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Housing Stock Characterization Study: An Innovative Approach to Measuring Retrofit Impact

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Building Energy Efficient Housing for America

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Definitions

ACB	Annual Community Baselines
ANOVA	Analysis of variance
BEEHA	Building Energy Efficient Housing for America
CI	Confidence interval
DOR	Florida Department of Revenue
DSM	Demand side management
EC	Energy consumption
EEFP	Energy Efficient Finance Program
EP	Energy performance
HP	Heat pump
HVAC	Heating, ventilation, and air conditioning
M&V	Measurement and verification
OCPA	Orange County Property Appraiser
OEI	Osceola Energy Initiative
OLS	Ordinary least squares
OUC	Orlando Utilities Commission
SEER	Seasonal Energy Efficiency Ratio
SFD	Single-family detached

1 Introduction

This report details an evaluation of Orlando Utilities Commission (OUC) residential energy efficiency demand side management (DSM) programs to assess their impacts and relative measures of energy and economic performance. The primary objective of the end-use billing analysis is to estimate energy savings attributable to three of OUC's residential energy efficiency rebate programs, including seven individual retrofit measures. This analysis addresses the need to develop methods for characterizing existing housing stock, and understanding the energy and monetary benefits of making specific residential energy efficiency retrofit investments. Retrofit loan program criteria can incorporate historical energy savings estimates for local retrofit programs by providing a basis for prioritizing and targeting specific retrofit programs that are likely to optimize efficiency gains.

The Osceola Energy Initiative (OEI) Energy Efficient Finance Program (EEFP) plans to incorporate the technical findings of this analysis directly. As a U.S. Department of Energy, Energy Efficiency and Conservation Block Grant initiative under the American Recovery and Reinvestment Act of 2009, the OEI must show measurable and verifiable success in its programmatic goals and objectives. In turn, the EEFP relies on the availability of valid, transparent comparisons of energy consumption (EC) data to measure and verify the efficacy of property improvement measures to be implemented as part of a retrofit loan program for Osceola County. OUC provides electric service to residential customers in Osceola County. Analysis of consumers' end-use billing data, merged with housing characteristics data, provides the means to generate the types of energy performance (EP) comparisons necessary for successful implementation of the OEI EEFP. This analysis aims to not only provide estimates of program impact for direct use by OUC DSM managers, but also to directly inform key components of the OEI EEFP, such as market segmentation and targeting, loan risk assessment, and pre-intervention versus post-intervention measurement and verification (M&V).

To accomplish these analysis objectives, Building Energy Efficient Housing for America (BEEHA) uses the Annual Community Baselines (ACB) (Jones et.al. 2011) analytical method to compare the pre-retrofit versus post-retrofit EP of households participating in OUC residential energy efficiency rebate programs during calendar year 2009. The analysis uses metered consumption data from January 2008 to December 2010. This study evaluates three of OUC's residential rebate programs: ceiling insulation upgrade, duct repair/replacement, and high-efficiency heat pump (HP) air conditioner unit installation. Five subsets of HP rebate program participants are evaluated separately based on the Seasonal Energy Efficiency Ratio (SEER) of the unit installed (SEER 14, 15, 16, 17 and 18), resulting in seven retrofit measures evaluated for impact.

The ACB approach is unique in that it:

- Uses a census (or very large sample) of publicly available data for the population of interest, merging end-use billing data with DSM program and property appraiser data
- Constructs a simple analytical model that is easily replicable, portable, and cost effective
- Estimates household-level EP baselines using ordinary least squares (OLS) regression techniques that effectively normalize for community EC patterns in any given year

- Generates reliable performance measures for comparison within years (to assess static performance), over time (to assess performance persistence), and before versus after upgrade/installation (to assess program impact).

1.1 Energy Savings

This study evaluates 297 rebate-participant homes for first-year (2010) energy savings. Across DSM measures, estimates of *percent* energy savings average 10.6%, and range from 5.8% for SEER 18 HP installations to 13.9% for SEER 16 HP upgrades. BEEHA estimates that the ceiling insulation, duct repair, and high-efficiency HP programs overall achieved first-year percent energy savings of 7.2%, 8.7%, and 11.4%, respectively (Figure 1).

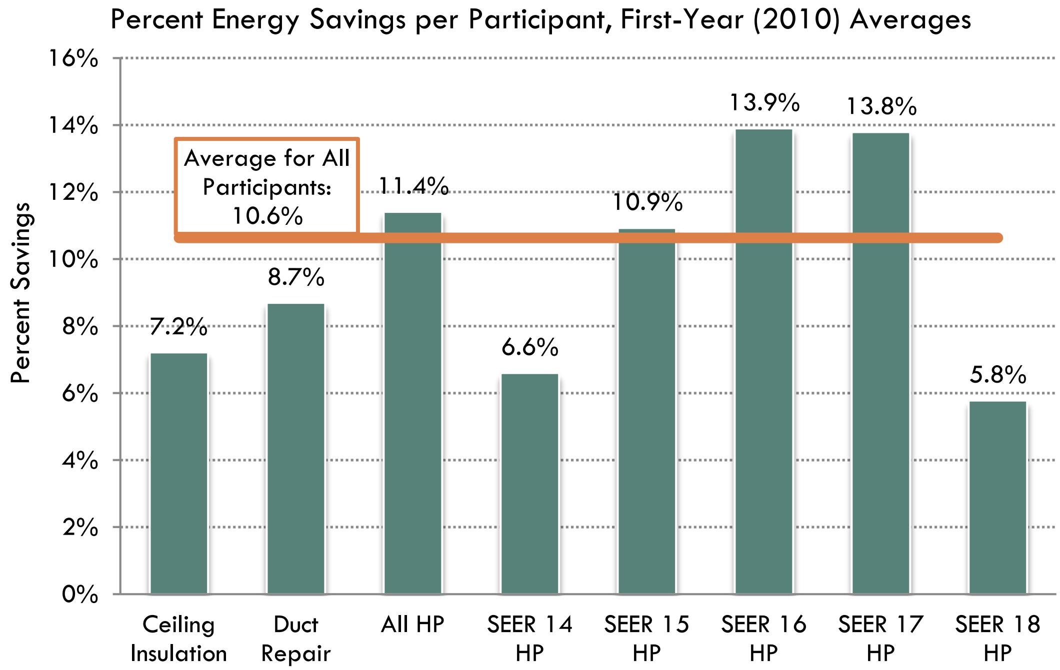

Figure 1. Summary results: percent energy savings, first-year (2010) averages

Across DSM measures, estimates of *absolute* energy savings average 1,963 kWh and range from 1,108 kWh for SEER 18 HP installations to 2,783 kWh for SEER 17 HP upgrades. BEEHA estimates that the ceiling insulation, duct repair, and high-efficiency HP programs overall achieved first-year absolute energy savings of 1,266 kWh, 1,499 kWh, and 2,128 kWh, respectively (Figure 2). Table 1 summarizes findings of the DSM program analysis of energy savings.

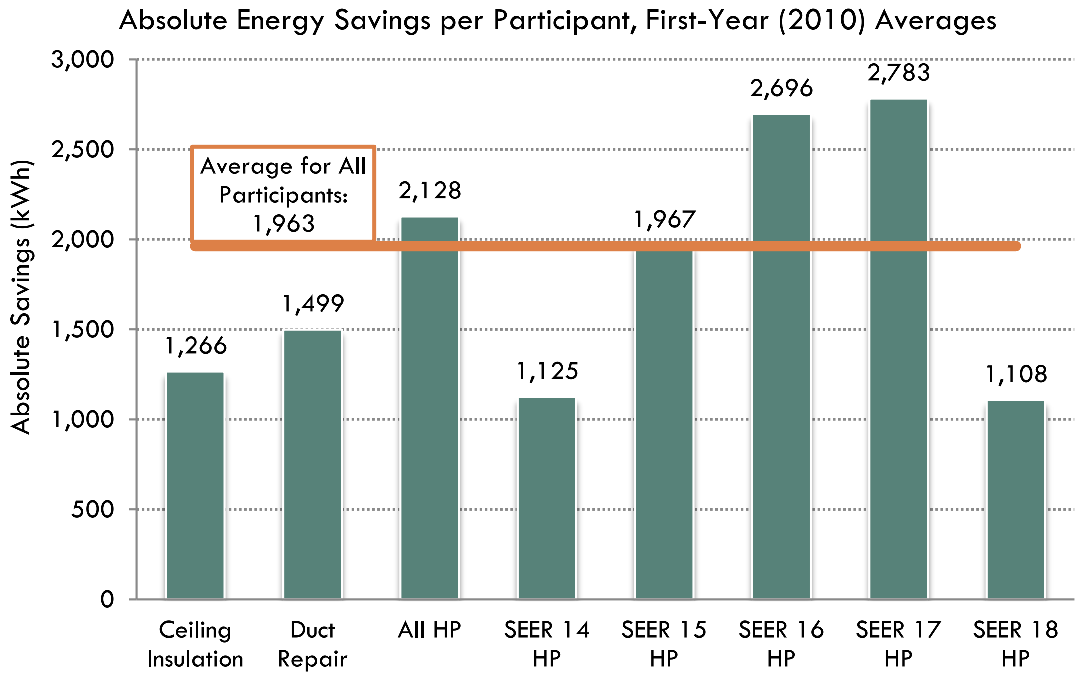

Figure 2. Summary results: absolute energy savings, first-year (2010) averages

Table 1. Summary Results: DSM Energy Savings, First-Year (2010) Averages

DSM Program or Installation Measure	Number of Participants Evaluated (n)	Average First-Year (2010) Energy Savings‡	
		(%)	(kWh)
Ceiling Insulation	44	7.2 ***	1,266 ***
Duct Repair/Replacement	17	8.7 **	1,499 **
HP	236	11.4 ***	2,128 ***
SEER 14 HP	15	6.6 *	1,125 *
SEER 15 HP	138	10.9 ***	1,967 ***
SEER 16 HP	44	13.9 ***	2,696 ***
SEER 17 HP	31	13.8 ***	2,783 ***
SEER 18 HP	8	5.8	1,108
All Participants	297	10.6	1,963

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

1.2 Cost-Effectiveness Measures

BEEHA uses energy savings estimates to calculate measures of DSM program and retrofit cost effectiveness. BEEHA first considers the rebate incentive cost ($/kWh) saved in the first year post-retrofit. Across the 297 DSM-participant homes and DSM measures, estimates of rebate cost effectiveness average $0.22/kWh saved, and range from $0.18/kWh saved (most cost effective) for the SEER 14 HP retrofit to $0.54/kWh saved (least cost effective) for the SEER 18 HP retrofit. BEEHA estimates that the ceiling insulation, duct repair, and high-efficiency HP programs overall cost $0.22, $0.20, and $0.22/kWh saved, respectively (Figure 3).

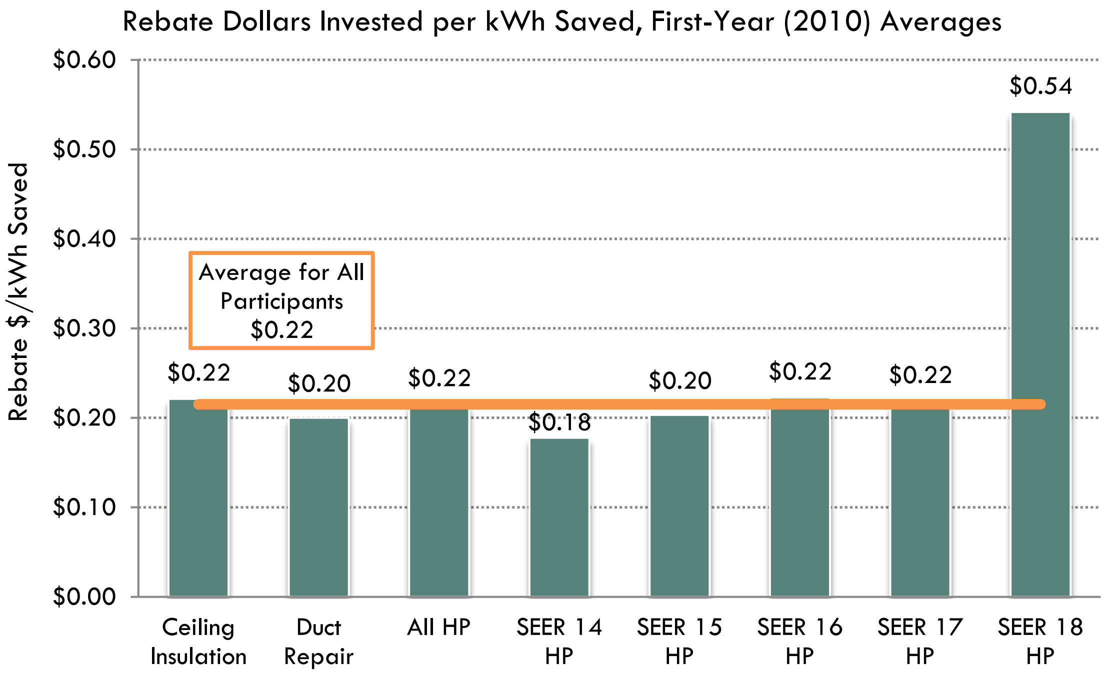

Figure 3. Summary results: rebate cost effectiveness, first-year (2010) averages

The study also considered the effectiveness of the retrofits from the homeowners' perspective, and calculated first-year electricity bill savings per participant and lifetime marginal cost of the investment ($/kWh) saved. Across DSM measures, estimates of homeowner first-year electricity bill savings average $236, and range from $133 saved as a result of the SEER 18 HP retrofit to $334 saved as a result of the SEER 17 HP retrofit. BEEHA estimates that the ceiling insulation, duct repair, and high-efficiency HP programs overall resulted in average participant first-year electricity bill savings of $152, $180, and $255, respectively (Figure 4). Across DSM measures, estimates of lifetime marginal investment saved average $0.03/kWh (with the rebate incentive excluded from the benefit-cost calculation). The marginal investment cost-effectiveness measures ranged from $0.00/kWh saved (immediate payback) for the SEER 14 HP participants to $0.07/kWh saved (9.7-year payback); all were less than the unit cost of each avoided kilowatt-hour consumed ($0.12). These results show that all the retrofit investments were cost effective, on average, for DSM participants. Table 2 summarizes findings of the analysis of rebate/retrofit cost effectiveness.

Next, this report presents a brief discussion of the rationale for the evaluation. Section 3 describes the data and data management and Section 4 explains the ACB methodology. Sections 5 to 7 detail the results, conclusions, and recommendations.

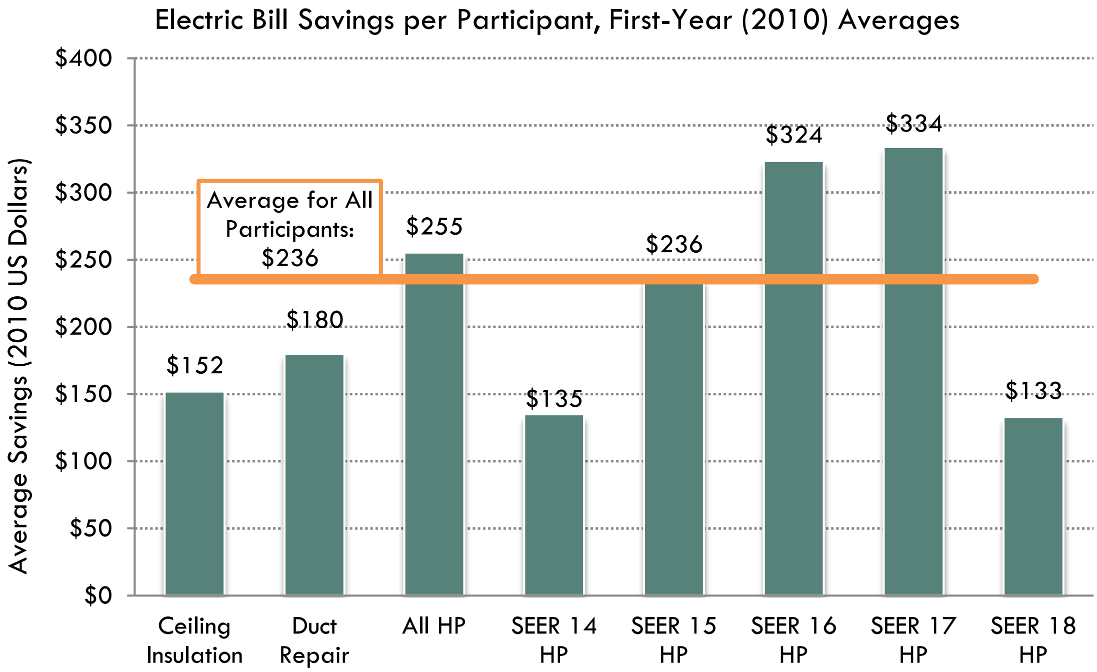

Figure 4. Summary results: homeowner electricity bill savings, first-year (2010) averages

Table 2. Summary Results: Rebate Cost Effectiveness and Homeowner Savings

DSM Program or Installation Measure	Number of Participants Evaluated (n)	Rebate Cost Effectiveness ($/kWh Saved)	Homeowner First-Year (2010) Electricity bill Savings ($)	Homeowner Lifetime Return on Investment Without Rebate ($/kWh Saved)
Ceiling Insulation	44	$0.22	$152	$0.04
Duct Repair/ Replacement	17	$0.20	$180	$0.05
HP	236	$0.22	$255	$0.03
SEER 14 HP	15	$0.18	$135	$0.00
SEER 15 HP	138	$0.20	$236	$0.02
SEER 16 HP	44	$0.22	$324	$0.03
SEER 17 HP	31	$0.22	$334	$0.03
SEER 18 HP	8	$0.54	$133	$0.07
All Participants	297	$0.22	$236	$0.03

2 Objectives

The primary objective of this housing stock characterization study and end-use billing analysis was to estimate energy savings attributable to three of OUC's residential energy efficiency rebate programs, including seven individual retrofit measures, for participants who implemented one retrofit measure in 2009.

2.1 Rationale

This evaluation addresses the need to develop methods for characterizing existing housing stock and for understanding the energy and monetary benefits of making specific retrofit investments. Retrofit loan program criteria can incorporate historical energy savings estimates for local retrofit programs, providing a basis for prioritizing and targeting specific retrofit programs that are likely to optimize efficiency gains.

The premise of the OEI EEFP is that the success of a residential energy efficiency retrofit loan program depends on developing and deploying a self-sustaining finance option merged with optimized retrofit measures. Such a program should require each loan to:

- Generate energy savings (i.e., utility bill reductions) that are greater than loan costs incurred.
- Compare retrofit options based on anticipated energy savings, useful life, and cost-effectiveness indicators as determined by an analysis of metered consumption data.
- Provide ongoing M&V based on metered EC data to ensure persistence of program impacts.
- Provide targeted feedback on comparative performance of retrofitted houses to facilitate the concurrent homeowner and contractor behavioral changes critical to perpetuating energy savings.

By using historical EC data to quantify the impacts of residential energy-efficiency retrofits in OUC territory, BEEHA intends to provide program impact analysis to OUC DSM managers and to generate reliable data for direct use in the OEI EEFP.

2.2 Scope

This technical report provides information about the measured performance of residential energy retrofits in the OUC service territory (Orlando, Florida) for integration into a prototypical residential energy efficiency retrofit loan program in Osceola County, Florida. BEEHA uses an ACB analysis to estimate energy savings from three residential energy efficiency rebate programs (including seven specific retrofit measures), rebate cost effectiveness, and homeowner cost effectiveness. All metered consumption sites evaluated in this study are single-family detached (SFD) homes located within Orlando city limits and all the retrofit measures assessed for program impact were implemented in 2009. The aggregate savings estimates are valuable for measuring program impacts; the individual savings estimates for homes, when merged with housing characteristics data, are also valuable signals to the local market for energy efficiency retrofit loans.

The ACB approach (described in Section 4) that BEEHA uses to measure EP and estimate energy savings is suited to a wide range of uses in the market for energy efficiency, including application for loan risk assessment, market segmentation and targeting, program efficacy M&V (both pre-intervention versus post-intervention and performance persistence), program vendor quality assurance/quality control, building energy code analysis, and energy policy innovation.

Although the methods are replicable and portable for many energy utilities and regions across the United States, the energy savings and estimates of cost effectiveness presented in this technical report should not be used as proxies for generating deemed savings estimates and cost-effectiveness measures for similar utility DSM programs in other regions. BEEHA expects findings from applying the analytical approach described in this report to vary significantly from one utility, DSM program, housing population, and time period to another. Findings should, therefore, be interpreted and applied specifically in the context of the specific area of investigation.

3 Data

3.1 Collecting, Merging, and Screening

BEEHA followed a specific data management process:

1. Collected end-use billing data for all SFD homes in the OUC service area.
2. Collected DSM program participation data, including dates and details of specific installation or retrofit measures and rebate incentives provided to program participants. OUC provided these two datasets.
3. Collected property appraiser housing characteristics data for all residential properties in Orange County, Florida. Orange County Property Appraiser (OCPA) provided this dataset. These raw data comprise the *original datasets*.
4. Merged the original datasets, using physical addresses to match OUC and OCPA records, and using premise numbers to match OUC billing and rebate program records. These merged data comprise the *primary analysis datasets*.
5. Screened the primary analysis datasets to ensure complete and reliable annual consumption data for the pre-intervention and post-intervention time periods and for rebate participant and nonparticipant homes. This step creates the *final analysis datasets* that were used in the ACB analysis model.

Figure 5 summarizes this data management process and shows the number of complete records in each stage.

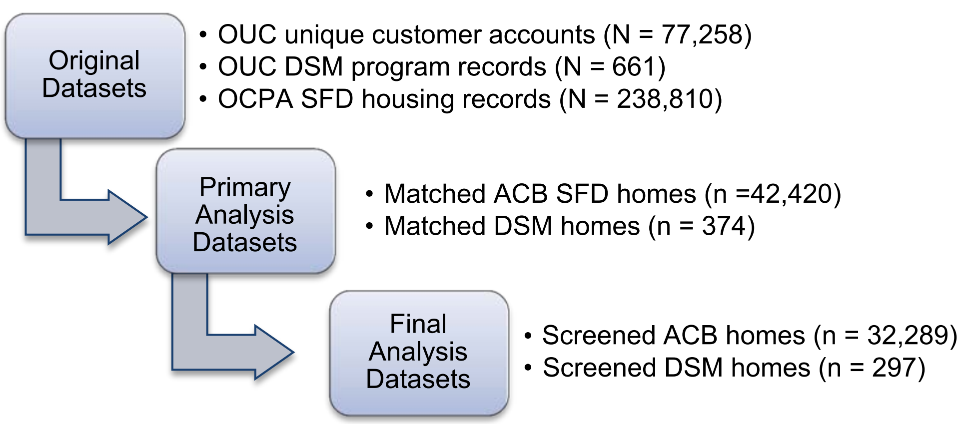

Figure 5. Merging and screening the original and primary analysis datasets

3.1.1 Original Datasets

The original data used for this analysis include end-use billing data, residential energy efficiency rebate program data, and housing characteristics data. OUC and OCPA provided the data. OUC provided two datasets. The first includes monthly, account-level, site electricity consumption data (in kilowatt-hours)[1] from January 2008 through December 2010 for all OUC's residential customers. This original OUC dataset included 77,258 unique customer accounts. The second original OUC dataset included records of all residential energy efficiency rebate program participants from January 2009 through December 2010; a total of 661 homes. OCPA provided data on the housing characteristics and location of all properties in Orange County, Florida, current as of March 2011. This original dataset included 238,810 SFD housing records, with SFD identified by Florida Department of Revenue (DOR) tax code. Table 3 lists data fields included in each of the original datasets.

Table 3. Original Data Fields

Original Datasets		
OUC End-Use Billing (January 2008 to December 2010)	**OUC DSM Rebate Programs (January 2009 to December 2010)**	**OCPA Housing Characteristics (Current as of March 2011)**
Premise Number	Premise Number	Parcel Number
Customer ID Number	Customer ID Number	Physical Address
Physical Address	Rebate Type	Building Type
Meter Read Date	Installation Date	DOR Tax Code
Billed Consumption (kWh)		Number of Bedrooms
Billed Consumption ($)		Number of Bathrooms
		Conditioned Area
		Year Built

3.1.2 Primary Analysis Datasets

When merging data to create the primary analysis dataset, fields were selected based on availability, reliability, and their demonstrated or expected relation to residential EC. Monthly, account-level, end-use billing data linked to the premise, customer identification number, and physical address were selected from the OUC datasets. Parcel number, physical address, building type, DOR tax code, number of bedrooms, number of bathrooms, conditioned floor area, and year built are selected from the OCPA database. Physical address was used to link and merge the OUC and OCPA databases into a primary dataset for screening and analysis. OUC residential rebate participant data, including the type of retrofit and installation/upgrade date, were then tagged to the analysis dataset by premise and customer numbers.

Once the data were merged, monthly electricity consumption records within each calendar year were summed for each record/home to quantify total annual energy use (in kilowatt-hours). The

[1] There is no natural gas service in the OUC service territory. In other utility territories, BEEHA accounts for electricity and natural gas customers by combining electricity and natural gas units and expressing them in terms of equivalent kilowatt-hours, but this approach is not applicable in the OUC service area.

resulting primary analysis dataset included 42,420 OUC/OCPA-matched records (55% of original OUC and 18% of original OCPA records). Within the primary analysis dataset, 374 homes (< 1%) took part in the residential energy efficiency rebate programs of interest in calendar year 2009. This dataset formed the primary census list, from which final ACB analysis subsets were created for calendar years 2008, 2009, and 2010.

3.1.3 Final Analysis Datasets

Records in each annual primary analysis dataset were screened to ensure the statistical and practical validity and reliability of data used to estimate energy savings to DSM program participants. BEEHA imposed limits on home size, total EC, energy intensity, and percent change in annual consumption to provide the most accurate account of typical and consistently occupied residences in the area. BEEHA screened against the annual EC records to include only homes with single owners/account holders. The utility customer identification number relates to a unique customer at a specific location (i.e., SFD home). Therefore, this data management strategy resulted in account holders who remained consistent throughout the study period, and excluded homes with a customer change during the analysis period. For instance, if an account holder moved during the study period, the dataset contains early records but later records are blank.

In the derivation of each ACB, this study considered only homes that were reasonably occupied with a single account number over the study period. Single account holder records were then screened based on the number of recorded months in each year, total annual EC, energy intensity, and change in annual EC to provide reasonable assurances of continuous occupancy during each calendar year and over the study period. The final analysis dataset retains records that met the following inclusion criteria:

1 Home conditioned area ≥ 500 ft^2 and ≤ 5,000 ft^2

2 12 months of consumption data in each calendar year

3 Year 2008 pre-retrofit) annual absolute consumption ≥ 3000 kWh and ≤ 40,000 kWh

4 Year 2010 (post-retrofit) annual absolute consumption ≥ 3000 kWh

5 Year 2008 (pre-retrofit) energy intensity ≥ 3 kWh/ft^2/yr and ≤ 25 kWh/ft^2/yr

6 Year 2010 (post-retrofit) energy intensity ≥ 3 kWh/ft^2/yr

7 Year 2008 to 2010 percent change in absolute EC ≥ the median percent change in absolute EC –35% and ≤ the median percent change in absolute EC +35%.

The limits set on total consumption and energy intensity (criteria 3–6) were selected based on the 2.5 to 97.5 percentile range of the population distributions for EC and intensity over the study period. These helped to create a study group representative of typical SFD home EC patterns in the OUC service territory. Homes were not screened directly on extreme high consumption values for the post-retrofit period (criteria 4 and 6) because criterion 7 effectively captured this screening, in which limits excluded homes with fluctuations in energy consumption between the pre-intervention and post-intervention periods that are beyond the reasonable range of expected impact from a major retrofit or behavioral change. These percent change limits were imposed around the median percent change for the entire population because BEEHA expected annual fluctuations in consumption from year-over-year changes in climate, economic conditions, etc.

The overall intent of screening criterion 7 was to remove homes that underwent an extreme (atypical) change that would skew ACB measures for any given subgroup of homes, and in turn skew final estimates of retrofit impact.

The final ACB analysis dataset includes 32,289 cleaned and screened records/homes (76% of those in the primary dataset) with complete EC, building characteristics, and program participation data. The same 32,289 homes make up the 2008 (pre-retrofit) and 2010 (post-retrofit) final analysis datasets. Of these, 297 participated in a single residential energy efficiency rebate program in calendar year 2009, accounting for 79% of those from the population of participants in the primary analysis dataset. These final data provided an estimate of ACB performance measures for each home in the near census, which sum (and average) to zero within any given year. As discussed in Section 4, this is an intentional and expected outcome of using regression residuals as the static performance measures.[2] Then, change in pre-intervention and post-intervention ACB performance measures were used to estimate energy efficiency rebate and retrofit impacts and test savings estimates for statistical significance. Energy savings estimates were used to calculate additional measures of program effectiveness (e.g., homeowner simple payback period on energy efficiency investments).

3.2 Orlando Utilities Commission Rebate Programs and Measures

Once the final analysis dataset was complete, BEEHA identified the OUC rebate/retrofit programs of interest and with sufficient data to estimate pre-intervention and post-intervention energy savings. BEEHA excludes multi-retrofit DSM participants and retrofit subgroups with fewer than five participants in 2009.[3] Although they do not represent the complete set of residential energy efficiency rebates offered by OUC, BEEHA chose to evaluate the performance of homes in three rebate programs designed to maximize heating, ventilation, and air conditioning (HVAC) system efficiency: ceiling insulation upgrade, duct repair/replacement, and HP air conditioner unit installation.[4] Participants in the HP program could choose to install or upgrade to one of five SEER rating levels (14, 15, 16, 17, or 18), and BEEHA evaluated each SEER-level participant group separately. In all, the analysis assessed the impacts of three rebate programs and seven specific retrofit measures, capturing 297 of the 374 rebate participants, or 79% of those from the primary analysis dataset. Table 4 lists the incentives offered by OUC and the minimum criteria for customer participation in the rebate programs. Table 5 lists the number and percent of these rebate participants in the final versus primary analysis datasets.

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[2] Average deviation from the population mean approaches zero for any regression residual-based statistic, given a normal distribution for the population parameter of interest.

[3] For example, OUC offers a cool/reflective roof rebate to its customers. In 2009, only four residential customers participated in this program, so although they were included in the ACB population, these homes were not tested against comparable homes for energy savings.

[4] The analysis evaluated the impact of rebates for window tinting (n = 32), window replacement (n = 20), and combined duct repair and heat pump (n = 6) programs, but does not report those savings estimates because of the relatively low participation numbers and high variability in program qualification criteria over the study period.

Table 4. OUC Residential Energy Efficiency Rebate Programs Evaluated

DSM Program or Installation Measure	Rebate Incentive (per Participant)	Description
Ceiling Insulation Upgrade	\$100 + \$0.10/ft^2, up to a total of \$400	Add attic insulation. To qualify, final insulation level must be R-19 or higher.
Duct Repair/ Replacement	50% of cost, up to \$300	Repair or replace ducts. To qualify, customer must have a 5.5-ton or smaller central air conditioning system and ducts must be sealed with mastic and Underwriters Laboratories-approved duct tape.
High-Efficiency HP	\$200–\$600	Install new HP air conditioner unit. To qualify, new system must be rated 14 SEER or higher, and customer must provide copy of Air Conditioning, Heating and Refrigeration Institute-(AHRI) certified efficiency data form and a copy of invoices and model numbers for both the air condenser and air handler units.
SEER 14 HP	\$200	Same as for High-Efficiency HP
SEER 15 HP	\$400	Same as for High-Efficiency HP
SEER 16 HP	\$600	Same as for High-Efficiency HP
SEER 17 HP	\$600	Same as for High-Efficiency HP
SEER 18 HP	\$600	Same as for High-Efficiency HP

Table 5. Records in Primary Versus Final Analysis Datasets

DSM Program or Installation Measure	Number of Program Participants		
	Primary Dataset (n)	Final Dataset (n)	% of Primary Records Evaluated
Ceiling Insulation	50	44	88%
Duct Repair/Replacement	19	17	89%
High-Efficiency HP	305	236	77%
SEER 14 HP	20	15	75%
SEER 15 HP	173	138	80%
SEER 16 HP	58	44	76%
SEER 17 HP	43	31	72%
SEER 18 HP	11	8	73%
All Participants	355	297	84%
ACB Population	42,420	32,289	76%

First-year (2010) energy savings estimates were derived using these original data. Extrapolating from the energy savings estimates, BEEHA also applied additional data, as specified in Sections 5.3 to 5.5 of this report, to estimate monetary savings and efficiency indicators for each residential energy efficiency rebate program and measure.

3.3 Study Population Descriptive Statistics

This section presents summary descriptive statistics for the 297 program participants and ACB population (n = 32,289) in the final analysis dataset; providing a first look at the raw data and information about how the participant housing characteristics and EC/efficiency compare to those of all SFD residential homes in the OUC service territory. BEEHA refers to the entire population of SFD homes as the ACB population, but does not adjust these numbers in any way to normalize individual homes against one another (which we do in the actual ACB analysis). Tables 6 to 9 provide descriptive statistics for each rebate subgroup as well as for the baseline population.

Table 6. OUC Customer Housing Characteristics: Conditioned Area and Age[5] (Averages)

DSM Program or Installation Measure	Conditioned Area (ft^2)		Age (yrs)	
	Mean	Range	Mean	Range
Ceiling Insulation	1,844	906–4,671	44	10–90
Duct Repair/Replacement	1,700	936–2,899	43	7–70
High-Efficiency HP	1,914	800–4,602	39	6–101
SEER 14 HP	1,764	1,153–2,818	43	9–87
SEER 15 HP	1,868	800–4,602	38	7–87
SEER 16 HP	2,154	975–4,046	39	6–101
SEER 17 HP	1,991	1,067–4,432	37	6–85
SEER 18 HP	1,377	1,127–1,594	51	19–80
All Participants	1,892	800–4,671	40	6–101
ACB Population	1,726	528–4,995	47	3–110

[5] Home age is measured as post-retrofit year (2010) – year built.

Table 7. OUC Customer Housing Characteristics: Bedrooms and Bathrooms (Averages)

DSM Program or Installation Measure	# Bedrooms		# Bathrooms	
	Median	Range	Median	Range
Ceiling Insulation	3	2–5	2	1–4.5
Duct Repair/Replacement	3	2–5	2	1–3
High-Efficiency HP	3	2–7	2	1–4.5
SEER 14 HP	3	2–5	2	1–3
SEER 15 HP	3	2–5	2	1–4.5
SEER 16 HP	3	2–5	2	1–3.5
SEER 17 HP	3	2–7	2	1–4.5
SEER 18 HP	3	2–4	2	1–2.5
All Participants	3	2–7	2	1–4.5
ACB Population	3	1–11	2	1–8

Table 8. OUC Customer EC and Intensity (Averages)

DSM Program or Installation Measure	Absolute Consumption (kWh)			Intensity (kWh/ft^2)		
	2008	2010	% change	2008	2010	% Δ
Ceiling Insulation	18,530	18,756	+1.2%	10.9	11.0	+1.1%
Duct Repair/Replacement	19,124	19,179	+0.3%	11.8	11.8	0.0%
High-Efficiency HP	17,844	17,118	–4.1%	9.6	9.2	–4.7%
SEER 14 HP	13,656	13,631	–0.2%	7.8	7.7	–1.3%
SEER 15 HP	17,211	16,593	–3.6%	9.6	9.2	–4.3%
SEER 16 HP	20,223	19,091	–5.6%	9.9	9.2	–6.9%
SEER 17 HP	20,790	19,649	–5.5%	10.5	9.9	–5.6%
SEER 18 HP	12,112	12,051	–0.5%	8.5	8.6	+0.6%
All Participants	18,019	17,478	–3.0%	9.9	9.6	–3.4%
ACB Population	16,784	18,106	+7.9%	10.3	11.1	+7.8%

Table 9. OUC Customer Nominal Annual Electricity bills (Averages)[6]

DSM Program or Installation Measure	Nominal Annual Electricity bills ($)				
	2008 Mean	2008 Range	2010 Mean	2010 Range	% Δ 2008–2010
Ceiling Insulation	$1,148	$454–$2,520	$1,377	$543–$2,666	+20%
Duct Repair/Replacement	$1,188	$768–$1,688	$1,412	$705–$2,217	+19%
High-Efficiency HP	$1,107	$339–$2,574	$1,252	$396–$3,352	+13%
SEER 14 HP	$830	$365–$1,290	$983	$396–$1,836	+18%
SEER 15 HP	$1,064	$413–$2,473	$1,211	$408–$3,352	+14%
SEER 16 HP	$1,264	$381–$2,497	$1,404	$536–$2,763	+11%
SEER 17 HP	$1,302	$418–$2,574	$1,449	$513–$2,815	+11%
SEER 18 HP	$739	$339–$1,566	$868	$454–$1,853	+17%
All Participants	$1,117	$339–$2,574	$1,280	$396–$3,352	+15%
ACB Population	$1,035	$176–$2,715	$1,330	$210–$4,114	+29%

Tables 6 and 7 show group averages and ranges for housing characteristics: conditioned area, age,[7] number of bedrooms, and number of bathrooms. Note that the typical home in the OUC service territory was built in the early 1960s, has three bedrooms, two bathrooms, and approximately 1,700 ft^2 of conditioned area. Rebate participant homes are approximately 10% larger and approximately seven years newer, on average, than the typical OUC home. Within the rebate *program* subgroups, duct repair/replacement participant homes are the smallest (slightly smaller than the population average) and high-efficiency HP participants are the oldest, on average. Within the rebate *measure* subgroups, note that the SEER 18 HP subgroup homes are approximately 20% smaller and four years older, on average, than the ACB population of homes.

Tables 8 and 9 show group averages related directly to EP, including absolute consumption (kWh), energy intensity (kWh/ft^2), and annual electricity bills.[8] Across the entire population of homes, average absolute EC increased by approximately 8%; across the rebate participant homes, it decreased by 3%—statistics that suggest that the retrofits had real impacts on EP. Within the rebate participant subgroups, the SEER 14 and SEER 18 HP homes consumed the least absolute energy in the pre-retrofit year—approximately 20% and approximately 30% less, respectively (on average) than the ACB population of homes and the SEER 17 HP participant homes consumed the most in the pre-retrofit year—approximately 20% more, on average, than the ACB population of homes.

[6] The billing data shown in this table account for only the base portion of customers' average electricity bill because billing records provided by OUC excluded per-unit fuel charges. The combined base and fuel electricity rate increased by 22% from 2008 to 2010.
[7] Measured as post-retrofit year (2010) (year built).
[8] Data in Table 9 exclude electricity fuel surcharges.

The average percent change in the base electricity bill between 2008 and 2010 for the ACB population was 29% compared to 15% for the rebate participants. Two main factors likely account for the 29% population-level increase in nominal bills: the per-unit electricity rate increased by 22%[9], and average annual absolute EC per household increased by 8% over the same time period (Table 8). Differences in weather (heating and cooling degree days), economic conditions, or other across-year variables may explain the 8% shift in energy consumption across the population, but an explanation of why the entire population baseline shifted across years is beyond the scope of our analysis.

Two key factors that affected the potential for relative and absolute energy savings by rebate participants were conditioned living area and pre-retrofit consumption. Larger homes with higher pre-retrofit consumption have the greatest potential to benefit from rebate programs that address HVAC efficiency. Of the rebate participant subgroups SEER 18 HP participants had the lowest pre-retrofit EC (12,112 kWh/yr), while SEER 17 HP participants had the highest (20,790 kWh/yr). SEER 18 HP participants had the lowest average conditioned floor area (1,377 ft^2), and SEER 16 HP participants had the highest (2,154 ft^2). These data suggest that SEER 16 and 17 homes have the greatest savings potential of all rebate measure subgroups.

[9] Inclusive of base and fuel charges, the 2008 rate was $0.104/kWh and the 2010 rate was $0.120/kWh.

4 Methods

This section explains technical details of the ACB approach used in this study. To assess OUC residential energy efficiency retrofit impact, BEEHA used an evaluation protocol based on a near census[10] of utility and property appraiser household data for SFD homes in the OUC service territory (Jones et al. 2010a). The principal goal of the ACB methodology is to calculate objectively normalized measures of EP, from which statistically and practically valid estimates of energy savings can be derived. Analyses that rely solely on engineering estimates of EP can be unreliable for quantifying net energy savings (Metcalf and Hassett 1999), so this analysis used a census-level end-use billing analysis approach to measure retrofit impact. A secondary goal of the methodology, critical for planning and policy applications of ACB results, is that the methodology be easily replicable, portable, cost effective, and rapidly deployable for evaluating a wide range of energy efficiency programs, technical measures, and behavioral interventions. A necessary condition for meeting these methodological goals is access to a census (or very large sample) of end-use billing and property appraiser data.

4.1 Annual Community Baselines Protocol

The ACB analysis method adopts key elements of conventional comparison-group, regression, and difference-in-difference techniques for measuring energy savings and combines them in an innovative, yet fairly simple way that we believe maximizes reliability of results and minimizes cost of implementation. Jones et al. (2010a) present a detailed explanation of the ACB method and an analysis that compares its results directly to those of other common methods of estimating energy savings (Schiller 2007), including time series, time series with normalized annual consumption, and time series with comparison groups. The analysis involved four main steps:

1. **Normalized performance baselines.** Using EC and housing characteristics data, BEEHA generated community-normalized EP baselines for every home in the study population and for each year of the study period. BEEHA refers to these performance baselines as ACBs. The study derived ACBs using an OLS regression model, measured in total energy (e.g., kWh)[11] consumed per year per home, to normalize each home's observed consumption against all homes in the population with similar building characteristics. The baseline value represents expected or predicted EC for a given home or group of homes. In practical terms, this baseline is a comparison group step, allowing the regression model to select each home's unique comparison group that determines its baseline consumption, and doing so for all homes in the population.
2. **Static (within-year) performance measures.** The analysis compared each home's metered annual EC in each year to its ACB-predicted consumption for the same year. BEEHA refers to this within-year measure for each home as its *static* ACB-normalized EP. Static performance measures were calculated as the difference between each home's metered EC and its ACB-predicted consumption (i.e., regression residuals), and show each home's performance (e.g., energy efficiency or intensity) relative to all similar

[10] Although BEEHA has the full census of households in the OUC service territory, after screening to ensure stable home occupancy over the study period, the resulting final analysis dataset is a "near census," including 32,289 (76%) of OUC SFDs.
[11] For populations with electric and natural gas service, units are combined and expressed in equivalent kilowatt-hours.

homes in the ACB population. This step resulted in the first difference calculated as part of the approach, with comparison groups embedded in the differences and measures estimated for all homes in the population. This step was applied in all ACB analyses and can generate population-level within-year performance metrics for multiple years. Use of regression residuals to measure performance is not common, but is a statistically sound concept if applied correctly, and is used by experts in other disciplinary fields (Dranove 2011; Hong et al. 2011).

3. **Dynamic (across-year) performance measures.** BEEHA calculated changes in static ACB-normalized performance across years. BEEHA refers to this across-year measure for each home as the home's *dynamic* ACB-normalized performance. The study calculated dynamic ACB-normalized performance simply as the difference between the static ACB-normalized performance of a given home across any two years and, the measures are calculated for all homes in the population. This step is the second ACB difference, and is applied primarily for analyses where a known energy efficiency intervention has occurred and the study is intended to measure its impact (i.e., a pre-intervention versus post-intervention assessment of energy savings). However, these dynamic performance measures can be applied simply to estimate a home's or group of homes' change in static performance from one year to another.
4. **Energy savings, within and across years.** This analysis estimated energy savings from specific residential energy efficiency programs or interventions by comparing ACB-normalized performance across participant and nonparticipant groups of homes. For the ACB protocol, BEEHA distinguished between the terms *energy performance* and *energy savings* by using the term energy savings only when testing a particular subgroup of homes (e.g., DSM participant homes) for performance relative to a comparable group of homes in the population (e.g., similar nonparticipant homes). This step used fixed-effects analysis of variance (ANOVA) to measure and test the magnitude and significance of differences between mean ACB performance (static or dynamic) for program participant/treatment subgroups of homes and nonparticipant/control subgroups of homes. Energy savings are the third and final difference calculated as part of the ACB. They can be estimated both within a year (i.e., static energy savings) and across years (i.e., dynamic energy savings), and are expressed in absolute (i.e., total energy savings) and relative (i.e., percent savings) terms.

4.2 Annual Community Baselines-Normalized Performance Measures

For practical purposes, EP metrics (e.g., absolute EC or energy intensity) are meaningful only in the context of their respective baselines, benchmarks, or comparison groups, against which performance is evaluated (Reichl and Kollmann 2011). This study estimated ACB measures of EP and interpreted them in the context of annual comparison-group baselines constructed using end-use billing, energy efficiency program/retrofit measure, and housing characteristics data on a census (or a near census) of homes in a given utility territory or region over annual (e.g., individual calendar year) timeframes.

Data screening based on practical and statistical criteria are valid for the scope of the impact analysis,[12] an OLS regression model,[13] and difference-in-difference techniques estimate ACB EP

[12] Described for this study in Section 3.1.
[13] Detailed for this study in Section 4.1.2.

measures in each year for every home/record in the final analysis dataset. First, the census-level ACB regression equation (Equation 1) is constructed to estimate within-year performance baselines that are normalized by housing stock characteristics. Absolute EC (EC) for a given home, i, in a given year, j, is modeled as a function of home i's building characteristics (BC) (e.g., conditioned area and year built):

$$EC_{ij} = \beta_0 + \beta_1 * BC_{1i} + \beta_2 * BC_{2i} \dots + \varepsilon_i \tag{1}$$

where

EC = energy consumption

BC = building characteristics

Collectively, this report refers to the predicted performance measures ($\widehat{EC}$) during a given year, j, as year j's ACB. Within each ACB, each home, i, has its own specific ACB-derived EP baseline against which metered EC is compared. These ACB measures, snapshots of performance in time, are calculated using a comparison-group approach to normalizing consumption. Yet the ACB technique captures valuable attributes of conventional comparison-group approaches in a manner that minimizes unintentional outcomes from the inherent subjectivity or uncertainty associated with choosing small samples of comparison-group homes. The approach maximizes the number of truly comparable homes used to gauge performance.

Unlike traditional interpretations and applications of linear regression models, which emphasize the explanatory power and statistical significance of the estimated population parameters, the key regression-derived ACB metrics are the estimated errors terms: the residuals, deviations, or unexplained variations around a sample mean. An important technical point is that the regression model must be valid (practically and statistically) in its construction, using appropriate dependent/outcome and independent/predictor variables to model EC. ACB measures are used in a simple, consistent, and cost-effective manner to evaluate static (stationary) and dynamic (non-stationary) performance of a single home and/or groups of homes in and across any given time period. This key attribute of the ACB method distinguishes it from traditional statistical regression, comparison-group, and difference-in-difference models for evaluating program impact.

4.2.1 Static: Within Years

The study used ACB energy performance for a given home, i, or group of homes, to measure static energy performance, providing snapshots of relative efficiency of each home, i, in each year, j. Mathematically, the ACB EP measures (EP_{ij}) are the regression residuals: the difference between actual/observed consumption (EC_{ij}) and ACB-regression predicted consumption ($\widehat{EC}_{ij}$). In absolute terms, such as total quantity of energy consumed above or below the ACB, these static (within-year) ACB performance measures were calculated as shown in Equation 2 and Equation 3 (for an individual home and average for a group of homes, respectively).

For each equation in this section, BEEHA provides a statistical notation and a narrative explanation or description.

$$EP_{ij} = \hat{\varepsilon}_{ij} = EC_{ij} - \widehat{EC}_{ij} \quad (2)$$

$$=> Absolute\ energy\ performance, single\ home$$

$$= (EC_{Actual} - EC_{Predicted})$$

where

EP = energy performance

$$\overline{EP}_{ij} = \left[\sum_{i=1}^{n} \hat{\varepsilon}_{ij}\right]/n = \left[\sum_{i=1}^{n} (EC_{ij} - \widehat{EC}_{ij})\right]/n \quad (3)$$

$$=> Average\ absolute\ energy\ performance, group\ of\ homes$$

$$= \text{Average}\ (EC_{Actual} - EC_{Predicted})$$

where

EP = energy performance

Static annual EP is measured in relative (percentage) terms, as shown in Equations 4 and 5 (for an individual home and average for a group of homes, respectively).

$$\%EP_{ij} = \hat{\varepsilon}_{ij}/\widehat{EC}_{ij} * 100 \quad (4)$$

$$=> Relative\ energy\ performance, single\ home$$

$$= \frac{(EC_{Actual} - EC_{Predicted})}{EC_{Predicted}} * 100$$

$$\overline{\%EP}_{ij} = \left[\sum_{i=1}^{n} \left(\hat{\varepsilon}_{ij}/\widehat{EC}_{ij}\right)\right]/n * 100 \quad (5)$$

$$=> Average\ relative\ energy\ performance, group\ of\ homes$$

$$= \text{Average}\left[\frac{(EC_{Actual} - EC_{Predicted})}{EC_{Predicted}}\right] * 100$$

If actual absolute EC is greater than ACB-predicted absolute consumption, the ACB residual/normalized performance measure will be positive (above the baseline). If actual EC is less than ACB-predicted consumption, the ACB residual/performance measure will be negative (below the baseline). Therefore, the signs on static ACB performance values are indirectly related to performance: positive signs indicate poor performance relative to the baseline, whereas negative signs indicate superior performance relative to the baseline.

A critical assumption for applying these ACB performance measures to impact evaluation is that, all else held constant, year-over-year observed performance of individual homes remains stable *relative to its own individual ACB* (normalized baseline). For example, if home *i*'s absolute consumption in year j is measured as 10% greater than its ACB-normalized consumption ($\widehat{EC}_{ij}$), the analysis assumes that home i's consumption in year $j+1$, with no interventions, will remain stable around +10% of its year $j+1$ ACB ($\widehat{EC}_{ij+1}$). This assumption should hold regardless of the direction and magnitude of year-over-year shifts in average population-level EC.[14]

Static measures of ACB-normalized performance (both absolute and relative) are particularly useful for evaluating new home construction performance and post-occupancy energy efficiency benefits and costs of certified green buildings, when historical consumption data are not available to benchmark or interpret absolute energy efficiency measures. Relative measures (%EP) are particularly useful indicators of whether homes certified under green building programs meet their performance targets. These targets are typically expressed in terms of percent savings or efficiency relative to standard homes. Furthermore, absolute and relative ACB measures can ground-truth/verify deemed savings estimates that depend on model/test home data, small sample sizes, and engineering software and efficiency ratings. Although they cannot directly explain changes in performance, a series of static ACB measures can assess trends in performance for a given home, a set of homes, or an entire population of homes over time.

4.2.2 Dynamic: Across Years

Similar to static (within-year) performance, dynamic (across-year) ACB performance can be measured in both relative (percent) and absolute terms. Relative performance can be compared directly year-over-year, but absolute performance cannot (because of the known or expected shifts in the population-level ACB from year to year). Therefore, this analysis calculated dynamic ACB-normalized absolute performance as a function of dynamic ACB-normalized percent performance and provides the calculations for changes in percent performance measures first. Dynamic percent energy performance ($\Delta\%EP$) is calculated as the difference between the %EP in one year (referred to as the pre-year) and the next (referred to as the post-year). Equations 6 and 7 show the calculations for these ACB measures for a single home and average for a group of homes, respectively.

$$\Delta\%EP_{i,Pre|Post} = \%EP_{i,Pre} - \%EP_{i,Post} \tag{6}$$

$$=> Change\ in\ relative\ performance, single\ home$$

$$= (\%Residual_{Pre} - \%Residual_{Post})$$

$$\overline{\Delta\%EP}_{i,Pre|Post} = \left[\sum_{i=1}^{n}(\%EP_{i,Pre} - \%EP_{i,Post})\right]/n \tag{7}$$

$$=> Change\ in\ relative\ performance, group\ of\ homes$$

$$= \text{Average}\ (\%Residual_{Pre} - \%Residual_{Post})$$

Changes in absolute EP are calculated as the difference between actual absolute post-performance and expected post-performance, which is a function of the dynamic performance measures shown in Equations 6 and 7. Because the ACB model assumes that static measures of relative performance (i.e., the percent residuals) for a given home remain stable over time (all

[14] To date, BEEHA has not worked with any residential end-use billing datasets that violate this assumption.

other things being equal), BEEHA calculated dynamic performance by normalizing the post-year expected absolute consumption using the pre-year relative performance measures (Equations 4 and 5), as shown in Equations 8 and 9, for a single home and group of homes, respectively.

$$\Delta EP_{i,Pre|Post} = \left[\frac{(EC_{i,Pre} * \widehat{EC}_{i,Post})}{\widehat{EC}_{i,Pre}}\right] - EC_{i,Post} \tag{8}$$

$$=> Change\ in\ absolute\ performance, single\ home$$

$$= (\mathrm{EC_{Pre,Actual}} * \%\Delta \mathrm{EP_{i,Pre-Post}}) - EC_{Post,Actual}$$

$$\overline{\Delta EP}_{i,Pre|Post} = \langle \textstyle\sum_{i=1}^{n} \left\{\left[\frac{(EC_{i,Pre} * \widehat{EC}_{i,Post})}{\widehat{EC}_{i,Pre}}\right] - EC_{i,Post}\right\}\rangle / n \tag{9}$$

$$=> Average\ change\ in\ absolute\ performance, group\ of\ homes$$

$$= \mathrm{Average}\left\{(\mathrm{EC_{Pre,Actual}} * \%\Delta \mathrm{EP_{i,Pre-Post}}) - EC_{Post,Actual}\right\}$$

Estimates for change in relative/absolute ACB performance (dynamic ACB performance measures) are calculated so that signs on the final estimates are intuitive: measures calculated using Equations 6 and 7 that have positive signs indicate improvements in efficiency/performance and those with negative signs indicate degradation of efficiency/performance across years.

4.2.3 Energy Savings: Within and Across Years

For energy efficiency research and program impact evaluation, potentially the most valuable application of ACB performance measures is to estimate net energy savings when a known intervention, such as an energy efficiency retrofit or targeted social marketing effort, has occurred. In such cases, BEEHA used dynamic ACB-normalized measures to evaluate post-intervention energy savings. Because static ACB performance measures have been normalized within years and dynamic ACB performance measures have been normalized across years for the full population of homes in a given utility territory, BEEHA used them to directly compare participant (intervention/retrofit) and nonparticipant (no known intervention/retrofit) groups. For this step, access to complete and reliable DSM program data is a critical prerequisite for estimating savings that are truly attributable to the known intervention.

To assess energy savings from a specific DSM retrofit or suite of retrofits implemented in a specific year (the intervention year), BEEHA first calculated static and dynamic ACB performance metrics for the entire population of homes in the pre-intervention and post-intervention years. Next, BEEHA screened the results using program participant data for the pre-intervention and post-intervention years to remove homes that installed the same retrofits of interest in either of those two years. This ensured that when testing the energy savings of the intervention-year participants, the dynamic ACB performance measures for the nonparticipant population (against which BEEHA tested participants' dynamic ACB performance) were truly nonparticipants. This step excluded subsequent and prior-year program participants' ACB performance. To simplify the model and ease interpretation of results, BEEHA also excluded intervention-year program participants who implemented multiple retrofits.

BEEHA then used a basic fixed-effects ANOVA to test differences in dynamic pre intervention and post-intervention ACB performance ($\Delta EP_{i,Pre|Post}$) across DSM participant and nonparticipant homes (energy savings), coded using dummy variables. Equation 10 shows the basic ANOVA model to estimate each home's savings ($\widehat{ES}_{i,Pre|Post}$) and construct 95% confidence intervals (CIs) around the resulting mean energy savings estimates for groups of participant homes (DSM_D).

$$\widehat{ES}_{i,Pre|Post} = \Delta EP_{i,Pre|Post} = \gamma_z(DSM_D) + \varepsilon_{i,Pre|Post} \qquad (10)$$

The resulting ANOVA parameter estimate, γ_z is the energy savings estimate for a particular DSM program or measure, z. In this step of the analysis, changes in residuals between one year and the next (*ES*) for each rebate participant subgroup (calculated using Equations 7 and 9) are the dependent variables and program/retrofit measure subgroups (coded as dummy variables) are used as the explanatory variables to distinguish the population subgroup of interest from all other comparable homes in the analysis dataset. The parameter coefficient, γ_z, estimated for a particular DSM intervention tells us the magnitude and direction of change in EP (i.e., energy savings) post-intervention. The P-test on the F-statistic provides a measure of statistical significance for the mean energy savings estimates.

The ACB screening process removes statistical and practical outliers from the analysis, which results in exclusion of some treatment (participant) and control (baseline) records. Thus, confidence in the mean savings estimates should always be considered when extrapolating to an entire population of rebate participants (to estimate overall/aggregate program impact, for example). In addition to levels of statistical significance, the ANOVA also provides CIs around the mean savings estimates, which address this need.

4.3 Orlando Utilities Commission Annual Community Baselines-Normalized Performance Model

To specifically apply the ACB protocol to evaluate OUC residential energy efficiency DSM impact, BEEHA assessed the energy savings from three programs and seven specific installation/retrofit measures implemented in calendar year 2009 (the intervention year). ACB performance measures were estimated for the near-census population of OUC SFD homes, the pre-intervention year is 2008, and the post-intervention year is 2010.

Equation 11 shows the specific OLS regression model used to estimate ACB performance measures (following Equation 1), where annual absolute energy consumption (*EC*, measured in kilowatt-hours) functions as the dependent/outcome variable and conditioned area (*CA*), number of bedrooms (*BR*), number of bathrooms (*BA*), and year built (*YB*) functions as the independent/predictor variables.

$$EC_{ij} = \beta_0 + \beta_1 * CA_{i,j} + \beta_2 * BR_{i,j} + \beta_3 * BA_{i,j} + \beta_4 * YB_{i,j} + \varepsilon_i \qquad (11)$$

Number of bedrooms and bathrooms, and square feet of conditioned area are important explanatory factors for EC because they indicate the number of people living in each home and HVAC demand, respectively (Macdonald and Livengood 2000). Year built is also considered an important energy use predictor variable, as it captures the building code under which the home was constructed and the common building practice used in that particular time period (DOE 2012).

Each calendar year dataset was analyzed independently using this basic ACB model (following Equations 2 to 9). The pre-retrofit (2008) to post-retrofit (2010) dynamic ACB performance measures for DSM/rebate participant groups was compared to the respective change for nonparticipants using one-way ANOVA (Equation 12), where γ_z is a vector of the OUC rebate measures evaluated. The results represent first-year (2010) savings estimates attributable to each DSM/rebate program and provide 95% CIs around the mean energy savings estimates.

$$\widehat{ES}_{i,08|10} = \Delta EP_{i,08|10} = \gamma_z(DSM_D) + \varepsilon_{i,08|10} \qquad (12)$$

Section 5 provides results of the ACB analysis of OUC DSM program impact.

5 Results

Using the ACB analysis protocol detailed in Section 4, this analysis evaluated the first-year (2010) post-retrofit performance of seven of OUC's retrofit/upgrade measures (within three rebate programs) implemented in calendar year 2009: ceiling insulation, duct repair/replacement, SEER 14 HP, SEER 15 HP, SEER 16 HP, SEER 17 HP, and SEER 18 HP.[15] Relative (percent) and absolute (kilowatt-hour) energy savings were estimated for each DSM program and measure by comparing the mean changes in ACB-normalized performance between the pre-retrofit year (2008) and the post-retrofit year (2010) for rebate participant groups versus nonparticipant groups.

5.1 Pre-Retrofit and Post-Retrofit Static Performance

Figures 6 and 7 show pre-retrofit (2008) versus post-retrofit (2010) absolute consumption in both actual/measured (directly from the final analysis dataset) and ACB-predicted (calculated using Equation 11 from Section 4.1.2) values. These static performance measures are also listed in Table 10.

Table 10. DSM Participant Actual and ACB-Predicted Consumption

DSM Program or Installation Measure	(n)	Actual Consumption (kWh)			ACB-Predicted Consumption (kWh)		
		2008	2010	% Δ	2008	2010	% Δ
Ceiling Insulation	44	18,530	18,756	1.2%	17,520	18,911	7.9%
Duct Repair/Replacement	17	19,124	19,179	0.3%	17,014	18,373	8.0%
High-Efficiency HP	236	17,844	17,118	–4.1%	17,918	19,314	7.8%
SEER 14 HP	15	13,656	13,631	–0.2%	17,481	18,870	7.9%
SEER 15 HP	138	17,211	16,593	–3.6%	17,518	18,880	7.8%
SEER 16 HP	44	20,223	19,091	–5.6%	19,371	20,855	7.7%
SEER 17 HP	31	20,790	19,649	–5.5%	18,452	19,889	7.8%
SEER 18 HP	8	12,112	12,051	–0.5%	15,570	16,912	8.6%
All Participants	297	18,019	17,478	–3.0%	17,807	19,200	7.8%
ACB Population	32,289	16,784	18,106	7.9%	16,764	18,087	7.9%

[15] Savings estimates for HVAC upgrades reflect total energy saved after upgrade and account for savings differentials from original equipment (assumed to be nominally SEER 10) and new equipment. The current building code requirement for new HVAC equipment is minimum SEER 13. This study contains no data related to energy efficiency gains from replacing older systems with code-minimum HVAC systems. Furthermore, because original equipment efficiencies and code-minimum upgrade rates in 2009 are unknown, savings estimates may be slightly skewed. See Section 7 for further details.

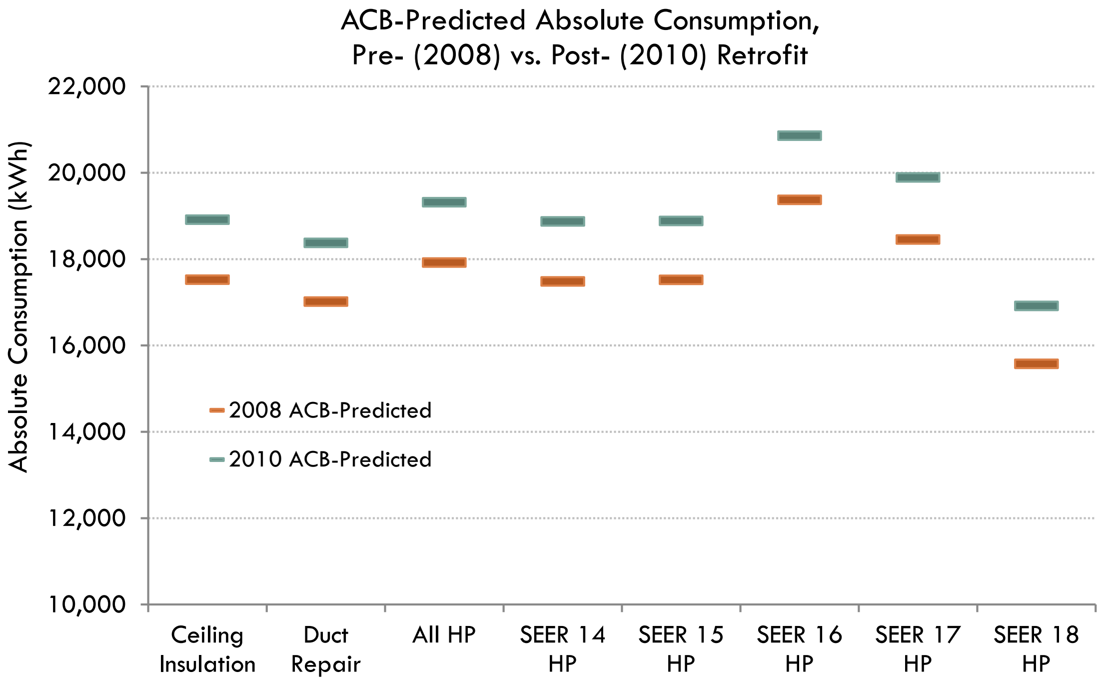

Figure 6. ACB-predicted absolute consumption, pre-retrofit versus post-retrofit

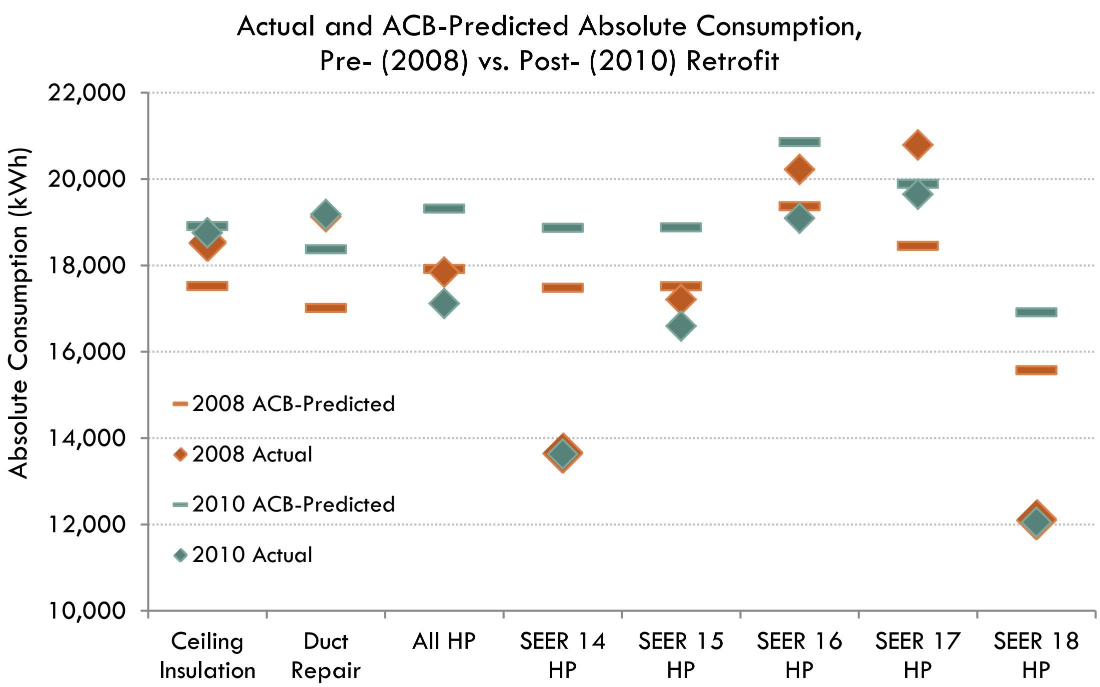

Figure 7. Actual and ACB-predicted absolute consumption, pre-retrofit versus post-retrofit

Figure 6 graphs only the ACB-predicted values in each year for each rebate participant subgroup. ACB-predicted absolute EC increases (i.e., comparison-group baselines shift up) for all participant subgroups from 2008 (orange markers) to 2010 (green markers). This result is as expected given that, at a population level within years, average ACB-predicted consumption should always match average absolute consumption, so year-over-year percent shifts in these averages should also match. Also, because each ACB is derived as a function of each individual home's building characteristics, the average ACB-predicted values for each subgroup vary across the three DSM programs and five HP retrofit measures. In pre-retrofit and post-retrofit years across all rebate participant subgroups, the SEER 18 HP participants were predicted to perform the best (i.e., consume the least absolute energy), on average; the SEER 16 HP participant subgroup was predicted to perform the worst, on average. Overall, the 297 rebate participants are expected to consume approximately1,000 kWh more, on average in both years, than the entire ACB population, while both of their respective baselines shifted up by approximately 8%[16] (Table 10).

To quantify and test the magnitude and significance of these shifts in static ACB performance, BEEHA first calculated absolute and relative performance in both years (using Equations 2–5 from Section 4.1.1.1). These static performance measures are graphed in Figures 8 and 9 and listed in Table 11. Using the SEER 15 HP participants as an example, Figures 8 and 9 show that this group's performance, on average, shifted from 2% (307 kWh) below the baseline to 12% (2,288 kWh) below the baseline between 2008 and 2010, suggesting a 10% (approximately 2,000 kWh) average energy savings. In fact, all rebate participant subgroups improve performance relative to their baselines, and three of the four subgroups with pre-retrofit consumption above their baselines improved performance enough that their consumption, on average, dropped below their post-retrofit (2010) baselines. Duct repair participants were the only subgroup that did not consume below their ACB-predicted baselines, on average, in 2010. However, this group of homes consumed 12% above their baselines, on average, in 2008, so they would have had to save a minimum of 12% from the duct repairs to achieve this performance goal (consuming below their baselines in 2010), and it may not be realistic to expect savings of this magnitude from duct repair alone.

[16] As noted previously, this shift in consumption from the pre-intervention period to the post-intervention period for the population could be explained by differences in weather, economic conditions, or other across-year variables, but an explanation of why this shift occurs is beyond the scope of this analysis.

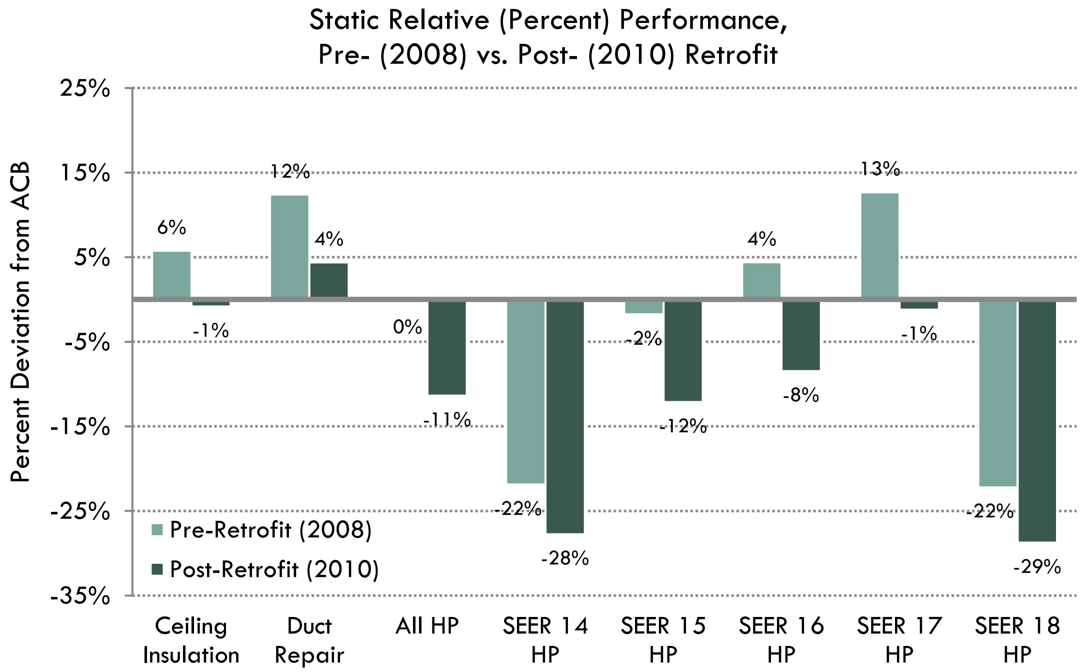

Figure 8. Static relative (percent) ACB performance, pre-retrofit versus post-retrofit

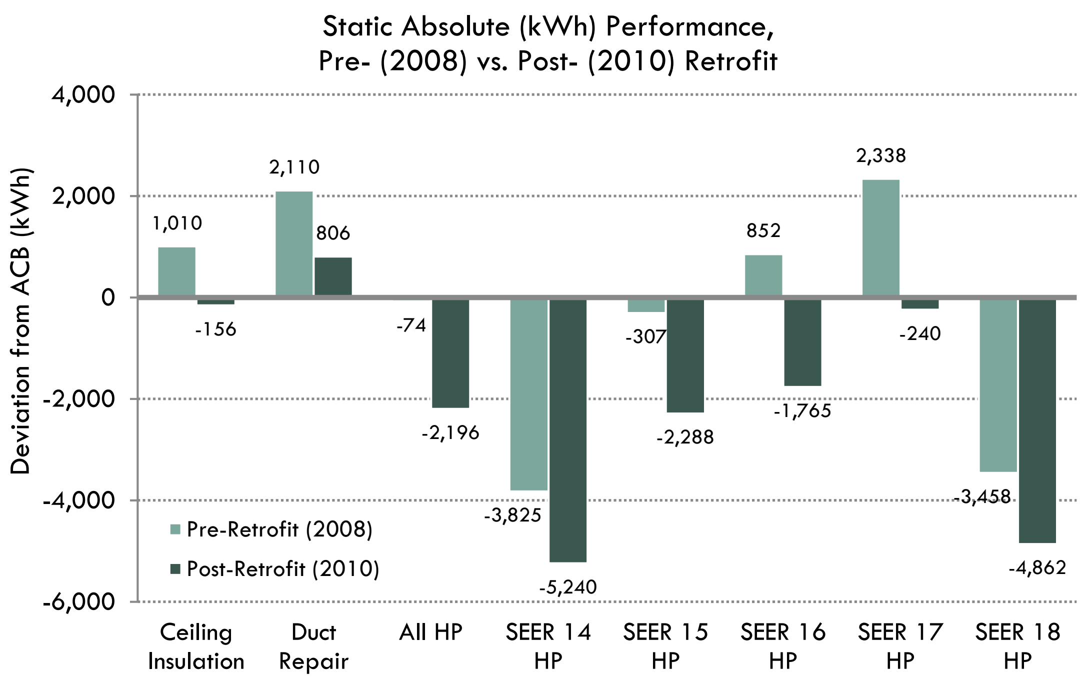

Figure 9. Static absolute (kWh) ACB performance, pre-retrofit versus post-retrofit

Table 11. DSM Participant Static (Within-Year) ACB Performance Measures

DSM Program or Installation Measure	(n)	EC/Performance Measures				
		Actual	Static ACB-Predicted			
		2008 (kWh)	2008 (%)	2010 (%)	2008 (kWh)	2010 (kWh)
Ceiling Insulation	44	18,530	6%	–1%	1010	–156
Duct Repair/Replacement	17	19,124	12%	4%	2110	806
High-Efficiency HP	236	17,844	0%	–11%	–74	–2196
SEER 14 HP	15	13,656	–22%	–28%	–3825	–5240
SEER 15 HP	138	17,211	–2%	–12%	–307	–2288
SEER 16 HP	44	20,223	4%	–8%	852	–1765
SEER 17 HP	31	20,790	13%	–1%	2338	–240
SEER 18 HP	8	12,112	–22%	–29%	–3458	–4862
All Participants	297	18,019	1%	–9%	212	–1722
ACB Population	32,289	16,784	0%	0%	20	19

Next, BEEHA plotted actual pre-retrofit and post-retrofit consumption against the ACB averages for each rebate participant subgroup (Figure 7, with actual values indicated by the diamonds). In both years, the SEER 17 HP participants consumed the most absolute energy, on average (20,790 kWh in 2008 and 19,649 in 2010) and the SEER 18 HP participants consumed the least, on average (12,112 kWh in 2008 and 12,051 kWh in 2010). When measured as percent change in consumption between pre-retrofit and post-retrofit years, the SEER 16 HP participants seemed to improve the most (consuming 5.6% less) and the ceiling insulation participants improved the least (consuming 1.2% more). However, these changes in absolute consumption are not reliable measures of performance. Instead, the post-retrofit consumption shifts down *relative to baseline* in this figure showing reliable measures of energy savings. For example, the SEER 15 HP participants' actual pre-retrofit average absolute consumption of 17,211 kWh was less than and close to its ACB-predicted pre-retrofit average consumption of 17,518 kWh. Although the baseline/expected absolute consumption for this group of homes shifted up (by 7.8%) in 2010 relative to the 2008 baseline, the SEER 15 HP participants' actual absolute consumption fell from 17,211 to 16,593 kWh. This pre-retrofit versus post-retrofit change is small when measured in terms of a shift in actual absolute consumption (–618 kWh or –3.6%), but Figures 6 and 7 depict it as a significant shift when measured in terms of pre-retrofit versus post-retrofit actual consumption relative to ACB-predicted consumption.

Figures 8 and 9 show wide variation in pre-retrofit static ACB performance across the rebate participant subgroups. Four start above their respective baselines, four start below, and the high-efficiency HP participants overall start on their ACB. It was reasonable to expect that the greatest energy savings would be achieved by those consuming above their respective baselines in the pre-retrofit years (e.g., the ceiling insulation, duct repair, and SEER 17 subgroups), because they have the greatest potential consumption to offset with efficiency measures. From an engineering and building science perspective, diminishing returns to energy efficiency investments are common, and the SEER 14 and SEER 18 HP participants apparently were already efficient (i.e., performing well) relative to comparable OUC homes. Our analysis of pre-retrofit static performance suggests that these particular homes/customers may not be the best candidates to achieve substantive energy savings at the margin.

5.2 Energy Savings

Next, the analysis moved from static to ΔEP to assess the impact of OUC's residential energy efficiency rebate programs/retrofit measures. The study used the measured shifts in absolute consumption relative to ACB consumption to calculate post-retrofit changes in EP (using Equations 6–9 in Section 4.1.1.2), tests for energy savings, and construct CIs around the participant subgroups' mean savings estimates relative to those of nonparticipants (Equations 10 and 12). Figures 10 and 11 and Table 12 show rebate participants' first-year mean percent savings estimates and 95% CIs for the means by program and rebate measure. Figures 12 and 13 and Table 13 show mean absolute savings estimates and 95% CIs.

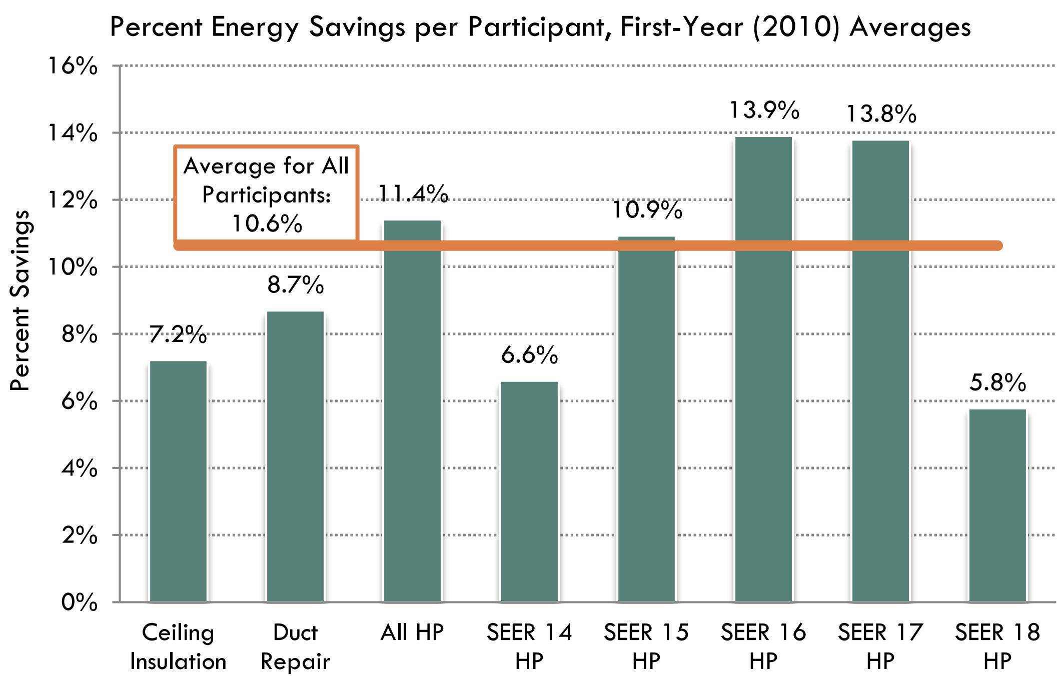

Figure 10. Percent energy savings

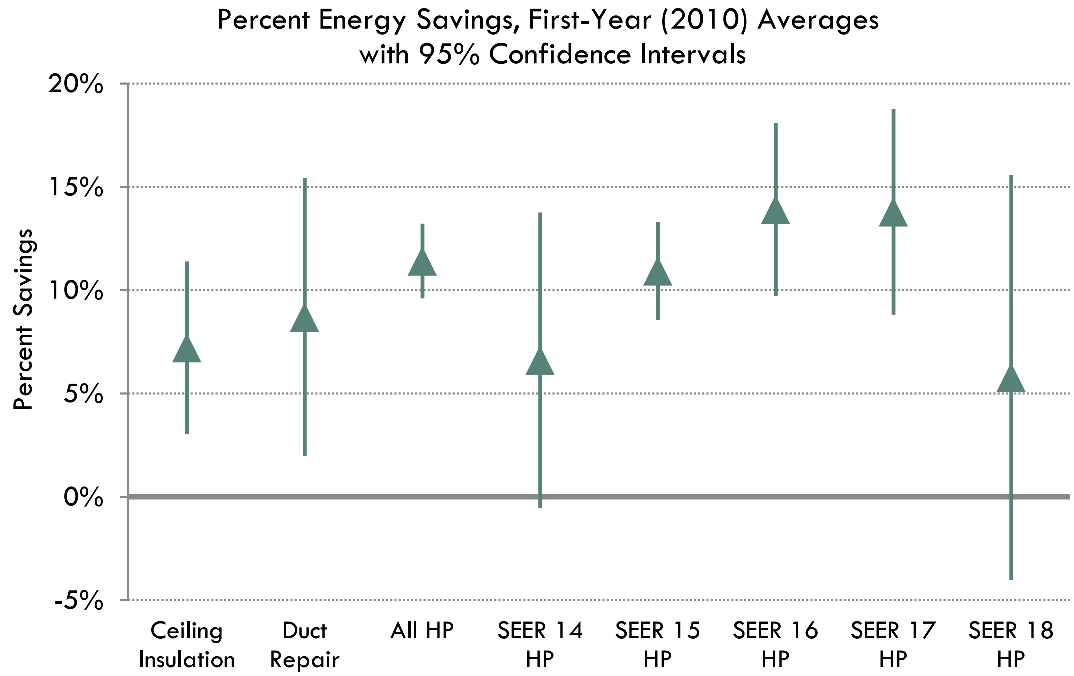

Figure 11. Percent energy savings, including 95% Confidence Intervals

Table 12. Percent Energy Savings, P-Values, and 95% CIs

DSM Program or Installation Measure	(n)	Average First-Year (2010) Percent Energy Savings			
		Savings (%)‡	P-Value	Lower 95% CI	Upper 95% CI
Ceiling Insulation	44	7.2 ***	0.0007	3.0	11.4
Duct Repair/Repl.	17	8.7 **	0.0112	2.0	15.4
All HPs	236	11.4 ***	<.0001	9.6	13.2
SEER 14 HP	15	6.6 *	0.0705	-0.6	13.8
SEER 15 HP	138	10.9 ***	<.0001	8.6	13.3
SEER 16 HP	44	13.9 ***	<.0001	9.7	18.1
SEER 17 HP	31	13.8 ***	<.0001	8.8	18.8
SEER 18 HP	8	5.8 –	0.2475	-4.0	15.6
All Participants	297	10.6 ***	<.0001	9.0	12.2
ACB Population	32,289	0.0 ***	<.0001	-0.1	0.1

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

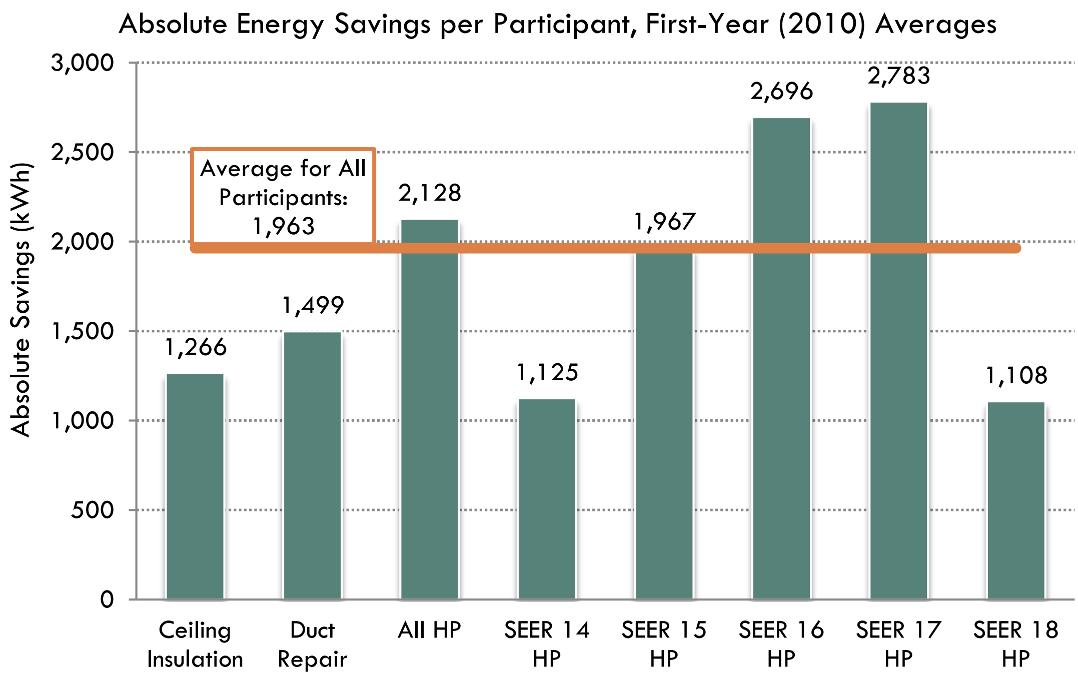

Figure 12. Absolute energy savings

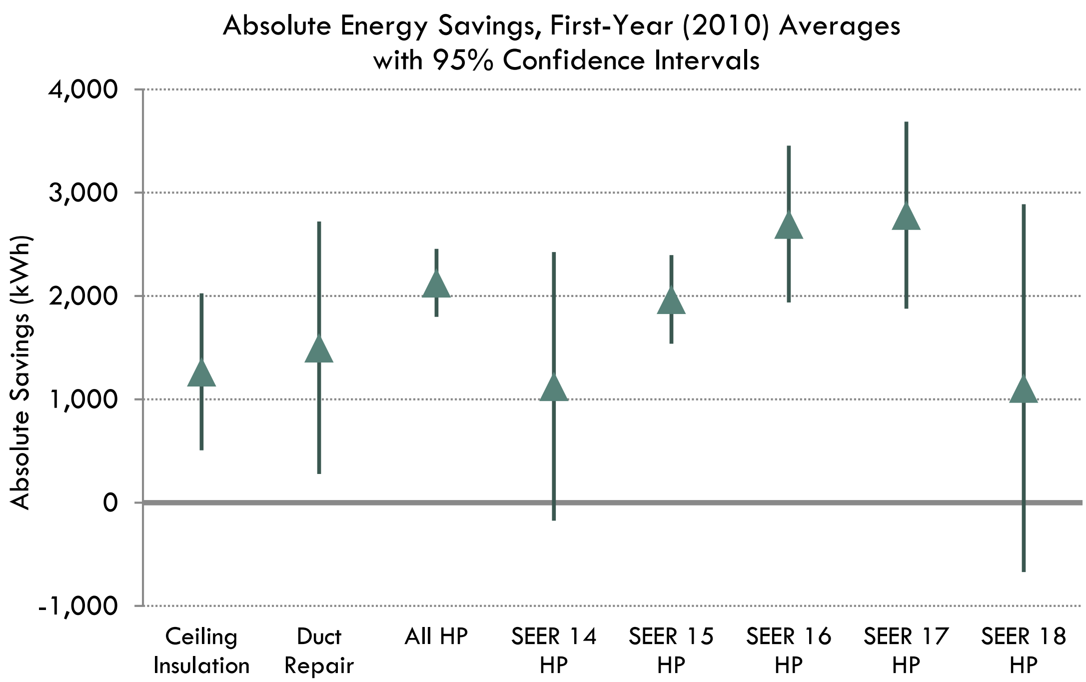

Figure 13. Absolute energy savings, including 95% Confidence Intervals

Table 13. Absolute Energy Savings, P-Values, and 95% CIs

DSM Program or Installation Measure	(n)	Average First-Year (2010) Absolute Energy Savings			
		Savings (kWh) ‡	P-Value	Lower 95% CI	Upper 95% CI
Ceiling Insulation	44	1,266 ***	0.0011	506	2,025
Duct Repair/Repl.	17	1,499 **	0.0161	278	2,720
All HPs	236	2,128 ***	<0.0001	1,799	2,456
SEER 14 HP	15	1,125 *	0.0899	–175	2,425
SEER 15 HP	138	1,967 ***	<0.0001	1,538	2,397
SEER 16 HP	44	2,696 ***	<0.0001	1,937	3,456
SEER 17 HP	31	2,783 ***	<0.0001	1,878	3,687
SEER 18 HP	8	1,108	0.2226	–673	2,888
All Participants	297	1,963 ***	<0.0001	1,670	2,257
ACB Population	32,289	0 ***	<0.0001	–28	28

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

5.2.1 Demand Side Management Program/Retrofit Measure Impact

The energy savings estimates for all rebate measures were positive, averaging 10.6% (1,963 kWh) across the three DSM programs. The study shows with at least 95% confidence that all programs and all measures except SEER 14 and SEER 18 HP result in statistically significant first-year energy savings relative to nonparticipant ACB comparison groups.[17] Across the three programs (ceiling insulation, duct repair, and all high-efficiency HPs), the HP retrofits performed the best, on average, as measured by both relative and absolute energy savings (11.4% and 2,128 kWh first-year savings) and the ceiling insulation retrofits resulted in the least savings (7.2% and 1,266 kWh first-year savings). Across the seven individual rebate measures, savings ranged from a low of 5.8% (1,108 kWh) for the SEER 18 units to a high of 13.9% for SEER 16 and 13.8% (2,783 kWh) for SEER 17 HP retrofits. Although BEEHA does not have data on the SEER ratings of the pre-retrofit HVAC systems, the absolute energy savings estimates trend as engineering models and deemed savings estimates would predict—with marginal increases in the efficiency ratings of the HPs returning marginal increases in absolute savings (with the exception of the SEER 18 units).[18] In other words, between SEER 14 and SEER 17, participants who installed HPs with higher SEER ratings had greater absolute energy savings, on average, than those who installed lower SEER-rated systems.

[17] This is in part due to the small samples of participants in these two rebate subgroups (15 of SEER 14 and 8 of SEER 18). The SEER 14 participant average energy savings estimate of 6.6% (1,125 kWh) is significant at the 90% level.

[18] BEEHA believes that the SEER 18 HP performance can be explained by the fact that participating homes were consuming significantly less energy pre-retrofit than comparable OUC homes, suggesting that the marginal opportunity for savings among these particular homes is nominal.

When interpreting savings estimates, it is important to understand the statistical interpretation of the CIs and confidence levels for the means. The CIs for the mean estimates provide a range of savings that captures the true mean savings 95% of the time. For example, repeatedly taking random samples from the full population of ceiling insulation rebate participants and measuring their mean energy savings indicate that 95% of the time our CIs of 3%–11.4% and 506 to 2,025 kWh savings would capture the true/actual percent and absolute savings of these rebate participants. Confidence levels associated with savings estimates indicate the likelihood of the average EC of rebate participants differing from that of nonparticipants. For example, the average absolute first-year savings of the ceiling insulation participants is 1,266 kWh. The study found with 99% confidence that, on average, the ceiling insulation rebate participants save more energy in 2010 versus 2008 than did comparable nonparticipants: the average position relative to the average baseline/expected performance improves significantly pre-retrofit versus post-retrofit.

5.2.2 Energy Savings, Housing Characteristics, and Static ACB Performance

Next, the study considered the energy savings estimates and their relation to housing characteristics and pre-retrofit EP of rebate participant homes. Although a detailed quantitative analysis of these relationships is beyond the scope of this analysis, BEEHA provides examples of the types of ACB-based analyses that offer potential for targeting DSM programs/retrofit measures to maximize energy savings. Table 14 shows the average conditioned area, age, pre-retrofit absolute consumption, first-year post-retrofit percent energy savings, and first-year post-retrofit absolute energy savings for each OUC residential energy efficiency rebate participant subgroup. The participant subgroups with newer, larger homes consuming relatively high levels of pre-retrofit absolute EC saved more energy post-retrofit, on average, than the participant subgroups with older, smaller homes. Perhaps it is intuitive that the high energy consumers and homes would have the greatest potential at the margin to save energy, and static measures of ACB performance might help utilities target specific retrofits to specific homes to maximize overall energy savings.

Table 14. Housing Characteristics and Energy Savings (Averages)

DSM Program or Installation Measure	(n)	Home Area (ft^2)	Home Age (yrs)	2008 Actual EC (kWh)	Average First-Year (2010) Energy Savings‡	
					(%)	(kWh)
Ceiling Insulation	44	1,844	44	18,530	7.2 ***	1,266 ***
Duct Repair/Repl.	17	1,700	43	19,124	8.7 **	1,499 **
HP	236	1,914	39	17,844	11.4 ***	2,128 ***
SEER 14 HP	15	1,764	43	13,656	6.6 *	1,125 *
SEER 15 HP	138	1,868	38	17,211	10.9 ***	1,967 ***
SEER 16 HP	44	2,154	39	20,223	13.9 ***	2,696 ***
SEER 17 HP	31	1,991	37	20,790	13.8 ***	2,783 ***
SEER 18 HP	8	1,377	51	12,112	5.8	1,108
All Participants	297	1,892	40	18,019	10.6	1,963 ***

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

For example, targeting specific homes may maximize savings using the SEER 15 HP participant subgroup. BEEHA divided the 138 SEER 15 participants into two new subgroups using their pre-retrofit (2008) static ACB EP as the delineator. Homes that consume more energy than their ACB-predicted value in 2008 fall into the high group (n=64), and homes that consume less than their ACB-predicted value in 2008 fall the low group (n=74). Next, BEEHA used the same ACB methods described previously to calculate first-year post-retrofit energy savings for these two SEER 15 participant subgroups (Table 15). The high pre-retrofit absolute consumption group saves an estimated 17.8% (3,088 kWh) in 2010; the low pre-retrofit absolute consumption group saved only about 5.7% (963 kWh) in 2010. The low pre-retrofit households may have pulled the mean energy savings for the SEER 15 rebate participant subgroup down (or similarly the high pre-retrofit households may have pulled the mean energy savings for the participant subgroup up). In practical terms, this suggests the potential to improve average and overall savings by targeting and marketing retrofits to the relatively high energy users (as measured using static absolute or relative ACB performance).

Table 15. Targeting Retrofits: SEER 15 HP Example

DSM Program or Installation Measure	(n)	2008 Actual Cons (kWh)	2008 Static ACB EP (kWh)	Average First-Year (2010) Energy Savings‡	
				(%)	(kWh)
Ceiling Insulation	44	18,530	1,010	7.2 ***	1,266 ***
Duct Repair/Replacement	17	19,124	2,110	8.7 **	1,499 **
HP	236	17,844	–74	11.4 ***	2,128 ***
SEER 14 HP	15	13,656	–3,825	6.6 *	1,125 *
SEER 15 HP	138	17,211	–307	10.9 ***	1,967 ***
SEER 15 HP Pre-Retrofit High	64	21,660	4,236	17.8 ***	3,088 ***
SEER 15 HP Pre-Retrofit Low	74	13,362	–4,236	5.7 ***	963 ***
SEER 16 HP	44	20,223	852	13.9 ***	2,696 ***
SEER 17 HP	31	20,790	2,338	13.8 ***	2,783 ***
SEER 18 HP	8	12,112	–3,458	5.8	1,108
All Participants	297	18,019	212	10.6	1,963 ***

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

5.3 Rebate Cost Effectiveness

Next the study addressed rebate cost-effectiveness measures. Rebate dollars invested by OUC for each retrofit program and measure evaluated were applied to the average first-year energy savings estimates to calculate implicit measures of OUC's rebate cost ($/kWh saved) and kWh saved per rebate dollar invested (kW/$) (Figure 14 and Table 16). Using housing characteristics data for each program and retrofit measure subgroup and applying them to OUC's rebate incentive criteria (described in Table 4), BEEHA calculated the average rebate incentive provided to customers of each retrofit subgroup.

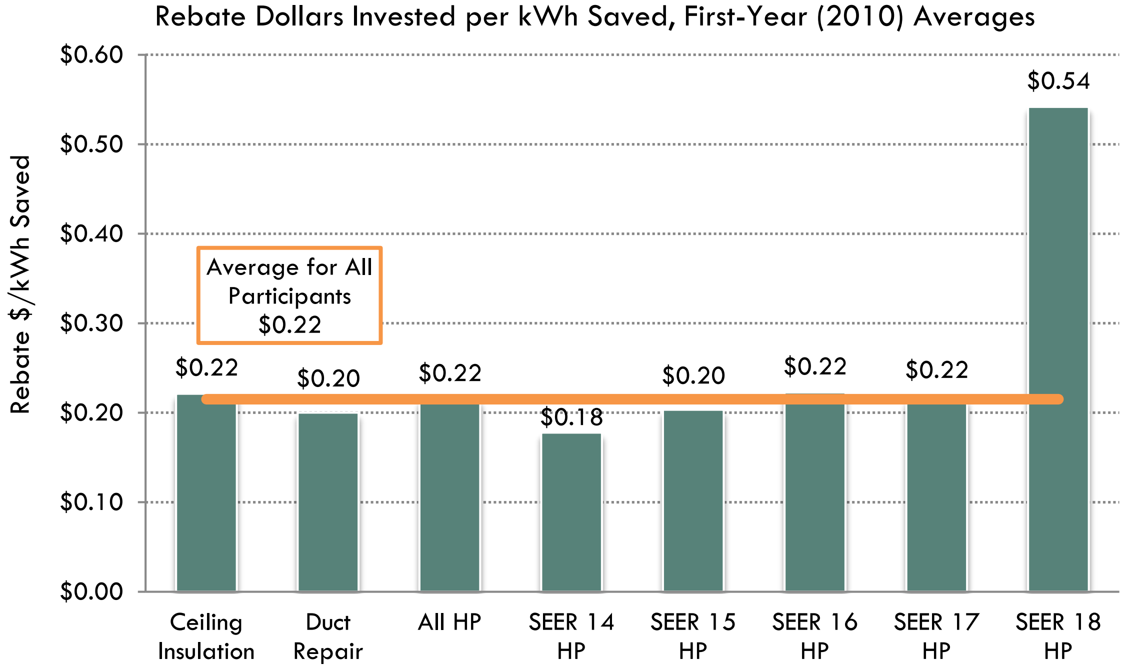

Figure 14. Rebate cost effectiveness

Table 16. Rebate Cost Effectiveness

DSM Program or Installation Measure	(n)	Average First-Year (2010) Energy Savings (kWh)‡	Average Rebate Amount	Average 2010 Rebate ($/kWh Saved)	Average kWh Saved per 2010 Rebate ($)
Ceiling Insulation	44	1,266 ***	$280	$0.22	4.5
Duct Repair	17	1,499 **	$300	$0.20	5.0
All HPs	236	2,128 ***	$458	$0.22	4.6
SEER 14 HP	15	1,125 *	$200	$0.18	5.6
SEER 15 HP	138	1,967 ***	$400	$0.20	4.9
SEER 16 HP	44	2,696 ***	$600	$0.22	4.5
SEER 17 HP	31	2,783 ***	$600	$0.22	4.6
SEER 18 HP	8	1,108	$600	$0.54	1.8
All Participants	297	1,963 ***	$422	$0.22	4.7

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

Measures of program effectiveness in rebate $/kWh saved are relatively consistent across programs and retrofits. The average across the three DSM programs is $0.22/kWh saved and all fall within the range $0.18 to $0.22/kWh saved, except the SEER 18 HP (at $0.54/kWh saved).

The inverse rebate cost-effectiveness measures (kWh saved per rebate dollar invested, Table 16) for specific retrofits range from a low of 1.8 kWh/$ for the SEER 18 HP to 5.6 kWh/$ for the SEER 14 HP. Although the SEER 14 HP absolute and percent savings per participant were the second-lowest across all retrofit measures, they were the most effective as measured in terms of rebate incentive cost effectiveness.

The energy savings used to estimate rebate invested $/kWh saved and kWh/$ invested are estimated *only* for the first year following the retrofit, and participants receive the rebate incentive as a one-time payment. Therefore, BEEHA expects the rebate cost-effectiveness ratios presented in this report to decrease over time as participants realize additional energy savings with no additional utility investment. Because these cost-effectiveness measures are derived using the energy savings estimates, the mean energy savings estimates are only marginally statistically significant ($P < .10$) for the SEER 14 HP participant group, and are not statistically significant ($P = 0.2226$) for the SEER 18 HP participant group.

5.4 Homeowner Electricity Bill Savings

Next, this study analyzed the implications of the energy savings from the homeowner perspective and estimated the average first-year (2010) post-retrofit electricity bill savings (or more precisely, avoided electricity costs) for each of the rebate participant groups. Assuming that each kilowatt-hour of energy saved translates directly to an annual avoided cost of $0.12 (OUC's 2010 residential electric rate per kilowatt-hour over 1000 kWh/month including base and fuel charges), rebate participants first-year electricity bill savings averaged $236 and ranged from $133 for the SEER 18 HP retrofit homes to $334 for the SEER 17 HP retrofit homes (Figure 15 and Table 17). Across the three programs evaluated, the aggregate first-year post-retrofit savings for the 297 participants evaluated amount to $69,996. These findings have important implications for energy efficiency loan programs, because they provide context for the likely magnitude and variability of energy and monetary savings resulting from specific retrofits to specific types of homes. The data can be investigated further and in subsequent years using ACB methods to characterize the relationships between housing characteristics and the likelihood of significant, consistent, and persistent energy savings from specific retrofit measures.

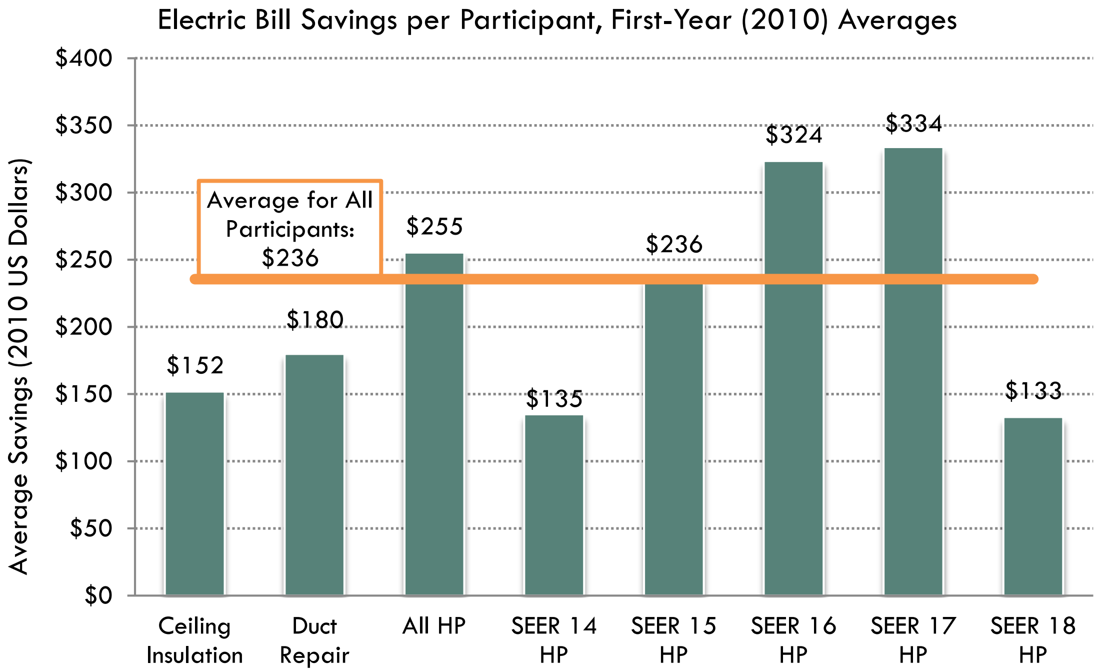

Figure 15. Homeowner electricity bill savings

Table 17. Homeowner Energy and Electricity Bill Savings

DSM Program or Installation Measure	(n)	Average First-Year (2010) Energy Savings (kWh)‡	Average Rebate Amount	Average 2010 Electricity bill Savings ($)	Aggregate 2010 Electricity bill Savings ($)
Ceiling Insulation	44	1,266 ***	$280	$152	$6,683
Duct Repair	17	1,499 **	$300	$180	$3,058
All HPs	236	2,128 ***	$458	$255	$60,255
SEER 14 HP	15	1,125 *	$200	$135	$2,025
SEER 15 HP	138	1,967 ***	$400	$236	$35,579
SEER 16 HP	44	2,696 ***	$600	$324	$14,237
SEER 17 HP	31	2,783 ***	$600	$334	$10,351
SEER 18 HP	8	1,108	$600	$133	$1,063
All Participants	297	1,963 ***	$422	$236	$69,996

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

5.5 Homeowner Investment Cost Effectiveness

Finally, this study used estimates of electricity bill savings, total and marginal material and installation costs, and projected useful lifetimes for each DSM retrofit to calculate homeowner energy efficiency upgrade cost-effectiveness measures. Total and marginal upgrade costs were calculated using average estimates for each upgrade/retrofit (including material and installation costs) from two sources: the National Renewable Energy Laboratory National Residential Efficiency Measures Database (NREL 2011) and Ferran Services & Contracting (Ferran 2011), one of OUC's primary residential contractors. Average costs for each upgrade/retrofit measure from each source were calculated based on the mean conditioned floor area of homes in each rebate participant group so that they were realistic for typical homes in the OUC region and specific to the participant homes of interest. For the high-efficiency HP upgrades, BEEHA assumed HVAC system sizing of 1 ton/450 ft^2 of conditioned area.

Total upgrade/retrofit costs include all materials and installation, while marginal retrofit costs account for only the differential between total cost at the installed efficiency level and total cost at the base (or minimum) level required to qualify for the rebate. For ceiling insulation and duct repair, the alternative (base) retrofit scenarios are assumed to be no action, so the total and marginal costs are the same for these retrofit measures ($1,383 and $1,122 per participant home, respectively). For the high-efficiency HP, marginal costs are calculated for each SEER rating level as those incurred beyond the expected cost for purchasing and installing a new SEER 13 unit of equal quality.[19] These marginal costs range from $0 for the SEER 14 HP[20] to $1,328 for the SEER 17 HP[21] and average $1,080 across all participants (Table 18). (Ferran 2011; NREL 2011).

[19] This analysis assumed that all homes replaced units at the end of their useful lives and, similarly, that prospective high-efficiency HP rebate participants chose to participate only if their units are at or near the end of their useful lives.

[20] Both the National Efficiencies Measures Database and Ferran Services and Contracting quoted a $0 cost differential for upgrade to a SEER 13 versus upgrade to a SEER 14 unit.

[21] In a given home, the costs were higher for a SEER 18 HP system than for a SEER 17 system of the same size. This analysis calculates costs specific to the typical home in each of the rebate participant subgroups, including assumptions about the sizing of the HP system installed. Because the SEER 18 HP participant homes were smaller, on average, than the SEER 17 homes, their average marginal installation costs presented here are lower than those of the SEER 17 HP subgroup.

Table 18. Homeowner Energy Efficiency Investment: Benefits and Costs

DSM Program or Installation Measure	First-Year (2010) Energy Savings (kWh)‡	2010 Electricity bill Savings	Rebate Received	Total Upgrade Cost	Marginal Upgrade Cost	Life of Retrofit (Yrs)
Ceiling Insulation	1,266 ***	$152	$280	$1,383	$1,383	30[22]
Duct Repair	1,499 **	$180	$300	$1,122	$1,122	15
All HPs	2,128 ***	$255	$458	$7,146	$1,021	16
SEER 14 HP	1,125 *	$135	$200	$5,645	$0	16
SEER 15 HP	1,967 ***	$236	$400	$6,475	$498	16
SEER 16 HP	2,696 ***	$324	$600	$8,042	$1,149	16
SEER 17 HP	2,783 ***	$334	$600	$7,700	$1,328	16
SEER 18 HP	1,108	$133	$600	$5,690	$1,285	16
All Participants	1,963 ***	$236	$422	$5,948	$1,080	18

‡Levels of statistical significance denoted by * (<0.10), ** (<.05) and *** (<.01).

The homeowner investment cost-effectiveness measures (lifetime cost per kilowatt-hour saved and simple payback period on the marginal investment) were calculated both with and without the rebate incentive (Figures 16 and 17 and Table 19). BEEHA used these cost-effectiveness measures rather than other commonly-applied indicators of cost effectiveness (such as the Total Resource Cost Test) because of its relevance and ease of interpretation and because of debate about the most appropriate measure to use in the field (Neme and Kushler 2010).

[22] The useful lifespan for attic insulation is quoted in the National Residential Efficiency Measures Database as 999 years (NREL 2011). BEEHA adjusted this number to 30 years to represent a more conservative estimate of the expected lifespan in a hot, humid climate.

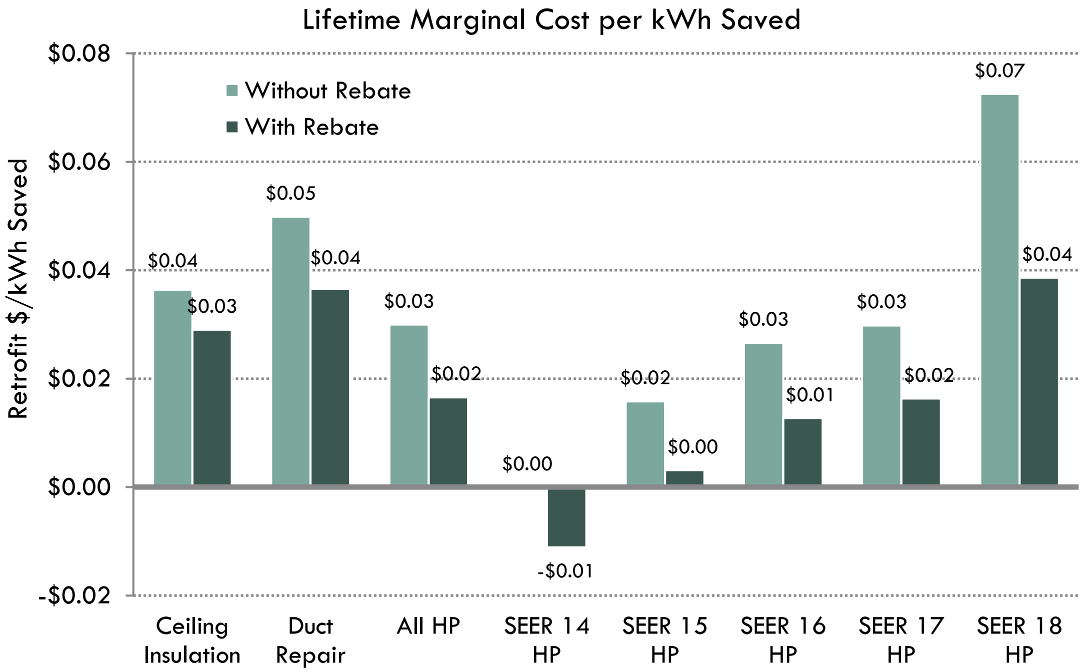

Figure 16. Homeowner energy efficiency investment: lifetime marginal cost per kilowatt-hour saved

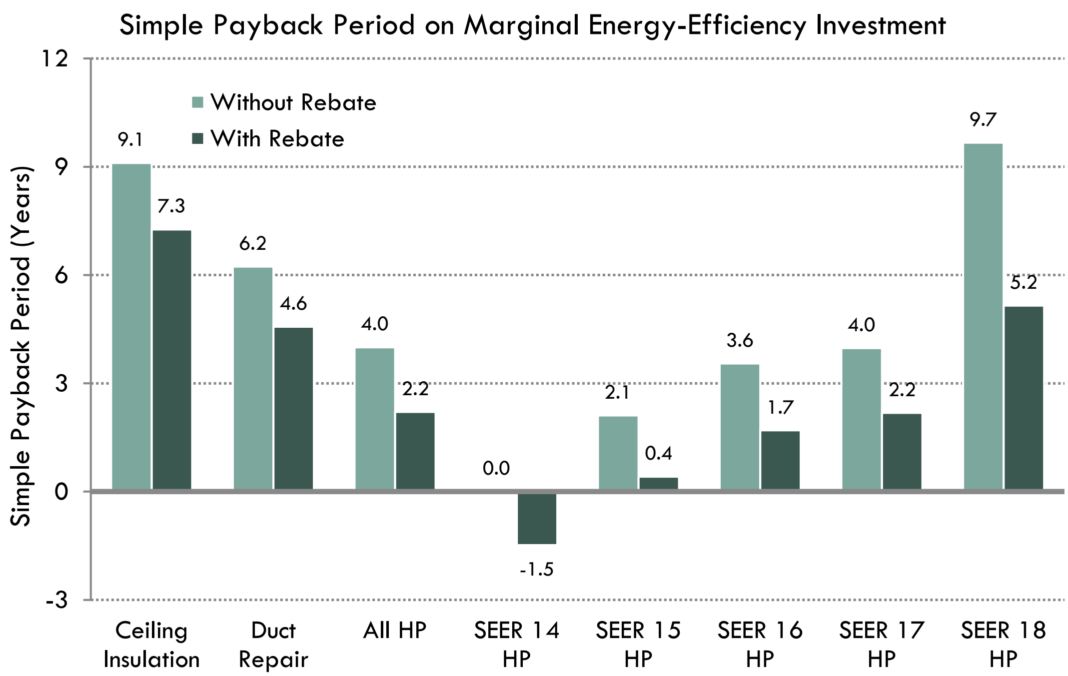

Figure 17. Homeowner energy efficiency investment: simple payback period

Table 19. Homeowner Energy Efficiency Investment: Lifetime Cost Effectiveness and Simple Payback Period

DSM Program or Installation Measure	First-Year (2010) Energy Savings (kWh)‡		Life of Retrofit (Yrs)	Lifetime Cost per kWh Saved		Simple Payback Period (Years)	
				With Rebate	Without Rebate	With Rebate	Without Rebate
Ceiling Insulation	1,266	***	30	$0.03	$0.04	7.3	9.1
Duct Repair	1,499	**	15	$0.04	$0.05	4.6	6.2
All HPs	2,128	***	16	$0.02	$0.03	2.2	4.0
SEER 14 HP	1,125	*	16	–$0.01	$0.00	–1.5	0.0
SEER 15 HP	1,967	***	16	$0.00	$0.02	0.4	2.1
SEER 16 HP	2,696	***	16	$0.01	$0.03	1.7	3.6
SEER 17 HP	2,783	***	16	$0.02	$0.03	2.2	4.0
SEER 18 HP	1,108		16	$0.04	$0.07	5.2	9.7
All Participants	1,963	***	18	$0.02	$0.03	2.8	4.6

‡Levels of statistical significance denoted by * (<0.10), ** (<0.05) and *** (<0.01).

The lifetime marginal cost per kilowatt-hour saved assumes that energy savings persist over the useful life of the equipment and that the nominal electricity rates remain stable (around $0.12/kWh) when adjusted to 2010 U.S. dollars over the same time period.[23] The simple payback period is calculated as the number of years before the aggregate electricity bill savings offset the marginal installation costs for the retrofit. Average measures of homeowner marginal energy efficiency investment cost effectiveness (excluding the rebate incentive) range from $0.00/kWh saved (immediate payback) for the SEER 14 HP to $0.07/kWh saved (approximately 10-yr simple payback period) for the SEER 18 HP. Across all programs and without the rebate incentive, the average was $0.03/kWh saved (a 4.6-yr simple payback period). From the homeowner (and the lender) perspective, a retrofit measure is effective if the investment cost is less per kilowatt-hour saved than the price per kilowatt-hour consumed (or in this case, electricity consumption avoided). For OUC’s customers who participated in one of these rebate programs, their investments are likely to be more than offset by savings from reduced electricity bills during the life of the energy efficiency upgrade: in all cases, even net of the rebate incentive, participants of the three programs invested, on average, $0.03 to avoid a $0.12/kWh cost of electricity consumed. These measures of homeowner investment cost effectiveness are perhaps the most valuable data from this report for application to energy efficiency retrofit loan programs in Osceola County, because they indicate potential loan recipients’ ability to repay as a direct consequence of the energy efficiency investment.

[23] BEEHA recognizes that neither assumption is realistic on its own and expects degradation of energy savings and increasing electricity rates in real dollars. Given the uncertainty associated with projecting persistence of performance and future electricity rates, the assumptions for this analysis were kept as simple as possible.

6 Conclusions

This study demonstrates that end-use billing and housing characteristics data can be acquired and analyzed to provide an effective assessment of the potential of various energy efficiency investments within the context of a retrofit loan program. Results of the analysis of OUC's residential energy efficiency programs provide valuable insights about past performance and potential savings for future rebate participants. The results also offer early indicators about the relative performance outcomes of various retrofit measures, which can be used to target and optimize retrofits, maximize performance, and reduce risk to potential lenders.

For broader application to the retrofit market, the most basic indicator of a successful retrofit project is that the unsubsidized marginal material and installation costs of the retrofit are fully recouped through energy bill savings during the expected useful life of the upgrade. This analysis suggests that added attic insulation, duct sealing and high-efficiency HP retrofits all provide solid investment opportunity (and simple payback periods less than 9 years without a rebate and less than 7 years with a rebate) for homeowners in the Orlando area. In addition, replacing HVAC equipment at the end of useful life with SEER 15 or SEER 16 equipment can provide maximum value, given the tradeoff between incremental cost of upgrade and expected energy savings. Findings are directly relevant to—and will be used by—the OEI EEFP to identify and target specific energy efficiency retrofit loans to Osceola County homes and loan applicants with the greatest potential to maximize both energy savings and investor returns.

7 Recommendations

This study details findings from a methodological approach that relies on end-use consumption, DSM program and housing characteristics data to analyze and assess the effectiveness of specific retrofit measures. However, because it targets a specific location (central Florida) and is intended to demonstrate a novel methodology, its scope is narrow. Three significant restrictions, which point directly to this report's three primary recommendations for future work in this subject matter. The study:

- Considered only a single utility
- Reviewed only three retrofit programs (seven measures)
- Analyzed performance for only the first post-retrofit year.

BEEHA recommends that:

The study should be replicated in other utility territories to assess the potential for wide applicability of the ACB methodology. BEEHA recommends that the Jacksonville, Gainesville and Tallahassee municipal utilities provide easy opportunities for study in terms of data sharing, although variable data formatting can present unique problems.

The number of retrofit measures evaluated should be expanded to include weatherization, lighting, domestic hot water, interventions targeting homeowner behavior, and others. This recommendation would be a natural result of following the first recommendation because different utilities have different DSM programs and emphasis areas (for example Gainesville and Tallahassee are natural gas as well as electric utilities and have DSM programs promoting natural gas domestic hot water and heating systems). Aside from providing data on additional retrofit measures, it would be possible to compare similar programs across utilities.

The persistence of the savings identified in this study covers only the first year after retrofit. BEEHA has seen degradation in performance over time in homes certified under the ENERGY STAR® for New Homes program (Jones et al. 2010b) and suspect that the performance of retrofits may not persist beyond the first two or three years of program or retrofit implementation. BEEHA recommends identifying older retrofit programs and analyzing them over multi-year time frames to characterize performance persistence.

Databases need to be developed of households retrofitted with code-minimum equipment and information about DSM participant pre-retrofit conditions and HVAC system efficiencies. This helps to accurately differentiate the savings provided by above-code retrofits.

Forward-looking fuel pricing scenarios should be developed for comparisons of expected economic impacts. This study shows that the increased cost of power from 2008 to 2010 more than offset the decreased consumption of the DSM participating households.

The aggregated databases should offer an opportunity to analyze relationships between savings potential and pre-retrofit consumption patterns, size of home, and other factors. Some homes/households may not receive enough benefit to warrant subsidies for retrofits.

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