,266
Oct-17	119	1,017	76	1,212
Total	2,580	8,336	970	11,886
Average Annual	323	1,042	121	1,486

Columbia Gas of Kentucky, Inc.
Energy Efficiency/Conservation Program Participants

County	Appliance Rebate Program	Low-Income Furnace Replacement Program	Energy Audit Program	All Programs
Bourbon	124	90	37	251
Boyd	795	38	145	978
Bracken	4	-	-	4
Carter	1	-	-	1
Casey	1	-	-	1
Clark	220	12	88	320
Clay	2	-	-	2
Estill	25	11	9	45
Fayette	5,180	736	1,658	7,574
Floyd	5	1	16	22
Franklin	495	3	247	745
Grant	1	-	-	1
Greenup	437	18	107	562
Harrison	65	53	24	142
Jessamine	152	-	27	179
Johnson	-	-	1	1
Knott	1	-	3	4
Laurel	1	-	-	1
Lawrence	16	1	11	28
Lewis	-	-	2	2
Madison	15	3	7	25
Martin	3	-	2	5
Mason	89	-	19	108
Montgomery	115	-	25	140
Nicholas	1	2	-	3
Perry	1	-	-	1
Pike	6	-	4	10
Scott	283	2	69	354
Taylor	5	-	2	7
Woodford	293	-	77	370
Total	8,336	970	2,580	11,886

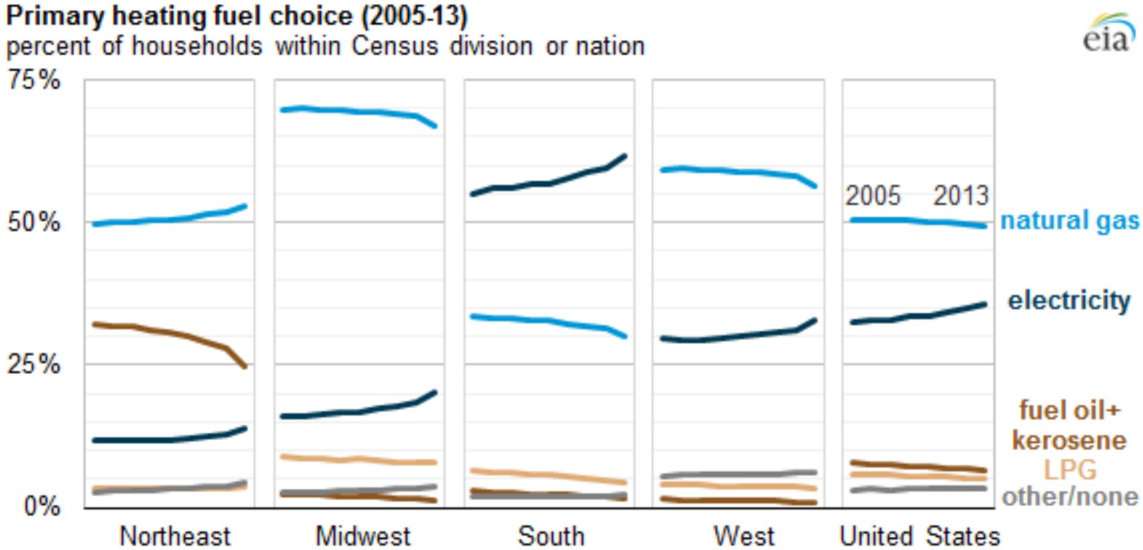
Seelye Exhibit-6

U.S. Energy Information Administration

Today in Energy

September 25, 2014

Everywhere but Northeast, fewer homes choose natural gas as heating fuel



Source: U.S. Energy Information Administration, based on Census Bureau American Community Survey
Note: Geographic areas based on Census regions. LPG is liquefied petroleum gas.

On a national basis, natural gas has long been the dominant choice for primary heating fuel in the residential sector. Lately, electricity has been gaining market share while natural gas, distillate fuel oil, kerosene, and liquefied petroleum gas (propane) have declined.

Part of the national change in heating fuel choice can be attributed to population migrations farther west and south. But even within Census regions, electricity has been gaining market share at the expense of natural gas. The Northeast is the exception, as both natural gas and electricity have been increasing while distillate fuel oil and kerosene have declined.

In the Midwest, most homes are heated by natural gas. The Midwest also has the highest percentage of homes heated by propane, although both natural gas and propane have lost market share to electricity since 2005. The South is the only Census region where electricity is the main space heating fuel in the majority of homes. Heating fuel preferences in the West largely mirror the national average, although households in the West are more likely to use wood as their primary heating fuel or to report not using heating equipment at all.

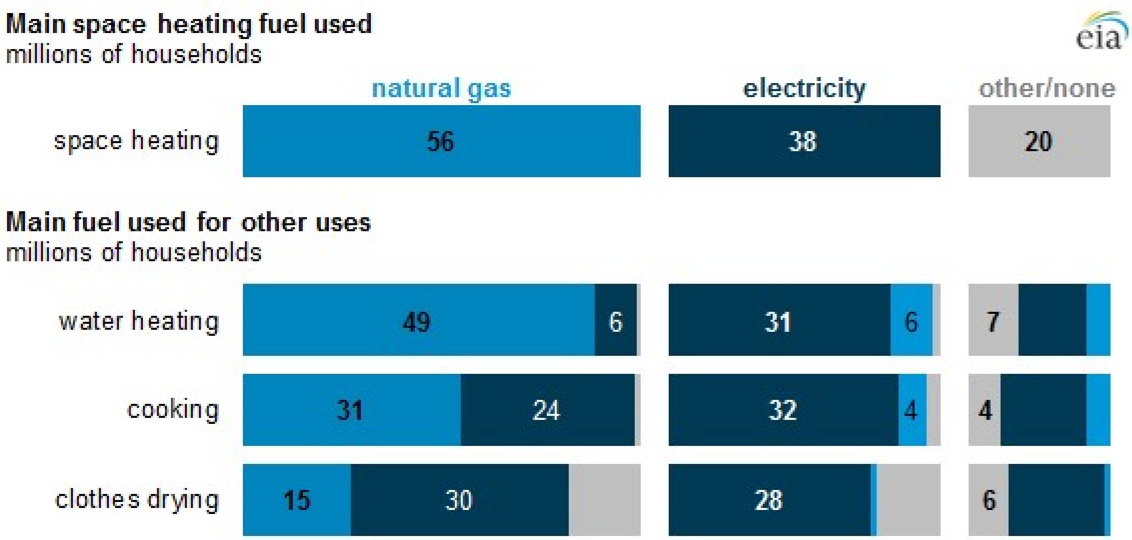
Improvements in electric heat pump technology have improved efficiency and extended the range of temperatures that heat pumps can operate in before resorting to back-up heating, which is most often an electric resistance element similar to that used in a toaster or an electric dryer. Electric resistance heating is effective but relatively expensive to operate.

Heating fuel choice reflects decisions made by home builders and owners. EIA data show that homes built since 1970 use electricity and natural gas as their main heating fuel in roughly equal proportions. Often the choice of heating fuel in new construction has long-term implications, as fuel switching can be expensive. In addition to buying new equipment and removing old equipment, ductwork, pipes, flues, pumps, and fans may need to be installed or removed.

Space heating is the largest portion of household energy use in most areas of the country, and the choice of main heating fuel also influences the fuels chosen for other end uses such as water heating, cooking, and clothes drying. EIA's Residential Energy Consumption Survey (RECS) collects data on fuels used for these purposes, which account for about 65% of 2014 residential delivered energy consumption. The most recent survey data show that homes using natural gas as their main space heating fuel are

Seelye Exhibit-6

more likely to also use natural gas for other purposes. Nationally, only 20% of clothes dryers use natural gas, but in homes with natural gas as their main space heating fuel, that percentage increases to 34%. Of the homes using electricity as their primary heating fuel, about 96% used electric clothes dryers.



Source: U.S. Energy Information Administration, Residential Energy Consumption Survey 2009

Principal contributor: Owen Comstock

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Economics of residential gas furnaces and water heaters in US new construction market

Alex B. Lekov · Victor H. Franco · Gabrielle Wong-Parodi · James E. McMahon · Peter Chan

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Abstract New single-family home construction represents a significant and important market for the introduction of energy-efficient gas-fired space heating and water-heating equipment. In the new construction market, the choice of furnace and water-heater type is primarily driven by first cost considerations and the availability of power vent and condensing water heaters. Few analysis have been performed to assess the economic impacts of the different combinations of space and water-heating equipment. Thus, equipment is often installed without taking into consideration the potential economic and energy savings of installing space and water-heating equipment combinations. In this study, we use a life-cycle cost analysis that accounts for uncertainty and variability of the analysis inputs to assess the economic benefits of gas furnace and water-heater design combinations. This study accounts not only for the equipment cost but also for the cost of installing, maintaining, repairing, and operating the equipment over its lifetime. Overall, this study, which is focused on US single-family new construction households that install gas furnaces and storage water heaters, finds that installing a condensing or power-vent water heater together with condensing furnace is the most cost-effective option for the majority of these houses. Furthermore, the findings suggest that the new construction residential market could be a target market for the large-scale introduction of a combination of condensing or power-vent water heaters with condensing furnaces.

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Keywords Residential · Gas appliances · Venting · New construction · Life-cycle cost analysis · Water heating · Space heating

Introduction

Residential space and water heating account for 39% of total residential primary energy consumption and

91% of all residential gas[1] consumption in the USA (4.9 quads in 2007; US Department of Energy 2009a). A gas furnace and a gas water heater are the most common combination of space and water-heating equipment in existing single-family homes, where on average about half of all new homes (about 0.8 million from 1999 to 2007) are installed with this combination (US Department of Energy 2005; US Department of Commerce 2008).

In new single-family construction, the builder, contractor, or the architect is primarily responsible for the selection of space and water-heating equipment (Ashdown et al. 2004). Several criteria play a role in the equipment choice: lowest first cost (equipment and installation cost), familiarity with equipment by installers, code acceptability, and home buyer preference (Ghent and Keller 1999). As consumers' interest grows for equipment choices that offer significant long-term energy cost savings and reduce environmental impact, builders can find it beneficial to market their homes with more efficient equipment. In addition to consumer pressure, the federal Energy Star program and state's building codes are providing incentives and promoting more efficient equipment. Despite this, two factors contribute to the routine failure to select both more efficient furnaces and more efficient water heaters: lack of availability of condensing water heaters and lack of awareness of the economic impacts of the different combinations of space and water-heating equipment.

This study applies a life-cycle cost (LCC) analysis[2] to calculate the economic advantages and disadvantages to consumers, comparing alternative gas furnace and water-heater combinations installed in new single-family homes. In the past, the US Department of Energy (DOE) has performed separate LCC analysis on residential furnaces and on water heaters (Lekov et al. 2006, 2000). However, little research has been performed to assess the economics of gas space and water-heating equipment combinations regionally and nationally. This study uses data from recent analyses by DOE that examine the energy savings and economic benefits at the household level for six selected furnace and water-heater combinations that include equipment currently available and promoted by the Energy Star program. The study also includes a National Impact Analysis (NIA) to estimate the national energy savings and the national economic impacts from installing different gas furnace and water-heater combinations in new homes.

[1] Includes both natural gas and liquid petroleum gas.

[2] An LCC is a cost/benefit analysis over the lifetime of the equipment from a consumer perspective.

US space heating and water-heating market characterization

The US space heating and water-heating market differs significantly from other major markets (e.g., Europe or Japan). The US market is dominated by air-distribution systems and storage type water heaters, whereas other major markets are dominated by hydronic and heat pump systems.

Space heating

Central heating systems (air distribution and hydronics) in the USA account for 82% of residential heating equipment stock in 2001: 92% of single-family households built from 1980 to 2001 (US Department of Energy 2001) and 98% of all single-family new construction built during 1997–2007 (US Department of Commerce 2008). Most of the remaining heating systems are direct heating equipment (room heaters, wall furnaces, fireplaces, etc.). The US central space heating market is dominated by forced air furnaces (85% of the stock and 97% of all single-family new constructions built during 1997–2007), while hydronics accounts for a smaller fraction (15% of stock and 3% of all single-family new construction built during 1997–2007). Table 1 shows the fraction of heating systems in single-family households by fuel type. These heating systems show significant regional differences. For example, based on US Census Regions (US Department of Commerce 2009), almost all hydronic systems are located in the northeastern US (census region 1), while electric heating equipment dominates the southern US (census region 3; see Table 1).

Water heating

The current stock of residential water-heating equipment is almost entirely storage water heaters (US Department of Energy 2001). The rest of the stock (about 1%) includes all other water-heating catego-

Table 1 US space heating market for single-family households (built from 1980 to 2001)

Heating system types	Fuel	Region 1 (Northeast, %)	Region 2 (Midwest, %)	Region 3 (South, %)	Region 4 (West, %)	National (%)
Central air	Gas	45	91	45	71	59
	Electricity[a]	13	6	48	15	29
	Oil	8	0	0	0	1
	Other	3	0	0	1	0
Hydronics	Gas	5	0	0	1	1
	Oil	12	0	0	0	1
DHE, other[b]	Electricity	9	2	2	5	3
	Gas	0	0	3	2	2
	Oil	2	0	0	0	0
	Other	2	0	1	5	2

Source: RECS 2001 Survey

DHE direct heating equipment

[a] Electric resistance and heat pumps

[b] Other includes solar, wood, and no heating

Table 2 US Water heating market for single-family households (built after 1980)

Fuel	Region 1 (Northeast, %)	Region 2 (Midwest, %)	Region 3 (South, %)	Region 4 (West, %)	National
Gas	48	81	46	80	60
Electric	34	19	54	19	38
Oil	10	0	0	0	1
Combination/other	8	0	0	0	1

Source: RECS 2001 Survey

ries: tankless water heaters, combined space heating and water-heating appliances,[3] solar water heating, district heating, and others. As shown in Table 2, storage water heaters in single-family households built after 1980 are about 60% gas-fired, 38% electric, 1% fuel oil, and 1% combination or other.[4] Regionally, gas-fired water heating is dominant in all regions except in the South.

Availability of natural gas is a major driver in the selection of the heating and water-heating equipment. Newly constructed homes with natural gas access in almost all cases are equipped with gas-fired furnaces and water heaters. Regionally the gas households are mostly in the Northern and Western parts of USA. As shown in Fig. 1, for single-family houses built after 1980, the dominant combination of water heating and space heating is a gas furnace with a gas water heater (53%) followed by an electric furnace or heat pump and electric water heater (26%; US Department of Energy 2001).

This paper focuses on households that have both a gas furnace and a gas storage water heater. This market is projected to maintain its dominance into the future (US Department of Energy 2009a). Thus, new single-family construction represents a significant and important market for the introduction of higher energy-efficient gas space heating and water-heating technologies.

US gas space heating and gas water-heating technology characterization

Gas furnaces and water heaters are often distinguished by whether they use condensing or non-condensing technology. Gas non-condensing water heaters can be further distinguished between natural draft and power-vent technologies.

[3] Combined space heating and water heating appliances are integrated units that provide both space heating and domestic hot water and are not related to the furnace/water heater combinations evaluated in this study.

[4] Water heater fuel types in the single-family market segment are about the same as the national.

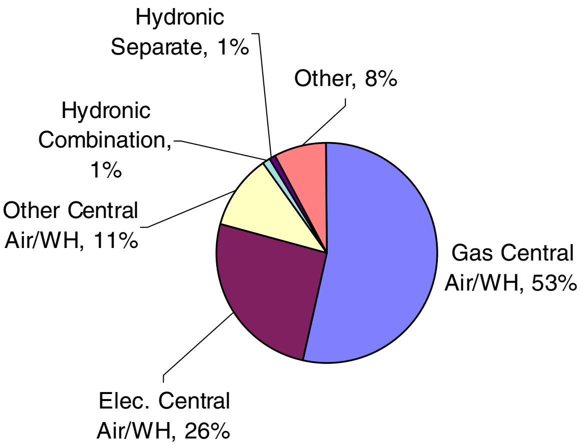


Fig. 1 US space heating and water-heating market for single-family households (built from 1980 to 2001, RECS 2001)

A typical non-condensing gas furnace has an efficiency rating of about 80% annual fuel utilization efficiency (AFUE), while a condensing furnace has an efficiency rating at or above 90% AFUE. In 2007, the most common furnace installed for replacement and in new construction[5] was a non-condensing gas furnace (approximately 63%; Air-Conditioning, Heating, and Refrigeration Institute 2008a).

The efficiency of water heaters, depending on the rated volume and other design considerations, ranges from 0.50 to 0.62 energy factor (EF) for non-condensing natural draft, from 0.60 to 0.70 EF for non-condensing power vent, and above 0.75 EF for condensing water heaters. In 2007, nearly all gas water heaters installed are non-condensing, with approximately 98% natural draft and 2% power-vent models (Air-Conditioning Heating and Refrigeration Institute 2008b). There are currently no shipments of residential condensing water heaters,[6] but there are prototype models available, and condensing water heaters are included in the current Energy Star program (Energy Star 2008).

The electricity and venting installation requirements are different for the various furnace and water-heater designs. Condensing and non-condensing furnaces as well as non-condensing power-vent water heaters and condensing water heaters require electricity to operate, while non-condensing natural-draft water heaters usually do not. Also, non-condensing natural-draft equipment is typically vented vertically through the roof, while condensing and non-condensing power-vent equipment is vented horizontally through the wall.

Figure 2 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. Configuration D is the least expensive, since it uses plastic venting materials (compared to more expensive steel venting materials required in non-condensing furnaces and non-condensing natural-draft water heaters) and shorter vent lengths. Configuration A uses a single vent system for both appliances. Config-

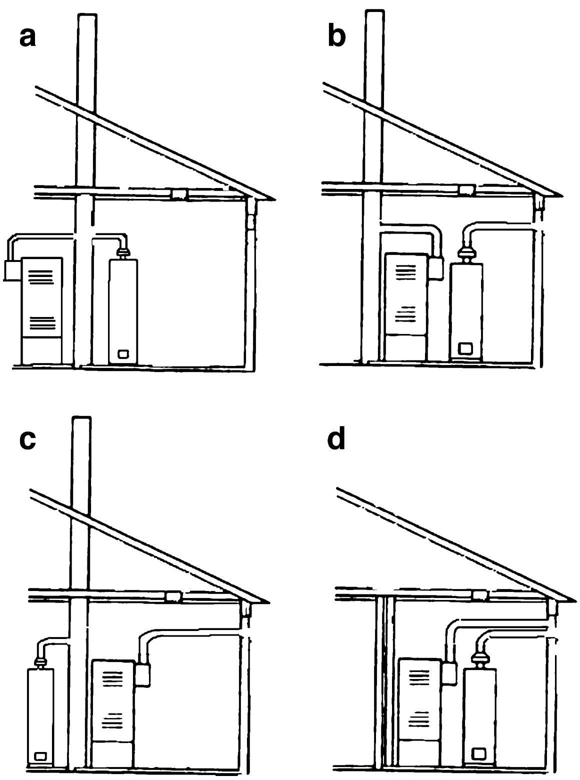


Fig. 2 Four gas furnace and gas water-heater venting configurations: **a** gas furnace and water heater vented through the roof, **b** gas furnace vented through the roof and gas water heater vented through the sidewall, **c** gas furnace vented through the sidewall and gas water heater vented through the roof, and **d** gas furnace and gas water heater vented through the sidewall

[5] Data on the share in new construction only are not available.
[6] There are some "non-residential" condensing models that are being used in residential applications (e.g., A.O. Smith's Vertex models).

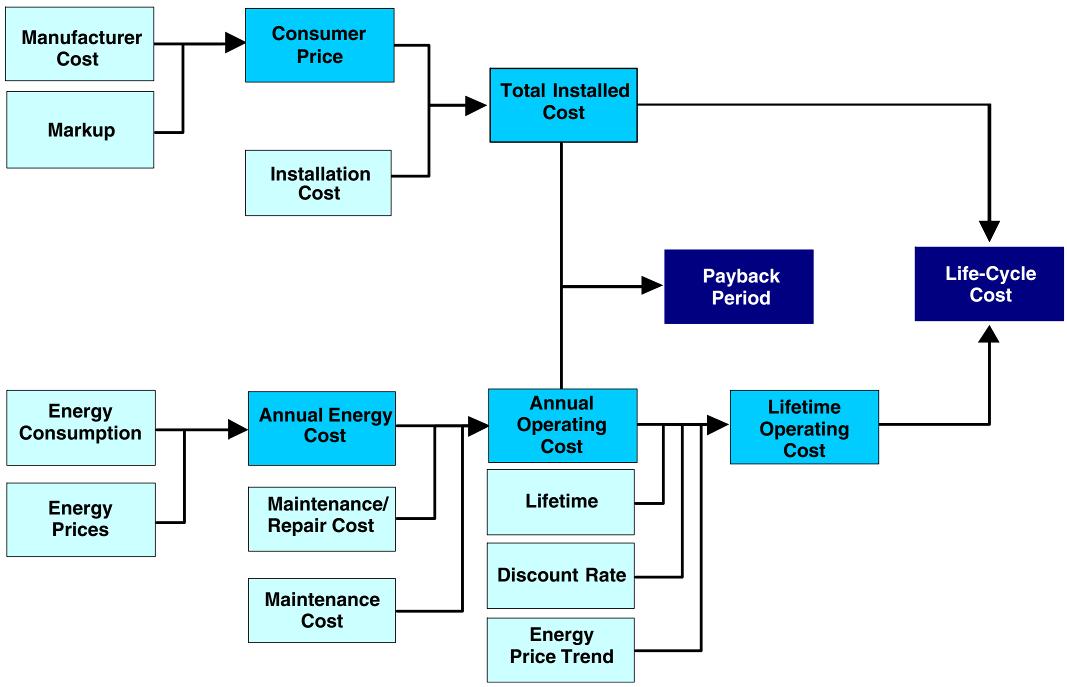


Fig. 3 Life-cycle cost analysis flowchart

urations B and C are the most expensive because of the need to apply two different venting types.

Methodology

This study assessed the energy savings and economics of the elected water-heater and furnace configurations installed in new 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. Figure 3 shows the LCC analysis components. The lighter-colored boxes represent the required inputs, the darker-colored boxes represent the values calculated by these inputs, and the darkest colored boxes show the analysis results. The total installed cost is the sum of the price to the consumer of the equipment and the cost to install the equipment. The operating cost takes in account the energy consumption of the furnace and the water heater and the price of energy as well as the repair and maintenance costs. The total installed cost and the operating cost are used to calculate the payback periods and the life-cycle cost of each of the selected water-heater and furnace options.

Table 3 Gas furnace and gas water-heater options

Option	Furnace type	Gas water-heater type (EF at 40 gallon rated volume[a])	Venting configurations
1	Non-condensing (80%)	Non-condensing natural draft (0.59)	Configuration a
2		Non-condensing power vent (0.64)	Configuration b
3		Condensing (0.80[a])	
4	Condensing (90%)	Non-condensing natural draft (0.59)	Configuration c
5		Non-condensing power vent (0.64)	Configuration d
6		Condensing (0.80[b])	

[a] Efficiency at 40-gal capacity tank. Efficiency varies with capacity

[b] Efficiency based on current Energy Star efficiency levels

Table 4 New construction households by region

Region labels	Census region	HDD criteria	Average number of single-family homes built with a gas furnace in 1999–2007[a]		Regional weights in national analysis (%)
			In thousands per year	%	
Region 1	Northeast	All	69.5	8.0	8.0
Region 2	Midwest	All	231.4	26.5	26.5
Region 3—cold	South	>3,000	278.8	31.9	20.4
Region 3—warm		<3,000			11.5
Region 4—cold	West	>3,000	293.6	33.6	16.3
Region 4—warm		<3,000			17.3
National totals			873.2	100.0	100

[a] US Department of Commerce 2008

To account for the uncertainty and variability of the inputs to the LCC analysis, we applied Monte Carlo[7] simulations, with many of the variables used in the calculations (e.g., discount rate, energy prices, and 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 2001 Residential Energy Consumption Survey (RECS 2001; US Department of Energy 2001). We selected those households having both a gas water heater and a gas furnace[8] and built in or after 1980.[9]

Table 3 shows the six gas furnace and water-heating options. These options are ordered first from non-condensing to condensing furnaces and then by increasing efficiency for water-heater design options. Overall, option 1 represents the least efficient furnace and water-heater combination, and option 6 represents the most efficient combination. The efficiency values used in the calculations were mostly based on commonly available models (US Department of Energy 2007). The fact that options 5 and 6 use venting configuration D is significant, since this configuration is the least expensive one.

To calculate the relative advantages and disadvantages of an option, we assessed the life-cycle cost savings and the payback period (PBP) by comparing option 1, which is the most common, to higher efficiency options (2–6). Option 1 serves as the reference to which the other options are compared.

In addition to a national LCC analysis, we performed a regional LCC analysis for the four US Census regions (US Department of Commerce 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 variables. To account for climate differences within the regions, we divided Census regions 3 and 4 into warm and cold subregions (below and above 3,000 heating degree days (HDD)). To account for the differences in regional new construction trends, we calculated weights that represent the percentage of new single-family homes in each region (see Table 4). We assumed that these weights represent homes that are built with both a gas furnace and gas water heater, since almost all homes built with a gas furnace also have a gas water heater. The regional weights were then subdivided for regions 3 and 4 based on the number of households with gas furnace and water heater in RECS 2001.

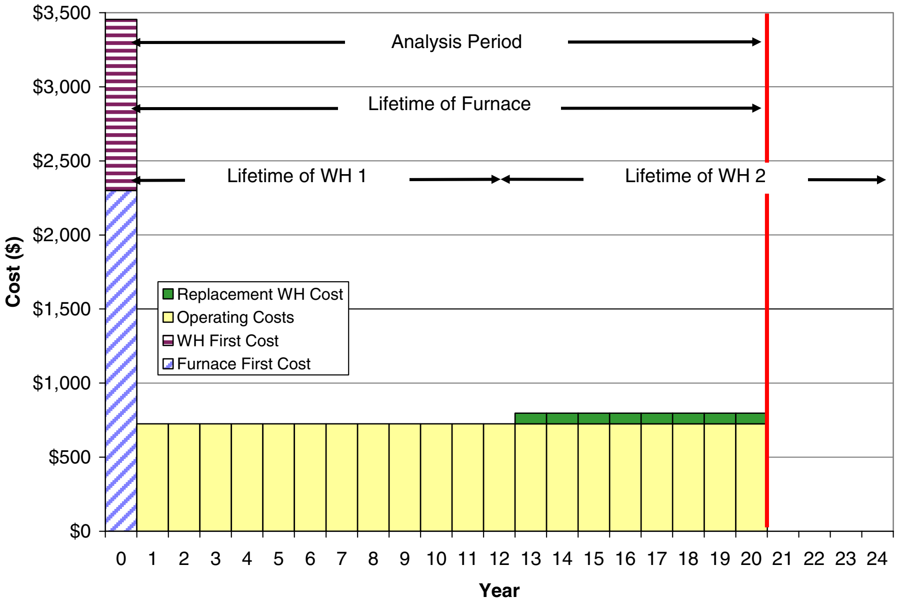
The analysis considered the period from initial furnace and water-heater installation to the end of the lifetime of the furnace. Given the lifetime distributions for the water heater and the furnace, about 95% of the

[7] The Monte Carlo method utilizes 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.

[8] RECS does not distinguish between households that have weatherized gas furnaces (which are not included in this analysis) and non-weatherized gas furnaces.

[9] This is done to get a sample of households which approximates current new construction practices and allows us to generate a sufficiently large sample (447 household records representing 11.6 million households) for the analysis.

Fig. 4 Example of non-discounted components of life-cycle cost by year



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. Figure 4 illustrates how this calculation is included in the overall LCC analysis. The example assumes that the furnace lifetime is 20 years, and the lifetime of the first water heater and the replacement water heater is 12 years. Therefore, the annualized expense for purchase and installation of the replacement water heater is one twelfth of the total installed cost.

For the NIA analysis we calculated the net energy savings (NES) and net present value (NPV) for gas furnaces and water heaters installed in new construction and shipped over a 20-year period (2010–2030) using the average LCC results for the installed cost, maintenance and repair cost, and the annual energy consumption. We measured the impacts of each option against a base case, which reflects the current market share[10] of the different furnace and water-heater combinations. This base case reflects the fact that many builders are already installing products at higher efficiencies (especially condensing furnaces). We modeled the annual shipments in new construction by using the projected number of housing units built and the market share of gas furnaces and water heaters installed in new homes. We also accounted for the useful service life of both appliances to estimate how long they are likely to remain in stock.

[10] There are no disaggregated shipments data for new construction homes. We estimated the market shares in current installations based on 2007 Air-Conditioning, Heating, and Refrigeration Institute total shipments data (Air-Conditioning Heating and Refrigeration Institute 2008a, b). We then adjusted these shares to reflect the fact that a higher fraction of new homes is located in South and West regions, which have a lower penetration of condensing furnaces than the nation as a whole (US Department of Energy 2007).

Analysis

LCC and PBP analysis

The total installed cost includes the consumer price and the installation cost, which includes labor, overhead, and any miscellaneous materials and parts. The operating cost included the energy expenditures and the repair and maintenance costs as well as the total installed cost of a replacement water heater. We discuss each of these inputs below.

Consumer price

US DOE research derives the consumer price based on manufacturer cost and contractor/builder and distribu-

Table 5 Consumer price by option for typical gas furnace and gas water heater (2007$)

Option	Furnace (75 kBtu/h)		Water heater (40 gal)		Total consumer price[a]
	Manufacturing costs	Average markups	Manufacturing costs	Average markups	
1	$413	3.37	$160	2.56	$1,803
2	$413	3.37	$276	2.34	$2,038
3	$413	3.37	$425	2.23	$2,340
4	$610	3.00	$160	2.56	$2,238
5	$610	3.00	$276	2.34	$2,473
6	$610	3.00	$425	2.23	$2,775

[a] Consumer prices in this table may not add up exactly to manufacturing cost multiplied by average markup due to rounding

Table 6 Installation costs for furnace and water-heater options (2007$)

Option	Venting installation configuration	Basic installation		Venting		Total
		Furnace	Water heater	Furnace	Water heater	
1	Configuration A	$451	$340	$829		$1,620
2	Configuration B	$451	$340	$443	$777	$2,011
3	Configuration B	$451	$347	$443	$777	$2,018
4	Configuration C	$453	$340	$777	$443	$2,013
5	Configuration D	$453	$340	$213	$213	$1,219
6	Configuration D	$453	$347	$213	$213	$1,226

Table 7 Average total installed costs furnace and water-heater options (2007$)

Option	Consumer price[a]	Installation cost	Total installed cost	Incremental total installed cost
1	$1,858	$1,620	$3,478	–
2	$2,098	$2,011	$4,109	$631
3	$2,397	$2,018	$4,415	$937
4	$2,314	$2,013	$4,327	$849
5	$2,554	$1,219	$3,773	$295
6	$2,853	$1,226	$4,079	$601

[a] Consumer prices in this table are averages over the range of furnace and water-heater capacities, not just the representative capacities in Table 5

Table 8 House heating load and hot water use by region

		Region 1 (Northeast)	Region 2 (Midwest)	Region 3 cold (South)	Region 3 warm (South)	Region 4 cold (West)	Region 4 warm (West)	National
House heating load, MMBtu/year	Avg	49.0	54.2	39.5	17.7	48.1	18.8	39.4
	Med	45.7	51.4	35.3	14.5	41.6	13.5	35.6
Hot water use, gal/day	Avg	40.4	51.5	53.2	58.5	53.3	56.1	52.9
	Med	38.0	47.2	48.6	53.8	49.8	51.5	48.6

Table 9 Gas furnace and gas water-heater component repair cost and lifetime

	Component	Component lifetime	Repair cost (2007$)	Applied to option
Gas furnace	Electronic ignition	10	$204	1, 2, 3, 4, 5, 6
	Blower motor	12	$297	1, 2, 3, 4, 5, 6
	Inducer motor	15	$297	1, 2, 3, 4, 5, 6
Gas water heater	Pilot light ignition	10	$162	1,4
	Electronic ignition	15	$204	2, 3, 5, 6
	Power vent	15	$297	2, 3, 5, 6

tor markups for the gas furnace and the gas water heater (US Department of Energy 2007, 2009a, b).[11,12] Manufacturer costs vary by rated volume for water heaters and by heating capacity and blower size for furnaces. The incremental cost of a power-vent water heater compared to a standard water heater includes the cost of additional components (blower and electronic ignition). The manufacturer cost of a condensing water heater includes the cost of changes to the heat exchanger and the tank. The analysis used contractor/builder and distributor markups to transform the manufacturer costs into a consumer price. The markup methodology assumes lower overall markup for higher efficiency equipment (condensing furnaces and water heaters and power-vent water heaters), because some distribution costs do not increase with increased efficiency.[13] Table 5 shows the manufacturer costs and the applicable markups for furnace and water heater at representative capacities as used to derive the consumer prices used in the LCC analysis.

[11] DOE's research used a reverse-engineering approach to obtain the manufacturer's costs.

[12] The consumer prices (particularly for residential furnaces as well as for condensing water heaters) are not commonly available. Space heating and water heating equipment are sold through several different distribution channels that have different price structures. To avoid these uncertainties we derived the consumer prices using the manufacturer cost and markup multipliers.

[13] The lower overall markup cost for higher efficiency equipment is explained in the US DOE 2006 Furnace and Boiler Rulemaking TSD (US Department of Energy 2007).

Installation cost

The installation cost for each of the options is in Table 6. The installation cost values comes from US DOE research based on RSMeans cost estimates (US Department of Energy 2009b). 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, and the cost of locating and setting up the units. The only difference in basic installation cost between condensing and non-condensing equipment is the difference in cost of withdrawing the condensate via a horizontal plastic vent compared to withdrawing the exhaust via a vertical metal vent. We considered three different vent system installation costs: option 1 used a common vent through the roof; options 2, 3, and 4 used a combination of vertical metal vent and horizontal plastic vent; and options 5 and 6 used plastic vent.[14]

The total installed cost includes the consumer price and the installation costs and is presented as a distribution of values ("Appendix 2" and Fig. 12 of "Appendix 1"). Table 7 shows the average total installed costs from that distribution. The incremental total installed cost represents the difference between option 1 and each of the other options. Options 5 and 6, which feature a condensing furnace and power vent or condensing water heater, respectively, have the lowest incremental total installed costs because their lower installation costs partially offsets the higher consumer price.

Heating load and hot water use

Energy consumption for both the furnace and the water heater comes from calculations that used DOE test procedure parameters (see "Appendix 3"; Lutz et al. 1999, 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 8 shows the house heating load and hot water use average and median values for the

[14] Options 5 and 6 assume the equipment location is close to the wall to avoid long vent runs. In all cases, the water heater and furnace were assumed to be installed close to each other.

Table 10 Average energy use and operating costs (2007$)

Option	Annual gas use MMBtu/year	Annual elec use kWh/year	Annual maintenance/ repair cost[a] $/year	Avg operating cost $	Avg operating cost savings $
1	64.89	433	$178	$14,917	–
2	63.06	503	$202	$14,802	$116
3	59.47	493	$227	$14,195	$722
4	59.86	369	$178	$13,869	$1,049
5	58.03	438	$202	$13,753	$1,164
6	54.45	428	$227	$13,146	$1,771

[a] Including water-heater replacement if applicable

household sample by region (the resulting distribution of values is shown in Figs. 13 and 14 of "Appendix 2"). The national average hot water use (57.9 gal) is higher than the average value for gas water heaters (49.9 gal) reported in the DOE water-heater study (US Department of Energy 2005) because the household sample for new construction includes only RECS households built from 1980 to 2001 and not the entire stock. The new construction sample weights more toward warmer regions, and the number of occupants per household is higher than the national average.

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 inputs from household energy consumption and energy prices. Average monthly energy prices were determined separately for the nine Census divisions and four large states based on 2006 EIA data, historical monthly EIA data, and 2006 US Census Bureau population estimates (US Department of Energy 2005, 2006a, b; US Department of Commerce 2006). The derived energy prices were matched to each individual household depending on its location. To arrive at prices in future years, we multiplied the 2006 average prices by the forecast of annual average price changes in AEO2009 (US Department of Energy 2009a). "Appendix 1" provides more details about the energy prices used in the analysis.

Table 11 Furnace and water-heater lifetime

Product class	Minimum	Average	Maximum
Gas water heater	6	12	18
Gas furnace	10	20	30

The furnace maintenance cost accounts for regular maintenance, while no maintenance cost was associated with the water heaters. The analysis assumed 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; US Department of Energy 2009b).[15] Table 9 lists the repair cost of key components as used in the analysis.

The operating cost accounts for the household annual energy consumption as well as for the maintenance and repair and is expressed as a distribution of values (Fig. 15 of "Appendix 2"). Table 10 shows the average energy use and operating cost for the analyzed household sample. The operating cost savings reflect the difference between option 1 and each of the other options. Option 6 has the lowest average operating cost and the highest annual fuel savings.

Condensing water heaters on average show more fuel savings than condensing furnaces. This is due to the higher efficiency difference between non-condensing and condensing water heaters (about 37%) compared to the difference between non-condensing and condensing furnaces (about 13%).

Discount rate

The LCC analysis discounted future operating costs to 2010 and summed them over the lifetime of the furnace. The discount rate used reflects after-tax real mortgage rates and on average equals 3.2% (US Department of Energy 2007).

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

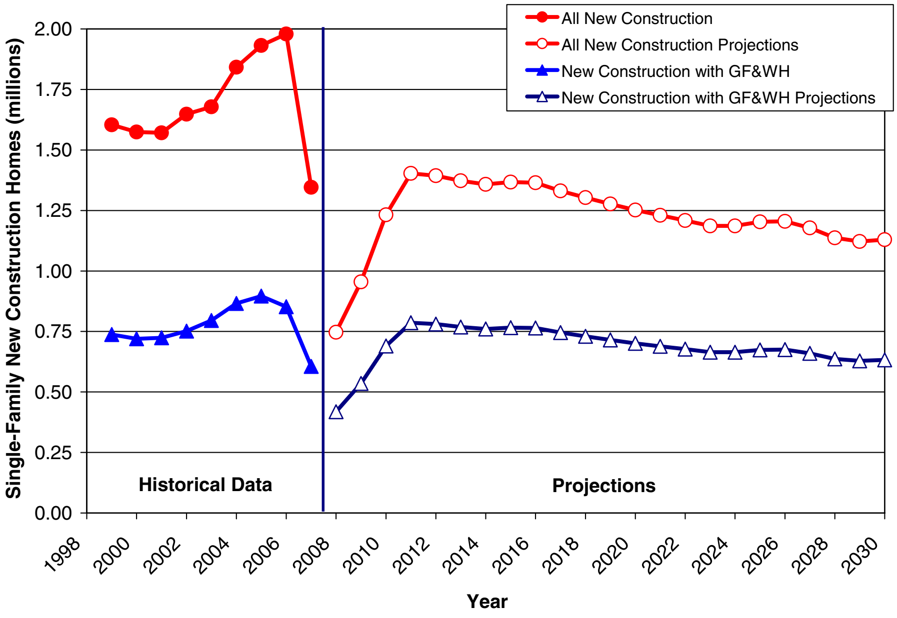


Fig. 5 New construction shipments (historical from 1999 to 2007 and projected from 2008 to 2030)

Lifetime

Lifetime estimates for furnaces and water heaters are shown in Table 11 (US Department of Energy 2007, 2008). In the analysis, lifetime is represented as a triangular probability distribution. The analysis uses the same lifetime for all furnace and water-heater designs.

National impacts analysis

The primary input parameters used in the NIA are discount rate, lifetime and energy prices along with the unit price, energy use and installation, and repair costs from the LCC analysis. Figure 5 shows the projected new construction shipments of gas furnace and water heaters in 2010–2030, which is based on new housing completion projections from the 2008 Annual Energy Outlook (AEO 2008; US Department of Energy 2008). The estimated average fraction of new housing completions with gas furnaces and gas water heaters is 49.5% based on US Census data (Table 2) and data from the 2005 American Housing Survey (US Department of Commerce 2005).

The NIA calculates national energy savings at the site level and then uses conversion factors from AEO 2008 to convert to primary energy use.[16] NIA also includes the impact of the rebound effect (also called a take-back effect or offsetting behavior), which refers to increased energy consumption resulting from actions that increase energy efficiency and reduce consumer costs.[17] To account for the rebound effect, national energy savings are reduced 10% for water heaters and 15% for furnaces (US Department of Energy 2007, 2009b).

Table 12 Average LCC and LCC savings (2007$)

Option	Total installed cost	Operating cost	Total LCC	LCC savings
1	$3,478	$14,917	$18,395	–
2	$4,109	$14,802	$18,911	($516)
3	$4,415	$14,195	$18,610	($215)
4	$4,327	$13,869	$18,196	$199
5	$3,773	$13,753	$17,526	$869
6	$4,079	$13,146	$17,225	$1,170

Negative savings within parentheses

[16] Site energy is the amount of heat and electricity consumed on site by a building as reflected in utility bills. Primary energy is the raw fuel that is burned to create heat and electricity, such as fuel used to generate electricity at a power plant, plus other losses in producing and transporting the fuel and electricity.

[17] The logic behind the rebound effect is that more energy-efficient products lower the marginal cost of the end-use service relative to lower energy-efficient products so consumers take some of the energy savings back in increased comfort or service.

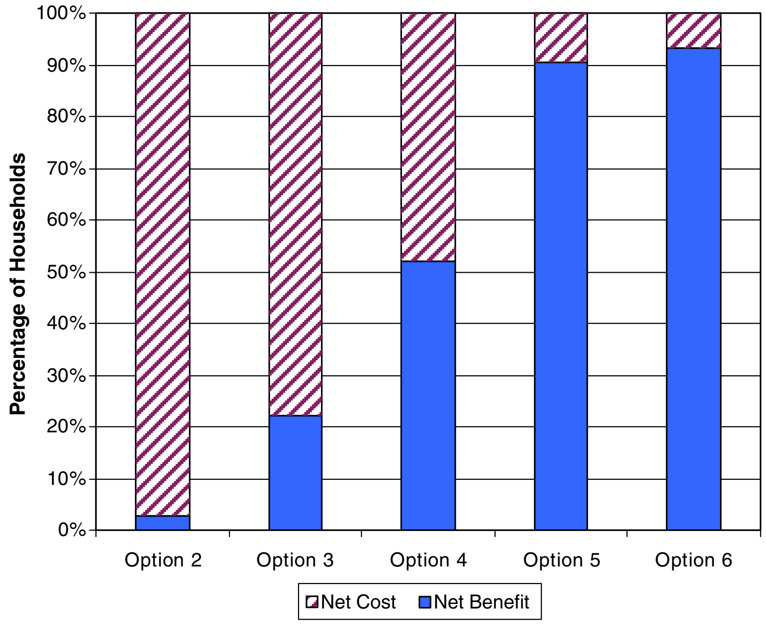


Fig. 6 LCC impacts for US new construction households

Results

Table 12 shows the average total installed cost, operating cost, total LCC, and average LCC savings for the six options (the distribution of LCC savings is in Fig. 16 of "Appendix 2"). Option 6 has the highest LCC savings ($1,170), followed by option 5 ($869). Options 2 and 3 have negative LCC savings or increased costs.

Figure 6 shows the percentage of all US new construction households that would experience a positive LCC savings (net benefit) or negative LCC savings (net cost) compared to option 1 if they were to install a combination of gas furnace and water heater as in options 2–6. All options with a condensing furnace (options 4–6) have net benefits for more than half of the households (52% for option 4, 90% for option 5, and 93% for option 6), while

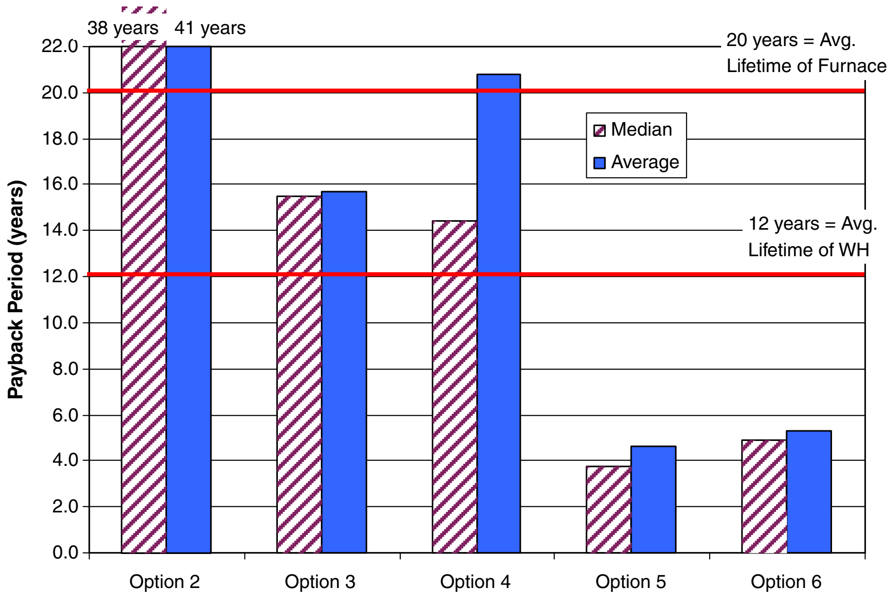


Fig. 7 Median and average household PBP

Table 13 Average LCC savings by region (2007$)

Option	Region 1 (Northeast)	Region 2 (Midwest)	Region 3 cold (South)	Region 3 warm (South)	Region 4 cold (West)	Region 4 warm (West)
1	–	–	–	–	–	–
2	($494)	($514)	($472)	($524)	($452)	($632)
3	($197)	($241)	($121)	($260)	$10	($473)
4	$611	$468	$198	($394)	$548	($323)
5	$1,302	$1,140	$912	$268	$1,281	$230
6	$1,599	$1,413	$1,263	$532	$1,743	$390

Values in parentheses indicate negative numbers

options 2 and 3 have net benefits for less than 50% of households (3% for option 2 and 22% for option 3).

Figure 7 shows the median and average payback period relative to option 1. Options 5 and 6 have the lowest payback periods (median payback period of 3.8 and 4.9 years, respectively). Options 3 and 4 have median paybacks of about 14–15 years, while option 2 has median and average payback beyond the lifetime of the equipment.

Table 13 shows the average LCC savings by region. The LCC savings vary by region because of the significant variations of the furnace heating load due to climate differences and regional energy prices. Option 6 shows the highest LCC savings for all regions. For regions above 3,000 HDD (regions 1, 2, and 3—cold; 4—cold), which account for about two thirds of the new construction homes, the average LCC savings for option 6 are between $1,263 and $1,743. The average LCC savings drop to $390 to $532 for the regions below 3,000 HDD (about one third of new construction households). Option 5 is also cost-effective in all regions. In general, option 4 shows savings in cold climates, but not in warm regions. Options 2 and 3 are generally not cost-effective (except option 3 in region 4—cold).

Table 14 shows the payback period by region for all options. In general, options 6 and 5 have median payback periods less than 8 years in all regions and less than 5 years in regions above 3,000 HDD. Options 3 and 4 offer median paybacks between 10 and 16 years in regions above 3,000 HDD, but median paybacks rise in regions below 3,000 HDD to 15 to 19 for option 3 and above the lifetime for option 4. Option 2 has median and average paybacks beyond the lifetime of either equipment in all regions.

The most cost-effective option (i.e., the lowest total LCC) for each household in each region is shown in Fig. 8. Option 6 has the lowest total LCC for 83% of all households, except for region 4—warm, where this fraction is approximately 65%.

Condensing water heaters, included in options 3 and 6, are not yet available for residential storage-tank applications. Figure 9 shows the most cost-effective for each household in wach region, excluding condensing waster heaters (i.e., options 3 and 6). Option 5, which combines condensing furnace and power-vent

Table 14 Payback period by region (years)

Option	Region 1 (Northeast)		Region 2 (Midwest)		Region 3 cold (West)		Region 3 warm (West)		Region 4 cold (South)		Region 4 warm (South)	
	Avg	Med	Avg	Med	Avg	Med	Avg	Med	Avg	Med	Avg	Med
1	–	–	–	–	–	–	–	–	–	–	–	–
2	34	34	39	39	34	33	35	42	32	33	64	63
3	14	14	16	16	15	15	15	16	13	13	19	19
4	10	11	11	12	14	16	35	43	12	12	36	37
5	2.8	2.9	3.2	3.4	3.7	3.9	6.8	7.2	2.9	3.1	7.8	7.9
6	4.0	4.0	4.4	4.5	4.8	4.8	6.9	7.0	3.9	4.0	7.6	7.7

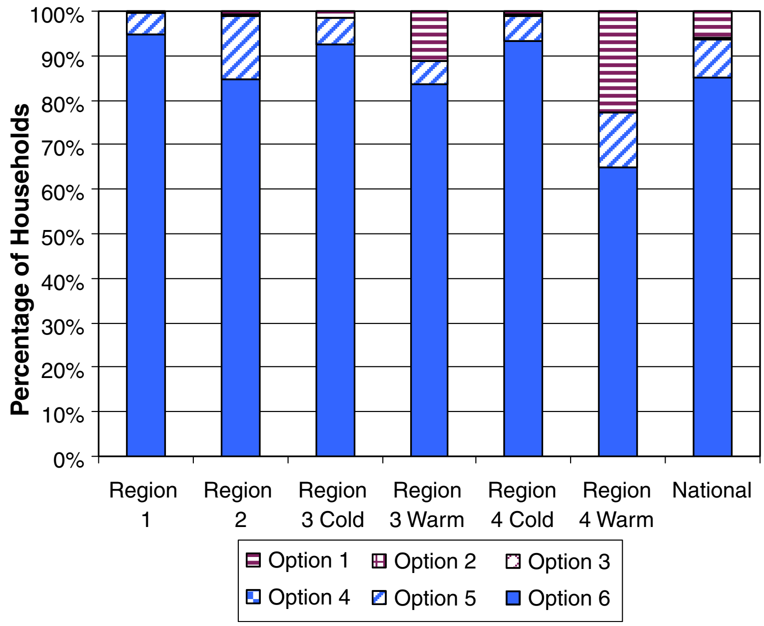


Fig. 8 Options with lowest total LCC by region

water heater, is the option with the lowest LCC for more than 90% of the households nationally and more than 95% of the households in all regions except regions 3—warm and 4—warm. Power-vent technology is readily available and currently maintains about a 2% share of the gas water-heater market.

The NES and NPV results for the six options are shown in Fig. 10. For the nation, option 6 has the highest NES (1.5 quads) and NPV ($8.0 billion) over the 2010–2030 period. Option 5 also has positive NES (0.7 quads) and NPV ($5.0 billion). Option 4 has a positive NES (0.6 quads) and NPV ($0.1 billion). Options 2 and 3 have positive NES results, but negative NPV results. The positive NPV for options 5 and 6 reflects their lower installation cost compared to options 2, 3, and 4 and their higher operating cost savings.

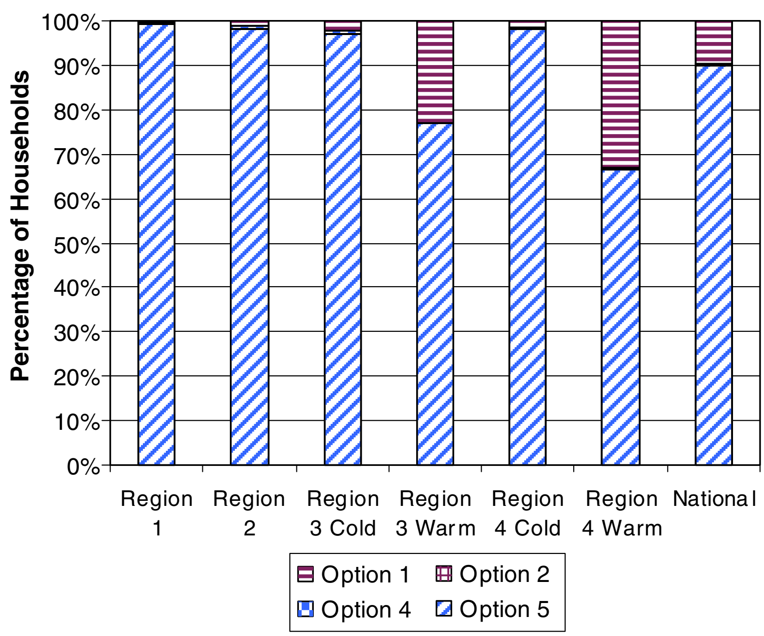


Fig. 9 Options with lowest total LCC (excluding condensing water heaters)

Conclusion

For the US single-family housing market the dominant combination of water heating and space heating is a gas furnace with a gas water heater. The results for the new construction segment of the single-family market show that options 4, 5, and 6 (condensing furnace with any type of water heating) show positive LCC savings. The LCC savings are very significant for options 5 and 6, which combine a condensing furnace with either a power-vent or condensing water heater. Over 90% of the natural-gas-using new single-family homes in the US would benefit from installing either options 5 or 6. These two options also have the lowest average payback (3.8 years for option 5 and 4.8 years for option 6). In all US regions, options 5 and 6 have the highest average LCC savings and the lowest average payback.

Option 6 is the most cost-effective technology (with lowest LCC) for 83% of all US households. Option 6 also has the lowest LCC for 80% or more of households in all regions, except for region 4—warm, where this fraction is about 65%. Option 5 is the second most cost-effective technology. Option 5 is attractive because it uses the power-vent water-heater technology, which already has about 2% market share.

The national impact analysis shows that both options 5 and 6 have significant potential national energy savings and economic benefits over the 2010 to 2030 period. In particular, option 6 shows very large NPV greater than $8 billion due to lower installation costs and higher operating cost savings. Together these more than offset the higher consumer price for the equipment.

Presently, in the new construction market, the choice of furnace and water-heater type is primarily driven by first cost considerations and limited availability of power-vent and condensing storage-tank water heaters. This study suggests that homebuyers in most of the US would benefit from the installation of higher efficiency space and water-heating technologies. It also shows that important benefits may be overlooked when policy analysts evaluate the impact of space and water-heating equipment separately.

The economic results indicate that significant energy savings and consumer benefits may result from large-scale introduction of condensing or power-vent water heaters combined with condensing furnaces in US residential new construction.

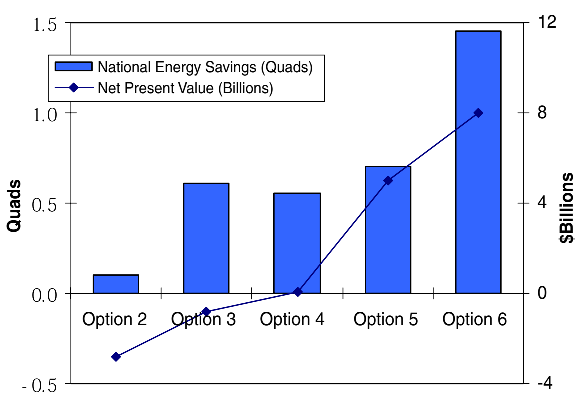


Fig. 10 NES and NPV results

Future work

The study was limited by factors that could be addressed in future research. Some of the potential future directions are as follows:

- Broaden the study to cover replacement situations as well as other residential building types (i.e., multifamily and mobile home).
- Broaden the scope to include gas tankless water heaters, variable-fire condensing tankless combined space/water heaters, solar water heaters, combined solar space/water heater, electric water heaters and furnaces, which include heat pump designs, and combination appliances.[18]

Acknowledgments The authors would like to thank Steven Meyers (LBNL), Jim Lutz (LBNL), and Lisa Thompson (LBNL) for providing valuable inputs and reviewing the paper.

Appendix 1: Energy prices

The energy use of furnaces and to a lesser extent water heaters varies by month. In general, US monthly energy prices also vary significantly by month. To more accurately capture the annual energy cost used by the

[18] Shipments of tankless water heaters are increasing significantly and are projected to be around 25% of the gas water heating market by 2015. DOE also projects a larger market for heat pump water heaters (US Department of Energy 2009b)

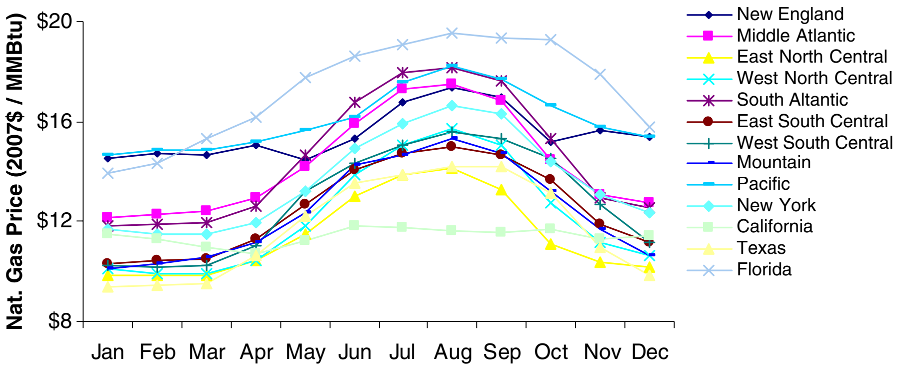


Fig. 11 Natural gas price forecast for 2010

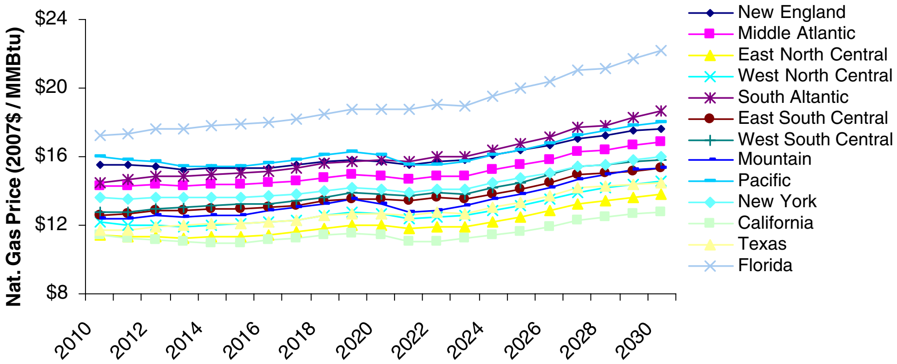


Fig. 12 Natural gas price forecast from 2010 to 2030

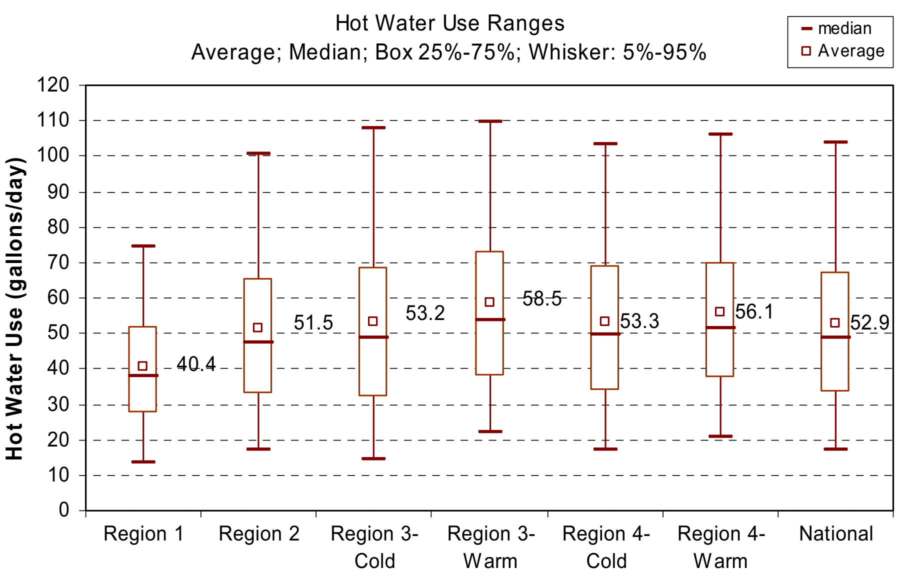


Fig. 13 Total installed price by option box plot

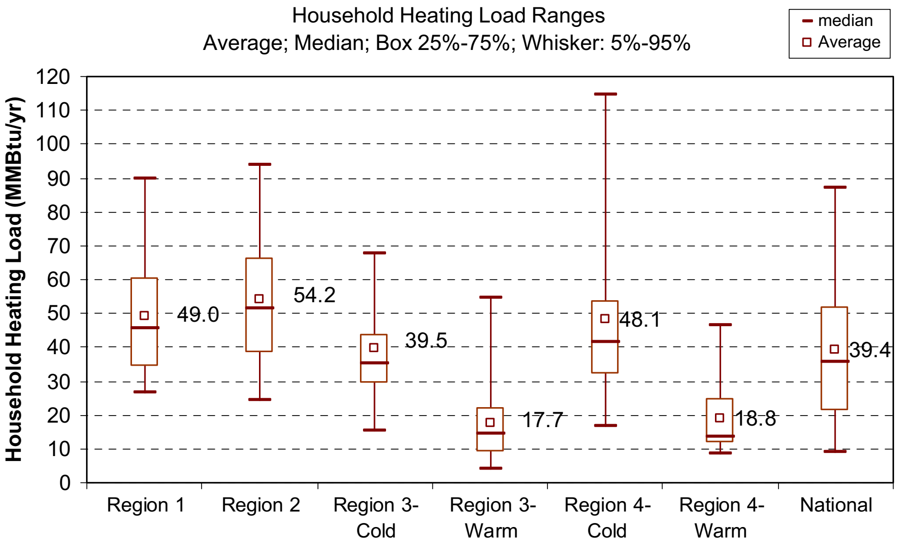


Fig. 14 Household heating load by region box plot

households, this analysis uses regional monthly energy prices instead of annual average energy prices.

The regional monthly energy prices are derived from historical monthly energy prices (US Department of Energy 2005, 2006a, b; US Department of Commerce 2005) and projected into the future using AEO 2009 annual regional energy price projections (US Department of Energy 2009b). As an example, Fig. 11 shows the monthly natural gas price forecast for 2010 for the nine Census Divisions and four large states. Using monthly prices results in lower operating costs, because most consumption occurs in the winter when the natural gas prices are lower compared to the average annual prices.

Figure 12 shows annual trends (based on AEO 2009 projections) for all Census Division and four large states for the period (2010–2030).

Appendix 2: Distribution of results

The outcome of the LCC analysis is a distribution of values from a sample size of 10,000 households. The following charts (Figs. 13, 14, 15, 16, and 17) show

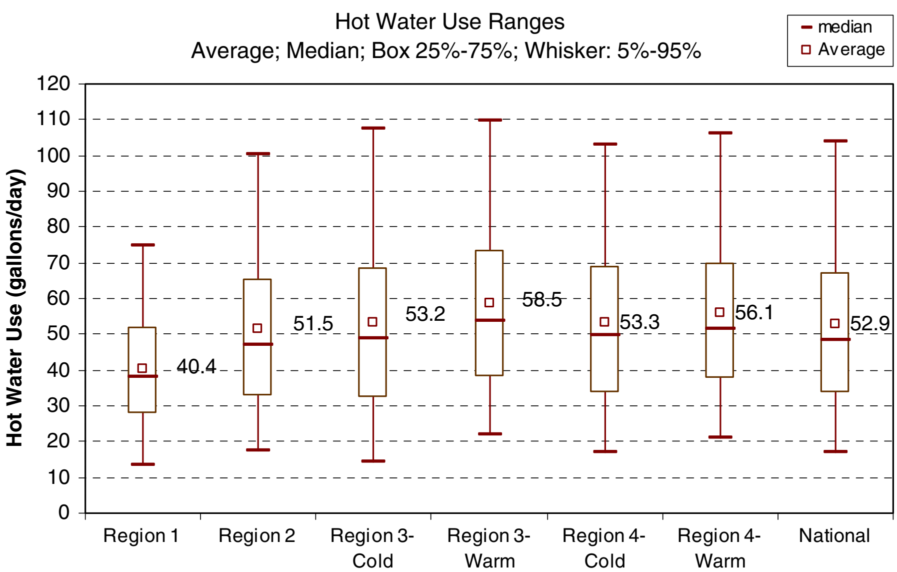


Fig. 15 Hot water use by region box plot

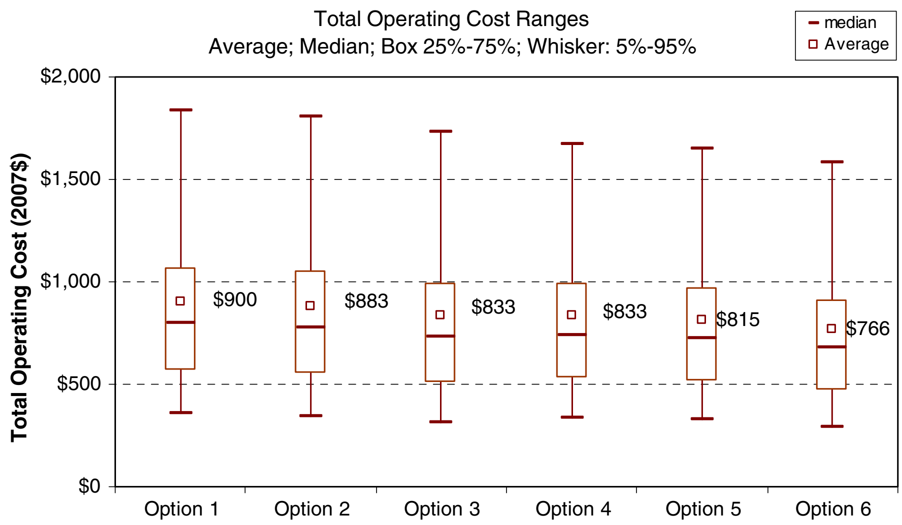


Fig. 16 Total operating cost by option box plot

the resulting distributions for the total installed cost, total operating cost and the LCC savings (by option), and for the house heating load and hot water use (regionally and nationally).

Appendix 3: Energy use calculations

This appendix offers an overview of the equations used to calculate energy use for gas water heaters and gas furnaces (Lutz et al. 1999, 2004).

The Water Heater Analysis Model (WHAM) method (Lutz et al. 1999) is used to derive the average daily water-heater energy consumption (Q_{in}):

$$Q_{\text{in}} = \frac{\text{vol} \times \text{den} \times C_{\text{P}} \times (T_{\text{tank}} - T_{\text{in}})}{\text{RE}} \times \left(1 - \frac{\text{UA} \times (T_{\text{tank}} - T_{\text{amb}})}{P_{\text{on}}}\right) + 24 \times \text{UA} \times (T_{\text{tank}} - T_{\text{amb}})$$

where

C_{p} specific heat of stored water, set constant at 1.000743 Btu/lb°F

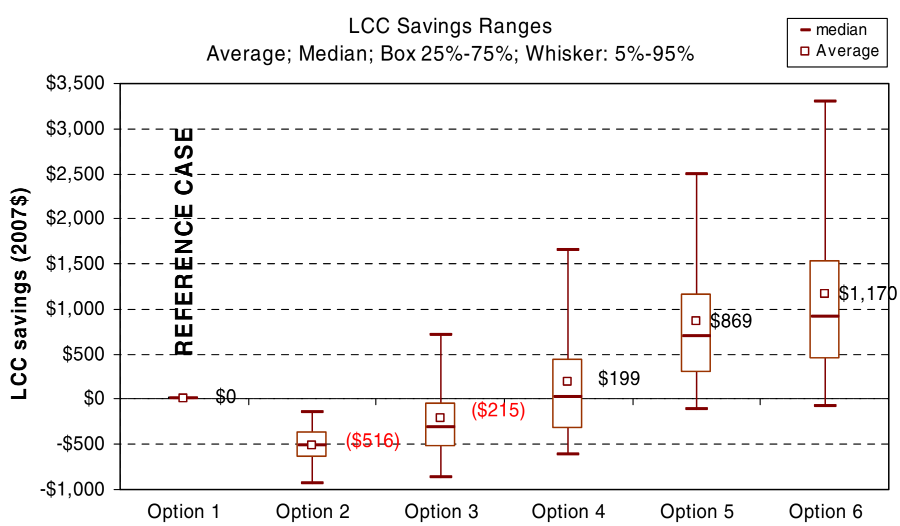


Fig. 17 LCC savings by option box plot (negative savings within parentheses)

den density of stored water, set constant at 8.29 lb/gal
P_{on} rated input power, Btu/h
Q_{in} total water-heater energy consumption, Btu/day
RE recovery efficiency, %
T_{amb} temperature of the air surrounding the water heater, °F
T_{in} inlet water temperature, °F
T_{tank} thermostat set-point temperature, °F
vol volume of hot water drawn in 24 h, gal/day
UA standby heat-loss coefficient, Btu/h °F

The volume of hot water drawn in 24 h is determined using a hot water draw model, which uses a set of household characteristics and water-heater performance parameters (US Department of Energy 2009b). WHAM yields total water-heater energy consumption (Q_{in}), which is disaggregated into electricity and fuel consumption.

The gas furnace fuel consumption (FuelUse) is calculated using:

$$\text{FuelUse} = \text{BOH}_{SS} \times Q_{IN}$$

where

BOH_{SS} steady-state burner operating hours (h)
Q_{IN} input capacity of existing furnace (kBtu/h)

The burner operating hours (BOH_{SS}) for each household are determined using the RECS' household energy use and the performance characteristics of the gas furnace.

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