Targeting the Best Performing Home Efficiency Programs with Advanced Metering Evaluation Supplemented by Simulation

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ABSTRACT

The authors investigated the impacts of seven residential rebate energy efficiency programs offered by a municipal utility. The evaluation examined energy use pre and post retrofit using the Advanced Metering Infrastructure (AMI) data, disaggregated by major end-use and weather-adjusted; and also by detailed simulations. Residences modeled were representative of typical participants for that measure based on factors such as year built, conditioned square feet and number of bedrooms.

Our analysis found the residential rebate programs to be of highly varied effectiveness, but important differences surfaced between the simulation and the AMI data evaluation. Not surprisingly, programs with larger samples tended to better match the simulation results for annual energy use.

Our evaluation showed that the following rebate segments for existing single family homes were highly effective:

- ENERGY STAR Water Heater Program (HPWH)
- Duct Repair Program
- Window Replacement Program

While the effectiveness of the HPWH segment was expected, the duct repair and window replacement programs evidenced large energy savings that were generally greater than predicted by simulation. However, beyond significant energy savings, the window replacement program showed sizable reductions to both summer and winter peak demand.

The other programs that were analyzed showed lower effectiveness:

- ENERGY STAR Clothes Washer
- Window Film Retrofit
- Wall Foam Insulation
- Solar Water Heating

We detail the evaluation procedures used for the heat pump water heater, duct repair and window replacement programs. Similar analysis was done for other incentives although some had small sample sizes. We summarize results for all programs.

Introduction

The objective of this paper is to describe the energy use evaluation and analysis methods used for a number of the Orlando Utilities Commission (OUC) residential efficiency rebate programs.[1] The primary intention is to estimate the programs' savings in energy (kWh) and coincident peak demand impacts (kW).

Demographics

Table 1 summarizes characteristics for all of the approximately 95,000 residential OUC customers. The demographic data came from linking OUC customers to the property database using information provided to OUC by the University of Florida. In some instances, the property database is missing information, such as number of bedrooms. Data may be entered incorrectly also; For example, some homes are listed as four floors, but when examined online the homes appear to be three story townhomes.

The mean average OUC customer lives in a home built in 1980, with a floor area of 1,980 square feet and a market value of $217,100 [data from late 2018]. The median year built of a single-family residential customer is 1983, the median floor area is 1791 square feet, and the median market value is $187,500. Very old homes cause the mean age to be lower than the median, while large and expensive homes almost always show mean square footage and house price higher than median. Thus the median home energy use and savings will be more conservative than the mean. Eighteen percent of these customers have a swimming pool.

Table 1. Statistical Characteristics of Overall OUC Households

Single family home customer statistic	Year built	Conditioned Floor Area (CFA)	Bedrooms	Floors	Market value
Mean	1980	1,980	3.2	1.2	$217,101
Minimum	1884	0	0.0	0.0	$12,497
1st Quartile	1958	1,365	3.0	1.0	$123,890
Median	1983	1,791	3.0	1.0	$187,500
3rd Quartile	2004	2,359	4.0	1.0	$263,007
Maximum	2016	13,618	18.0	5.0	$6,514,147
std dev	25.1	867	0.9	0.5	$160,659
Sample Size	*94,471*	*94,471*	*94,471*	*94,471*	*94,471*
With Pools	*17,198*	*Percent with Pools*			18.2%

Table 2 shows the demographics of all residential rebate participants. The median house vintage is from 1995—so the rebate homes tend to be much newer than the average residential OUC account. Nearly one third of the rebate households have swimming pools—a much higher percentage than the 18% found in the overall population. The houses are also more expensive with a market value $50,000 more than the average home in OUC service territory.

[1] The specific utility rebate programs are described here: https://www.ouc.com/residential/save-energy-water-money/residential-rebates-information

Table 1. Statistical Characteristics of Overall Rebate Households

All single family rebate participant statistics	Year Built	Conditioned Floor Area (CFA)	Bedrooms	Floors	Market Value
Mean average	1984	2,354	3.4	1.3	$286,242
Minimum	1901	531	0.0	0.0	$18,010
1st Quartile	1961	1,712	3.0	1.0	$186,470
Median	1995	2,157	3.0	1.0	$244,375
3rd Quartile	2004	2,850	4.0	2.0	$329,314
Maximum	2016	10,674	8.0	4.0	$3,270,953
std dev	23.9	934	0.9	0.5	$181,291
Sample Size	*4,605*	*4,605*	*4,605*	*4,605*	*4,605*
With Pools	*1,496*	*Percent with Pools*			32.5%

Pre-Rebate Home Electrical Use

The average annual electric use of overall OUC residential customers in recent years is about 12,000 kWh; In 2015 it was 12,421, in 2016 12,369, and in 2017 11,987 kWh/residential customer.[2] OUC indicates it has over 200,000 residential customers, which include multi-family and manufactured housing – a segment excluded from our tables.

Table 2 provides the average annual, weather-normalized energy use estimates we made from the metered data for each program. The process is detailed later, but the table provides a comparison of annual energy use against the 12,000 kWh customer average.

Table 2. Pre-Retrofit Estimated Electrical Use of Rebate Households

Program	Median annual electrical use estimate pre-retrofit (kWh)
ENERGY STAR Water Heater	16,976
ENERGY STAR Clothes Washer	13,859
Window Replacement	14,863
Window Film Retrofit	13,725
Duct Repair and Replacement	13,870
Wall Foam Insulation	13,050
Solar Thermal Program	11,326

Except for the solar thermal sample (which only contained three customers), the median pre retrofit annual electricity use of each segment exceeded the average annual residential customer use of 12,000 kWh. However, this finding is not unexpected since utility program participants are often high users.

[2] From OUC ten-year site plans as filed with the Florida Public Service Commission in 2018. See page 59. http://www.psc.state.fl.us/Files/PDF/Utilities/Electricgas/TenYearSitePlans/2018/Orlando%20Utilities%20Commission.pdf

Evaluation Methods for Determining Rebate Program Impacts

The analysis was completed by examining the pre and post retrofit metered data for each rebate segment as well as simulation. The simulation used the median characteristics of homes in the dataset. The metered methodology used the available 15 minute AMI data and statistically deriving total heating and total cooling energy use, pre and post installation for each site, by regressing measured kWh/day on average daily outdoor air temperature. This regression procedure was used to determine a balance point temperature for cooling and heating (chosen by best fit correlation) for each site so that pre and post retrofit energy can be compared.

Data Filtering, Bias and Quality Issues

Filtering procedures were used to avoid sites with misleading data. For the seven rebate measures evaluated in this report, OUC provided FSEC about 2,200 records associated with existing home, single family rebates administered between January 2015 and September 2018. However, 82% of these records were not suitable for evaluation. There are many reasons for this large reduction in sample size:

- The same premise had a known confounding energy rebate installed within the evaluation period or the premise had a known electric vehicle charger or solar photovoltaics.
- The measure was installed too early to have enough pre retrofit data or too recently to have enough post-retrofit data
- The property was sold or the account number was otherwise changed within a year before or after the retrofit measure

Generally, a 12-month pre retrofit period and 12-month post retrofit period was required for evaluation. However, this did not always translate into 24 consecutive months. If the rebate measure was missing an installation date, an additional seven months before the adjustment date were lost/ignored to increase the likelihood that the installation happened outside of the baseline evaluation period. This seven-month period was derived from evaluating the existing home heat pump rebate program which showed both an install date and rebate request. The chances that the record was excluded from evaluation because of the reasons above increased if the installation date was missing.

After reducing the evaluation sample sizes as described above, further filtering was necessary to avoid bias once we examined AMI data. This included filtering for missing data (a year pre and post were generally used), low regression correlation (described in more detail below), as well as drastic changes in energy use pre and post that did not appear to be associated with weather. In one case a major electrical load (greater than 100 kWh/day) was intermittently used throughout the post retrofit period which altered the analysis results unexpectedly. To improve the quality control of this assessment, individual sites had their daily average AMI data plotted to ascertain the viability of the data stream. Other attrition occurred:

- for the demographics evaluation, if the home did not have a match in the property database,
- for the annual energy use evaluation, if there were less than 90% valid AMI data points,
- for peak hour analysis, if all four fifteen minute values (100%) of good data were not available.

AMI Data Analysis Methods

We created a program to conduct pooled regression of groups against daily outside temperature recorded at Orlando International Airport. Pooled regression of groups against weather is among those recommended for utility program evaluation (Agnew and Goldberg, 2013). We also used another method—more powerful-- which was regression of each site against weather and then using the predicted average for groups based on the individual regressions. This is the method recommended by ASHRAE for retrofit evaluation (Haberl et al., 2005) and was found to be superior for our purposes.

The daily evaluation method against outdoor temperature shows a somewhat reasonable result-- estimating on average 35% - 77% of the variation in daily total energy use in the retrofit groups — meaning the regression could explain about half of the observed variation in electric use. This is quite good since many other household operations such as dryer use, cooking, hot water consumption and appliance use are not dependent on outside temperature. During the regression analysis the minimum acceptable coefficient of determination (R^2) value used for cooling and heating were 0.30 and 0.15 respectively. Any sites with less than either of these minimum values were removed from the analysis. Further, each site was reviewed for nominal daily energy use to identify sites with large unexpected changes in daily energy use.

A lower coefficient of determination was used for the heating analysis to retain as many sites as possible. In Florida, heating is much less predictable since much of daytime heating is discretionary and the thermal conditions inside often vary in response to the weather the day before. In Florida, two cold days in a row often lead to heating whereas a single day may not.

Measure Changes in Peak Demand

For analysis of utility coincident peak, we took the sum of the 15-minute AMI data and the commensurate count of these data for each site immediately before and after the retrofit for both the winter and summer peak day, for each year. We evaluated only one occurrence of a peak per premise, as near to the retrofit date as possible. These data were then averaged over each year to capture all sites (Pre- and Post-average). The 30-min average peak demand over that hour was then calculated to represent utilities with a 30-minute demand window. The average difference was then calculated.

The average demand reduction over the entire peak demand hour is the kW demand for winter from 7 AM – 8 AM and summer peak, respectively (i.e., using the maximum average demand of the 4 data points representing the coincident peak hour in the pre- and post-retrofit average columns). Given that the summer peak demand for OUC occurred during two different hours: 16-17 hours and 17-18 hours, between 2015 -2018, we computed summer peak demand for both hours.

Using the available sites, we regressed average hourly demand by outdoor temperature for the peak hours over a one year pre and post period segmented by season, filtering for valid heating and cooling days within each season using a 65 °F balance point temperature. The cooling season window was April through September and the heating season window was December through March. Results showing low confidence (coefficient t-statistic < 1.65 or 90% confidence level) were removed. Each site was evaluated at 91.9 °F outdoor temperature for cooling and 28 °F for heating providing a peak demand estimate for each site pre and post retrofit. These were the corresponding 2018 utility peak hour coincident outdoor temperatures at Orlando International Airport.

Simulation Analysis Approach

For each rebate program three home simulation models were developed representing the 25%, median and 75% values for square footage, age, number of bedrooms and number of floors. From these data, the rest of the inputs were determined. Insulation, wall height, air infiltration and duct tightness were all dependent on the vintage of the home modeled. If the home was built before 1982 a poor thermal envelope was assumed, e.g, R16 ceiling insulation and an ACH50 of 11. If it was built between 1982 and 2000 we assumed a better envelope, e.g, R30 ceiling insulation and ACH50 of 8, and if it was built since 2000 then it had a fairly good envelope, e.g, R30 ceiling insulation and ACH50 of 5.5 . An example of the specific characteristics for the pre 2000 time periods is provided under the window replacement program later in the paper.

Equipment was assumed to be more recent as shorter lifetimes result in equipment replacement. The baseline for all water heaters were EF of 0.9 and heat pumps were SEER 13. The size of the heat pump was modeled as slightly oversized based on what is often found in homes. Early simulations showed that for the older homes (pre 1982 and 1982 – 2000) with poor insulation, the model could not meet load at peak cooling with just slightly oversized systems. In order to provide a peak savings number those older homes were modeled with oversized equipment- a circumstance often seen in the field. Refrigerators, clothes washers and dryers, ranges and dishwashers were the equivalent of 2006 models used for RESNET energy rating reference homes. Lighting was assumed to be 50% incandescent and 50% LED or equivalent.

The three models were run as a baseline for each program and then again with a single improvement based on the retrofit applied. Commercially available EnergyGauge USA© 6.1.03 was used for all simulation analysis using Orlando TMY3 weather data.

ENERGY STAR Water Heater Segment (Heat Pump Water Heaters)

Other FSEC research conducted in Florida show large savings for heat pump water heaters. The heat pump water heater (HPWH) replacements in the OUC retrofit project yielded significant energy savings and significant peak cooling peak reductions. HPWHs draw heat from the space they occupy and use a compressor to heat water in a very efficient manner to significantly reduce the energy needed for water heating. All of the systems in the OUC HPWH retrofit segment were substitutions for standard electric resistance tanks. As they remove heat from the space where operated, they can influence space cooling or heating when they are located inside the conditioned space, as shown in FSEC's Phased Deep Retrofit project and lab experiments (Colon et al., 2016).

Demographics of HPWH segment

Table 4 shows the typical characteristics of the HPWH rebate customer in the OUC territory. On average, participants tend to be in larger, newer homes, in households which tend to use more electricity and are much more likely to own a pool than the typical OUC rebate customer. We expect higher electricity use in pool homes as pool pump and pool heating are often significant electrical loads.

Annual Energy Results for Heat Pump Water Heaters

As water heating is not strictly impacted by daily air temperatures, the expectation for the analysis method of the AMI data was that most of the savings would show up as a change in the estimated baseload electricity use. The baseload analysis did show significant reduction in energy consumption. Water heating energy is highly dependent on hot water use, which is driving largely by occupancy (Parker et al., 2015). Unfortunately, the program did not collect data on household occupancy, which becomes a recommendation for future utility programs.

Table 4. Demographics of the HPWH segment

HPWH statistic	Year built	Conditioned floor area	Bedrooms	Floors	Market value
Mean average	1994	2,497	3.6	1.4	$269,294
Minimum	1940	914	2.0	1.0	$67,760
1st Quartile	1992	1,861	3.0	1.0	$186,381
Median	2001	2,398	4.0	1.0	$247,422
3rd Quartile	2005	3,043	4.0	2.0	$311,269
Maximum	2015	4,664	5.0	2.0	$733,137
std dev	17.4	790	0.8	0.5	$107,488
Sample Size	*104*				
With Pools	*46*	*Percent with Pools*			44.2%

In most older Florida homes, the water heater is located in the garage where the heat removed from the space by a HPWH would likely not be of large impact on energy use. However, newer homes often have the water heaters in a utility room that is typically conditioned. The fraction of homes with the HPWH located in the garage vs. utility room or interior locations is not known. However, in the analysis no statistically significant cooling or heating interaction was observed—likely due to some installations being inside and others not.

For the HPWH segment, fundamental energy impact results from weather-normalized analysis of the AMI data are given in Table 5. This summarizes the cleaned sample of 62 and 52 sites that could be evaluated for baseload or cooling and heating savings, respectively. The savings were significant as demonstrated by paired t-test of means.

Total savings estimated from measured data on the OUC HPWH replacements program averaged 1,734 kWh/year per customer. The mean savings represented an estimated a total household energy savings of about 10% (total household electric use was estimated at 16,976 kWh before the retrofits). The median savings was 1,507 kWh/year giving confidence in the average.

Peak Impact Results for Heat Pump Water Heaters

Table 6 presents the AMI estimated pre and post electrical use during the appropriate peak hours which are 7 – 8 AM during the winter months and from 4 – 5 PM and 5 – 6 PM during the summer hours. These numbers are estimated by regression at a 28 °F temperature in winter and at 91.8 °F during summer.

Table 5. Annual kWh AMI Analysis for Heat Pump Water Heater Rebate Participants

Statistics	Cooling			Heating			Baseload			Annual		
	Pre	Post	Sav-ings	Pre	Post	Sav-ings	Pre	Post	Sav-ings	Pre	Post	Sav-ings
Mean	6509	6328	181	1014	1083	-68	9699	8082	1617	16976	15242	1734
Min	2364	2094	-3255	62	91	-1248	417	1140	-8164	3530	5982	-3778
25% Quartile	5011	4944	-820	508	485	-324	6014	4704	224	11946	11573	-39
Median	6244	5876	108	814	837	-121	9618	7507	1421	16734	14438	1507
75% Quartile	7799	7775	1255	1351	1441	220	12515	10513	3216	20397	16558	3158
Max	15227	18481	6996	3229	3031	2434	22542	21107	3216	35364	32176	8172
Std Dev.	2381	2512	1673	705	822	560	4809	4338	2679	6205	5784	2611
Sample	*62*			*52*			*62*			*62*		

Table 6. Peak kWh AMI Analysis for Heat Pump Water Heater Rebate Participants

Time	16:00 - 17:00			17:00 - 18:00			7:00 - 8:00		
Statistics	Cooling						Heating		
	Pre	Post	Reduc-tion	Pre	Post	Reduc-tion	Pre	Post	Reduc-tion
Mean	4.38	4.05	0.33	4.34	4.00	0.34	4.60	4.24	0.36
Min	1.29	1.50	-1.48	1.49	0.87	-1.57	1.53	1.03	-6.24
25% Quartile	3.38	3.23	-0.18	3.27	3.17	-0.14	2.91	2.36	-0.67
Median	4.11	3.65	0.30	4.10	3.69	0.24	4.48	3.69	0.42
75% Quartile	5.23	4.69	0.79	5.25	4.62	0.77	5.55	5.58	1.44
Max	9.35	9.83	2.49	8.86	9.23	2.35	11.32	12.13	5.56
Std Dev.	1.64	1.58	0.73	1.52	1.55	0.74	2.21	2.31	2.02
Sample	*70*			*73*			*52*		

The average summer peak demand reductions were 0.33 kW from 4 – 5 PM and 0.34 kW from 5 – 6 PM; and average winter peak demand reduction was 0.36 kW.

Using a slightly different data set than what was used in the table presented above, the peak summer demand averaged 0.41 (±0.19) kW lower post HPWH replacement. This was a 9.5% drop in total household energy demand—meaning that the reduction was similar to the energy reduction percentage seen over the year. The median reduction on the cooling peak was 0.34 kW, suggesting the mean reduction may be on the high side of the true impact.

As expected, winter peak reductions were smaller, given likely negative performance for interior located systems. The change in winter peak, using a slightly different dataset that was used in the preceding result table, was 4.14 kW against 4.03 kW post (2.7% reduction in total electrical demand). The mean reduction 0.10 (±0.52) kW was not significant at any acceptable confidence due to a smaller sample (n= 38) and more variable results.

Simulations of Heat Pump Water Heaters

Three modeled prototype homes were simulated with water heating characteristics shown in Table 7. The homes were evaluated with an electric resistance water heater with an EF of 0.9 and a heat pump water heater of EF of 2.75. The largest of the prototype homes, was run with the heat pump water heater inside the conditioned space, the others were simulated with the water heater in the garage.

Table 7. Water Heater Parameters for Simulation Runs

Type	Size	Home conditioned floor area ft^2	Bed-rooms	HW EF	Capacity	HW location	Gallons per day base	HW temp ºF
Electric Resis-tance	1st Qrtl	1861	3	0.9	50 gallon	Garage	42.8	125
	Median	2398	4	0.9	50 gallon	Garage	51.1	125
	3rd Qrtl	3043	4	0.9	50 gallon	Main	51.1	125
Heat Pump Water Heater	1st Qrtl	1861	3	2.75	60 gallon	Garage	42.8	125
	Median	2398	4	2.75	60 gallon	Garage	51.1	125
	3rd Qrtl	3043	4	2.75	60 gallon	Main	51.1	125

Table 8. Annual Simulation Results for Heat Pump Water Heaters

Simulation model	Statistic	Annual simulation results (kWh)			
		Cooling	Heating	Hot water	Total kWh
Electric Resistance Water Heater, EF = 0.90	1st Quartile	4,926	357	2,208	14,222
	Median	4,911	183	2,562	15,475
	3rd Quartile	6,421	344	2,544	18,078
Heat Pump Water Heater, EF= 2.75	1st Quartile	4,917	357	864	12,869
	Median	4,902	183	955	13,858
	3rd Quartile	5,929	401	934	16,032
Savings (kWh)	1st Quartile	9	-	1,344	1,353
	Median	9	-	1,607	1,617
	3rd Quartile	492	(57)	1,610	2,046
Savings (%)	1st Quartile	0.2%	0.0%	60.9%	9.5%
	Median	0.2%	0.0%	62.7%	10.4%
	3rd Quartile	7.7%	-16.6%	63.3%	11.3%
Average kWh Savings	All	170.0		1520.3	1672.0
Average Percentage Savings	All	2.7%		62.3%	10.4%

Annual Simulation Results of Heat Pump Water Heaters

Annual simulation shows a median home with 15,475 kWh prior and 13,858 kWh after the retrofit as indicated in Table 8. Using an average of the three homes, 1,672 kWh of savings are estimated. This consists of 170 kWh of cooling and 1,520 kWh of hot water savings, as it includes cooling savings in the 3rd quartile home as it was modeled with the HPWH in the conditioned space. Hot water energy use estimated was reduced by 62.3% by incorporating a HPWH. Simulated results of 1,520 kWh/year savings for the HPWH are very similar to the AMI estimate of 1,420 kWh given strong confidence in these results.

Simulated Peak Savings for Heat Pump Water Heaters

The simulation estimate for peak savings for the three simulated homes is 0.22 kW during summer peak and 0.29 kW during winter peak. This compares well to values not found statistically significant in the AMI data. The simulation has a draw profile based on data from occupied homes (RESNET, 2019) that suggests higher hot water use during the winter peak times, but lower ones during the summer afternoon peak.

Window Replacement Segment

The OUC requirement for window replacement is "Windows must be National Fenestration Rating Council (NFRC) certified and meet ENERGY STAR southern regionally-accepted standards of a U-Factor that equals 0.4 or less and a Solar Heat Gain Coefficient (SHGC) that equals 0.25 or less. Rebate submitted invoices must reflect either the separately itemized dimensions for each type of window installed or the total square footage." Rebate data collection sometimes included the SHGC, U-Factor and square footage of window replaced. OUC offers a $1.50/sq. ft. rebate.

Demographics of Window Replacement Segment

The demographics of the window replacement segment in Table 9 show that the program participants tended to be in houses that were slightly older than the overall rebate sample and typical OUC customer. This is not surprising as windows usually last a long time and are expensive so people may opt for repair before replacement. Looking at the window area replaced as a percentage of the conditioned floor area, one may speculate that a number of homes only replaced a portion of their windows. Average installed new window U-factor was 0.29 and the SHGC is 0.21. One third of the homes had pools compared to 18% in the overall OUC database.

Energy Savings of Window Replacement Segment

Fundamental results are given in Table 10 for the cleaned sample of 112 and 103 sites that could be evaluated for cooling and heating savings, respectively. The window replacements yielded both significant energy savings and large peak reductions. Savings were seen both for cooling and heating.

The windows replacements created heating savings 249 ($\pm$ 130) kWh and was significant at any statistical level. Mean heating savings going from 1322 kWh per year to 1073 were 19.0%-- very respectable. Total savings from the window replacements are estimated from the AMI data at 660 kWh/year. We did see that non-weather sensitive baseload in the homes rose over the two-three year period, although windows arguably have little to do with this phenomenon.

Table 9. Demographics of Window Replacement Segment

Statistic	Year built	Conditioned floor area (CFA)	Bedrooms	Floors	Market value	Window area replaced	Replacement cost	Window Area Replaced as % of CFA	New Window U-Value	New Window SHGC
Mean	1976	1996.9	3.19	1.14	$230,133	180	$8,702	9.4%	0.29	0.21
Min	1930	680.0	1.00	1	$31,838	12	$264	1.0%	0.22	0.18
25% Quartile	1957	1449.8	3.00	1	$165,499	117	$4,923	6.3%	0.28	0.19
Median	1976	1874.0	3.00	1	$211,801	163	$7,277	8.7%	0.29	0.21
75% Quartile	1994	2299.5	4.00	1	$277,685	236	$11,950	12.0%	0.30	0.21
Max	2014	4221.0	5.00	2	$586,814	536	$22,620	56.1%	0.54	0.27
std dev	20	702.4	0.74	0.35	$100,616	91	$5,260	5.2%	0.04	0.02
Sample Size	*196*	*196*	*196*	*196*	*196*	*196*	*196*	*196*	*86*	*86*
With Pools	*66*	*Percent with Pools*			33.7%			*With Pools*	27	31.4%

Peak Impact Results for Window Replacement Segment

The peak reductions from window replacement shown in Table 11 were even more robust than the energy savings. As improved windows significantly reduce conduction losses which are highest on peak load summer and winter days, this influence was expected. The peak cooling demand was 0.28 (±0.10) kW lower post window replacement. This was a 7.0% drop in total household energy—meaning that the space conditioning reduction was much larger than the energy reduction percentage seen over the year since cooling only accounts for a portion of consumption. As expected, heating peak reductions are greater-- twice as large, although more variable-- likely partly due to resistance heat in some homes, particularly during early morning on very cold days. The reduction 0.55 (±0.52) kW was significant at a 98% confidence level with a smaller (n= 74) and more variable sample. The winter peak was larger at 5.28 kW against 4.73 kW post.

Table 10. Annual kWh AMI Analysis for Window Replacement Rebate Participants

Statistics	Cooling		Heating		Baseload		Annual	
	Pre/Post	Sav-ings	Pre/Post	Sav-ings	Pre/Post	Sav-ings	Pre/Post	Sav-ings
Mean	6485/5971	513	1245/1042	203	8267/8638	-371	15713/15414	299
Min	2274/1729	-6917	59/97	-1284	-1144/1124	-6858	4301/4034	-11183
25% Quartile	4500/3952	-280	629/546	-54	4830/4603	-1374	10895/10512	-553
Median	5849/5521	381	1026/913	133	7932/8055	-290	14862/14113	235
75% Quartile	7646/7531	1321	1601/1373	383	11666/11704	630	19772/19405	1422
Max	15465/16981	4860	4278/3972	2310	24951/26964	11853	31951/37374	13153
Std. Dev.	*2645/2639*	*1592*	*871/736*	*625*	*4671/4778*	*2217*	*6006/6309*	*2516*
Sample	*112*		*103*		*112*		*112*	

Table 11. Peak kWh AMI Analysis for Window Replacement Rebate Participants

Time	16:00 - 17:00			17:00 - 18:00			7:00 - 8:00		
Statistics	Cooling						Heating		
	Pre	Post	Reduction	Pre	Post	Reduction	Pre	Post	Reduction
Mean	4.04	3.82	0.22	4.00	3.75	0.24	5.26	4.70	0.55
Min	0.64	0.86	-4.14	1.31	1.11	-3.45	1.34	0.31	-4.60
25% Quartile	2.80	2.60	-0.17	2.67	2.65	-0.08	3.37	3.00	-0.57
Median	3.66	3.44	0.17	3.85	3.49	0.23	4.54	4.29	0.42
75% Quartile	5.11	4.88	0.57	5.01	4.92	0.51	7.33	6.08	1.40
Max	7.67	11.56	2.78	7.39	10.54	2.77	10.99	11.25	6.20
Std Dev.	*1.61*	*1.64*	*0.75*	1.52	1.54	0.69	2.58	2.20	2.01
Sample	*139*			*138*			*98*		

Simulation of Window Replacement Segment

The envelope and equipment parameters used are given in Table 12. For this analysis, we used a typical overhang of 16” located 12” above the window. The window area for each modeled home was set to the area of the 25%, median and 75% replacement values. This may be low as it could represent just part of the windows replaced. However, more windows would mean more potential run-time and likely more savings even though replacing only a portion. In any case, these results may be conservative in their savings estimates. Like other simulation runs, windows were divided into walls on four cardinal directions evenly. The total window area modeled was 91.35 square feet or 6.3% of the conditioned floor area (CFA), 163 square feet of window area or 8.7% of CFA for the median house, and 276 square feet or 12% of the CFA of the larger house modeled.

Simulation Outputs for Window Replacement Segment

The results shown in Table 13 indicate a savings of a total house savings of 6.6%, with cooling and heating savings each of about 20%. The simulations indicated good savings at peak, reducing the cooling by over 14% and the heating peak by almost 19%. The house peak load is reduced by 10.8% in summer and 13.8% in winter.

Table 12. Envelope and Equipment Parameters for Window Replacement Simulations

Size	25% Qrtl	Median	75% Qrtl	Size	25% Qrtl	Median	75% Qrtl
Vintage	1957	1976	1994	Duct Loc	Attic	Attic	Attic
CFA	1450	1976	1874	Supply Area ft^2	290	375	460
Stories	1	1	1	Return Area ft^2	73	94	115
Avg. Ceiling Height ft	8	8	9	Duct-R oF-ft2-hr /Btu	4.2	4.2	6.0
Slab Area ft^2	1450	1976	1874	AHU Loc	Garage	Garage	Garage
Nbr	3	3	3	Qn out	0.12	0.12	0.09
Perim ft	152.3	177.8	173.2	Temp °F	68,78	68,78	68,78
Wall Length ft	38.08	44.45	43.29	Appliances	2006 default	2006 default	2006 default
Wall Height ft	8	8	9	Lighting	50% Tier II	50% Tier II	50% Tier II
Win Height ft	4	4	4	Fans	Yes, std	Yes, std	Yes, std
Win Width ft	5.71	10.74	14.06	MV	None	None	None
Pre Win-U Btu/°F-ft2-hr	1.30	1.30	1.3	System Sizing kBtu/hr*	32.21	39.30	35.13
Post Win-U Btu/°F-ft2-hr	0.29	0.29	0.29	Installed kBtu/hr**	48	54	48
Pre SHGC	0.75	0.75	0.66	SEER	13	13	13
Post SHGC	0.21	0.21	0.21	HSPF	7.7	7.7	7.7
Ceil-R oF-ft2-hr /Btu	16	16	30	DHW EF	0.9	0.9	0.9
Knee Wall Area ft^2	0	0	68	DHW Cap. Gals	50	50	50
Knee Wall R	NA	NA	11	Pipe Length ft	86.2	96.6	105.9
Wall Type	CMU	CMU	CMU	HERS2014 Method Gals Per Day	42.8	42.8	42.8
Wall-R °F-ft^2-hr /Btu	0.01	0.01	4	DHW Set Point °F	125	125	125
ACH50	11	11	8				

Table 13. Simulated Annual Savings for Window Replacement

Window Parameters	Simulation model Home Size	Annual simulation results Cooling kWh	Heating kWh	DHW kWh	Total kWh
Original Window SHGC= 0.75, U-value =1.3, Window Area = 91 sq. ft.	1st Quartile	4378	371	2208	13668
Original Window SHGC= 0.75, U-value =1.3, Window Area = 163 sq. ft.	Median	5522	480	2208	15546
Original Window SHGC= 0.66, U-value =1.3, Window Area = 276 sq. ft.	3rd Quartile	5219	372	2208	15176
Window Replaced SHGC = 0.21, U-value=0.29, Window Area = 91 sq. ft.	1st Quartile	3936	342	2208	13197
Window Replaced SHGC = 0.21, U-value=0.29, Window Area = 163 sq. ft.	Median	4681	423	2208	14648
Window Replaced SHGC = 0.21, U-value=0.29, Window Area = 276 sq. ft.	3rd Quartile	3904	236	2208	13725
Savings	1st Quartile	442	29	0	471
	Median	841	57	0	898
	3rd Quartile	1315	136	0	1451
Percent	1st Quartile	10.1%	7.8%	0.0%	3.4%
	Median	21.4%	16.7%	0.0%	6.8%
	3rd Quartile	25.2%	36.6%	0.0%	9.6%
Average Savings	All	866	74	0	940
Average Percentage	All	18.9%	20.3%	0.0%	6.6%

Seven Program Analysis

Our analysis found the residential OUC rebate programs to be of highly varied effectiveness. Table 14 shows the typical AMI estimated and simulated savings of the various program segments. Table 15 shows summarized peak impacts for the same measures with similar bold type used to indicate the estimated savings.

Four programs (Clothes washers, window film, foam wall, and solar thermal) that were evaluated had fewer participants than the three we have detailed in this paper.

Due to the new federal clothes washer standard our estimate of savings for selecting an ENERGY STAR clothes washer unit over another new unit is small (40kWh).

The window film retrofit program, wall foam program and solar thermal program had few takers and analysis was limited. The window film retrofit program has a small sample of usable data (6 households) with an average AMI savings of -35 kWh. The simulations suggest modest reductions to cooling energy (4.4%) and increases to heating (-6.5%) with fairly moderate estimates of overall annual energy reductions (176 kWh).

The foam wall program had some issues and was discontinued by OUC. The Wall Foam Insulation program shows high simulated savings because it assumes the block walls were uniformly insulated with the foam. OUC indicated in practice it was difficult to verify the actual installed R-value of the insulation and if all of the concrete block cells were filled. The AMI analysis of six customers indicated average negative kWh savings.

Only three homes had enough data to analyze solar thermal systems and showed mixed results with estimates of savings of -951 kWh to 1178 kWh. As other items may be occurring in the home, occupancy or other changes, such small samples are not reliable.

Table 14. OUC Residential Efficiency Program Annual kWh Savings Estimate*

Segment	AMI sample	AMI estimated savings	Simulation estimated savings
ENERGY STAR Water Heater	62	**1734**	1520
ENERGY STAR Clothes Washer	30	97	**40*** **
Window Replacement	196	**716**	940
Window Film Retrofit	6**	-35	**176**
Duct Repair and Replacement	17**	**876**	447
Wall Foam Insulation	6**	-30	**817**
Solar Thermal Program	3**	476	**2173**

* If AMI data was statistically significant that value is bold, else simulation value is bold.

** Difference of medians used because of small sample size (<20)

***Savings based on difference between new standard clothes washer and new ENERGY STAR unit

Table 15. OUC Residential Efficiency Program Summer/Winter Peak kW Reduction Estimate*

Segment	AMI sample	AMI estimate	Simulation estimate
ENERGY STAR Water Heater	70/52	**0.33 / 0.36**	0.22 / 0.33
ENERGY STAR Clothes Washer	37/26	0.07 / 1.23	**0.01 / 0.01*** **
Window Replacement	138/98	**0.23 / 0.55**	0.53 / 0.68
Window Film Retrofit	6/4**	0.31 / 2.98	**0.08 / -0.02**
Duct Repair and Replacement	22/20**	0.32 / -0.07	**0.28 / 0.24**
Wall Foam Insulation	6/3**	-0.23 / 1.19	**0.37/ 0.97**
Solar Thermal Program	3/2**	0.14 / 0.61	**0.22 / 0.05**

* If AMI data was statistically significant that value is bold, else simulation value is bold.

** Difference of medians used because of small sample size (<20)

***Savings based on difference between new standard clothes washer and new ENERGY STAR unit

Conclusions

The ENERGY STAR heat pump water heater program, window replacement and duct repair program all had significant measured annual energy savings. The AMI annual kWh savings for the Duct Repair segment was greater than the FSEC simulation and the OUC prediction suggesting the impact of the program is more effective than previously assumed. FSEC's simulations indicated summer peak demand savings of 0.28 kW and winter peak savings of 0.24 kW per household for the duct repair program.

The largest sample was of the OUC window replacement program which showed excellent peak reduction impacts—particularly for winter-- both by AMI evaluation and simulation. The reductions suggested by the AMI evaluation are less than those provided by the simulation. It may be that the occupants window shading was greater than predicted. Since the sample size was adequate and the results statistically significant the AMI data are probably most realistic of future expectations and OUC should base their rebate value using the AMI savings. The AMI data indicate a healthy 0.55 kW reduction per household in winter peak.

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