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Improving Energy Savings and Peak Demand Reduction Estimates Using AMI Data for Utility Commercial Rebate Programs

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ABSTRACT

Solar reflective, or cool roofs, are a demonstrated method of reducing air conditioning energy, particularly in cooling-dominated climates. Similarly, efficient lighting or mechanical equipment replacement programs have a reputation for achieving large savings in commercial buildings. Savings estimates for such measures have historically used monthly utility bills, which only provide a macroscopic view of utility program savings. Advanced Metering Infrastructure (AMI) is commonly used in the U.S. by utilities for residential and commercial customers and provides not only a valuable record of changing premise energy use and demand profiles but in much greater detail than utility bills, if desired.

Partnering with Orlando Utilities Commission (OUC) in Florida, we developed a sophisticated weather-responsive methodology that disaggregates site space heating, cooling, and baseload energy using 15-minute AMI kWh and local weather data. This evaluation technique was applied to OUC's commercial "cool roofs" and "custom incentives" programs to provide improved utility program energy and peak demand savings estimates.

Introduction

This paper describes the energy use evaluation and analysis methods used for the Orlando Utilities Commission (OUC) commercial cool roof and custom incentive rebate programs. Custom incentives are primarily efficient lighting only or lighting plus other measures such as those aimed to reduce heating ventilation and air conditioning (HVAC) energy use. The primary intention of the work was to provide our partner an estimate of the annual energy savings (kWh) and coincident peak demand (kW) impacts and to allow them to compare the AMI meter data to their preliminary rebate program estimates for each site. Since the time this work was conducted for OUC, we have refined some of the analysis; hence there is variation between what is presented here and what was reported in the proprietary report.

Background

The energy savings associated with reflective roofs and efficient lighting is well documented. Traditionally, architects in hot climates have recognized that reflective roof colors (cool roofs) can reduce building cooling loads. Early research showed that white roofing surfaces can significantly reduce surface temperatures and cooling loads (Givoni and Hoffmann 1968; Griggs and Shipp 1988; Bansal et al. 1992).

More recently, in research spanning the three most recent decades, solar reflective cool roofs have been reliably shown to reduce cooling (Rosenfeld et al. 1998, Parker and Barkaszi

1997; Parker et al. 1998; Akbari and Kolokotsa 2016). Available cooling energy savings from white reflective roofing on buildings have been found to be on the order of 10-20% vs. darker, less reflective colors.

In Florida's cooling-dominated climate, experiments verified the potential in commercial buildings through several before and after tests in a heavily instrumented setting. Parker et al. (1996) showed a 10% measured cooling energy reduction in a school building in Cocoa Beach, Florida which had a reflective roof applied. The peak reduction was even larger at 35%. A similar series of experiments in several storefronts in a retail strip mall in Cocoa, Florida a year later (Parker et al. 1997) showed an average 25% cooling energy savings (range 13-48%) and a 40% average reduction to coincident peak load.

Konopacki et al. (1998) showed similar advantages for commercial buildings in tests performed in California with measured savings of 12-18%. Other experiments showed that rooftop temperatures around the inlet of common roof-top commercial cooling systems were favorably depressed (Wray and Akbari 2008). Meanwhile, Taylor and Hartwig (2018) showed that the popularity of cool roof solutions in commercial buildings is increasing in North America as simulations showed favorable energy savings across climates.

Our other focus for evaluation was energy efficient lighting. According to the U.S. Energy Information Administration, "17% of all electricity consumed in U.S. commercial buildings is consumed by lighting, making it the largest end use of electricity besides the *Other* category" (2017). Efficient lighting renovations have become more popular with the greatly reduced cost of low-wattage lamps, specifically light emitting diodes (LED) in recent years (Romm 2016). A recent case study for a commercial renovation using LEDs showed 47% energy savings with a payback period of 1.4 years (Muneeb et al 2017).

In the OUC programs, the lighting option was included within a "custom incentive program," which could include other mechanical measures such as controls. Some buildings only pursued the lighting rebate, others sought the broader program. Thus, implementation varied from one site to another. This complicates simulation analysis and provides justification for developing a robust evaluation method to examine program-wide impacts through AMI data.

One question emerges from research literature on these energy efficiency measures: Is the space conditioning energy reduction signature large enough in a commercial setting so that impacts will show up reliably using whole site premise data? A recent research project with OUC aimed to find out if using whole building smart meter (AMI) data could leverage statistical techniques to reveal the HVAC-related energy signatures. The efficacy of such an approach has already been suggested by Birt et al. (2012) in analyzing homes in Canada where portions of the electrical demand are weather-driven, while other segments are not. There are many analytical energy management tools relating energy use to variables such as outdoor temperature, and more emerging with the recent advent of robust AMI data. Granderson et. al. (2016) developed and applied a test procedure to evaluate several such tools.

Evaluation Methods for Determining Rebate Program Impacts

Our evaluation approach was two-fold: 1) statistically examine the pre- and post-retrofit metered data and 2) evaluate through simulation with two U.S. Department of Energy (DOE) reference buildings. The metered methodology attempted to derive total cooling energy use by regressing measured kWh/day on average daily outdoor air temperature. This regression procedure was used to determine a balance point temperature for cooling chosen by best fit correlation for each site so that pre- and post-retrofit can be compared. The results disaggregate AMI loads into those that were weather-responsive (e.g., HVAC) and those that were not (baseload). The simulations modeled a 53,000 ft^2 3-story medium office building and a 74,000 ft^2 single-story primary school. Roof construction in simulated models was a rubberized membrane on insulated metal decking.

Data Filtering, Bias and Quality Issues

Filtering procedures were used to avoid sites with misleading data. OUC provided FSEC a total of 283 records associated with commercial cool roof and custom incentive rebates administered between January 2015 and September 2018. Unfortunately, there were many problems with the majority of the sites. The filtering process, including a building's removal for detectable onsite generation, left seven cool roof and 95 custom incentive rebate measures which were evaluated in this report. There were two primary reasons for the large attrition in sample size:

- Timing of Installation: The measure was installed too early to have enough pre-retrofit data or too recently to have enough post-retrofit data. In certain cases, the install date was uncertain which led to large reductions in the sample because those records required an even longer span of data to capture pre- and post-retrofit.
- Gaps in Data: The property had insufficient AMI meter data available. OUC implemented AMI data only in 2015 which resulted in large attrition for sites where there was limited pre-retrofit data.

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. When the installation date was known, a single day separated the evaluation periods. If the installation date was not known, but rather only the rebate recording date was known, 7 months separated the evaluation periods. Guided by rebate records with both dates to compare, this 7-month gap provided a reasonable assurance that the measure had been installed between evaluation periods.

Energy Saving Evaluation Using AMI Data

A simple linear regression based on the best fit between total daily energy use and concurrent weather data was applied to disaggregate consumption related to heating, cooling, and baseload needs for the pre- and post-retrofit periods for each home. The analysis method used here followed the recommended protocol endorsed by U.S. DOE for evaluation of utility programs as described by Agnew and Goldberg (2013). It is also recommended by ASHRAE for energy retrofit evaluation (Haberl et al., 2005).

Daily energy use was estimated regressing the pre- and post-daily energy used for each building against the average daily outdoor temperature. Florida's climate is cooling-dominated, so that some reviewed commercial accounts evidenced no heating energy use at all. In Orlando, the five year historic annual average 65 °F base Cooling Degree Days are 3638, but with only 564 Heating Degree Days. With such limited heating in this climate, especially in commercial buildings which typically have a large amount of internal heat generation, the AMI data evaluation is limited to the cooling energy use and summer peak demand.

The energy use evaluation method shows reasonable result for certain sites, estimating on average 20% - 45% of the variation in daily cooling energy use — meaning that outdoor temperature impacted up to about half of the observed variation in electric use. Other sites showed far less correlation with outdoor temperature due to smaller cooling or heating loads. Regression strength was weakened by different weekday and weekend operating schedules or changes in operations, though sites were retained for evaluation given strong signatures observed when regressing combined weekday and weekend use. Figure 1 is an example of a Cool Roof site with very different energy use signatures between weekday and weekend. However, despite poor coefficients of determination, the regressions show limited scatter for weekends and weekdays separately, and the composite regression line is an appropriate balance between the two. A more sophisticated model including a day-of-week variable is warranted especially for commercial building evaluation, but was not possible within the constraints of this project.

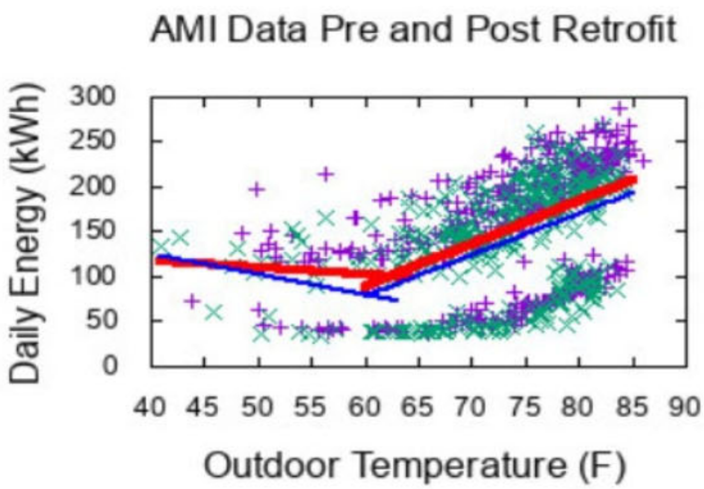

Figure 1. Site 5 weekday (100+ kWh) and weekend (~50 kWh) energy use signature pre (purple) and post (green) cool roof retrofit. Regression lines for pre R^2=0.18 (red) and post R^2=0.19 (blue).

Measured Changes in Peak Demand Using AMI Data

Using the available sites, the sum of the 15-minute AMI energy data during the coincident peak hour was an appropriate proxy for the hourly demand. It was regressed against outdoor temperature for a one year pre- and post-period segmented by season, filtering for valid cooling (summer) days using a 63 °F balance point temperature. This balance point assures that the cooling analysis includes only days at a time of no heating, although a number of Orlando buildings will continue to have cooling below 63°F. We further restricted the demand evaluation data to April through September to coincide with typical utility peak summer loads. If all four 15-min AMI readings were available during a given hour that hour was considered valid for that particular site.

Between 2015 and 2018, OUC's peak summer demand hour has occurred during two different hours: hour 16-17 and hour 17-18. The AMI data evaluated for this report show consistently higher demand at the 16-17 hour, which is the peak hour used for this evaluation. Each site was evaluated at 91.9 °F outdoor temperature for summer (this was the 2018 utility coincident peak hour outdoor temperature at Orlando International Airport), providing a peak demand estimate for each site pre- and post-retrofit.

Simulation Analysis Approach for Energy and Demand Changes

Two building models were selected from DOE's model reference building stock for performing simulation analysis. Specifically, a medium office and primary school building (constructed post-1980 in climate zone 2A) were utilized. The building construction and equipment efficiency levels are those prescribed according to prevailing national building codes.

The two models were run as a baseline and then again with a single elastomeric reflective roof coating improvement based on the applied retrofit. EnergyPlus™ V9.1 and Orlando Executive Airport TMY3 hourly weather were used for all simulation analysis.

Cool Roof Rebates

Demographics of Cool Roof Customers

The customers taking advantage of the cool roof rebate program tended to occupy commercial buildings of older construction. The cool roof program had lower levels of participation than other rebate programs. Table 1 presents statistics of six parameters based on the rebate database and the property appraiser database. For the purpose of computing demographics, roof type and cover, and wall type were included as reference. The median building vintage is from 1997.

Table 1. Building characteristics of cool roof rebate program

Parameter	Sample Size	Minimum	Average	Median	Maximum
Year Built	6	1969	1990	1997	2000
Conditioned Area	6	6,327	54,716	50,515	106,700
Cool Roof Area	6	3,863	22,103	23,748	51,732
Market Value	6	754,288	5,360,207	5,607,835	8,979,360
Roof Reflectance	7	0.74	0.80	0.78	0.88
Number of Floors	6	1	2	2	3
Roof Type	6	5-Steel Frame/Truss, 1-Gable/Hip			
Roof Cover	6	1-Modular, 1-Membrane, 2-Built up, 1-Shingle, 1-tilt			
Wall Type	5	4-Concrete Block, 1-Metal			
Pools (%)	6	0			

AMI Evaluation of Cool Roofs

The analysis of changes in energy consumption due to the installation of a reflective roof included a review of AMI data to identify which sites had changes in energy commensurate with the application of a cool roof. In Table 2, the regressed cooling energy is shown for pre- and post-retrofit. The cooling energy is identified by the regression program by walking through a series of temperatures, then adjusting the balance point until the regression's goodness of fit is maximized. Then cooling energy use is calculated according to the cooling balance point and associated regression coefficients.

A review of the AMI meter data showed Site 7 had a dramatic change in energy use pattern indicating rescheduling likely due to reasons other than the cool roof installation. For this reason, the summary results below do not include Site 7.

For the six sites where cooling energy estimates seemed reliable pre and post, cooling energy savings ranged from -20,276 kWh (-16%) to 97,144 kWh (20%), representing buildings with vastly different installation application areas (Sites 1-6). The median annual cooling energy savings for these six buildings was 1.8 kWh/ft^2 of applied roof area.

Table 2. Energy analysis results for cool roof sites

	Cooling Energy					
	Pre	Post	Savings		Area	Savings
Site	(kWh)	(kWh)	(kWh)	(%)	(ft^2)	(kWh/ft^2)
1	319,205	268,321	50,884	16	5,000	10.2
2	498,490	487,407	11,084	2	11,568	1.0
3	1,532,497	1,478,957	53,540	3	51,732	1.0
4	490,527	393,383	97,144	20	30,461	3.2
5	49,323	45,084	4,239	9	3,863	1.1
6	130,159	150,435	-20,276	-16	23,748	-0.9
7	2,556,791	2,603,249	-46,458	-2	28,347	-1.6
Median Normalized Savings						1.8

Site 7 cells are grey for reasons of operations schedule change unrelated to measure being evaluated and excluded from total and area savings, and the summary in Table 3.

The analysis results provided in Table 3 are organized into a statistical profile that represents the range of estimates and the mean and median cooling energy use. These buildings as a group had a median cooling savings of 30,984 kWh, or 6%. Given the very small sample, the median is likely the best indicator of central tendency.

Table 3. Statistical analysis for filtered cool roof sites

	Cooling Energy			
(n=6)	Pre	Post	Savings	
Statistic	(kWh)	(kWh)	(kWh)	(%)
Min	49,323	45,084	-20,276	-16
Mean	503,367	470,598	32,769	6
Median	404,866	330,852	30,984	6
Max	1,532,497	1,478,957	97,144	20
Standard Dev.	536,405	519,137	42,431	13

Peak Impact Results for Cool Roofs

The AMI meter data used to estimate coincident peak demand were also reviewed for reasonableness. During meter data processing, the coincident peak hour during summer months are gathered and analyzed and normalized according to the evaluation method described in the Measure Changes in Peak Demand Using AMI Data section above. The peak summer hour demand estimate for each building, pre- and post-retrofit, are shown in Table 5.

Table 5. Coincident peak demand reduction for cool roof rebates sites

	Summer Peak: 16:00 – 17:00			
	Pre	Post	Reduction	
Site	(kW)	(kW)	(kW)	(%)
1	58.0	60.0	-2.0	-3
2	196.3	188.7	7.6	4
3	298.5	269.1	29.4	10
4	109.7	94.8	14.9	14
5	15.1	12.0	3.0	20
6	49.6	45.2	4.5	9
7	464.0	463.9	0.1	0

April through September was evaluated as summer peak. Site 7 cells are grey for reasons of operations schedule change unrelated to measure being evaluated and excluded from the summary in Table 6.

Results for demand savings from the sample of six sites used in this analysis show a median cooling demand savings of 6.0 kW, or 9% (Table 6), or 0.5 W/ft^2. Median is likely a better measure of central tendency than mean, given results are skewed. As the sample for our analysis of the impacts of cool roofs on peak was very limited with only six sites, the changes seen must be considered indicative of magnitude and direction of effect rather that statistically representative.

Table 6. Coincident peak demand statistical analysis for cool roof rebate sites

(n=6)	Summer Peak: 16:00 - 17:00			
Statistic	Pre	Post	Reduction	
	(kW)	(kW)	(kW)	(%)
Min	15.1	12.0	-2.0	-3
Mean	121.2	111.6	9.6	9
Median	83.8	77.4	6.0	9
Max	464.0	463.9	29.4	20
Standard Dev.	107.3	98.0	11.2	8

April through September was evaluated as summer peak.

Simulations of Cool Roofs

Two DOE reference buildings were simulated in Energy Plus to model a 74,000 ft^2 single-story primary school and a 53,000 ft^2 3-story medium office building. The reference building properties are provided in Table 7. No changes were made to these reference buildings except to add a material layer to the roof construction to examine cool roof impacts. In both building types the roof covering is a rubberized membrane on a built up roof system. A layer of acrylic elastomeric coating was applied to the rubberized membrane. Roof construction was changed to include a single layer of 9-mil thick roof coating representing two layers of the reflective coating product applied directly to the roof membrane.

Table 7. DOE reference building properties of roof membrane and cool roof product

Property	Roof Membrane Properties	Cool Roof Coating Properties
Thickness (m)	0.0095	0.0005
Conductivity (W/m-K)	0.16	0.13
Density (kg/m^3)	1121.3	1461.9
Specific heat (J/kg-K)	1460.0	1280.0
Thermal absorptance	0.9	0.9
Solar absorptance	0.7	0.2
Visible absorptance	0.7	0.2

Annual Simulation Results of Cool Roofs

Equipment characteristics for the primary school include VAV systems with air-cooled DX cooling coils and hot water heating coils. The hot water plant uses a natural gas fired boiler. The energy use of the heating coils is converted to kWh for comparison purposes. Simulated total energy savings are 0.8% and 2.7% annually for these reference buildings, as provided in Table 8. Summer and winter energy savings for the multi-story office building are 2.6% and -0.2%, respectively. For the single-story school these savings are larger at 10.8% and 5.3%, respectively. For the 3-story office building with 17,879 ft^2 of roof area the summer savings were 0.4 kWh/ft^2, winter savings were -0.003 kWh/ft^2 and total savings were 0.42 kWh/ft^2. For the

73,958 ft^2 single-story school the summer savings were 0.48 kWh/ft^2, winter savings were 0.034 kWh/ft^2 and total savings were 0.54 kWh/ft^2. Negative savings in winter are expected since there is less heat absorbed by the roof assembly in winter.

Table 8. Simulated energy savings of cool roof rebate

Building	Baseline Summer Energy	Savings		Baseline Winter Energy	Savings		Baseline Total Energy	Savings	
Type	kWh	kWh	%	kWh	kWh	%	kWh	kWh	%
Medium Office	268,231	7,065	2.6	31,125	-57	-0.2	969,493	7,536	0.8
Primary School	328,951	35,537	10.8	47,953	2,521	5.3	1,457,657	40,025	2.7

Simulated Peak Savings for Cool Roofs

The Medium Office simulation showed a peak energy use in Orlando on January 2 (heating) and October 4 (cooling) as shown in Figure 2. For these days the hourly simulation results were compared to determine the difference in coincident hour energy consumption. Heating and cooling energy is included in these figures. The blue lines are the baseline energy use while the orange dotted lines are the energy use of the cool roof simulation. The green line shows the difference between the baseline and cool roof simulations. The winter and summer coincident peak hour demand savings are -4.1 and 3.1 kW, respectively. As expected, this represents a simulated 1.6% coincident peak *increase* in winter and 1.3% reduction in summer.

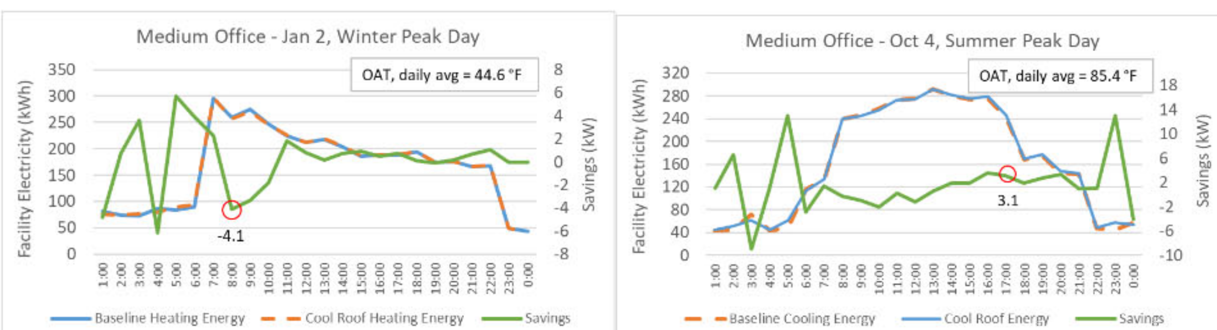

Figure 2. Simulated medium office energy use on coincident peak winter and summer day.

The Primary School simulation showed a peak energy use on January 10 (heating) and October 4 (cooling) as shown in Figure 3. For these days the hourly simulation results were compared to determine the difference in coincident hour energy consumption. Heating and cooling energy is included in these figures. The blue lines are the baseline energy use while the orange dotted lines are the energy use of the cool roof simulation. The green line shows the difference between the blue and orange lines. The winter and summer coincident peak hour demand savings are 33.2 and 24.4 kW, respectively. This represents a simulated 5.7% coincident peak reduction in winter and 6.7% in summer.

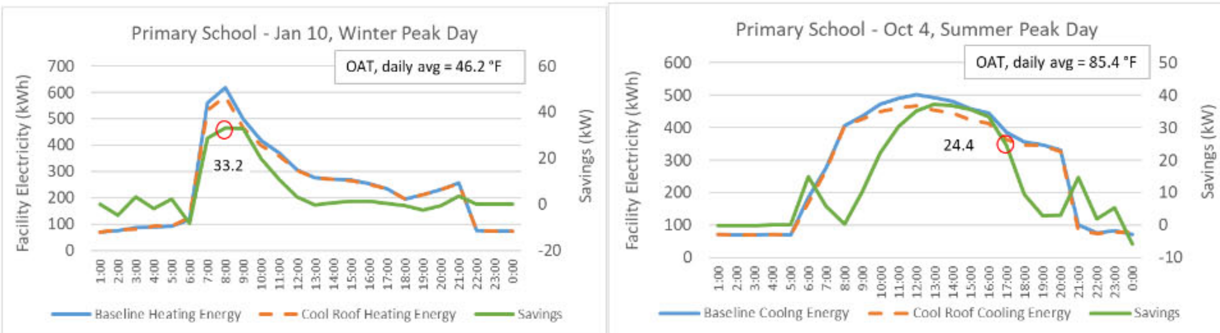

Figure 3. Simulated primary school energy use on coincident peak winter and summer day.

The simulated peak demand results are disparate from both each other and the measured changes. We note that simulation can suffer from unaccounted physical-thermal phenomenon. For instance, neither EnergyPlus nor DOE-2 account for the fact that the conductance of fibrous insulation goes up with the mean temperature across the insulation itself such that in summer an R-30 batt in the attic acts like an R-25 batt under peak conditions and the cool roof then allows the insulation to actually perform better (Levinson et al 1996; Parker et al. 1998).

Benefits and Costs of Cool Roofs

As an indication of our utility partner's rebate program efficacy, the retrofit and program costs and projected demand savings were normalized and compared. Results are provided in Table 9. Normalized summer peak reduction in kW is the maximum summer peak demand savings from Table 5.

Table 9. Cool roof rebate program projected and measured normalized savings estimates

Site	Project Cost ($/ft^2)	OUC Projected Summer (W/ft^2)	AMI Normalized Summer Peak Reduction (W/ft^2)	Summer Peak Realization Rate (%)	Floor Area (ft^2)
1	29	.13	-0.4	-30	5,000
2	11	.13	0.7	49	11,568
3	35	.13	0.6	43	51,732
4	2	.13	0.5	37	30,461
5	5	.13	0.8	58	3,863
6	4	.13	0.2	14	23,748
Average	15	.13	0.4	29	21,062
Median	8	.13	0.5	40	17,658

These results provide the utility a site specific indication of predicted demand savings and measured peak demand reduction. The measured energy use reductions were compared to OUC's original estimates to generate realization rates. (Realization rate is the percentage of realized savings to those anticipated for the programs). In all but one case, measured demand reduction was greater than anticipated by OUC.

Custom Incentive Rebates

Demographics of Custom Incentive Customers

The customers taking advantage of the custom incentive rebate (which often includes lighting and other non-specified mechanical options) show a wider range of building age. They also show a higher levels of rebate program participation. As with the cool roof program, evaluation of impact on energy consumption due to the custom incentive rebate program included a review of the AMI data to assure data quality and reasonableness. The review revealed several sites with insufficient data to provide a robust estimate of energy use, resulted in 95 sites available for evaluation.

Table 10 presents statistics of four parameters based on the rebate database and the property appraiser database. For the purpose of computing demographics, roof type and cover and wall type were included as a reference. The median building vintage is from 1990. In this group of commercial buildings 7.7% have swimming pools.

Table 10. Building characteristics of custom incentive rebate program

Parameter	Minimum	1st Quartile	Average	Median	3rd Quartile	Maximum
Year Built	1954	1975	1990	1990	2005	2016
Conditioned Area	626	7,482	16,278	70,644	106,527	608,597
Number of Floors	1	1	1	1	1	4
Roof Type	66-Steel Frame/Truss, 4-Concrete, 14-Wood Frame/Truss, 11-Unknown					
Wall Type	61-Concrete Block, 9-Metal, 4-Wood Frame, 10-Brick, 1-Glass, 10-Unknown					
Sample\ Size	95					

AMI Evaluation of Custom Incentives

Annual Energy Results for Custom Incentives

Table 11 presents the regressed cooling energy use pre- and post-retrofit, according to the same procedure followed in the cool roof AMI data evaluation for the sample of 95 sites to receive custom incentive rebates.

Unknown for this evaluation are the building baseline characteristics (e.g., is the site migrating from fluorescent or halogen lamps?) or the specifications of the upgrade (e.g., are high efficiency mechanical system and/or building automation system being installed?). However, for our utility partner, the purpose of this evaluation was to indicate the program's general success regardless of specific upgrades involved. Another unknown is the building area the rebate was applied to.

As reflected in Table 11, the energy savings results ranged widely and were highly skewed. The median cooling energy savings among the sites evaluated was 4,847 kWh or 8% of total electricity use.

Table 11. Energy use statistical analysis for filtered custom incentive rebate sites

	Cooling Energy			
(n=95)	Pre	Post	Savings	
Statistic	kWh	kWh	kWh	%
Min	2,847	1,654	-205,784	-448
25% Quartile	28,444	26,792	-10,021	-21
Mean	189,585	168,784	20,801	-7
Median	60,153	53,384	4,847	8
75% Quartile	155,071	156,884	20,492	30
Max	2,140,017	2,146,901	928,901	88
Standard Dev.	352,585	306,099	113,946	76%

Peak Impact Results for Custom Incentives

Results for demand savings from the sample of 95 sites used in this analysis show a median summer demand savings of 7.2 kW—which is 12% of the overall total premise demand kW shown in Table 13. As this is an average, the expected demand savings for these sites would be 684 kW (i.e., 7.2 kW * 95 sites). However, as Table 13 conveys, not all of these sites showed reductions and customer take-back and equipment reconfiguration (e.g., scheduling, controls, etc.) are likely responsible for outcomes unrelated to rebate programs.

Table 13. Coincident peak demand statistical analysis for filtered custom incentive rebate sites

(n=95)	Summer 16:00 - 17:00			
	Pre	Post	Reduction	
Statistic	(kW)	(kW)	(kW)	(%)
Min	5.3	4.7	(17.4)	-42
25% Quartile	24.4	21.3	2.2	5
Mean	161.7	148.5	13.2	13
Median	56.0	48.8	7.2	12
75% Quartile	128.0	102.2	15.5	19
Max	2,658.5	2,577.3	95.6	61
Standard Dev.	317.0	306.0	19.5	13

April through September was evaluated as summer peak.

Benefits and Costs of Custom Incentives

As an indication of the rebate program efficacy, the custom incentives program costs and projected demand reduction were normalized and compared. Results are provided in Table 14.

Table 14. Custom Incentive rebate program projected and measured normalized average reduction estimates

Rebate Type	Sample Size	Project Cost	OUC Projected Summer Peak Reduction (kW)	AMI Normalized Summer Peak Reduction (kW)	kW Realization Rate
Lighting Only Average	73	$33,540	12	20	166%
Lighting Inclusive Average	22	$29,951	7	12	178%

As seen in Table 14, for the lighting-only rebates, the average summer coincident peak demand reduction was 20 kW for a 166% realization rate, greater than that anticipated by OUC. For the custom incentives that were mixed, the average summer coincident peak demand reduction was 12 kW for a 178% realization rate against what OUC had projected.

Generally, the lighting and custom incentive programs proved effective at reducing both energy use and summer utility peak coincident demand.

Conclusions

Using 15-minute AMI kWh and local weather data a statistical evaluation methodology was developed where the total building energy use was disaggregated into site specific space heating, cooling, and baseload energy using. This technique allowed evaluation of energy and demand impacts of two of OUC's commercial rebate programs -- "cool roofs" and "custom incentives." Results using the AMI data showed that cool roof participants had an annual cooling energy savings of 1.8 kWh/ft^2 (6%) and peak summer demand reductions of 0.5 W/ft^2 (9%). For the custom incentives recipients, median annual cooling energy savings were 4,847 kWh with a median site peak summer demand reduction was 7.2 kW.

For comparison, simulation models predicted the annual energy and demand savings for the cool roof program. Simulated cool roof energy savings of 0.40 kWh/ft^2 (2.6%) and 0.48 kWh/ft^2 (10.8%) were in line with the median results from the AMI technique results of 0.5W/ft^2, with a similar central tendency of 6%. However, the simulations estimated 3.1 kW and 24.4 kW (1.3 & 6.7%) reduction in utility summer peak demand, with percentage reductions both less than the AMI estimates at 6 kW (9)%.

The difference in the measured and simulated demand reduction is larger than expected and explanations must be speculative, although a small sample could not be representative of results that would be seen from a larger program. There are also potentially unsimulated physical phenomenon involved (increased insulation conductance on peak). Commercial buildings also have inherent differences in operation throughout the week which could have influenced these results. A more advanced model including a day-of-week variable to predict energy use might provide higher confidence in the results presented herein.

This AMI data evaluation allowed our utility partner to evaluate measured commercial utility program impacts and provides a layer of validation to historical estimation techniques with implications for program design and improvement. Increasing sample size and reducing rebate program participant evaluation attrition is important. To enhance future AMI program evaluation, rebate programs should be sure to collect installation measure related information such as exact installation dates, baseline and installation specifications, and the rebate measure's applicable area.

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References

Agnew, Ken and M. Goldberg. 2013. "Whole Building Retrofit with Consumption Data Analysis Evaluation Protocol: The Uniform Methods for Determining Energy Efficiency Savings for Specific Measures", DNV KEMA, NREL/SR-7A30-53827, National Renewable Energy Laboratory. https://www1.eere.energy.gov/wip/pdfs/53827-8.pdf

Akbari, H. and D. Kolokotsa. 2016. *Three decades of urban heat islands and mitigation technologies research,* Energy Build., 133, pp. 834-842, 10.1016/j.enbuild.2016.09.067.

Bansal, N.K., S.N. Garg, and S. Kothari. 1992. "Effect of Exterior Surface Color on the Thermal Performance of Buildings," Building and Environment, Permagon Press, Vol. 27, No. 1, p. 31-37, Great Britain.

Britt, Benjamin J., G.R. Newsham, I. Beausoleil-Morrison, M.M. Armstrong, Neil Saldanha, and I.H. Rowlands. 2012. "Disaggregating categories of electrical energy end-use from whole-house hourly data," Energy and Buildings, Volume 50, Pages 93-102.

Energy Information Administration (EIA). 2017. Commercial Buildings Energy Consumption Survey (CBECS), Trends in Lighting in Commercial Buildings. https://www.eia.gov/consumption/commercial/reports/2012/lighting/.

Givoni, B. and M.E. Hoffman. 1968. "Effect of Building Materials on Internal Temperatures," Research Report, Building Research Station, Technion Haifa, April, 1968.

Granderson, J., S. Touzani, C. Custodio, M. D. Sohn, D. Jump, and S. Fernandes. 2016. "Accuracy of Automated Measurement and Verification (M&V) Techniques for Energy Savings in Commercial Buildings" Lawrence Berkeley national Laboratory, Berkeley, CA. https://buildings.lbl.gov/sites/default/files/applied-energy-173-2016.pdf

Griggs, E.I., and P.H. Shipp. 1988. "The Impact of Surface Reflectance on the Thermal Performance of Roofs: An Experimental Study," ASHRAE Transactions, Vol. 94, Pt. 2, Atlanta.

Haberl, J.S., C. Culp, and D.E. Claridge. 2005. *ASHRAE's Guidelines 14-2002 for Measurement of Energy and Demand Savings: How to Determine What Was Really Saved by the Retrofit.* Fifth International Conference for Enhanced Building Operations, Pittsburgh, PA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Konopacki, S., H. Akbari, L. Gartland, and L. Rainer. 1998. Demonstration of Energy Savings of Cool Roofs. Report number LBNL-40673. Berkeley, CA: Lawrence Berkeley National Laboratory.

Levinson R. and H. Akbari. 2010. Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy Efficiency. 3:53-109.

Levinson R., H. Akbari, and L. Gartland. 1996. Impact of the Temperature Dependency of Fiberglass Insulation R-Value on Cooling Energy Use in Buildings In Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings. Washington, DC: ACEEE.

Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA.

Muneeb, A., S. Ijaz, S. Khalid, and A. Mughal. 2017. Research Study on Gained Energy Efficiency in a Commercial Setup by Replacing Conventional Lights with Modern Energy Saving Lights, Journal of Architectural Engineering Technology, Architectural Engineering Department, University of Engineering and Technology, Lahore, Pakistan.

Parker, D., Y.J. Huang, S. Konopacki, L. Gartland, J. Sherwin, L. Gu. 1998. "Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings," Florida Solar Energy Center and Lawrence Berkeley National Laboratory, FSEC-PF-331-98. Cocoa, FL. http://www.fsec.ucf.edu/en/publications/html/fsec-pf-331-98/

Parker, D., J. Sherwin, J. Sonne, and S. Barkaszi. 1996. "Demonstration of Cooling Savings of Light Colored Roof Surfacing in Florida Commercial Buildings: Our Savior's School," Florida Solar Energy Center, FSEC-CR-904-96, June.

Parker, D., J. Sonne, and J. Sherwin. 1997. "Demonstration of Cooling Savings of Light Colored Roof Surfacing in Florida Commercial Buildings: Retail Strip Mall," Final Report, FSEC-CR-964-97, October.

Parker, D. and S.F. Barkaszi. 1997. Roof solar reflectance and cooling energy use: field research results from Florida, Energy and Buildings, Volume 25, Issue 2, Pages 105-115.

Romm, J. 2016. Think Progress, '5 Charts That Illustrate The Remarkable LED Lighting Revolution' https://thinkprogress.org/5-charts-that-illustrate-the-remarkable-led-lighting-revolution-83ecb6c1f472/.

A.H. Rosenfeld, H. Akbari, J.J. Romm, M. Pomerantz. 1998. *Cool communities: strategies for heat island mitigation and smog reduction*, 10.1016/s0378-7788(97)00063-7.

Taylor, T.J. and C. Hartwig. 2018. Cool roof use in commercial buildings in the United States: An energy cost analysis. ASHRAE Trans.124, 88–96.

Wray, C.P. and H. Akbari. 2008. "The effects of roof reflectance on air temperatures surrounding a rooftop condensing unit." *Energy and Buildings* 40.111-28.