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Keys to the House: Unlocking Residential Savings With Program Models for Home Energy Upgrades

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Keys to the House: Unlocking Residential Savings With Program Models for Home Energy Upgrades[1,2]

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Overview

After more than 40 years of effort, energy efficiency program administrators and associated contractors still find it challenging to penetrate the home retrofit market, especially at levels commensurate with state and federal goals for energy savings and emissions reductions. Residential retrofit programs further have not coalesced around a reliably successful model. They still vary in design, implementation and performance, and they remain among the more difficult and costly options for acquiring savings in the residential sector. If programs are to contribute fully to meeting resource and policy objectives, administrators need to understand what program elements are key to acquiring residential savings as cost effectively as possible. To that end, the U.S. Department of Energy (DOE) sponsored a comprehensive review and analysis of home energy upgrade programs with proven track records, focusing on those with robustly verified savings and constituting good examples for replication. The study team reviewed evaluations for the period 2010 to 2014 for 134 programs that are funded by customers of investor-owned utilities. All are programs that promote multi-measure retrofits or major system upgrades. We paid particular attention to useful design and implementation features, costs, and savings for nearly 30 programs with rigorous evaluations of performance. This meta-analysis describes program models and implementation strategies for (1) direct install retrofits; (2) heating, ventilating and air-conditioning (HVAC) replacement and early retirement; and (3) comprehensive, whole-home retrofits.[4] We analyze costs and impacts of these program models, in terms of both energy savings and emissions avoided. These program models can be useful guides as states consider expanding their strategies for acquiring energy savings as a resource and for emissions reductions. We also discuss the challenges of using evaluations to create program models that can be confidently applied in multiple jurisdictions.

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[1] An earlier and much abridged version of this brief was presented at the American Council for an Energy-Efficient Economy's Summer Study on Energy Efficiency in Buildings conference in August 2016 and appears in the conference proceedings. This brief covers more data and thus is more comprehensive and up to date.
[2] The authors are indebted to our reviewers, including Lisa Schwartz at LBNL; Scott Reeves of Cadmus Consulting; and several individuals at Vermont Energy Investment Corporation, who submitted their comments in aggregate.
[3] LBNL engaged John Shenot, Regulatory Assistance Project, to provide estimated air emissions impacts associated with energy savings from our program models. See emissions tables in main text and Appendix B.
[4] Even though programs for low income households were the precursors to today's Home Performance with ENERGY STAR retrofit programs, we focus on market-rate programs because low income programs have many other policy drivers and objectives and correspondingly different policies, delivery features, costs, and outcomes.

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Introduction

In the United States, more than half of the states have mandatory targets[5] for using energy efficiency as an energy or environmental resource. The residential sector accounts for 21% of U.S. carbon dioxide emissions from burning fossil fuels,[6] so saving energy in homes—especially through long-lived equipment and shell measures that deliver savings for many years—can contribute significantly to meeting these federal and state policy objectives.

At the same time, utility customers, regulators, and trade allies are demanding more—more value for the customer, sustained efficiency as a cost-effective energy resource, more utility brand recognition, and more profitability for contractors. DOE's Better Buildings Neighborhood Program, funded by the American Recovery and Reinvestment Act of 2009, provided one-time grants to states and localities to stimulate economic activity, create jobs and improve energy efficiency in homes and buildings. These entities worked with nonprofits, building energy efficiency experts, financial institutions, utilities, and other organizations to develop and incubate community-based programs and incentives to spur demand for building energy upgrades. A comprehensive evaluation of the program (Research Into Action et al. 2015a; Research Into Action 2015b) documented insights and lessons that can benefit future programs. In addition, a Better Buildings Residential Program Solution Center (https://rpsc.energy.gov) provides an online repository for key lessons, resources, and knowledge collected from the experience of these efforts. It is intended to help program administrators and their partners plan, operate, and evaluate residential energy efficiency programs.

Since 2010, numerous assessments have offered strategies for driving comprehensive and enduring residential efficiency (see State and Local Energy Efficiency Action Network 2015; Neme et al. 2011; Fuller et al. 2010). But with notable exceptions, such as the evaluation of the Better Buildings Neighborhood Program, there has not been a systematic, uniform validation of successful residential energy efficiency program design and implementation across the United States through rigorous evaluations of multiple programs. Such a meta-analysis could highlight successful design and implementation elements that could be replicated with confidence.

DOE engaged Lawrence Berkeley National Laboratory (LBNL), working with its contractor Energy Futures Group (EFG), to research three widely employed types of residential energy efficiency programs to see if it would be possible to develop replicable "model" program approaches that program administrators (PAs), particularly those relatively new to energy efficiency or ramping up efforts, could use to meet energy and environmental goals.

DOE sought to identify program models to achieve deep program savings as cost effectively as possible. In short, because the objective is significant savings across multiple measures and because the initial costs can

[5] Savings targets here include energy efficiency resource standards (EERSs) as well as binding utility-specific targets that flow from other policies and practices. These include approved efficiency program plans and mandates to acquire "all cost-effective energy efficiency." In those cases, regulators commonly set binding targets on an annual or multi-year cycle.
[6] This figure includes emissions from power plants supplying electricity for the sector and direct burning of fuels in homes for heating and other purposes.

be high, the program types that are the focus of this work represent some of the most challenging efforts to save energy in the residential sector.

It was deemed imperative that these program models were based on the proven success of actual programs. To this end, the research focused on programs that (1) have a minimum of two years of field implementation and (2) have conducted independent and rigorous third-party evaluations to validate their savings as well as other key indicators of success, such as customer and contractor satisfaction and market penetration. Self-reported success was not considered sufficient.

LBNL engaged the Regulatory Assistance Project to estimate changes in air emissions resulting from implementation of each model program.

Elements of Program Design

In research for this project, LBNL and EFG focused on identifying those program elements that distinguished more successful programs—the "success factors" that could be isolated for inclusion in program models. Our review of program evaluations suggests that successful programs meet the following conditions:

1. Market potential for energy savings is sizable.
2. The technology being promoted is reliable.
3. The "right" participants are engaged (the ones for whom the opportunity is sufficient from the program's perspective).
4. The program works financially and "emotionally" for participants (meets their values in some way), and the process is not overly burdensome.
5. The program is in the interests of contractors and vendors—it either aligns with their business models or, if it is disruptive, the rewards are sufficient to overcome that resistance.
6. The savings are verifiable.

Research Approach

LBNL and EFG looked to multiple sources to identify programs to review and available evaluations: the LBNL Demand-Side Management (DSM) Program Database,[7] "best-practice" program studies conducted by the American Council for an Energy Efficient Economy, the existing homes program guide produced by the Consortium for Energy Efficiency (CEE 2015), and the Regional Energy Efficiency Database (REED) maintained by the Northeast Energy Efficiency Partnerships. LBNL and EFG also contacted numerous industry experts for recommendations on successful programs to consider.

LBNL and EFG assembled a starting list of nearly 400 program years of data[8] for three types of programs: (1) direct install retrofits; (2) heating, ventilation and air conditioning (HVAC) replacement and early retirement; and (3) comprehensive or whole-home retrofits involving multiple efficiency measures.

[7] Detailed descriptions of the database and analyses of the data to date may be found at https://emp.lbl.gov/what-it-costs-save-energy, specifically in Hoffman et al. (2015) and Billingsley et al. (2014). These reports may be found, respectively, at https://emp.lbl.gov/publications/total-cost-saving-electricity-through and https://emp.lbl.gov/publications/program-administrator-cost-saved

[8] A program year (PY) is a year's worth of data for each program.

In all, 134 distinct programs had some type of publicly available evaluation for the period 2010 to 2014. On closer examination, however, only about half of these comprehensive efficiency programs had recent evaluations, and only 28 evaluations offered both robust, independent savings verification—chiefly through billing comparisons—and insight into the reasons for success of the programs. Appendix A is a list of those programs with links to their evaluations.

Many evaluations limited their approach to verifying adherence to Technical Reference Manual (TRM) protocols or an engineering review of the savings calculation methodologies rather than billing analyses. Evaluations with these narrower objectives did not offer much insight into the detailed nature of program savings or relationship of those savings to program design and implementation;[9] those evaluations were thus excluded from our review. Figure 1 illustrates this winnowing of programs and evaluations by availability, currency and relevance. Some evaluations encompassed statewide programs (e.g., CT, MA, and CA). Thus, the number of evaluations is somewhat lower than the number of evaluated programs.

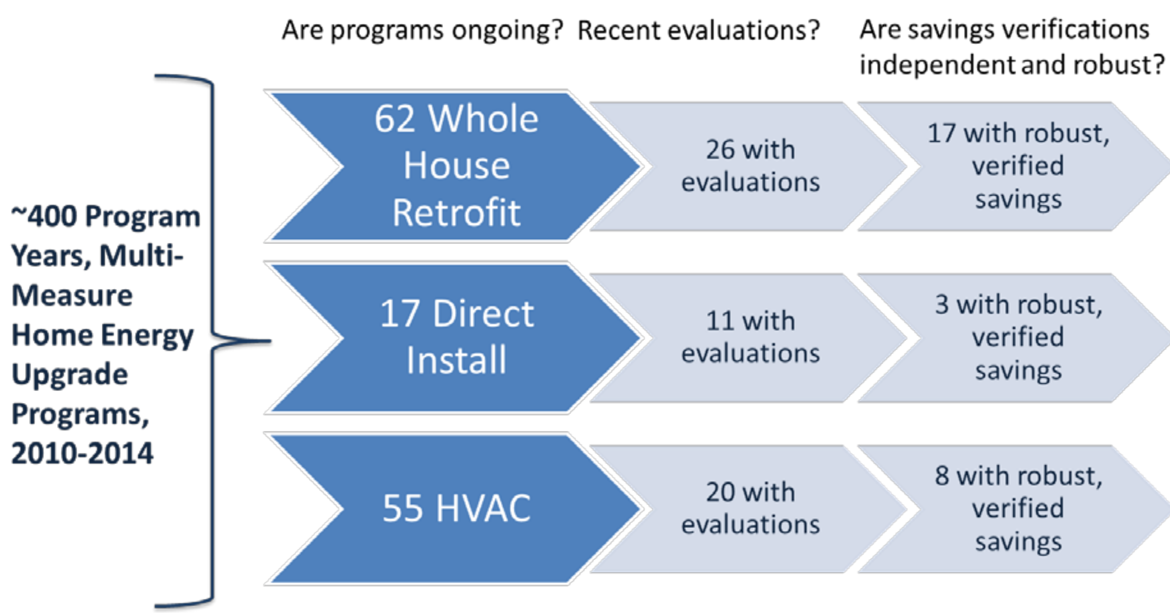

Figure 1. Identifying Programs With Sufficiently Rigorous Evaluations to Examine for Possible Elements of Program Models

The limited availability of comprehensive evaluations is frustrating but unsurprising for several reasons:

- Comprehensive evaluations can be complicated and costly, and producing viable billing data is often challenging.
- Limited evaluation resources are often focused on large-scale programs, such as those promoting efficient lighting or large commercial and industrial retrofits, that deliver a higher proportion of savings across a given efficiency program portfolio. Residential direct-install, HVAC, and whole-

[9] Billing analysis is important for accounting for interactive effects among measures. TRMs typically contain savings values for standalone measures and do not account for reduced savings attributable to the influence of other measures — e.g., lower heating savings due to the installation of more efficient electric end uses that reduce thermal waste in the home and can raise energy consumption for space heating. TRM values may therefore overestimate savings, and billing analysis thus becomes critical for quantifying actual savings.

house programs do not contribute the same level of savings to program portfolios and so are regarded as a lower priority for evaluation.

- Similarly, smaller programs may not provide a sufficient sample of projects for evaluators or, if a utility program administrator does not supply the primary heating fuel, often not a large enough share of savings to persuade regulators to prioritize spending on an evaluation.
- Evaluations are often narrowly focused on determining compliance with regulatory or statutory obligations. These obligations vary in definition and interpretation, and there is a corresponding variability in the ways in which evaluations are conducted.
- If evaluation contracts are administered by the PA that is being evaluated, critical perspectives may be softened despite the learning opportunities they present.
- PAs may be reluctant to share information critical of performance if doing so could cast a negative light on their program implementation.

We pored through these 28 most relevant evaluations to glean insights into successful program design for each of the three program types.

In the team's view, impact analyses aimed at verifying compliance with deemed values in a TRM, for example, may confirm that a program is meeting its regulatory obligations but do little to further our fundamental understanding of which program elements are critical in producing savings, whether those savings can be expected to last, and what, if anything, can be done differently to improve results. Evaluations with the necessary insight and rigor can take more time and money[10] and have limitations due to the availability and reliability of consumption and program data. Such evaluations are essential nonetheless to our understanding of the impacts of these programs and can provide high value in guiding more effective program implementation.

In the following sections we report several metrics for each program model:

- Spending per unit ($/home) – the average program administrator spending on each home, calculated as total program cost divided by the number of units retrofitted or replaced
- Spending per annual energy savings ($/MWh, $/therm) – total program administrator spending per unit of energy saved in the first year after retrofit or replacement
- Energy savings per unit (kWh/home, therms/home) – estimated average energy savings per home in the first year after retrofit or replacement
- Levelized program administrator cost of saved electricity – the cost of the program to the program administrator, levelized over the lifetime of the energy savings for the installed measures

To calculate a levelized cost of saved electricity, it was necessary to assess the lifetime of the energy savings. For several of the HVAC programs we studied, we were able to obtain measure lifetimes from the evaluations or TRMs in those states. None of the direct-install or whole-home retrofit program evaluations explicitly provided estimates of lifetime savings or average measure lifetimes, so a different approach was required. We drew average measure lifetimes from the same program types in the LBNL DSM Program Database. Because the direct-install and whole-home programs included in this study are full-featured and

[10] It can be difficult, especially without large sample sizes, to disentangle variability in estimates of measure savings or savings lifetimes from the relative influence of implementation approaches, quality of installation, and customer behavior.

target deep, long-lived savings, we took the average measure lifetimes for peer programs in the database with measure lifetimes above the median. See Table 1.

Table 1. Average Measure Lifetimes Assumed for Levelized Cost of Saved Electricity Analysis

Program Type	Program Average Measure Lifetime (years)	Source
Enhanced Direct-Install Retrofit	12.9	LBNL DSM Program Database
Enhanced HVAC Replacement (Central Air Conditioning)	15.3	Program evaluations and technical reference manuals used by the program administrator
Whole-Home Retrofit	17.4	LBNL DSM Program Database

The focus of this brief on challenging program types with rigorous, high-quality evaluations narrowed the field to programs aiming for deeper energy savings in mature markets where most low-cost energy savings have already been acquired. The costs per unit savings thus tends to be higher than other energy-saving initiatives, particularly in markets where energy efficiency programs are less mature.

We also report estimated reductions in emissions of select air pollutants for each model program. These reductions are both direct (e.g., lower emissions from direct combustion in a furnace or boiler) and indirect (lower emissions from electricity generators due to reduced load). To generate these estimates, air emissions expert John Shenot at the Regulatory Assistance Project (RAP) applied two commonly used grid operations and emissions modeling tools—EPA's AVoided Emissions and geneRation Tool (AVERT) and Emissions & Generation Resource Integrated Database (eGRID)—to project the annual impact of the energy savings on generator operations and emissions of three types of air pollutants—carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x)—in 10 U.S. regions. AVERT and eGRID are most useful in estimating emissions reductions in the near term, based upon the existing mix of generators in those 10 regions. In the medium to long term, however, avoided emissions could come from a new generating unit. The most common fossil generator planned for addition to the grid is the natural gas combined cycle (NGCC) plant. Thus, RAP included estimated reductions in emissions from an NGCC plant as a proxy for this future generator.

Because each of these three distinct methods has its strengths and limitations, and the accuracy of any of the methods will vary based on the details of the energy efficiency program and regions being analyzed, we provide the results for all three. Summary tables of estimated emissions reductions appear throughout the main text for each program type. For details on the methodology, see Appendix B in this brief.

Approaches to Program Models

1. Enhanced Residential Direct Install

Many PAs have implemented "direct install" programs in which program staff or contractors install inexpensive measures such as efficient lighting products, smart strips, and water conservation measures at no additional cost[11] to the customer. These programs provide assurance that the measures are installed, therefore savings are typically considered to be reliable. However, the types of low-cost measures that are typically installed only scratch the surface of the savings opportunities that exist in many homes.

To address this, some PAs have offered direct install programs that seek to provide greater savings through the addition of more comprehensive measures such as air sealing, duct sealing, or insulation. DOE sought to characterize a direct install program model along these lines—an "enhanced" program that would result in larger, more persistent savings than those typically achieved in residential direct install programs. Such a program can provide a high level of savings assurance for longer lived measures in addition to the shorter lived, low-cost measures that direct install programs typically focus on.

Because direct install programs specify the measures that they offer, they can be used to obtain savings in targeted end uses that provide specific programmatic benefits. For example, in cooling climates where peak electric use is driven by air conditioning, a direct install program can focus on obtaining cooling savings to reduce peak loads.

Direct install programs are also sometimes thought of as "on-ramps" to engage customers to conduct more comprehensive retrofit projects that may include whole-house insulation and air sealing or HVAC replacements. Most direct install programs include some type of assessment and "kitchen table" conversation with the customer. These conversations can be vehicles toward a customer path to greater efficiency, in some cases qualifying customers for progressive incentives—e.g., higher-tier rebates for shell and heating, ventilation and air conditioning equipment replacements that would deliver deeper, longer lasting savings. Indeed, failure to take advantage of this opportunity can make it less likely that participants will pursue subsequent efficiency projects. If the program does not actively try to engage customers to do more, there is a risk that they will "check energy efficiency off of their list" as a task that has been completed.

Direct install programs can require significant program incentives to obtain customer participation, making it critical that program costs are managed well in order to maintain cost effectiveness.

Factors Related to Success in Direct Install Programs

Evaluations of the following existing direct install (DI) programs provide examples of successful implementation practices:

- *Efficiency Maine's ARRA-funded direct install program* reached over 5,100 participants in a one-year period from July 2012 to June 2013. The program provided a $600 incentive for the completion of at least six hours of targeted air sealing and insulation work in conjunction with a home energy assessment.
- The *Connecticut Home Energy Savings Program (HES)* is a state-wide program that offered a $99 home energy assessment and direct-install lighting and air sealing, as well as additional incentives for the installation of more comprehensive measures such as shell improvements and HVAC upgrades. The program had over 21,000 participants in 2011. A recent evaluation of Connecticut's HES program looked closely at ways to increase per project savings. The report identifies steps the

[11] The measures are not technically free since customers pay energy efficiency charges on their electricity bills that fund the program. But unlike most other programs, participants are usually not asked to pay part of the cost of the direct-install measures for their homes.

program could take to ensure that air sealing and duct sealing projects capture more of the available savings opportunities while contractors are onsite installing measures. Importantly, the evaluation found that missed opportunities could be lessened not only through enhanced quality assurance, but also through structural changes in the program that could improve profitability and more closely align with the business needs of participating contractors.

- *PSE&G's Home Performance Direct Program* is offered to Long Island customers who have central air conditioning. The program provides a free home energy audit and air sealing and/or duct sealing, which is required for homes where site conditions allow it to be done. The program also offered up to 20 free CFL lamps per household in 2014 and served more than 2,200 customers.
- *Kentucky Power's Modified Energy Fitness Program* served 1,200 customers each year in 2012 and 2013. The program is available to customers that average at least 1,000 kWh per month. The program used an aggressive, targeted marketing approach to attract sufficient interest to meet its participation goals, and in addition to a home energy audit offered water conservation measures, weather stripping and caulking, duct sealing, and efficient lighting products.

The LBNL/EFG research team developed a program model based on the combined strengths of all of the programs reviewed. Where evaluations suggested areas for improvement in program operations we also addressed those in the program model. Characteristics of the resulting DI program model include the following:

- Capitalizes on significant opportunities for air sealing or duct sealing that could be combined with targeted insulation.
- Premised on one full day per job with priority given to air sealing so that obvious savings opportunities did not go untouched.
- Incentive is substantial enough to entice large numbers of customers to participate.
- Incentive set lower than 100% if upgrade is aligned with customer needs but may need to pay 100% if it isn't a customer priority.
- Effectiveness depends on contractors who do this full time, with dedicated crews who specialize in efficient project execution.
- A pre-visit walk-through may be useful to screen for health and safety problems.
- Program is most suited to a heating climate with older homes. Second best application is a cooling climate with high presence of central air conditioning.
- The program should have a strategic focus on engaging customers in follow-on projects.

Reported Program Costs and Savings

Two of the four programs for which cost and rigorously evaluated savings data were available focused solely on electric savings; a third focused on fossil fuel savings; and the fourth targeted both electricity and fossil fuel savings. Converting the reported savings to million British thermal units (MMBtu) for comparison purposes yielded a range of PA costs per MMBtu from $374 to $1,420. Program electricity savings ranged from 842 kilowatt-hours (kWh) to 1,222 kWh annually with Connecticut's dual-fuel HES program averaging 1,067 kWh and 58 therms annually. In MMBtu equivalents, the savings ranged from 2.87 to 9.44.

The total program cost per participating unit varied considerably among these four programs, as illustrated in Figure 2.

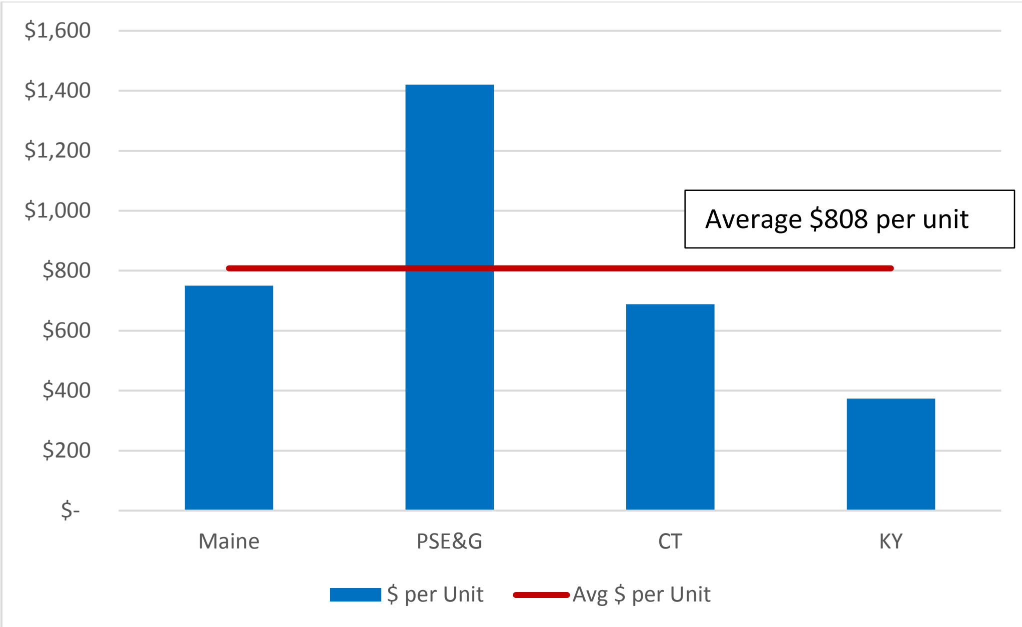

Figure 2. Evaluated Direct Install Cost per Home

The cost per unit of energy saved also varied, as Figure 3 illustrates for electricity.

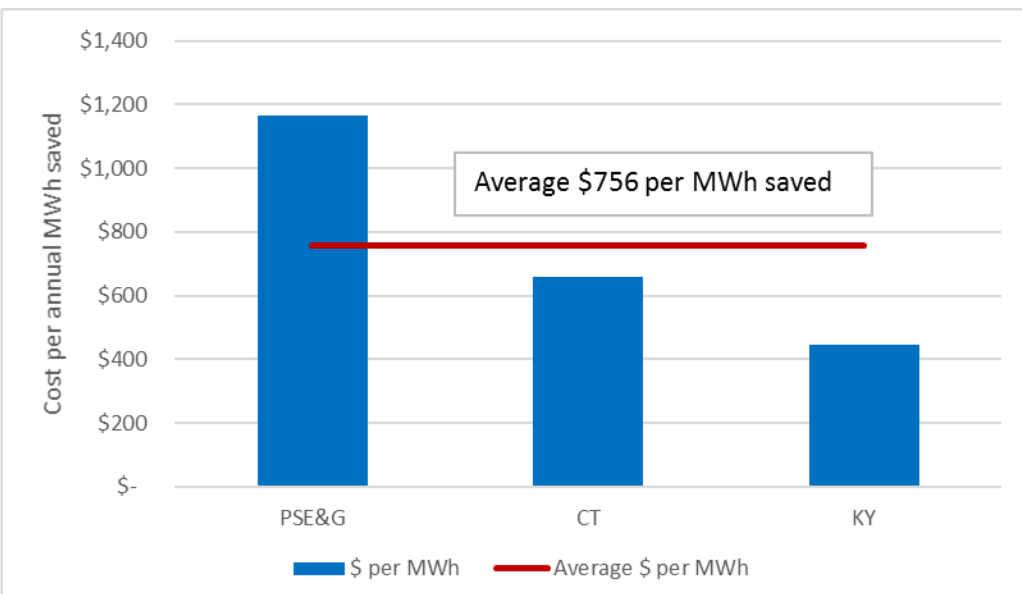

Figure 3. Evaluated Direct Install Cost per Annual Megawatt-Hour (MWh) Saved

The per-unit electric savings varied less than the cost per annual megawatt-hour (MWh) saved for the three programs that focused on electric savings, as Figure 4 shows. We also calculated a weighted average levelized program administrator cost of saved energy for the evaluated direct-install programs that we examined, using an average measure lifetime for similar programs from the LBNL DSM Program Database. The levelized program administrator cost of saved energy for the evaluated programs, weighted by their savings, was $0.08 per kilowatt-hour.

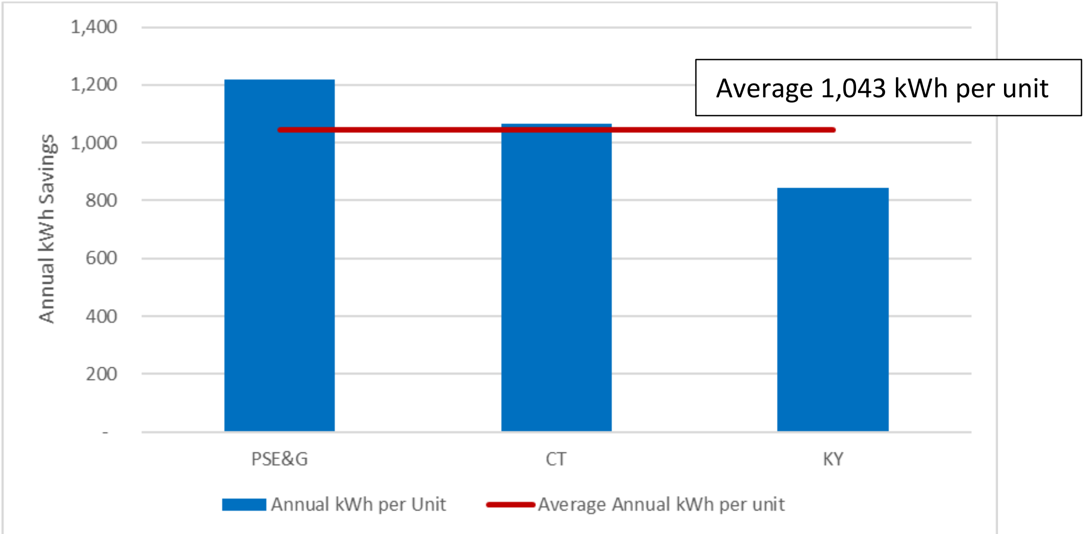

Figure 4. Evaluated Direct Install Annual kWh Saved per Home

Only two of the four programs that were reviewed reported non-electric savings, and as Figure 5 shows, the savings per participant also varied considerably.

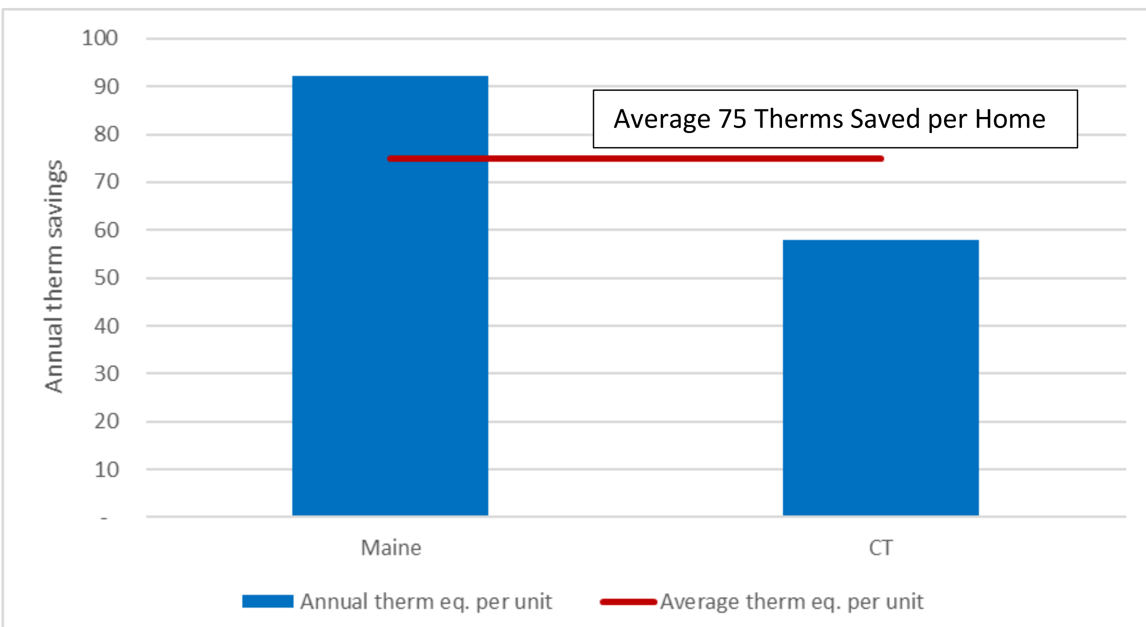

Figure 5. Evaluated Direct Install Annual Therms Saved per Home

Direct Install Program Model

The central tendencies for costs and savings among dual-fuel, direct install programs are reflected in Table 2. Costs for a single-fuel program would probably look different because of greater emphasis on, for example, electric measures and allocation of all costs to the electric program.

Table 2. Direct Install Program Model Costs and Savings (Dual-Fuel Program)

Units	Annual kWh per Unit	Annual Therms per Unit	$ per Unit	Total Annual MWh Saved	Total Annual Therms Saved	Annual Program Cost	$ per Annual MWh Saved	$ per Annual Therm Saved
2,000	800	60	$1,094	1,600	120,000	$2,187,600	$756	$8.15

Table 3. Annual Direct Avoided Emissions From Model Direct Install Program

Heat Source	Therms Saved	Natural Gas Results			Fuel Oil Results			Propane Results		
		CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)
Furnace	120,000	699	1,094	7	893	1,442	17	---	---	---
Boiler	120,000	699	1,164	7	893	1,602	17	785	1,633	7

Table 4. Annual Indirect Avoided Emissions From Model Direct Install Program

Region	Avoided Generation Considering Line Losses (MWh)	AVERT Results			eGRID Results			Proxy NGCC Results		
		CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)
California	1,698	800	800	100	865	597	474	934	1,189	0
Great Lakes/Mid-Atlantic	1,762	1,400	2,400	6,100	1,520	2,870	8,651	969	1,233	0
Lower Midwest	1,762	1,400	2,200	3,500	1,506	3,304	3,647	969	1,233	0
Northeast	1,762	900	1,100	1,100	1,005	1,312	2,255	969	1,233	0
Northwest	1,698	1,200	1,800	1,100	1,341	2,710	2,747	934	1,189	0
Rocky Mountains	1,698	1,400	2,700	1,200	1,417	3,791	2,572	934	1,189	0
Southeast	1,762	1,200	1,600	3,100	1,472	2,494	5,568	969	1,233	0
Southwest	1,698	1,000	1,500	1,100	1,049	1,750	552	934	1,189	0
Texas	1,721	1,100	1,100	2,300	1,102	1,248	3,494	947	1,205	0
Upper Midwest	1,762	1,500	2,400	4,100	1,698	4,223	8,599	969	1,233	0

2. Enhanced Residential HVAC

HVAC equipment uses a significant amount of energy in most homes, yet effectively addressing system and operational efficiency has been challenging. The incremental savings available from higher efficiency equipment are typically small, and the program administrator often must motivate distributors, contractors, and homeowners to change prevalent market practices. Influencing customers to replace functional equipment before it has reached the end of its useful life can provide greater savings, but this is not an easy task. Adding "quality installation and verification" (QIV) to a system replacement can increase savings, but this is not standard practice for many contractors and can be perceived as an obstacle to profitable business management. Improving the ducts used for distribution of conditioned air reduces energy use, but these added services can be challenging to sell to a customer already facing an expensive system replacement.

HVAC programs address potential "lost opportunities" by influencing customers to purchase efficient equipment at the time of replacement, thereby preventing inefficiencies that would persist for 10 to 20 years until the next replacement cycle. HVAC programs also address heating or cooling season demand issues by reducing peak loads. For simplicity, most HVAC programs focus on the nameplate efficiency of the equipment, providing rebates when customers make efficient equipment purchases. QIV program components may be offered on their own or as add-on program requirements to receive a rebate for the more efficient equipment itself. Most commonly, these add-ons include some combination of measuring airflow and refrigerant charge, proper equipment sizing, and duct sealing. In the interest of maximizing cost-effective savings, DOE has focused on HVAC programs that include some or all of these additional components and developed a program model that reflects this preference.

Factors Related to Success in HVAC Programs

Notable factors in success in HVAC program implementation include the following:

- *Focus on QIV.* Public Service Company of Colorado's (PSCo)[12] High Efficiency Air Conditioning program comprehensively addresses both equipment efficiency and QIV at the time of replacement. A thorough process evaluation conducted by Cadmus in 2012 referred to clear contractor participation requirements, including that contractors need to be registered with the program, complete a required certification course, pass an examination, and make a commitment to following the program's QIV guidelines. The evaluation also included a comparison of QIV practices with several other PAs and made recommendations for further improving the Colorado program.
- *Provide incentives to contractors.* Several programs, including the one administered by PSCo, provide incentives to customers for meeting participation criteria as well as to contractors for carrying out the required QIV practices and documentation. Because success in the HVAC program area is highly dependent on contractor participation, administrators of these programs concluded that providing supplemental compensation to the contractors in the form of incentives was required to secure their support and participation.
- *Collaborate across electric and gas utilities.* The Complete System Replacement program has been a collaborative program between ComEd and Nicor Gas, Peoples Gas, and Northshore Gas in Illinois. The program rewarded customers for installing a high efficiency gas furnace and high efficiency central air conditioner at the same time and achieved significant participation—over 11,000 customers in PY2013-14. The program did not address QIV but represents a successful model for dual-fuel collaboration that resulted in large participation numbers, significant customer savings, and benefits for both the electric and gas utilities. This collaboration is particularly notable because the cost effectiveness of both the electric and gas programs was improved by sharing administrative program costs, eliminating duplication.

While all these programs have a specific focus, such as central air conditioner or heat pump replacement, the success factors—dual-fuel coordination to reduce administrative costs, mandated use of registered

[12] A subsidiary of Xcel Energy.

contractors with QIV requirements, and financial incentives to contractors to elicit their participation—are broadly applicable.

Reported Program Costs and Savings

Few evaluations incorporating billing analysis are publicly available, and the results of those that are available do not easily transfer to other jurisdictions given the uniqueness of program offerings, climate zones, and local market conditions. This is true both for equipment-only programs and for programs incorporating QIV elements, where savings for three of the six evaluated programs ranged from 319 to 1,274 kWh/yr. Across all of the evaluated programs that were reviewed, the range in reported savings was even greater, as illustrated in Figure 6. Program administrators and evaluators differed in reporting savings as net or gross, both in annual reporting and in evaluations. These variations in reporting protocols and the mix of promoted measures make savings per home, as a metric, less helpful than desired. Savings also varied depending on whether equipment was being replaced on burnout or retired before the end of its useful life.

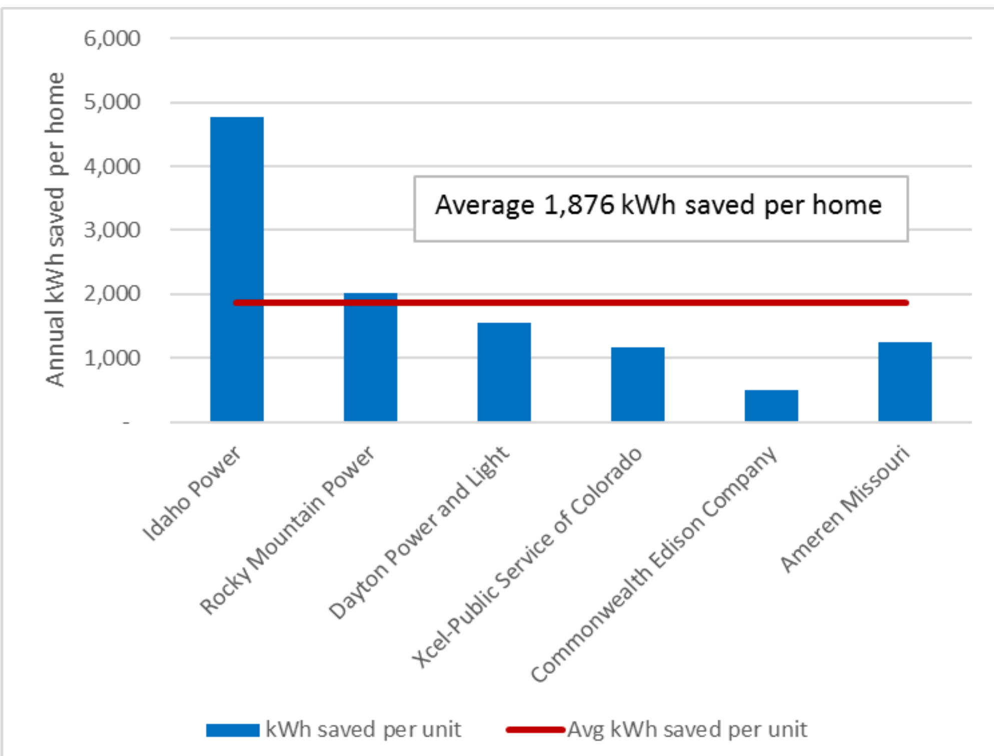

Figure 6. Evaluated HVAC Program kWh Saved per Home

Given the range in evaluated savings results, we attempted to determine whether a relationship could be observed between reported savings and the severity of the cooling climates in which the programs were operated. While this preliminary analysis only used state-level Cooling Degree Day (CDD) data,[13] the data in Table 5 are sufficient to show that weather-normalizing the various program results would not resolve the significant variation in savings results, as seen in the column "kWh saved per CDD." The results are grouped by the types of measures promoted so that the program focus is as similar as possible.

[13] We compared programs based on cooling degree days, not heating degree days, because the majority of programs were primarily air conditioning-focused.

Table 5. Evaluated HVAC Program kWh Saved per Cooling Degree Day

State	PA	Year	Measure	Measure type	Gross evaluated savings per unit	2013 CDD	kWh saved per CDD	QIV?
EARLY RETIREMENT								
OH	Dayton P & L	2014	AC 14/15 SEER	Early retirement	1,089	811	1.34	N
OH	Dayton P & L	2014	AC 16+ SEER	Early retirement	1,246	811	1.54	N
IL	Com Ed	6/2013-5/2014	AC 14.5+ SEER	Early retirement	634	849	0.75	N
CT	CT HES	2011-13	AC 14.5+ SEER	Early retirement	391	722	0.54	Req'd for financing
MO	Ameren	2013	AC SEER 14-16	Early retirement	1,822	1,182	1.54	Optional -additional incentive
				Average	**1,036**	**875**	**1.14**	
QUALITY INSTALLATION AND VERIFICATION								
CA	SCE	2010-2012	QIV	QIV				
UT	Rocky Mntn Pwr	2011-12	Sizing + TXV	QIV	239	970	0.25	
UT	Rocky Mntn Pwr	2011-12	Proper Installation	QIV	80	970	0.08	
			UT-Total for sizing, TXV, proper install		**319**			
SC	SC Electric & Gas	2013	System Optimizer	QIV	497	1,680	0.30	
SC	SC Electric & Gas	2013	Duct insulation	QIV	505	1,680	0.30	
SC	SC Electric & Gas	2013	Duct sealing	QIV	1,489	1,680	0.89	
SC	SC Electric & Gas	2013	Duct replacement	QIV	1,337	1,680	0.80	
		SC- System Optimizer only-Doesn't include duct treatment			**497**			
MO	Ameren Missouri	2013	HVAC Condenser cleaning	QIV	230	1,182	0.19	
MO	Ameren Missouri	2013	HVAC Refrigerant charge	QIV	687	1,182	0.58	
MO	Ameren Missouri	2013	HVAC Evaporator cleaning	QIV	183	1,182	0.15	
MO	Ameren Missouri	2013	HVAC Gen'l Maintenance	QIV	174	1,182	0.15	
		MO- Total cleaning, refrigerant charge, Gen'l Maintenance			**1,274**			
REPLACE ON BURNOUT								
OH	Dayton Power and Light	2014	RP AC 14/15 SEER	Replace on Burnout	196	811	0.24	N
IL	Com Ed CSR	6/2013-5/2015	RP CAC 14.5+ SEER	Replace on Burnout	197	849	0.23	N
CT	CT HES	2011-13	RP CAC 14.5+ SEER	Replace on Burnout	148	722	0.21	QIV req'd for financing
UT	Rocky Mountain Power	2011-14	15+SEER	Replace on Burnout	341	970	0.35	Optional- additional incentive
SC	South Carolina Electric & Gas	2013	All CAC	Replace on Burnout	247	1,680	0.15	N
NY	Con Edison	2009-11	CAC-all	Replace on Burnout	302	644	0.47	N
MO	Ameren Missouri	2013	CAC RP SEER 14-16	Replace on Burnout	364	1,182	0.31	Optional- additional incentive
				Average	**256**	**980**	**0.28**	

Cooling degree days are annual cumulative by state for 2013 from:
ftp://ftp.cpc.ncep.noaa.gov/htdocs/degree_days/weighted/legacy_files/cooling/statesCONUS/2013/December.txt

Participation levels and overall costs of these programs also varied considerably, at least in part because the mix of measures promoted differed from program to program. Some programs only addressed heat pumps while others also addressed central air conditioning, furnace blower fan motors, or thermostats. In some cases, such as with Connecticut's HES program, building shell and HVAC measures are included within a single program budget, making it difficult to dissect the costs and benefits related only to the HVAC component. Similarly, a significant portion of spending on South Carolina Electric and Gas' Heating and Cooling and Water Heating program is devoted to water heaters. Among the limited set of programs where data were available, the costs and savings varied significantly, with program costs per participant ranging from $247 to $1,514, as Figure 7 shows.

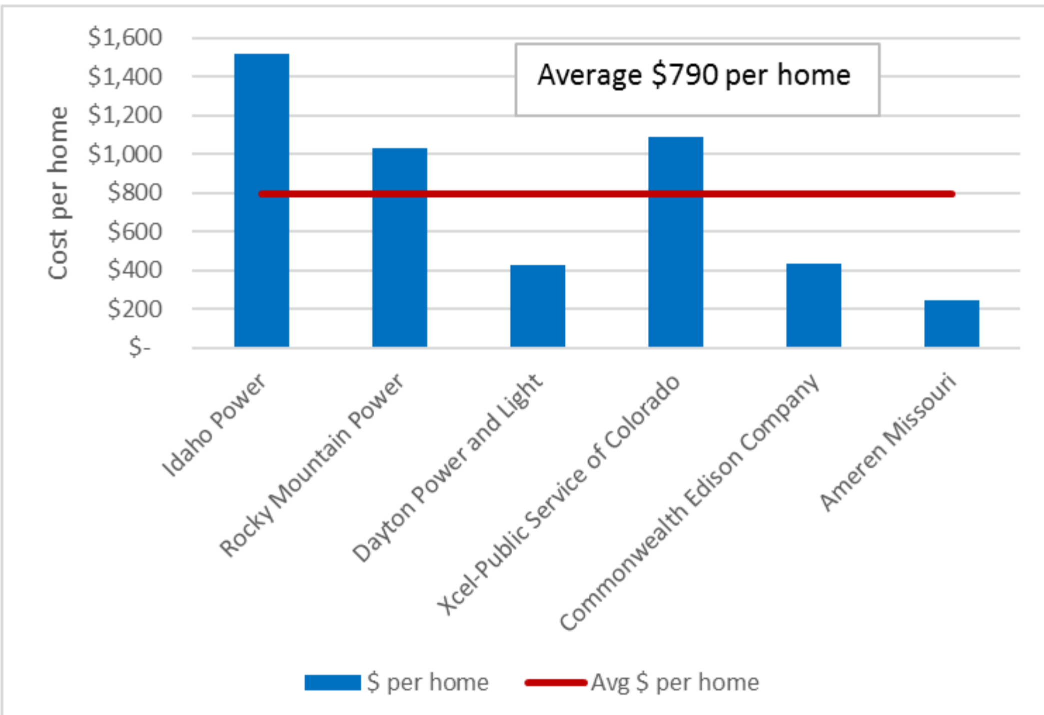

Figure 7. Evaluated HVAC Cost per Participant

Not surprisingly, there was a significant range in the cost per first-year MWh saved based on the evaluated data from these programs, as Figure 8 shows. The levelized program administrator cost of saved electricity for the evaluated programs, weighted by their savings, was $0.04/kWh.

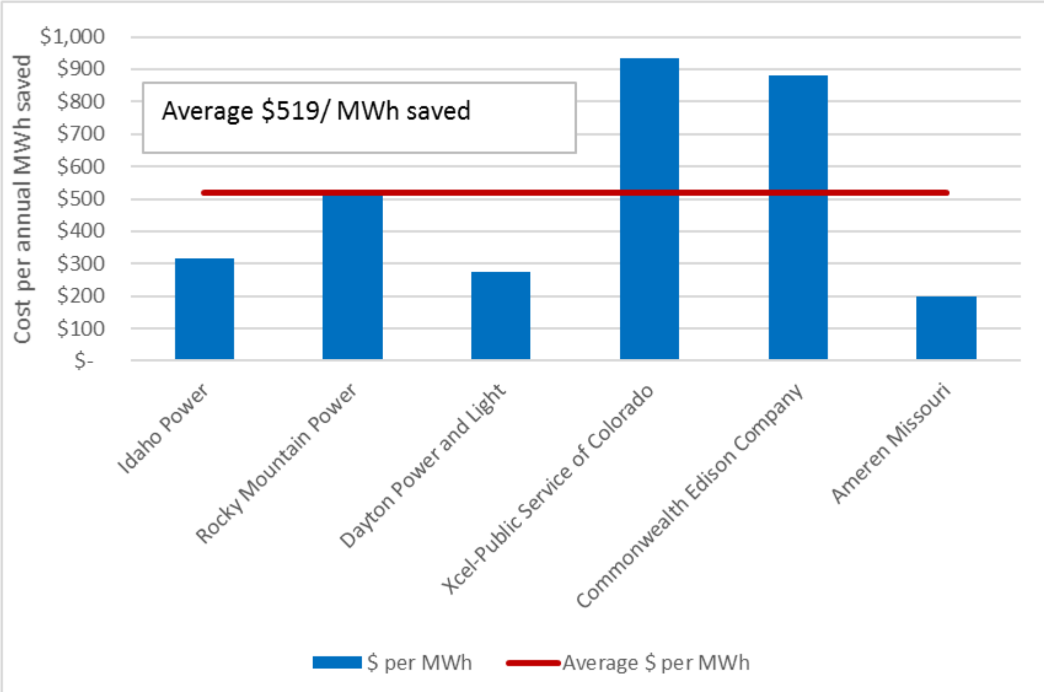

Figure 8. Evaluated HVAC Program Cost per Annual MWh Saved

Given these data constraints, we simplified our projections for a program model by choosing conservative values from the impact evaluation data. Analysis of savings potential for programs similar to the HVAC program model presented here would need to be conducted to reflect local conditions in order to estimate the potential benefits.

Model HVAC Program

Building on the success factors outlined above and savings documented in impact evaluations, we propose the following characteristics for a model HVAC program:

- *Consider early equipment retirement to increase savings.* HVAC equipment programs are premised on increasing the efficiency of replace-on-burnout equipment purchases, as this approach dovetails with the equipment failures that bring most participants into the program. But the same platform can be used to engage customers who may be well served by early retirement of existing equipment. Connecticut's HES program and Colorado's High Efficiency Air Conditioning program, among others, offer an additional incentive to motivate customers to "retire" equipment that is still functioning.[14]
- *Provide on-ramps for less experienced markets.* The equipment efficiency may be tiered or set at the highest efficiency level that is reliable and widely available depending on the maturity of the market, the range of efficiencies available for specific equipment, and the cost-effectiveness of different equipment options. In general, it makes sense to promote the highest efficiency that is cost effective, but in markets that are less experienced with energy efficiency, it can make sense to offer an "on-ramp" to the program by promoting cost-effective equipment that is not rated at the highest levels of efficiency. For example, Dayton Power and Light offered one rebate level for central air conditioning equipment with a SEER of 14-15 and a higher rebate for equipment with a SEER of 16+.

[14] Note that early retirement programs may require extra care in documentation and billing analysis in order to ensure the savings are real — i.e., that replaced units actually were operable at the time of replacement.

- *Contractors meet quality installation and verification requirements.* QIV should be required and incentives made available only to participants who use a registered contractor who has committed to meeting the required installation protocols. By adhering to installation standards and offering incentives for quality installation, energy efficiency programs can play a role in leveling the playing field for quality-minded contractors so that they are not forced to compete on price alone. Unfortunately, evaluated program savings consider many factors based on local regulatory requirements and do not necessarily show more savings for programs requiring QIV compared with those that do not. However, there is wide agreement within the industry that QIV improves system performance and reduces energy use, and that incorporating these requirements is a tool that program administrators can use to help drive transformation of the market to adopt these best practices more broadly. PSCo has clear eligibility requirements for contractors to ensure that equipment is installed to deliver the efficiency that the nominal ratings suggest. Note also the importance of regularly performing quality control to assure that contractors are meeting quality standards, and working with them to improve quality where it is deficient—and if it is not possible for them to meet program requirements, ultimately rescinding their eligibility to offer program services.
- *Train contractors in required installation practices.* The program will provide or support training as required to assure that contractors have the information they need to meet the requirements. Energy efficiency programs that support the development of a regional trade ally network can benefit both from near term increases in program participation and from long term transformation to more efficiency in standard installation and maintenance practices. The PSCo program, with its rigorous participation requirements, serves as a strong example among the programs we reviewed. A 2012 evaluation of the program conducted trade ally surveys and found that "…two-thirds of participating trade allies reported that they changed their standard CAC installation practices based on what they learned from the QI training required for becoming an Xcel Energy registered program contractor" (Cadmus 2012).

The values in Table 6 represent the central tendency of the enhanced HVAC programs that focused on central air conditioning as the primary measure and robustly verified savings.

Table 6. Model Enhanced HVAC Program Costs and Savings

Units	Annual kWh per Unit	Annual Therms per Unit	$ per Unit	Total Annual MWh Saved	Total Annual Therms Saved	Annual Program Cost	$ per Annual MWh Saved	$ per Annual Therm Saved
2,000	1,150	-	$1,070	2,300	-	$2,139,000	$930	-

Table 7 Annual Indirect Avoided Emissions From Model Enhanced HVAC Program

Region*	Avoided Generation Considering Line Losses (MWh)	AVERT Results			eGRID Results			Proxy NGCC Results		
		CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)
California	2,441	1,200	1,200	200	1,244	858	681	1,343	1,709	0
Southeast	2,532	1,700	2,400	4,400	2,115	3,584	8,001	1,393	1,772	0
Southwest	2,441	1,400	2,100	1,500	1,509	2,516	794	1,343	1,709	0
Texas	2,474	1,600	1,600	3,400	1,584	1,793	5,022	1,361	1,732	0

*Note: The design of the Enhanced HVAC model program was limited to replacement/early retirement of an AC unit only. So the savings here are limited to indirect savings (electricity savings, rather than energy savings from direct combustion of fuels) and limited to regions where AC-only programs are likeliest to be found.

3. Whole-Home Energy Upgrade Program Model

Comprehensive or "whole-home" energy upgrade programs, aimed at multiple end uses and systems, have been implemented by PAs across North America. These programs are designed to maximize the installation of energy efficiency measures in existing homes while also addressing building durability and occupant health and safety.

Program administrators and contractors face widely recognized barriers to increasing the number of retrofits from these programs:

- Audit-to-retrofit conversion rates are often low.
- Whole-home upgrades can be expensive – exceeding $15,000 in some territories.
- Lags between energy assessment and installation are common. It can be tough to keep customers engaged from the initial lead to an energy assessment all the way to retrofit.
- Installations are often not as comprehensive as the program administrator and contractors might like. Savings often are left on the table.
- Transactions cost per unit savings are often higher than with other programs.
- Accurate modeling of savings can be elusive but is critical.

Many of these programs have been based on the DOE's Home Performance with ENERGY STAR program model, which provides guidelines for targeting multiple savings opportunities across all fuels, as well as technical performance, and quality assurance. Other programs were developed to best suit the regulatory structures within which the PA works. DOE sought to identify successful programs that achieve these goals in a single engagement with the customer or by engaging with customers in a sustained manner that allows for comprehensive retrofits to be staged over a period of years. In either case, the program goal is to maximize the adoption of cost-effective energy efficiency in each participating home, across all end uses and fuels.

Unfortunately, the LBNL/EFG study team found relatively few impact evaluations of comprehensive energy upgrade programs that employ billing analysis to determine the energy saving impacts of these programs. The lack of data limits confidence in the savings and identification of design elements associated with those impacts.

Factors Related to Success in Whole-House Energy Upgrade Programs

Notable examples of whole-house energy upgrade program implementation include the following:

- *Provide high levels of customer support.* The evaluators for Eversource Energy's Home Performance with ENERGY STAR program in New Hampshire commented that the significant levels of customer support provided by the program through the upgrade process contributed to program success. This practice is similar to the support provided by Home Energy Advisors under the Better Buildings Neighborhood Program (Billingsley 2016). New Hampshire's program also reported unusually high conversion rates for Eversource in New Hampshire and for Unitil—on the order of 80% to 95%. This is attributed to a "Home Heating Index" screening process to pre-qualify candidates who are higher energy consumers and thus likely to have savings opportunities. Entergy Arkansas also incorporated program elements into its program design to increase the focus on homes with higher savings potential beginning in 2014, providing a larger incentive for assessments for larger homes and adding a tiered bonus incentive structure that increases as more measures are installed.

- *Go beyond single-fuel measures.* Programs addressing multiple fuels, such as those administered by Efficiency Vermont and Ameren Illinois, seem to save more energy overall than do programs that are limited to single-fuel measures. This makes sense, as programs that take advantage of all savings opportunities have more potential savings to capture. It would also make sense for these programs to have lower transaction costs per unit of savings, though it was not possible to determine if this was the case based on the available data.
- *Engage customers at the start and capture immediate savings.* Numerous programs provide opportunities for vendors who conduct energy use assessments to also directly install lighting and hot water conservation measures at no additional cost to customers. This approach can engage the customer with immediate energy savings and allow program administrators to claim savings for measures in homes that receive assessments regardless of whether those customers eventually install more comprehensive retrofit measures. However, it is critical that vendors not leave customers with the impression that by accepting the direct install measures, they can check energy efficiency off their list of priorities. Among the programs the study team reviewed that provide no-cost, direct install measures are Entergy Arkansas, Energize Connecticut, Commonwealth Edison, Efficiency Vermont, Ameren Illinois, MassSave, and EmPOWER Maryland.
- *Give a bonus for going deeper.* Numerous PAs offer tiered or bonus incentive structures that provide greater rewards for projects that save more energy. For example, Wisconsin's 2013 Focus on Energy Home Performance with ENERGY STAR program provided incentives of 33% of the measure cost, up to $1,250, but also offered a $250 bonus incentive for projects that achieved 25% or greater energy savings. Austin Energy also offered a "Home Performance Bonus Rebate" of between $250-$500 to customers who install a qualifying new air conditioner or heat pump and also install certain weatherization measures. Efficiency Vermont offered a $250 "Comprehensive Retrofit Bonus Package" to customers who achieved at least a 35% air leakage reduction and installed insulation such that the total area of insulation installed is equal to or greater than 75% of the home's finished floor area (e.g., a 2,000 square foot home would need to install at least 1,500 square feet of insulation in walls or ceilings). One conclusion that we draw is that, while programs that pay meager incentives are unlikely to get much uptake, rich or full-cost incentives are not always necessary for a successful program. What does seem important is whether customers consider the project to be a "good deal."
- *Upgrade or replace HVAC systems.* Significant savings opportunities may also exist for cost-effective HVAC improvements and replacements within home upgrade programs. Austin Energy achieved an average of 22% savings per home in its Home Performance with ENERGY STAR program in which 56% of participants installed HVAC measures. Heat pump installations was one of the predominant measures in BC Hydro's 2009-2011 program that saved electricity at a cost of $0.34 per first-year kWh.

Reported Program Costs and Savings

We focused on identifying programs with evaluations to verify participants' energy savings, but evaluations used several different methods to verify savings based on the availability of data, needs of the regulatory jurisdiction, and budgets. It thus was difficult to correlate results across programs. This challenge in turn made it difficult to use these results as predictors of what other programs might be able to achieve. For instance, per unit savings ranged from just under 500 kWh to nearly 3,000 kWh annually—even with outliers removed—as Figure 9 shows.

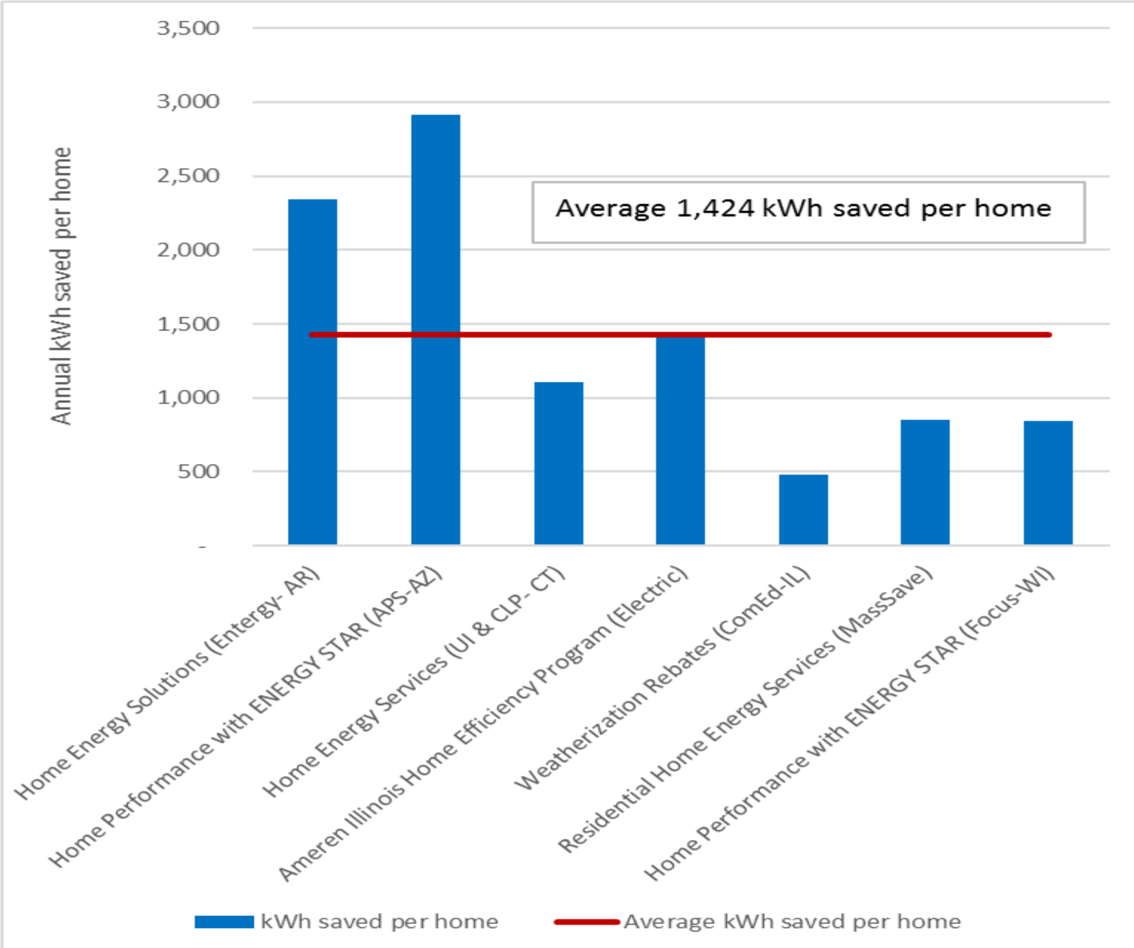

Figure 9. Evaluated Whole House Programs - Annual kWh Saved per Home

For natural gas programs the range in evaluated savings was also significant, as Figure 10 illustrates.

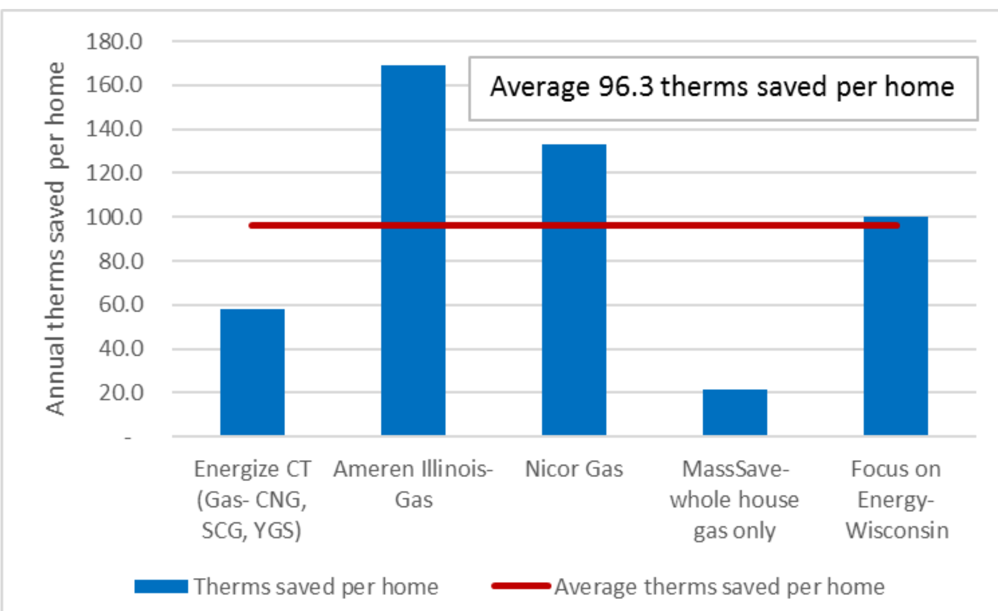

Figure 10. Evaluated Whole-House Programs - Annual Therms Saved per Home

The findings were often limited by the data available to the evaluators. Despite our best efforts, piecing together evaluated savings, participation, and costs for consistent time frames, even for individual programs, proved difficult. We strove to identify average savings by project for each program where data were sufficient, as well as provide average costs for those projects and, by extension, the average cost per MWh, therm, or MMBtu saved. Due to limitations in the available data, we had mixed success. Not surprisingly, the cost per annual MWh saved also varied across programs, as Figure 11 demonstrates.

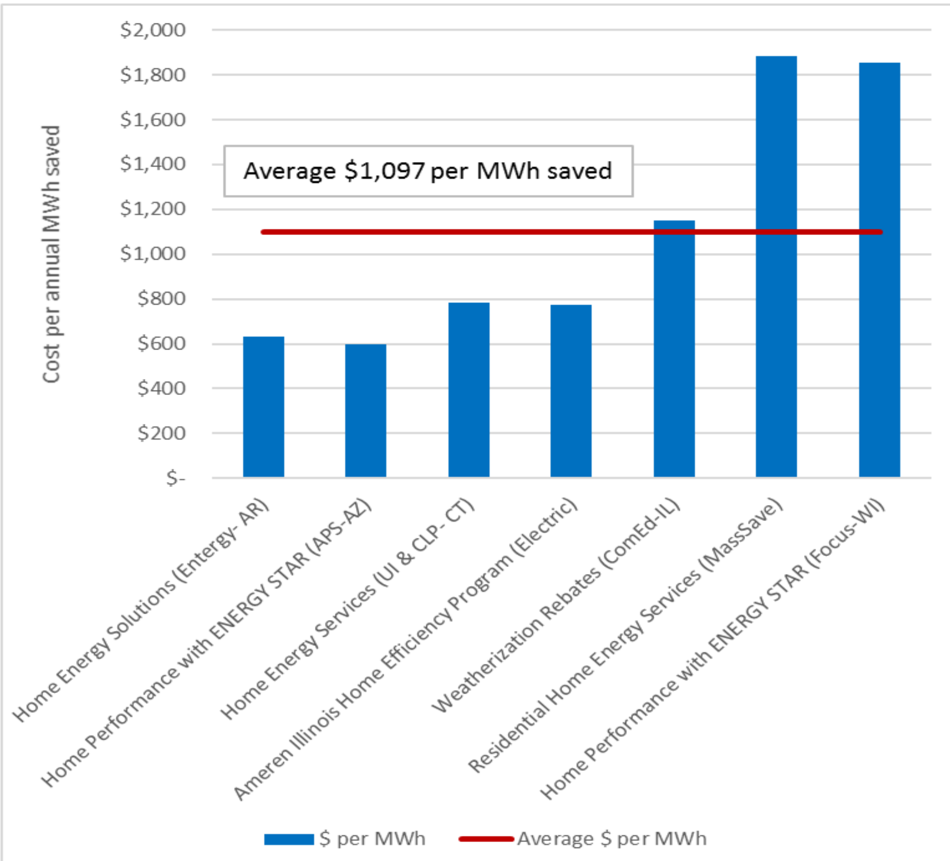

Figure 11. Evaluated Whole-House Programs - Cost per Annual MWh Saved

The levelized program administrator cost of saved electricity for the evaluated programs, weighted by savings, was $0.11/kWh.

As a comparison to the evaluated program data, we also looked at a larger set of *reported* (but usually not yet evaluated) whole-house retrofit program data that LBNL collected from annual reports. As with evaluated program data reviewed for this report, the range in reported cost per first-year MWh saved for whole-house programs in LBNL's DSM Program Database is large, but the average values for evaluated versus reported program cost per first-year MWh are relatively close ($1,097 versus $1,160 per MWh saved), as Figure 12 shows.

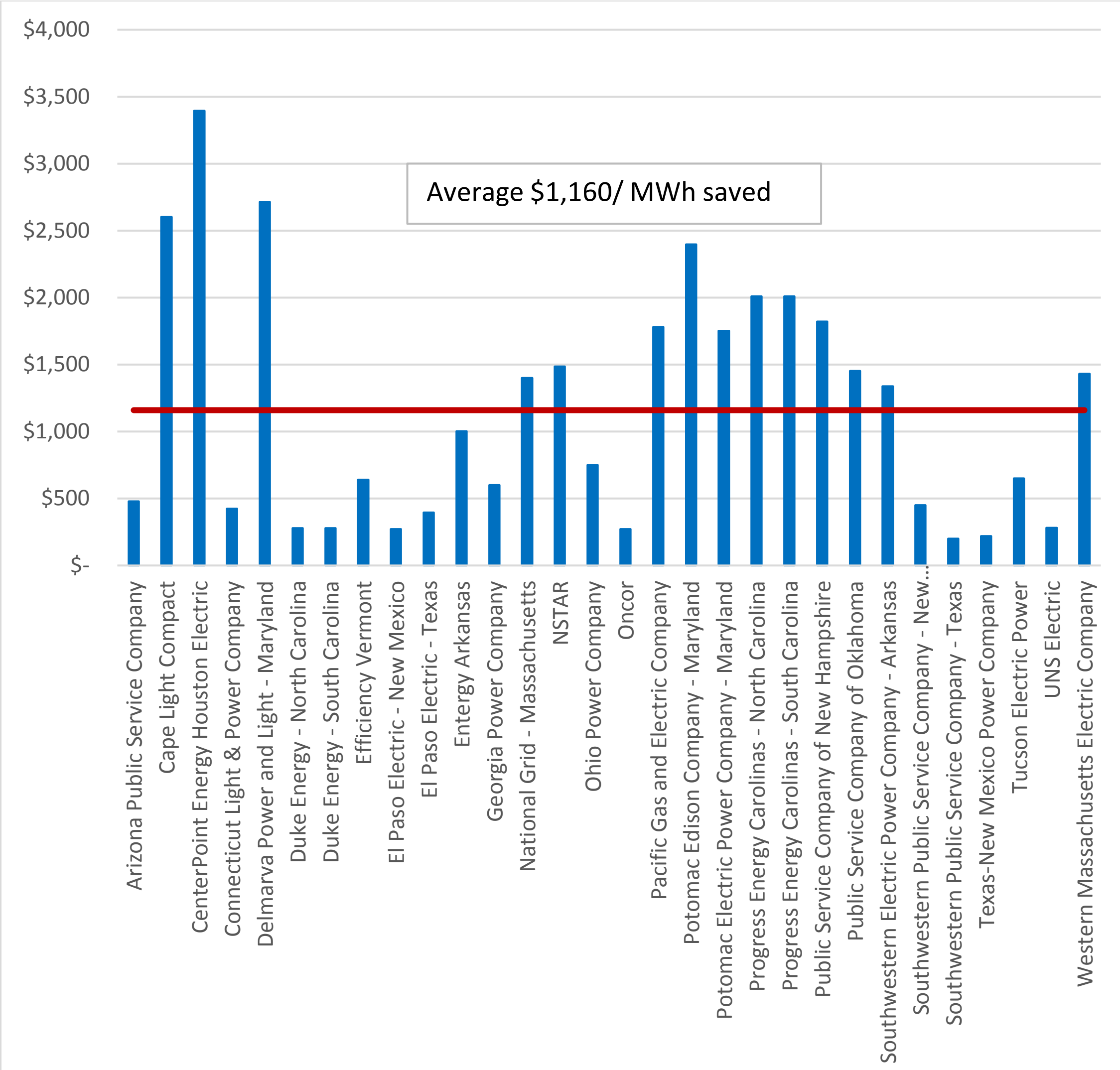

Figure 12. Whole-House Programs in LBNL's DSM Program Database - Average Cost per MWh Saved: 2012-2014

For evaluated whole-house programs that address natural gas efficiency, the average cost per therm saved was just under $9, as Figure 13 shows.

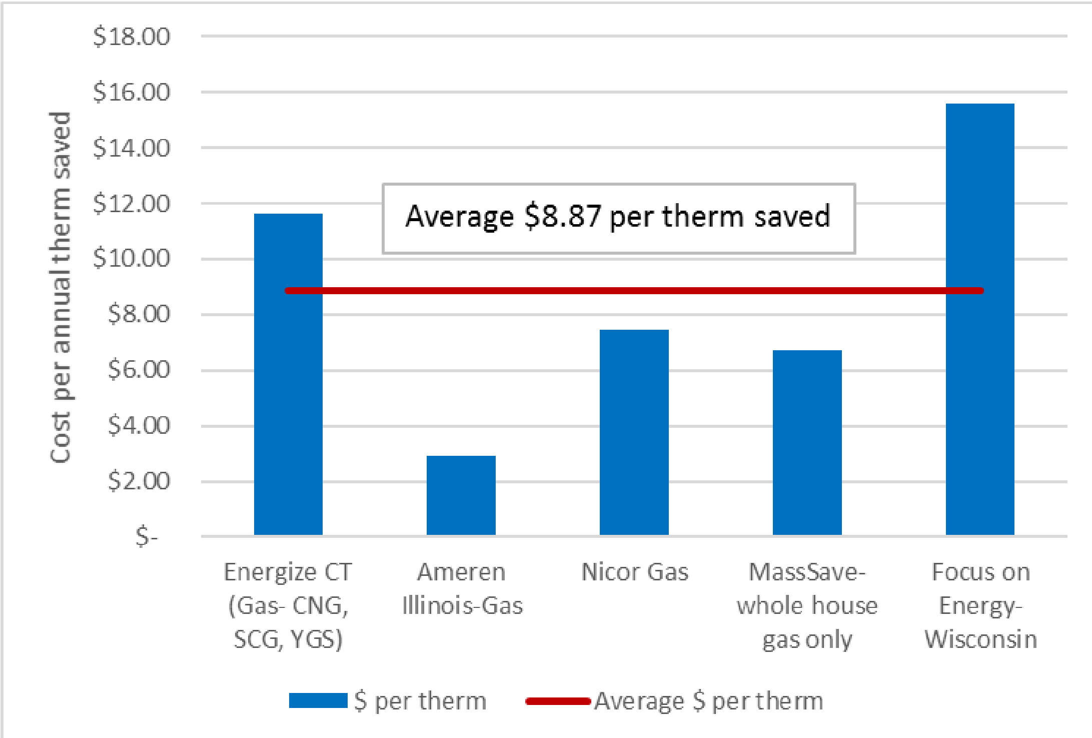

Figure 13. Evaluated Whole-House Programs - Cost per Annual Therm Saved

As was the case for electricity savings, the average reported cost of natural gas savings for a larger set of programs in LBNL's database was similar to the average cost evaluated programs reviewed for this report ($8.87 versus $9.56 per therm saved), as Figure 14 demonstrates.

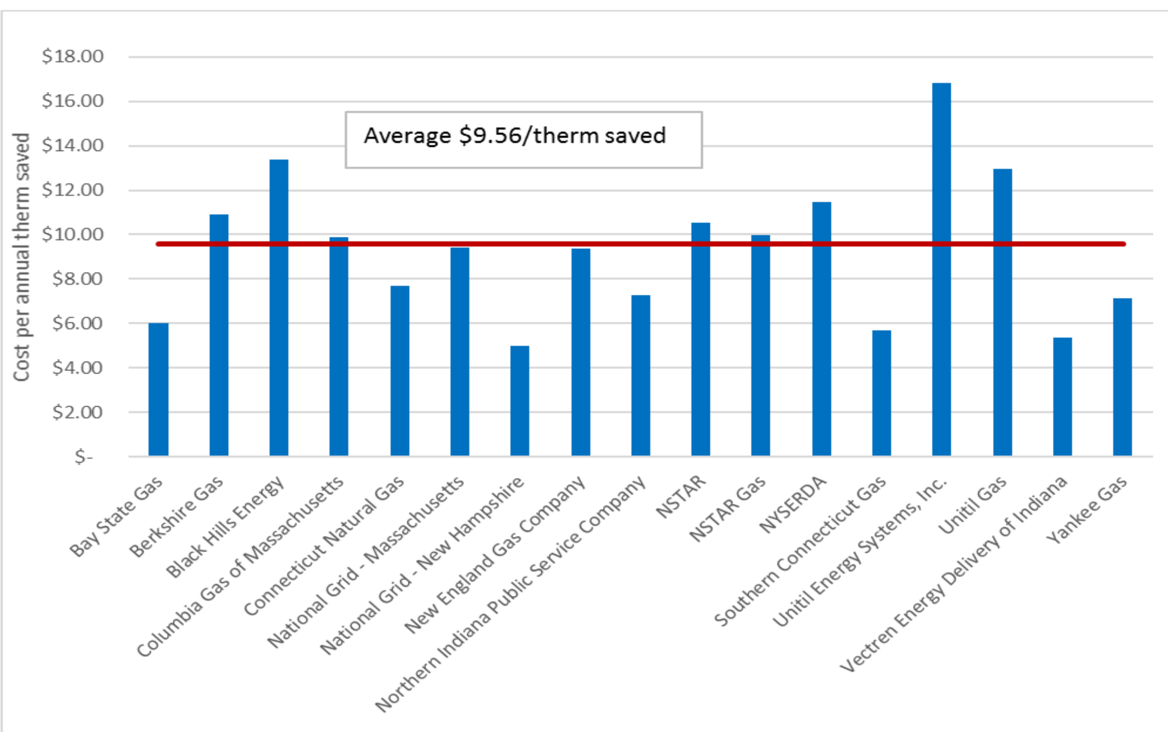

Figure 14. Whole-House Programs in LBNL's DSM Program Database - Average Cost per Therm Saved: 2009-2014

Whole House Energy Upgrade Program Model

Based on the observations above, we propose these key facets of a multi-measure, whole-house energy upgrade program:

- Pre-screening eligible homes for high energy use and thus high savings potential.
- Packaging audits with direct installations of no-cost lighting and hot water measures for immediate savings that can be counted even if the customer does not opt for more.
- Aligning the program with contractor business needs by streamlining contractor time spent reporting to program and collecting payment.
- Awarding of tiered or bonus incentives, scaling with more measures or a bonus for certain savings thresholds (e.g., $250 more if >20%).
- Improved audit-to-retrofit conversion rates through high levels of customer support during lags between energy assessment and installation.
- Enhanced quality assurance *while contractor is onsite* to ensure no missed opportunities (e.g., complete, high quality duct and air sealing).
- Take advantage of all cost-effective savings opportunities and target multiple-fuel savings to lower the transaction cost per unit of savings.
- Go beyond shell, lighting and appliance measures to make HVAC improvements and replacements a priority.

The values in Table 8 represent the central tendency of the cost and savings values for programs that we reviewed with robustly verified savings, assuming a dual-fuel approach.

Table 8. Model Comprehensive Home Energy Upgrade Program Savings and Costs

Units	Annual kWh per Unit	Annual Therms per Unit	$ per Unit	Total Annual MWh Saved	Total Annual Therms Saved	Annual Program Cost	$ per Annual MWh Saved	$ per Annual Therm Saved
2,000	1,424	96	$2,418	2,848	192,000	$4,835,840	$1,100	$8.87

Table 9. Annual Direct Avoided Emissions From Model Home Energy Upgrade Program

Heat Source	Therms Saved	Natural Gas Results			Fuel Oil Results			Propane Results		
		CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)
Furnace	192,000	1,118	1,751	11	1,429	2,307	28	---	---	---
Boiler	192,000	1,118	1,863	11	1,429	2,563	28	1,256	2,613	11

Table 10. Annual Indirect Avoided Emissions From Model Home Energy Upgrade Program

Region	Avoided Generation Considering Line Losses (MWh)	AVERT Results			eGRID Results			Proxy NGCC Results		
		CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)
California	3,022	1,500	1,500	200	1,540	1,062	843	1,662	2,115	0
Great Lakes/Mid-Atlantic	3,136	2,500	4,300	10,800	2,705	5,108	15,398	1,725	2,195	0
Lower Midwest	3,136	2,600	3,900	6,200	2,680	5,880	6,492	1,725	2,195	0
Northeast	3,136	1,700	1,900	1,900	1,790	2,336	4,014	1,725	2,195	0
Northwest	3,022	2,200	3,300	1,900	2,386	4,823	4,889	1,662	2,115	0
Rocky Mountains	3,022	2,500	4,800	2,100	2,523	6,748	4,577	1,662	2,115	0
Southeast	3,136	2,200	3,000	5,500	2,620	4,439	9,910	1,725	2,195	0
Southwest	3,022	1,800	2,600	1,900	1,868	3,115	983	1,662	2,115	0
Texas	3,063	2,000	2,000	4,200	1,961	2,220	6,218	1,685	2,144	0
Upper Midwest	3,136	2,700	4,300	7,300	3,022	7,516	15,304	1,725	2,195	0

Limitations to Application of the Analysis

When it comes to residential efficiency programs, one size—or design—does not fit all. No program model can, or necessarily should, be applied universally. Every territory has its own unique housing, end-use and equipment stocks, as well as other market and economic conditions. Further, the samples of evaluations that met our requirement for robustly verified savings for each program type were small. Therefore, a program administrator should temper any expectations that their implementation of the program models will have the same cost and savings profile as the models described here.

At least two of the three program types explored here—the Enhanced HVAC and Whole-Home Retrofit programs—can be challenging to implement. All three program models further will look more expensive than peers because the underlying programs are operating mostly in mature markets, the savings are not based upon deemed values but bill comparison or measurement and in several cases the savings are reported net of free ridership. These programs therefore tend to have a higher cost per unit savings than programs in relatively new markets and using deemed savings estimates.

For lack of data, we also cannot offer any observations on an important aspect of program and portfolio implementation—namely, how a program fits or interacts with other program offerings. Ideally, possible participants for the Enhanced HVAC and Whole-Home Retrofit programs who are income-eligible for low-income weatherization would be referred to that program. Further, those who show interest in saving energy or reducing bill charges but choose not to undertake these multi-measure programs would be referred to programs that promote single measures such as efficient lighting or appliances. The evaluations did not estimate effort or savings from these referrals, so these program features are not treated here.

Program administrators interviewed for this brief nonetheless emphasized the value of offering a spectrum of energy efficiency services and using programs such as the models offered here as gateways to other efficiency pathways.

Significantly, the program models are derived from evaluations of programs in earlier years and therefore are backward looking. Promising new program features and models are expanding the menu of successful design options. For example, financing is becoming prevalent in HVAC and whole-home program types, and anecdotal evidence from contractors indicates that attractive financing is a critical sales tool. But we did not find evaluations that clearly demonstrated additionality, meaning that financing was linked to additional sales or savings. Innovations such as use of HPXML as a project and program data specification clearly are winning converts among PAs and contractors, by streamlining project approvals, tracking and program reporting. HPXML is a fairly recent innovation in program process improvement, and we did not find evaluations that clearly linked HPXML to increased program savings or economy. These and other emergent program features bear watching and should be assessed by program planners as new programs are being developed.

Some "programs" such as pay-for-performance solicitations[15] are not really programs in the traditional sense but transactional platforms that set a price for energy and capacity savings and let market actors define their own means of acquiring savings.

The three program types we reviewed for this report are often not sharply defined from one another and don't necessarily need to be. In many territories, whole home and direct install programs and sometimes enhanced HVAC programs form a continuum of services offered under the umbrella of a single program: A contractor installs simple low-cost measures while conducting an audit to identify larger savings opportunities, of which the customer may choose a system replacement or a broader array of measures spanning the entire home. The challenge for the program administrator is orchestrating and coordinating these offerings and enabling contractors to present them to the customer in a simple, coherent fashion.

Lastly, we leave untouched several issues of importance to program administrators and contractors:

- How much should an administrator change its programs over time?
- When should major refinements stop or, put another way, when is reaching for better become an enemy of the good?
- At what point do new or added program requirements become onerous for trade allies?
- How might these programs fit or interact with other programs?

Program administrators often see program design and implementation as a continuous cycle of improvement. Each new program year and evaluation cycle provides lessons that in turn become opportunities for improvement in the future. At the same time, several prominent contractors and industry experts stress that stability and consistency in program design have real value. A constantly changing program environment can undermine a contractor's business model and create an impression of risk. Risk, real or perceived, can make it more costly for contractors to obtain capital to get equipped for enery efficiency work or for business expansion. Similarly, new program requirements can introduce new or

[15] See, for example, Pacific Gas & Electric Company's multi-year pilot in California (CPUC Rulemaking 13-11-005).

higher labor costs that can frustrate profitability and, indirectly, discourage contractors from "selling" retrofits or measures promoted by programs.

We stand aside from this debate in part because the evaluations examined for this work do not specifically address these issues and in part because the answers are not absolute. Certainly, a poor performing program should change. And new requirements clearly may be necessary but should be streamlined so that they are not unduly time consuming or burdensome for contractors and participants.

Summary

A high-quality meta-analysis of residential energy upgrade programs is difficult for several reasons. First, only about half of comprehensive programs have current evaluations. Second, evaluations differ widely in the methodology and rigor employed in verifying savings and providing insight into the relationship of program design to savings. Inconsistencies and low specificity frustrate the confident correlation of "success" with specific design elements.

It is possible nonetheless to draw out some key themes:

- Participants and contractors need programs to work for them—quickly, with minimal effort—and be either aligned with their interests or counterbalanced with incentives.
- Perceptions about incentives—"getting a good deal"—may matter as much as the actual reduction in customer costs.
- Tiered or bonus incentives can drive greater savings per project.
- Changing market practices requires sustained investments and supportive program policies, such as quality installation verification.
- Program requirements need to reflect practical work management needs of contractors.
- Timing matters: If customers can't make the recommended improvements all at once, use multiple touches and phases.
- Bundle measures to improve cost-effectiveness.
- Go after improvements in the building shell, lighting and appliances, but also target savings in HVAC, hot water and behavioral changes.
- Work on closing the gap in understanding in how to convert direct install approaches into more comprehensive projects and sustained engagement.
- Tailoring messages to the target market matters. Use broad appeal or targeted outreach depending on what you want to achieve.
- Quality controls have a cost, yet they protect multiple interests and ensure savings.
- "Participating contractor" requirements provide concrete expectations for both customers and contractors.

Undoubtedly, many programs not studied for this report for lack of sufficient available information could also provide great insights into program success and development of model features. We chose to base our program models on existing programs for which we could obtain third-party evaluations that coupled a high degree of rigor in savings verification with insight into program design and implementation. The lack of evaluations meeting these conditions sharply constrains the ability of researchers, program administrators and other market actors to assess what works and what doesn't with confidence.

More often than not, evaluations lack meaningful contributions to broader industry understanding of what works in comprehensive residential energy upgrade programs and what doesn't. This is not surprising, given the regulatory environment in which programs operate and the risks that program administrators face. In many cases, evaluations are geared to answering questions on short-term regulatory requirements rather than serving the larger, longer term interest in the ingredients of success and development of replicable models. For a better understanding of the dynamics between program design and impacts, the scope of evaluations will need to expand, with a shift in emphasis from validating first-year savings or compliance with deemed savings values to more rigorous verifications and explorations of program design. It may be worthwhile for policymakers and program administrators to weigh the merits of evaluations that provide more confidence in verified savings—and insights into the links between savings and design elements—as keys to future success.

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Appendix A. Program Evaluations Reviewed

State	PA Name	Evaluation Report	Author	Date	Report Link
WHOLE HOUSE PROGRAMS					
AR	Entergy Arkansas	Entergy DRAFT Energy Efficiency Portfolio Evaluation Report 2014 Program Year	Cadmus	Mar-15	http://www.apscservices.info/(X(1)S(bolw234500u5y445xkguag55))/EEInfo/EEReports/Entergy%202014.pdf
AZ	APS	APS MER Verification Report Program Year 2013	Navigant	Feb-14	http://images.edocket.azcc.gov/docketpdf/0000152867.pdf
BC	BC Hydro	Demand Side Management Milestone Evaluation Summary Report FY2013	Internal- BC Hydro staff	Feb-14	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/regulatory-planning-documents/revenue-requirements/directive-66-f2013-demand-side-management-milestone-evaluation-summary-report.pdf
CA	Pacific Gas and Electric, SDG&E, SCE, SoCal Gas	Whole House Retrofit Impact Evaluation, Evaluation of Energy Upgrade California Programs, Work Order 46	DNV-GL	Oct-14	http://www.energydataweb.com/cpucFiles/pdaDocs/1194/2010-2012%20Whole%20House%20Impact%20Study.pdf
CA	Sacramento Municipal Utility District	SMUD Home Performance Program Final Report April 2012	Internal- SMUD staff	May-14	http://www.energy.ca.gov/ab758/documents/ARRA-Programs/final_reports/Home_Performance_Program-SMUD-Final_Report_04-2012.pdf
CO	Xcel-Public Service Company of Colorado	COLORADO HOME PERFORMANCE WITH ENERGY STAR® PROGRAM EVALUATION	Cadmus	May-14	http://www.xcelenergy.com/staticfiles/xe/Marketing/Files/CO-2013-Home-Performance-ES-Evaluation.pdf
CT	Energize CT (UI and CL&P)	Final Report Impact Evaluation: Home Energy Services—Income Eligible and Home Energy Services Programs (R16)	Cadmus	Dec-14	http://www.neep.org/sites/default/files/resources/HES%20and%20HES-IE%20Impact%20Evaluation%20(R16),%20Final%20Report,%2012-31-14.pdf
CT	Energize CT (UI and CL&P)	Connecticut HES Air Sealing, Duct Sealing, and Insulation Practices Report (R151)	NMR	Dec-15	http://www.energizect.com/connecticut-energy-efficiency-board/evaluation-reports
IL	Ameren Illinois	Impact and Process Evaluation of the 2013 (PY6) Ameren Illinois Company Home Performance with ENERGY STAR® Program	Opinion Dynamics	Mar-15	http://ilsagfiles.org/SAG_files/Evaluation_Documents/Ameren/AIU%20Evaluation%20Reports%20EPY6/AIC_PY6_HPwES_Report_FINAL_2015-03-06.pdf
IL	Commonwealth Edison Company	ComEd Home Energy Savings EPY6/GPY3 Evaluation Report	Navigant	Feb-15	http://ilsagfiles.org/SAG_files/Evaluation_Documents/ComEd/ComEd%20EPY6%20Evaluation%20Reports/ComEd_HES_PY6_Evaluation_Report_2015-02-19_Final.pdf
IL	Nicor Gas	Home Energy Savings Program GPY3 Evaluation Report	Navigant	Aug-15	http://ilsagfiles.org/SAG_files/Evaluation_Documents/Nicor%20Gas/Nicor_Gas_GPY3_Evaluation_Reports/Nicor_Gas_GPY3_HES_Eval_Report_Final_2015-08-28.pdf
IN	Indiana State-wide CORE programs	2012 Energizing Indiana Programs	TecMarket Works et al	Jun-13	http://aceee.org/files/pdf/2012-indiana-emv-report.pdf

State	PA Name	Evaluation Report	Author	Date	Report Link
WHOLE HOUSE PROGRAMS (cont.)					
MA	MassSave`	Home Energy Services Impact Evaluation	Cadmus	Aug-12	http://ma-eeac.org/wordpress/wp-content/uploads/Home-Energy-Services-Impact-Evaluation-Report_Part-of-the-Massachusetts-2011-Residential-Retrofit-and-Low-Income-Program-Area-Evaluation.pdf
MD	EmPOWER Programs	EmPOWER Maryland Home Performance with ENERGY STAR Billing Analysis Study Evaluation Year 5 (June 1 2013-May 31 2014)	Cadmus/Navigant	Sep-15	http://www.psc.state.md.us/search-results/?keyword=EmPOWER+Maryland++Home+Performance+with+ENERGY+STAR%C2%AE+Billing+Analysis+Study+&x.x=21&x.y=15&search=all
ME	Efficiency Maine	Efficiency Maine Trust Home Energy Savings Program Final Evaluation Report	Cadmus	Nov-11	http://www.efficiencymaine.com/docs/Efficiency-Maine-Home-Energy-Savings-Final-Evaluation-Report-DOE.pdf
ME	Efficiency Maine	EVALUATION OF THE EFFICIENCY MAINE TRUST PACE, POWERSAVER, AND RDI PROGRAMS FINAL EVALUATION REPORT Volume I: PACE & PowerSaver Loan Program	Cadmus	Oct-13	http://www.efficiencymaine.com/docs/PACE-Final-Evaluation-Report-FINAL.pdf
NH	New Hampshire Utilities	Impact Evaluation: New Hampshire Home Performance with ENERGY STAR® Program	Cadmus	Jun-11	http://www.puc.state.nh.us/electric/Monitoring%20and%20Evaluation%20Reports/124%20NH%20HPwES%20Impact%20Evaluation%20Report%20June%2013%202011.pdf
NY	NYSERDA	NYSERDA 2007-2008 Home Performance with ENERGY STAR Program Impact Evaluation Report	Megdal and Associates	Sep-12	http://www.nyserda.ny.gov/About/Publications/Program-Planning-Status-and-Evaluation-Reports/Evaluation-Contractor-Reports/2012-Reports
OR	Energy Trust of Oregon	2013 Report on Energy Savings and Measure Costs of Existing Homes program tracks: Standard, Home Performance, and Clean Energy Works Oregon	ETO	Feb-14	http://www.energytrust.org/wp-content/uploads/2016/12/2013_report_on_savings_and_costs.pdf
RI	National Grid - Rhode Island	Rhode Island EnergyWise Single Family Impact Evaluation	Cadmus	Oct-12	http://www.rieermc.ri.gov/documents/evaluationstudies/2012/National%20Grid%20Rhode%20Island%20-%20EnergyWise%20Single%20Family%20Impact%20Evaluation_FINAL_31OCT2012.pdf
TX	Statewide Portfolio	Public Utility Commission of Texas Annual Statewide Portfolio Report for Program Year 2014	Cadmus/Tetra Tech	Oct-15	http://www.texasefficiency.com/index.php/emv
TX	Austin Energy	Home Performance with Energy Star: Evaluation of Austin Energy's Home Performance with ENERGY STAR (HPwES) Program	GDS	Sep-12	https://austinenergy.com/wps/wcm/connect/ad632863-c053-41bc-9804-1a9a8f2dd686/2012HPwESevaluationReport.pdf?MOD=AJPERES
VT	Efficiency Vermont	Efficiency Vermont's Home Performance with ENERGY STAR Program Impact Evaluation Final Report	West Hill Energy and Computing	Jun-13	http://www.neep.org/sites/default/files/resources/EVTImpactEvaluationFinalReport2013.pdf
WA	Puget Sound Energy	FINAL REPORT – VOLUME II Independent Third-Party Review of PSE's 2010-2011 Electric Conservation Energy Savings	SBW Consulting	May-12	
WI	Focus on Energy-Wisconsin	Focus on Energy Calendar Year 2014 Evaluation Report	Cadmus	May-15	https://www.focusonenergy.com/sites/default/files/Evaluation%20Report%202014%20-%20Volume%20II.pdf

State	PA Name	Evaluation Report	Author	Date	Report Link
HVAC PROGRAMS					
CO	Xcel-Public Service Company of Colorado	Colorado High Efficiency Air Conditioning Product Program Evaluation	Cadmus	Nov-12	https://www.xcelenergy.com/staticfiles/xe/Regulatory/Regulatory%20PDFs/CO-DSM/CO-2012-High-Efficiency-Air-Conditioning-Final-Evaluation.pdf
ID	Idaho Power	Idaho Power Residential Programs Process Evaluation	TRC	Dec-13	https://www.idahopower.com/pdfs/AboutUs/RatesRegulatory/Reports/2013Supplement2.pdf
IL	Ameren Illinois	Process and Impact Evaluation of the 2013 (PY6) Ameren Illinois Company HVAC Program	Opinion Dynamics	Mar-15	http://www.ilsag.info/ameren_il_eval_reports.html
IL	Commonwealth Edison Company	Complete System Replacement PY6 Evaluation Report	Navigant	Dec-14	http://www.ilsag.info/comed_eval_reports.html
MO	Ameren Missouri	Ameren Missouri CoolSavers Impact and Process Evaluation: Program Year 2013	Cadmus	May-14	https://www.efis.psc.mo.gov/mpsc/commoncomponents/viewdocument.asp?DocId=935842419
OH	Dayton Power and Light	2014 Evaluation, Measurement, and Verification Report	Cadmus	May-15	https://dis.puc.state.oh.us/CaseRecord.aspx?CaseNo=15-0777-EL-POR
SC	South Carolina Electric & Gas	South Carolina Electric and Gas EnergyWise Program Year 3: Evaluation, Measurement, and Verification Report	Opinion Dynamics	May-14	https://dms.psc.sc.gov/Attachments/Matter/08a7588a-155d-141f-23df441a01766b14
UT	Rocky Mountain Power	2011-2012 Cool Cash Program Impact Evaluation Report	Cadmus	Oct-13	http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Demand_Side_Management/2013/UT_CoolCash_2011-2012_Final_Report.pdf

State	PA Name	Evaluation Report	Author	Date	Report Link
DIRECT INSTALL PROGRAMS					
ME	Efficiency Maine	EVALUATION OF THE EFFICIENCY MAINE TRUST PACE, POWERSAVER, AND RDI PROGRAMS, FINAL EVALUATION REPORT Volume II: Residential Direct Install Program	Opinion Dynamics	Oct-13	http://www.efficiencymaine.com/docs/RDI-Final-Evaluation-Report-FINAL.pdf
CT	Eversource, UI	Final Report Impact Evaluation: Home Energy Services—Income-Eligible and Home Energy Services Programs (R16)	Cadmus/NMR	Dec-14	http://www.energizect.com/your-town/hes-and-hes-ie-impact-evaluation-r16-final-report-12-31-14
CT	Eversource, UI	Connecticut HES Air Sealing, Duct Sealing, and Insulation Practices Report (R151)	NMR	Mar-16	http://www.energizect.com/sites/default/files/R151%20-%20CT%20HES%20Air%20Sealing,%20Duct%20Sealing,%20and%20Insulation%20Practices%20-%20Final%20Report_3.24.16.pdf
NY	PSE&G	Efficiency Long Island and Renewable Energy Portfolios 2014 Annual Evaluation Report (Volume II – Program Guidance Document)	Opinion Dynamics	May-15	https://www.psegliny.com/files.cfm/eli_annual2014_v2.pdf
KY	Kentucky Power	Kentucky Power Company 2012-2013 Demand Side Management Portfolio Evaluation	AEG	Jul-14	http://psc.ky.gov/pscecf/2014-00271/jkrosquist@aep.com/08142014122220/Exhibit_2_AEG.pdf

Appendix B. Methodology for Estimation of Emissions Avoidance for Each Program Model

By John Shenot, Regulatory Assistance Project

Overview

Energy efficiency is an effective means of reducing air pollution, because it directly or indirectly reduces the need to combust fossil fuels. *Direct* reductions occur when fossil fuels are combusted in the same location where the energy is used; for example, in a residential furnace. A more efficient furnace can heat a home using less fuel and thus avoid emissions at that specific location. *Indirect* reductions occur when the energy use in one location affects fossil fuel combustion in another location, as is usually the case with grid-supplied electricity. If a residential customer reduces his or her electricity consumption, somewhere on the grid a generator will reduce its electric output (all else being equal), and if that generator is fossil-fueled, air emissions in that location are avoided. Because of the nature of the electric grid, these indirect emission reductions may or may not occur in the same state where the customer who saved the energy is located.

The amount of emissions directly avoided through thermal energy savings will depend on the type of equipment used by the customer (e.g., the size and vintage of the boiler or furnace used to heat a home) and the fuel used in that equipment (e.g., natural gas or heating oil). Estimating the amount of emissions indirectly avoided through electric energy savings is more complicated. It depends on the ability to identify the "marginal generators" that reduce their output due to lower customer demand (i.e., the units that generate less electricity than they would have, had customers not saved energy) and their emissions rates. The marginal generator concept is explained in more detail below.

Explanation of "Marginal Generators"

At every moment of every day, a system operator[16] works to ensure that the supply of electricity is in almost perfect balance with the demand for electricity within each "balancing area."[17] First, the system operator creates an advance schedule (e.g., a day-ahead schedule) for which generating units will operate and at what output levels. Then, the system operator monitors the system load in real time. During routine (non-emergency) operations, the system operator sends automated dispatch signals to generating units as needed to achieve balance, instructing specific units to adjust their electric output up or down by specified amounts at specified times.

Generating units are dispatched primarily based on "merit order." This means that the units with the lowest operating costs tend to be dispatched first, and the units with the highest operating costs are dispatched last. The most expensive unit within a balancing area that the system operator needs to dispatch to meet customer demand is sometimes called the *marginal generator.* If demand decreases, the

[16] In some parts of the country, utilities serve the role of system operator. In other parts, an independent system operator (ISO) or regional transmission operator (RTO) serves this role.
[17] If supply and demand get out of balance, the frequency of transmitted electricity will start to deviate from design values (60 hertz in the United States). Frequencies that are too high or too low can damage consumer appliances.

marginal generator is the unit that is most likely to be instructed to reduce its output.[18] Because demand varies throughout each day, the marginal generator in a balancing area can change from hour to hour and day to day. In most regions, for most hours of the year, the marginal generators will be fossil-fueled units because the fuel costs of those units tend to make them more expensive to operate than other units (e.g., wind turbines).

The emissions rates of the marginal generators in each balancing area will determine how much air pollution is avoided annually if any of the model energy efficiency programs is implemented within that balancing area. Although the emissions rates of all the generators on the U.S. grid can be found in free, publicly available databases, identifying which generators will be marginal at any given time can be a challenging task for the analyst. The most accurate method is to use a chronological dispatch model to predict which generating units will be dispatched to meet any given future load. These models include detailed information about the capabilities and operating costs of each generating unit on the system, as well as the transmission lines. The models simulate the decisions that system operators make. By modeling two scenarios—one including the impacts of a model energy efficiency program, and one without those impacts—the analyst can identify the specific generators that reduce their power output and develop values for avoided emissions.

Most of the dispatch models that might be useful for estimating avoided emissions from electric energy savings are proprietary software products that must be purchased from a private sector vendor. Use of these models also requires training, expertise and large amounts of time. Because of the investment needed to use these dispatch models, simpler and less expensive methods for estimating avoided emissions have been developed by and for the U.S. Environmental Protection Agency (EPA). The analysis used for this report relied on two such methods, using EPA's AVoided Emissions and geneRation Tool (AVERT) and Emissions & Generation Resource Integrated Database (eGRID). These methods are described below.

Methodology Used to Estimate Avoided Emissions

The primary purpose of this appendix is to explain the methodology that was used to derive estimates of the avoided emissions that might be expected if a utility, state, or third party implements one of the three model energy efficiency programs. A secondary goal is to provide enough of an explication of the methodology to enable program planners, implementers, or evaluators to develop their own estimates of avoided emissions using actual program data and relevant local data on home heating sources, electricity sources and other variables.

The methodologies for estimating direct avoided emissions from therm savings and indirect avoided emissions from megawatt-hour (MWh) savings are different, so they are explained here separately.

[18] This is an oversimplified explanation of merit order dispatch, but hopefully sufficient to explain the concepts used to estimate avoided emissions. In practice, system operators often must dispatch units out of merit order because transmission constraints make it more expensive or impossible to deliver power from the least costly unit to where power is needed, or for other reasons.

Therm Savings—Annual Direct Avoided Emissions from Model Programs

1. Estimate the annual end use energy savings, in therms, for each model energy efficiency program. The body of the report explains how the energy savings estimates were derived.
2. Find emission factors for residential furnaces and boilers in a document called AP-42, published by EPA.[19]
   a. An emission factor is a representative value that relates the emissions of an air pollutant to some measure of the activity that generates the air pollution. For example, the amount of air pollution emitted from burning fuel in a residential furnace can be estimated by multiplying the amount of fuel burned by an appropriate emission factor for each individual air pollutant. EPA develops the AP-42 emission factors from emissions test data, material balance studies and engineering estimates.
   b. We assumed for the sake of analysis that all therm savings from the model energy efficiency programs would reduce the need for *fossil-fueled* heating (not electric, wood, geothermal, etc.).
   c. For this analysis, we reviewed the AP-42 emission factors Volume I, Chapter 1 (External Combustion Sources), Sections 1.3 (Fuel Oil Combustion), 1.4 (Natural Gas Combustion), and 1.5 (Liquefied Petroleum Gas Combustion).
   d. Within the sections for each type of home heating fuel, we reviewed emission factors for residential furnaces and residential boilers. The section on liquefied petroleum gas (LPG, aka propane) did not include emission factors for residential furnaces or boilers, so we used the emission factors for small commercial boilers burning propane.
   e. AP-42 emission factors for residential furnaces and boilers do not vary regionally, but there is some significant regional variation in the fuel mix for these appliances. However, rather than assuming a fuel mix that would be affected by implementation of model energy efficiency programs in different regions, we developed separate estimates for each fossil fuel assuming *all* therm savings would reduce use of that fuel. This approach might be useful if an energy efficiency program specifically targeted, for example, customers that own oil-fired furnaces and boilers. If a program does not target specific heating fuels, composite estimates of avoided emissions could easily be developed using the amounts of each fuel saved and the corresponding emission factors for each fuel.
   f. The estimates for fuel oil combustion in this report assume that energy efficiency program participants will reduce their use of ultra-low-sulfur diesel fuel, which is 0.0015% sulfur by weight. Some fuel oils have much higher sulfur levels, but we made this assumption because most states in the northeastern United States, where the use of home heating oil is most prevalent, have adopted standards requiring ultra-low-sulfur diesel use. If a more accurate estimate is desired, one could enter the actual average sulfur percentage of home heating oils used in any state where the energy efficiency program is implemented.
   g. The estimates for natural gas combustion assume that customers participating in the model programs have boilers without any control devices for reducing nitrogen oxide (NO_x) emissions, such as low-NO_x burners.
3. For each model program, and for each relevant fossil fuel (gas, oil, propane), multiply the annual end use energy savings, in therms, by the appropriate emission factors to calculate annual avoided emissions of carbon dioxide (CO_2), NO_x, and sulfur dioxide (SO_2). Separate estimates were derived in this report for residential furnaces and residential boilers, though in most cases the avoided emissions estimates are very similar.

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[19] U.S. EPA. (1995). *AP-42: Compilation of Air Pollutant Emission Factors - Volume I*. Research Triangle Park, NC: EPA Office of Air Quality Planning and Standards. Retrieved from https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emission-factors.

MWh Savings—Annual Indirect Avoided Emissions from Model Programs

1. Estimate the annual end use energy savings, in MWh, for each model program. The body of the report explains how the energy savings estimates were derived.
2. Estimate the annual avoided generation, in MWh, for each model program if the program were to be implemented in each of the three continental U.S. interconnections. A map of these interconnections is provided below in the explanation of regions used for the analysis.
    a. End use energy savings reduce the need for electricity generation, which is how programs indirectly avoid emissions.
    b. Some of the electricity produced by generators is lost in the transmission and distribution systems before reaching end users. Because of these "line losses," more than one MWh of generation is required to deliver one MWh to customers, and conversely, each MWh of end use energy savings avoids the need to generate more than one MWh.
    c. The value that determines avoided emissions is thus avoided generation, rather than end use energy savings. Avoided generation can be calculated using the following formula:

$$\text{Avoided Generation (in MWh)} = \frac{\text{End Use Energy Savings (in MWh)}}{1 - \text{line loss percentage}}$$

    d. Line losses vary regionally and vary based on system conditions at any given time. For this analysis, we used average gross line losses for each interconnection, based on values derived by EPA from the Federal Energy Regulatory Commission (FERC) Form 714 filings, to estimate avoided generation. The line loss values used for each interconnection are as follows:
        - Eastern Interconnection = 9.17%;
        - Western Interconnection = 5.76%; and
        - ERCOT Interconnection = 7.03%.[20]
3. Run EPA's AVERT model to estimate avoided emissions of CO_2, NO_x and SO_2 attributable to each energy efficiency program.
    a. AVERT is a free, downloadable spreadsheet model that uses a simplified form of marginal generator logic to derive avoided emissions estimates. The spreadsheets, user manual and full documentation are available on EPA's website at https://www.epa.gov/statelocalclimate/avoided-emissions-and-generation-tool-avert. For this report, we used AVERT version 1.4 (dated July 2015).
    b. AVERT uses actual data from ten different regions of the continental United States to account for regional variations in generation mix, load and marginal generators. Users must select a region for analysis, and cannot redefine these regions. A map of the regions embedded in the AVERT model is provided below in the explanation of regions used for the analysis.
    c. There are several different ways to input the impacts of energy efficiency programs into the AVERT model. For this report, we used the simplest method: we entered annual values for avoided generation (what AVERT calls "reduced generation") and allowed AVERT to assume that the impacts are distributed evenly throughout every hour of the year. If more accurate estimates of avoided emissions are desired, one could manually apportion the avoided generation values to each hour of the year using data on the time-varying impacts of any given energy efficiency program. (So, for example, an HVAC efficiency program could attribute most of the avoided generation to summer hours, and little or none to winter hours.)
    d. For each AVERT model run, we selected one of the ten AVERT regions and entered the annual avoided generation value in that region for one of the three model programs. AVERT then

[20] Retrieved from eGRID2012 Summary Table 9 at https://www.epa.gov/sites/production/files/2015-10/documents/egrid2012_summarytables_0.pdf.

estimated the annual avoided emissions. Note that AVERT reports avoided emissions results rounded to the nearest hundred tons (CO_2) or nearest hundred pounds (NO_X and SO_2).

4. ALTERNATIVE METHOD: An even simpler—but generally less accurate—method for estimating indirect avoided emissions from MWh savings is to use emission factors. However, it is not appropriate to use AP-42 emissions factors for this purpose. Instead, it is better to use EPA's eGRID database, which was compiled specifically for this purpose.
   a. The eGRID database uses historic data on generation and emissions from different regions of the country to develop historical average emission factors for CO_2, NO_x, SO_2 and other air pollutants. The spreadsheets, summary tables and all other documentation files are available on EPA's website at https://www.epa.gov/energy/egrid. A map of the regions and subregions embedded in the eGRID database is provided below in the explanation of regions used for the analysis.
   b. For this report, we used the "non-baseload output emission rates" in the eGRID2012 data release from October 2015 to develop estimates of avoided emissions that could be compared to the AVERT-derived values. These "output" emission factors are expressed in units of pounds of emissions per unit of output (i.e., MWh of generation). We used "non-baseload" emission factors (there are other emission factors in eGRID) because they are more likely to reflect the average emission rates of marginal generators. This is because baseload generators, by definition, tend to operate at or near their full capacity whenever they are in service, and are not dispatched up or down in response to changes in load.
   c. For each model program, we multiplied the avoided generation value in MWh expected in each eGRID region or subregion by the appropriate non-baseload output emission rates to derive estimates of avoided emissions for CO_2, NO_x and SO_2. To allow for reasonable comparisons to AVERT results, we selected the eGRID region or subregion that most closely corresponded to each of the ten regions in AVERT.
5. ALTERNATIVE METHOD: Another option is to assume that a model program will reduce the output not of an existing marginal generator, but rather of a new, yet-to-be-built generator. Estimates of the avoided emissions from a new generator can be derived using typical emission rates for an assumed "proxy generator."
   a. In the short term, the energy savings from a model program will reduce the output of existing marginal generators. But in the medium to long term, an energy efficiency program might have the effect of deferring the need to build or operate a new generator that does not currently exist. If one wants to know the emissions impact in 2025, for example, of a model program implemented today, one benchmark to consider is the emissions that would be expected from a *new* generator that might not need to be built or might be operated less in that future year. We can assess this possibility using a hypothetical "proxy generator"—the new generator we assume would be built to meet that load but for the savings attributable to the energy efficiency program.
   b. Based on current market conditions and environmental regulations, we would expect the proxy generator to be either a zero-emission generator (most likely using wind or solar power) or a natural gas-fired combined cycle (NGCC) unit. For this report, we estimate avoided emissions from a proxy NGCC unit to provide another comparison to the AVERT and eGRID results.
   c. The avoided CO_2 and NO_x emissions from a proxy NGCC unit were estimated by assuming the unit would emit at a rate equal to the emissions limits in existing federal New Source Performance Standards for electric utility generating units. With few exceptions, new units may not legally exceed these emissions rates. Given that new utility generating units burning natural gas have extremely low SO_2 emissions rates, we assumed that the avoided SO_2 emissions from a proxy NGCC unit would be extremely low and therefore did not develop estimates for them. The proxy NGCC emission rates used for this analysis were as follows:
      - CO_2 = 1,100 lbs/MWh = 0.55 tons/MWh; and

- NO_x = 0.70 lbs/MWh.[21]

d. For each model program, we multiplied the avoided generation value in MWh expected in each AVERT region by the proxy NGCC emission rates above to derive estimates of avoided emissions for CO_2 and NO_x.

Regions Used for the Analysis

This report includes estimates of the avoided emissions that might be expected if model programs are implemented in different parts of the country. A regional approach is used to estimate avoided emissions because the emissions impacts of electricity savings vary regionally. The analysis considers regional variations in gross line losses and regional variations in marginal emissions rates that are embedded in the AVERT and eGRID datasets.

Line Losses

The electric grid serving the continental United States consists of three synchronous interconnections, as depicted in Figure B-1.

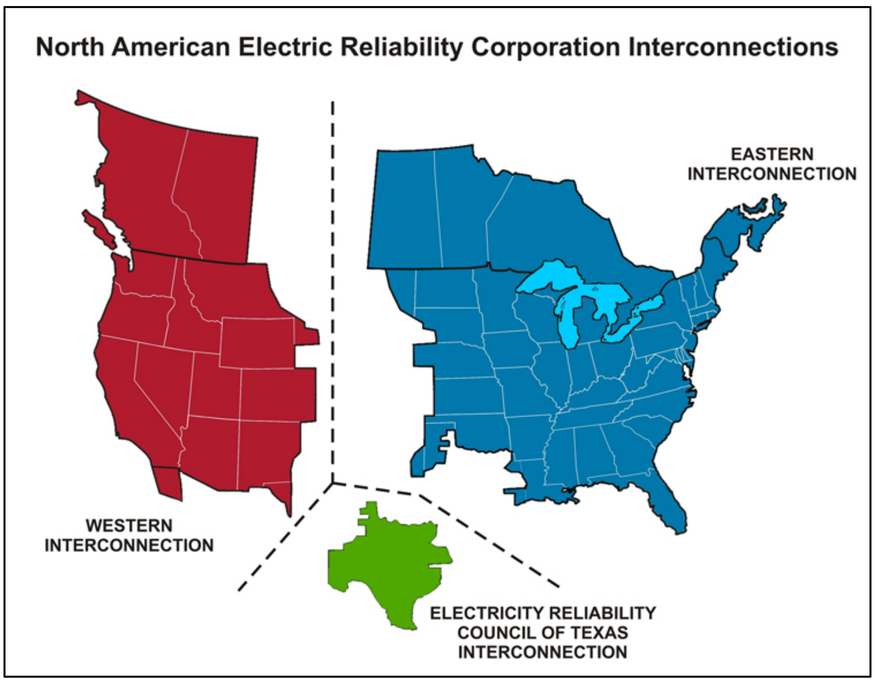

Figure B-1. North American Electric Reliability Corporation Interconnections[22]

For each region analyzed in this report, end use electricity savings (in MWh) from the model programs were scaled up to estimate avoided generation (in MWh) using the average gross line loss value for the interconnection containing the region, based on eGRID data derived from FERC Form 714 filings. The line loss values used for each interconnection are as follows:

- Eastern Interconnection = 9.17%;

[21] The applicable New Source Performance Standard for CO_2 emissions is established in 40 CFR Part 60, Subpart TTTT, Table 2. The applicable standard for NO_x emissions can be found in 40 CFR Part 60, Subpart Da.
[22] Map retrieved from U.S. Department of Energy at http://energy.gov/oe/downloads/north-american-electric-reliability-corporation-interconnections.

- Western Interconnection = 5.76%; and
- ERCOT Interconnection = 7.03%.

AVERT and eGRID Datasets

The AVERT model makes use of ten regional datasets. EPA's documentation for AVERT says, "AVERT regions are aggregates of EPA's eGRID subregions and based on regional boundaries used by the North American Electric Reliability Corporation (NERC). Each region generally represents an electrically autonomous area."[23] Figure B-2, copied from EPA's documentation, shows a map of the regions used for AVERT model runs.

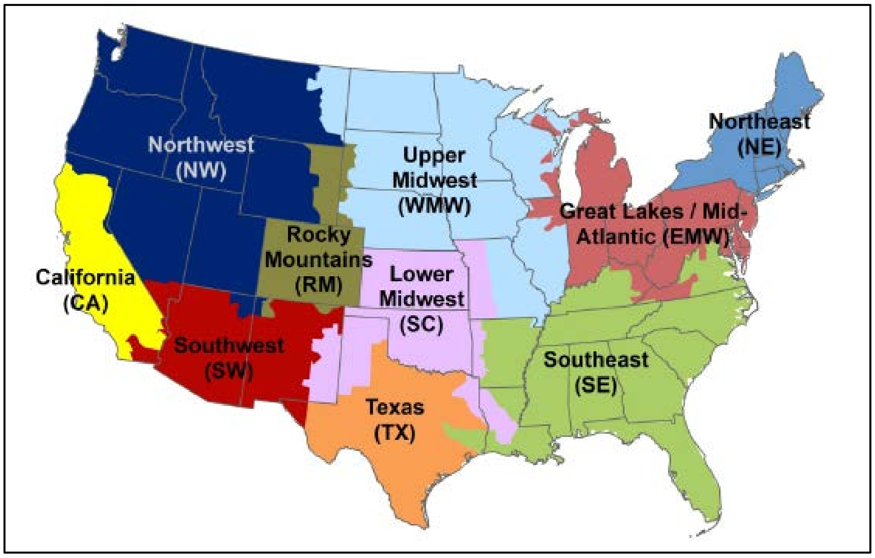

Figure B-2 AVERT Regions

Although the AVERT documentation says its regions are based on aggregates of eGRID subregions, the eGRID documentation shows regional and subregional boundaries that do not exactly correspond to the AVERT regional boundaries, as shown in Figure B-3and Figure B-4. Note, for example, that most of Illinois is included in the Upper Midwest region in AVERT but is included in the Southeast (SERC) region in eGRID.

[23] U.S. EPA. (2016). *AVoided Emissions and geneRation Tool (AVERT) User Manual, Version 1.4*. Washington, D.C.: EPA Office of Air and Radiation. Retrieved from https://www.epa.gov/statelocalclimate/avert-user-manual-0.

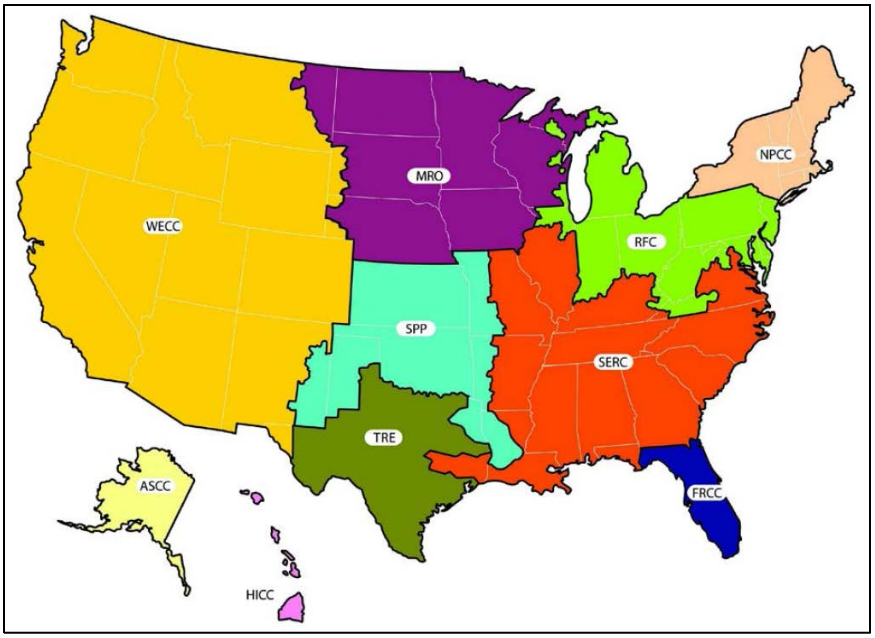

Figure B-3 eGRID Regions[24]

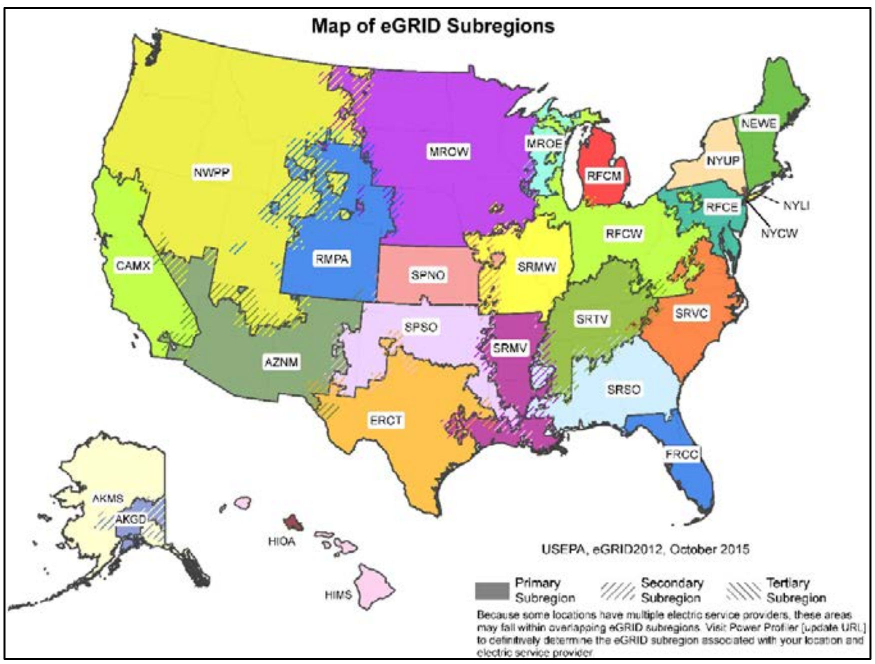

Figure B-4. eGRID Subregions[25]

To facilitate comparisons of avoided emissions estimates based on AVERT model outputs and eGRID emission factors, we used the eGRID emission factors for the eGRID region or subregion that most closely corresponded to each AVERT region. Table B-1 indicates the eGRID data used for comparison to each AVERT region:

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[24] Retrieved from eGRID documentation at https://www.epa.gov/sites/production/files/styles/large/public/2015-10/egrid2012_nerc_regions.jpg.

[25] Retrieved from eGRID documentation at https://www.epa.gov/sites/production/files/styles/large/public/2015-10/egrid2012_egrid_subregions.jpg.

Table B-1. AVERT and eGRID Regions and Subregions Used for Comparing Avoided Emissions Estimates

AVERT Region	Corresponding eGRID Region (or Subregion)	Interconnection (used to estimate line losses and avoided generation)
California	CAMX subregion	Western
Great Lakes/Mid-Atlantic	RFC	Eastern
Lower Midwest	SPP	Eastern
Northeast	NPCC	Eastern
Northwest	NWPP subregion	Western
Rocky Mountains	RMPA subregion	Western
Southeast	SERC	Eastern
Southwest	AZNM subregion	Western
Texas	TRE	ERCOT
Upper Midwest	MRO	Eastern

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