

# Impact Evaluation of 2009 Custom HVAC Installations

## Massachusetts Energy Efficiency Programs' Large Commercial & Industrial Evaluation



Prepared for: Massachusetts Energy Efficiency Program Administrators  
Massachusetts Energy Efficiency Advisory Council

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## 1. Introduction

This document summarizes the work performed by KEMA and DMI during 2010 and 2011 to quantify the actual energy and demand savings due to the installation of 29 Custom Heating, Ventilation and Air-Conditioning (HVAC) measures installed through the Massachusetts Energy Efficiency Program Administrator's (PA) C&I New Construction & Major Renovation and C&I Large Retrofit programs in 2009.

### 1.1 Purpose of Study

The objective of this impact evaluation is to provide verification or re-estimation of electric energy and demand savings estimates for 29 Custom HVAC projects through site-specific inspection, monitoring, and analysis. The results of this study will be used to determine the final realization rates for Custom HVAC energy efficiency measures installed in 2009. Realization rates will be separately determined for National Grid, NSTAR, Western Massachusetts Electric (WMECO) and Cape Light Compact (CLC), as well as at the statewide level. The evaluation sample for this study was designed in consideration of the 90% confidence level for energy (kWh) and the 80% confidence level for coincident peak summer demand (kW).

This impact study consists of the following four tasks:

1. Develop Sample Design
2. Develop Site Measurement and Evaluation Plans
3. Data Gathering and Analysis
4. Report Writing and Follow-up
5. Analysis Procedures

### 1.2 Scope

The scope of work of this impact evaluation covered the 2009 Custom HVAC end-use, which includes high efficiency HVAC equipment, HVAC controls as part of Energy Management Systems (EMS), O&M and retro-commissioning HVAC measures, and building shell improvements that impact HVAC loads. This impact evaluation includes only measures which primarily reduce electricity consumption.

## 2. Description of Sampling Strategy

The primary focus of the sample design was to examine various precision scenarios for the Custom HVAC programs in Massachusetts. The initial design approach was to support the estimation of annual kWh savings realization rates separately for National Grid and NSTAR while including appropriate representation for WMECO and CLC. The study population of 70 Custom HVAC projects from the 2009 program year is summarized in Table 1.

**Table 1: Population Statistics**

Program Administrator	Projects	Total Gross Savings (kWh)	Average Savings (kWh)	Minimum (kWh)	Maximum (kWh)	Standard Deviation	Coefficient of Variation
National Grid	46	9,281,937	201,781	1,519	1,190,210	251,758	1.25
WMECO	2	315,204	157,602	39,590	275,614	118,012	0.75
NSTAR	21	4,496,199	214,105	3,313	773,846	196,401	0.92
CLC	1	283,740	283,740	283,740	283,740	0	0.00
Totals	70	<b>14,377,080</b>					

The goal of the study is to design a sample that will allow KEMA to estimate realization rates for a number of measurements (annual kWh, percent of kWh savings on-peak, summer on-peak kW, and winter on-peak kW) with a relative precision of  $\pm 10\%$ . While the primary variable of interest for the sample design was annual kWh savings, the PAs also were interested in coincident peak summer kW because it is used in the ISO-NE Forward Capacity Market (FCM). The target for annual kWh was set at the traditional  $\pm 10\%$  at 90% confidence, while the target for summer kW was set at  $\pm 10\%$  precision at 80% confidence during the design. The summer kW target is based on the ISO-NE overall portfolio precision requirements, but need not be achieved in each individual study because the FCM precision may be calculated for each PA's overall portfolio of demand resources. Both are assessed in the following sections.

All of the sample design results for annual kWh were calculated at the 90% confidence level, while results for summer kW were calculated at the 80% confidence level.

### 2.1 Annual kWh Sample Design

KEMA presented several preliminary sample designs stratified by annual kWh for the Massachusetts PAs for the Custom HVAC end-use. The parameters considered in the sample design are the number of sample observations planned and the anticipated error ratio of

quantity being estimated. The error ratio is a measure of the strength of the relationship between the known characteristic (i.e., tracking system savings) and the quantity being estimated (i.e., evaluated savings).

The preliminary analyses looked at the impacts of samples of 10, 12 and 15 sites for National Grid, 8, 10 and 12 for NSTAR and 1 site each for WMECO and CLC. Multiple scenarios were run with assumed error ratios of 0.60 and 0.80. The ranges of error ratios and sample sizes considered was based on the results of two recent Custom HVAC evaluations done for National Grid. The 2005 study had 15 sample sites and an error ratio on the annual kWh savings estimate of 0.48. The 2006 study had 11 sample sites and an error ratio of 0.85.

Based on the results of the preliminary planning scenarios, samples were designed based on the population data provided by National Grid for HVAC 2009 sites for the four Massachusetts PAs. After some discussion about budgets and desired results, samples were designed using an error ratio of 0.6 and sample sizes of 15, 12, 1 and 1 for National Grid, NSTAR, WMECO and CLC, respectively. Table 2 shows the stratum cut points and distribution of sample sites in this scenario.

**Table 2: Sample Design based on Selected Scenario (15, 12, 1, 1)**

Program Administrator	Stratum	Maximum Total Gross Savings (kWh)	Projects	Total Gross Savings (kWh)	Planned Sample Size
National Grid	1	118,389	23	1,145,829	3
National Grid	2	217,393	9	1,583,579	3
National Grid	3	276,745	6	1,502,442	3
National Grid	4	406,545	5	1,935,493	3
National Grid	5	1,190,210	3	3,114,594	3
WMECO	1	275,614	2	315,204	1
NSTAR	1	142,112	10	740,735	3
NSTAR	2	215,267	4	768,925	3
NSTAR	3	325,715	4	1,115,287	3
NSTAR	4	773,846	3	1,871,252	3
CLC	1	283,740	1	283,740	1

Table 3 lists the calculated precision estimates for this scenario, following stratification. A precision of  $\pm 12.0\%$  was estimated for the overall results from all four PA's at the 90% confidence level. While the expected precision for the WMECO group is extremely high, its influence on the overall precision is minimal due to its relative size.

**Table 3: Estimated kWh Precision for Selected Scenario (15, 12, 1, 1)**

Program Administrator	Projects	Total Gross Savings (kWh)	Error Ratio	Planned Sample Size	Anticipated Relative Precision
National Grid	46	9,281,937	0.6	15	±17.0%
WMECO	2	315,204	0.6	1	±83.3%
NSTAR	21	4,496,199	0.6	12	±14.6%
CLC	1	283,740	0.6	1	±0.0%
<b>Totals</b>	<b>70</b>	<b>14,377,080</b>	<b>0.6</b>	<b>29</b>	<b>±12.0%</b>

## 2.2 Summer kW Sample Design

Before deciding on the final sample design, the analytical team examined the estimated summer kW precision that could be achieved with a sample of this size. A sample design for the four groups and 29 sites was created. The error ratios for summer kW savings realization rates in the prior National Grid studies ranged from 1.15 to 1.40, which are much higher than the Annual kWh savings error ratios. An average error ratio of 1.2 was used in the model. Given the ISO-NE requirement of 80/10 precision, this analysis was run at an 80% confidence level.

Table 4 estimates the summer kW precision using these parameters. Overall, the expected relative precision is ±17.9% at the 80% confidence level. While this does not quite meet the ISO-NE requirement, it is acceptable since the requirement is not applied to individual programs; each PA must achieve 80%/10% it for their entire portfolio of demand resources.

**Table 4: Estimated Precision for Summer kW using Selected Sample Size**

Program Administrator	Projects	Summer kW Savings	Error Ratio	Planned Sample Size	Anticipated Relative Precision
National Grid	46	1,489	1.2	15	±26.5%
WMECO	2	37	1.2	1	±129.8%
NSTAR	21	916	1.2	12	±22.7%
CLC	1	60	1.2	1	±0.0%
<b>Totals</b>	<b>70</b>	<b>2,503</b>	<b>1.2</b>	<b>29</b>	<b>±17.9%</b>

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After discussions with the PAs about evaluation objectives, KEMA recommended, and the PAs agreed that they proceed with this sample design for 29 sites in Massachusetts. This design is expected to produce good precision results state-wide and reasonable precision results for National Grid and NSTAR individually.

## **2.3 Final Sample**

Table 5 presents the list of 29 projects selected as the final sample for Custom HVAC. Note that projects that had not yet been fully commissioned at the time of the study were not considered for the evaluation. The final sample required the selection of two back-up sample points. NSTAR site CS7627 was a stratum 1 site that replaced CS7649, a stratum 2 site, because the primary selection was not yet commissioned, and there were no additional stratum 2 sites available for back-up. NSTAR site CS7824 replaced CS7487 because the primary selection declined the evaluation citing confidentiality concerns. Both of these sites were in stratum 3. Also presented in this table are the site assignments by evaluating company on the KEMA Team. KEMA evaluated 20 of the 29 projects and Demand Management Institute (DMI) evaluated the remaining nine projects.

**Table 5: Final Sample Selection**

Site ID	Program Administrator	Stratum	Project ID	Evaluator	Project Description
1	National Grid	1	N528586	KEMA	Office Building, VSDs on Chilled Water Pumps
2	National Grid	1	N528932	KEMA	Office Building, Demand Controlled Ventilation
3	National Grid	1	N547560	KEMA	College, Static Pressure Reset and VSDs on Lab Exhaust Fans
4	National Grid	2	N529184	KEMA	Manufacturing, Ultrasonic Humidifiers
5	National Grid	2	N533806	KEMA	College, New Heat Pumps and Condenser Unit
6	National Grid	2	N549060	DMI	High School, Reduced Summer Operation
7	National Grid	3	N525455	KEMA	Office Building, Retro-commissioning
8	National Grid	3	N546844	KEMA	School, Night Temperature Set Back, Weather Stripping, Lighting Controls
9	National Grid	3	N561104	KEMA	Manufacturing, Retro-commissioning
10	National Grid	4	N526240	DMI	Manufacturing, Process Exhaust Fan VSD
11	National Grid	4	N535094	KEMA	University, Lower Fan Speed by Replacing Cooling Coils
12	National Grid	4	N545636	DMI	College, Retro-commissioning
13	National Grid	5	N525453	KEMA	Office Building, OA Economization, Steam Leaks, and Reducing Ventilation Air
14	National Grid	5	N525819	KEMA	Museum, EMS Scheduling, Intelligent Ventilation, VSDs, Reduced Speed Unit Heaters
15	National Grid	5	N530145	DMI	University, VFDs on Dual Duct AHU Supply and Return Fans
16	WMECO	1	WM08S554	KEMA	Office Building, VSDs on Pumps, EMS Controls
17	NSTAR	1	CS1312_A	KEMA	Office/Lab, High Efficiency Chillers
18	NSTAR	1	CS7561	KEMA	Medical, Energy Recovery Ventilation
19	NSTAR	1	CS7787_B	KEMA	Office Building, Evaporative Condensing RTUs
20	NSTAR	1	CS7627	DMI	Medical, New Custom AHUs Instead of Commercial Grade AHUs
21	NSTAR	2	CS7726	KEMA	Office Building, New Chiller and Heat Exchanger
22	NSTAR	2	CS7812	DMI	Hospital, New Chiller
23	NSTAR	3	CS7824	KEMA	Manufacturing, New Chillers
24	NSTAR	3	CS7626	DMI	Hospital, New Custom AHUs Instead of Commercial Grade AHUs
25	NSTAR	3	CS7921	DMI	Office Building, New Chiller
26	NSTAR	4	CS1312_B	KEMA	Office/Lab, Free Cooling Heat Exchanger
27	NSTAR	4	CS1312_C	KEMA	Office/Lab, CO Sensors and Controls for Garage Ventilation
28	NSTAR	4	CS7459	DMI	Hotel, Replace PTAC Units with Heat Pumps
29	CLC	1	CLC99999	KEMA	Community Center, High Efficiency Brine Chiller Plant

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### **3. Description of Methodology**

#### **3.1 Measurement and Evaluation Plans**

Following the final sample selection of 2009 Custom HVAC applications and prior to beginning any site visits, KEMA and DMI developed detailed measurement and evaluation plans for each of the 29 applications. The plans outlined on-site methods, strategies, monitoring equipment placement, calibration and analysis issues. The PAs provided comments and edits to clarify and improve the plans prior to them being finalized.

Evaluators utilized the savings analysis methodologies from the Technical Assistance Study (TA) whenever possible. There were four instances where the TA methodology was found to be incorrect or inappropriate, and evaluators performed an analysis more appropriate to the measure being evaluated. Adjustments to savings methodologies were presented and agreed to in the measurement and evaluation plans.

The site evaluation plan played an important role in establishing approved field methods and ensuring that the ultimate objectives of the study were met. Each site visit culminated in an independent engineering assessment of the actual (e.g. as observed and monitored) annual energy, on-peak energy, diversified summer peak demand, and diversified winter peak demand savings associated with each project.

#### **3.2 Data Gathering, Analysis, and Reporting**

Data collection included physical inspection and inventory, interview with facility personnel, observation of site operating conditions and equipment, short-term metering of usage and EMS trends. At each site, KEMA performed a facility walk-through that focused on verifying the post-retrofit or installed conditions of each energy conservation measure (ECM). Several of the facilities utilized EMS controls which were either part of the application itself or controlled equipment that was included in the application. Evaluators viewed EMS screens to verify schedules and operating parameters where applicable. Instrumentation such as power recorders, Time-Of-Use (TOU) lighting loggers, TOU current loggers, and temperature loggers were installed to monitor the usage of the installed HVAC equipment and associated affected spaces. EMS trends were also collected, when available.

Savings analyses were used to estimate hourly energy use and diversified coincident peak demand. A typical meteorological year (TMY3) dataset of ambient temperatures closest to each

facility was used for all temperature sensitive calculations. Each site report details the specific analysis methods used specific for each project including algorithms, assumptions and calibration methods where applicable. Several sites were analyzed using building simulation models, including eQUEST, PowerDOE, and Visual DOE.

Engineers submitted draft site reports to the PAs upon completion of each site evaluation, which after review and comment resulted in the final reports found in Appendix B: Site Reports. This executive summary provides a concise overview of the evaluation methods and findings.

### 3.3 Analysis Procedures

In order to aggregate the individual site results from the Custom HVAC sample, KEMA applied the model-assisted stratified ratio estimation methodology described in References [1] and [2] in Appendix A: References. The key parameter of interest is the population realization rate, i.e., the ratio of the evaluated savings for all population projects divided by the tracking estimates of savings for all population projects. This rate is estimated for the overall Massachusetts program, as well as for individual PAs. Of course, the population realization rate is unknown, but it can be estimated by evaluating the savings in a sample of projects. The sample realization rate is the ratio between the weighted sum of the evaluated savings for the sample projects divided by the weighted sum of the tracking estimates of savings for the same projects. The total tracking savings in the population is multiplied by the sample realization rate to estimate the total evaluated savings in the population. The statistical precisions and error ratios are calculated for each level of aggregation.

The results presented in the following section include realization rates (and associated precision levels) for annual MWh savings, on-peak MWh savings, and on-peak demand (kW) savings at the times of the winter and summer peaks, as defined by the ISO New England Forward Capacity Market (FCM). All coincident summer and winter peak reductions were calculated using the following FCM definitions:

- Coincident Summer On-Peak kW Reduction is the average demand reduction that occurs over all hours between 1 PM and 5 PM on non-holiday weekdays in June, July and August.
- Coincident Winter On-Peak kW Reduction is the average demand reduction that occurs over all hours between 5 PM and 7 PM on non-holiday weekdays in December and January.

Note that WMECO historically utilizes the seasonal peak kW reductions as defined by the FCM, but that the numbers in this report are based on the on-peak definition above. Relative precision levels and error bounds are calculated at the 80% confidence level for demand values, since that is the requirement for participation in the FCM. For all MWh realization rates, the standard 90% confidence level is used.

## 4. Results

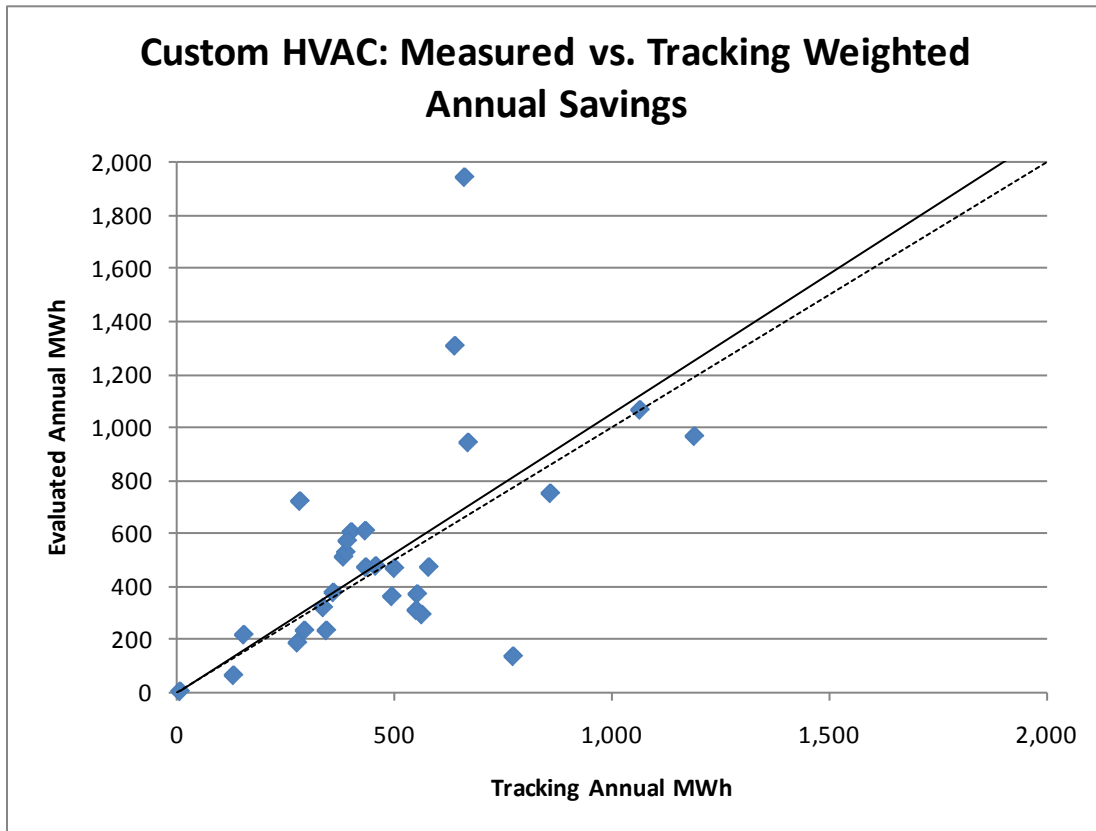
In preparation for analyzing the evaluation results collected for the Custom HVAC sample points, the original 2009 population stratum boundaries were used to calculate case weights for the each sample observation. These weights reflect the number of projects that each sample point represents in their respective populations, and allow for the aggregation of results across strata and PAs. The final case weights for the study, which reflect sample substitutions, are shown in the last column in Table 6.

**Table 6: Custom HVAC Case Weights**

PA	Stratum	Total Applications	Total Annual MWh	Applications in Sample	Case Weight
National Grid	1	23	1,146	3	7.67
National Grid	2	9	1,584	3	3.00
National Grid	3	6	1,502	3	2.00
National Grid	4	5	1,935	3	1.67
National Grid	5	3	3,115	3	1.00
WMECO	1	2	315	1	2.00
NSTAR	1	10	741	4	2.50
NSTAR	2	4	769	2	2.00
NSTAR	3	4	1,115	3	1.33
NSTAR	4	3	1,871	3	1.00
Cape Light Compact	1	1	284	1	1.00

### 4.1 Major Findings and Observable Trends

Figure 1 presents a scatter plot of evaluation results for annual kWh savings using all PA sample points. The dashed line represents a realization rate of one. The slope of the solid line in this graph is an indication of the overall realization rate, and can be seen to be close to one. These sample data are scattered pretty widely around the trend line, which supports the estimate made during the design process that the error ratio would be relatively high.



**Figure 1: Scatter Plot of Evaluation Results for Annual kWh Savings**

## 4.2 Presentation of Results

Table 7 presents a summary of the site level results for this impact evaluation.

**Table 7: Detailed Site Results**

Site ID	Application ID	Stratum	kWh/yr	On-Peak %	Peak Coinc.		kWh/yr	On-Peak %	Peak Coinc.	
					Sum. kW	Wint. kW			Sum. kW	Wint. kW
1	N528586	1	44,951	70%	13.3	0.0	30,292	80%	12.0	0.8
2	N528932	1	17,112	100%	32.8	0.0	8,145	100%	9.6	0.0
3	N547560	1	52,423	13%	0.0	0.0	78,866	38%	6.0	7.3
4	N529184	2	166,985	48%	0.0	19.0	155,853	48%	0.0	17.7
5	N533806	2	128,067	34%	1.9	38.9	170,166	24%	2.9	13.2
6	N549060	2	193,357	70%	294.0	0.0	157,265	93%	236.9	0.0
7	N525455	3	229,068	93%	191.0	143.0	238,010	104%	103.8	18.6
8	N546844	3	247,548	47%	40.0	30.0	180,520	69%	3.1	13.0
9	N561104	3	276,745	35%	26.0	26.0	184,918	46%	20.9	20.5
10	N526240	4	383,976	48%	43.8	43.8	785,440	47%	115.0	84.6
11	N535094	4	402,253	46%	40.2	39.7	565,947	47%	72.2	56.4
12	N545636	4	338,400	37%	2.0	2.0	175,306	1%	2.3	4.0
13	N525453	5	1,065,165	46%	87.0	42.0	1,066,509	53%	158.3	88.4
14	N525819	5	1,190,210	44%	99.1	66.9	966,911	44%	118.2	96.7
15	N530145	5	859,219	55%	177.8	138.0	751,003	63%	112.4	106.2
16	WM08S554	1	275,614	N/A	16.7	7.1	154,392	46%	11.9	25.7
17	CS1312_A	1	61,966	N/A	59.0	9.0	86,356	53%	31.0	0.0
18	CS7561	1	3,313	N/A	5.0	0.0	711	54%	0.4	0.0
19	CS7787_B	1	135,045	N/A	185.0	8.0	127,605	100%	120.7	3.1
20	CS7627	1	111,223	N/A	11.8	25.7	74,219	66%	15.7	10.1
21	CS7726	2	180,276	N/A	38.0	32.0	188,022	62%	7.3	10.7
22	CS7812	2	194,599	N/A	46.9	0.0	263,831	48%	54.4	1.6
23	CS7824	3	220,799	N/A	71.8	24.0	174,121	48%	41.2	2.0
24	CS7626	3	325,715	N/A	68.2	36.0	457,190	46%	54.7	50.9
25	CS7921	3	294,457	N/A	50.6	88.9	428,311	56%	95.5	15.3
26	CS1312_B	4	435,331	N/A	0.0	67.0	471,805	42%	0.0	122.0
27	CS1312_C	4	662,075	N/A	77.0	77.0	1,947,083	49%	279.9	280.9
28	CS7459	4	773,846	N/A	0.0	242.1	134,414	44%	1.6	14.6
29	CLC99999	1	283,740	100%	60.4	60.4	721,413	47%	62.6	107.5

Table 8 summarizes the savings realization rates and primary reasons for discrepancies between the tracking and evaluation estimates of annual energy savings. The site energy savings realization rates ranged from a low of 17% for Site 28 to a high of 294% for Site 27. Note that some of the ratios are “N/A” for the on-peak % and peak coincident demand

reductions because the tracking estimates were zero for some of these values.

**Table 8: Primary Site Discrepancies**

Site ID	Application ID	Ratio Evaluated/Tracking				Primary Reason for Discrepancy
		kWh/yr	On-Peak %	Peak Coinc.		
				Sum. kW	Wint. kW	
1	N528586	67%	115%	90%	N/A	Tracking savings calculated non-interactively with other measures. Evaluation savings based on building as-built.
2	N528932	48%	100%	29%	N/A	Building unoccupied. Evaluation assumed unoccupied 5 of the 13 years of the measure life.
3	N547560	150%	293%	N/A	N/A	Inconsistencies and errors in tracking calculations.
4	N529184	93%	100%	N/A	93%	Units out of service for 1 year out of the 15 year life of the measure.
5	N533806	133%	69%	157%	34%	Metered data shows more aggressive set-back is being used.
6	N549060	81%	133%	81%	N/A	Tracking calculation mistake that is magnified when a partial data set is extrapolated for entire summer periods.
7	N525455	104%	112%	54%	13%	Increased annual operating hours. Tracking savings based on 50 weeks per year.
8	N546844	73%	146%	8%	43%	Some measures not installed (weather stripping, night temp set back).
9	N561104	67%	131%	80%	79%	Equipment that was to be off was brought back on-line.
10	N526240	205%	98%	263%	193%	TA study did not include cooling savings; exhaust flow was further reduced beyond original estimates.
11	N535094	141%	101%	180%	142%	Lower fan turndown rates found onsite.
12	N545636	52%	4%	115%	199%	Lighting controls were not implemented, tracking did not account for interactivity between measures, AHU control not scheduled as aggressive as tracking.
13	N525453	100%	115%	182%	210%	Minor changes and discrepancies between monitored and tracking operation of equipment and temperature set points.
14	N525819	81%	101%	119%	145%	M1, setback savings significantly less due to diversity factor (80% tracking 30% evaluation).
15	N530145	87%	115%	63%	77%	Lower base-case fan energy and higher installed fan energy than predicted in tracking analysis. Also, fewer annual operating hours compared to tracking estimate (5,840 evaluation vs. 6,155 tracking).
16	WM08S554	56%	N/A	71%	361%	Site not using controls for chilled water and condenser pumps.
17	CS1312_A	139%	N/A	52%	0%	Higher ton-hrs in the evaluation. Tracking estimate assumed summer kW savings in the highest temperature bin, rather than during the summer peak hours.
18	CS7561	21%	N/A	9%	N/A	Error found in TA model that does not properly assess energy savings.
19	CS7787_B	94%	N/A	65%	39%	Building unoccupied. Evaluation assumed unoccupied 2 of the 20 years of the measure life.
20	CS7627	67%	N/A	133%	39%	Significantly lower supply airflow rates during unoccupied periods than predicted in the tracking analysis.

Site ID	Application ID	Ratio Evaluated/Tracking				Primary Reason for Discrepancy
		kWh/yr	On-Peak %	Peak Coinc.		
				Sum. kW	Wint. kW	
21	CS7726	104%	N/A	19%	34%	Tracking estimate assumed kW savings in the highest temp bins, rather than during the actual summer and winter peak hours.
22	CS7812	136%	N/A	116%	N/A	Increase in savings is due to higher chilled water loads and longer chiller operating hours.
23	CS7824	79%	N/A	57%	8%	The chiller curves (both base case and installed) used in the TA analysis did not match the manufacturer's performance data well.
24	CS7626	140%	N/A	80%	141%	Differences in the airflow profile and its effects on fan operation and performance.
25	CS7921	145%	N/A	189%	17%	Increase in savings is due to higher than predicted chilled water loads in evaluation vs. tracking.
26	CS1312_B	108%	N/A	0%	182%	Offsetting differences between free cooling load (tracking estimate higher) and part load efficiency of the installed chiller (evaluation estimate higher).
27	CS1312_C	294%	N/A	363%	365%	Significantly less runtime of garage supply and exhaust fans in the installed case (evaluation) than in the proposed case (tracking).
28	CS7459	17%	N/A	N/A	6%	Less full load heating hours (2,050 tracking, 925 evaluation). Less heating load served by heat pumps (55-60% tracking, 27% evaluation).
29	CLC99999	254%	47%	104%	178%	Estimated chiller loads were significantly higher in evaluation than in TA model.

The site-level evaluation results were aggregated using stratified ratio estimation. The PA realization rates are estimated, and then applied to each PA's total tracking savings to determine their total measured savings. The state-wide realization rate is the ratio of the total measured savings to the total tracking savings, each of which is calculated by summing across the PAs. Table 9 summarizes the state-wide results of this analysis. The table shows the results for three of the four measures of savings. State-wide on-peak kWh savings was not calculated because two of the four PAs did not provide tracking system data on this measurement. In the case of annual MWh savings, the realization rate for Custom HVAC measures was found to be 109.8%. The relative precision for this estimate was found to be  $\pm 6.6\%$  at the 90% level of confidence. The error ratio was found to be 0.48. Table 9 also shows the results for the on-peak summer and winter coincident demand savings, measured in kW. Since the design criteria for the demand realization rates were based on an 80% confidence level, the precisions and error bounds at this level are reported in the appropriate rows in Table 9 and Table 10. For the on-peak summer kW, the overall realization rate was 87.6%, with a relative precision of  $\pm 9.3\%$  at an 80% confidence level. For on-peak winter kW, the realization rate was a bit lower, at 86.4%. The grey cells in Table 9 and Table 10 represent the energy savings presented at 80% confidence, and demand savings at 90% confidence. These cells are

grey because the precision at these confidence levels were not required, but included for information purposes only

It is anticipated that WMECO will apply the on-peak summer and winter kW realization rates to their seasonal peak kW reductions. In future evaluations, a seasonal peak kW realization rate will be calculated for use by WMECO.

**Table 9: Summary of Custom HVAC Results**

Statistic	Annual MWh	On-Peak Summer kW	On-Peak Winter kW
Total Tracking Savings	14,377	2,503	1,860
Total Measured Savings	15,790	2,192	1,608
Realization Rate	109.8%	87.6%	86.4%
Relative Precision at 90% Confidence	6.6%	11.9%	18.6%
Error Bound at 90% Confidence	1,040	262	299
Relative Precision at 80% Confidence	5.1%	9.3%	14.5%
Error Bound at 80% Confidence	810	204	233
Error Ratio	0.48	0.68	1.20

The results of KEMA's analysis of realization rates by PA follow in Table 10. National Grid, NSTAR and Cape Light Compact all had annual MWh savings realization rates greater than 100%, at 100.5%, 123.7% and 254.3% respectively. Only WMECO had a low Annual MWh savings realization rate of 56%. The realization rates for percent on-peak MWh savings for National Grid and Cape Light Compact, the only PAs providing this information from their tracking system, were 107% and 47%, respectively.

Results for summer and winter on-peak kW savings varied widely. National Grid was pretty consistent with the summer and winter on-peak kW realization rates around 83%. NSTAR varied more by season, with a summer kW rate of 93.6% and a winter kW rate of 74.9%. The single evaluated sites in WMECO and CLC produced generally high realization rates for summer and winter on-peak kW.

The relative precisions of these estimates for the PAs with only one evaluated site (Cape Light Compact and WMECO) are zero. In the case of CLC, there is no error since the entire population of one project was sampled. For WMECO, the one sample site drawn from a population of two determined the realization rate and contributed no variation, resulting in precisions very close to zero. National Grid results, based on 15 evaluated sites include precisions ranging from  $\pm 10.7\%$  at 90% confidence for annual MWh to  $\pm 27.1\%$  at 80%

confidence for on-peak winter kW. For NSTAR, the best precision ( $\pm 5.3\%$ ) was on annual MWh savings, and the worst was on summer kW ( $\pm 15.0\%$ ).

**Table 10: Summary of Custom HVAC Results by Program Administrator**

Statistic	Annual MWh	On-Peak MWh	% On-Peak MWh	On-Peak Summer kW	On-Peak Winter kW
<b>National Grid</b>					
Total Tracking Savings	9,282	4,490	48.4%	1,489	1,001
Total Measured Savings	9,331	4,834	51.8%	1,245	825
Realization Rate	100.5%	107.7%	107.1%	83.6%	82.4%
Relative Precision at 90% Confidence	10.7%	10.8%	-	16.3%	34.8%
Error Bound at 90% Confidence	997	522	-	203	287
Relative Precision at 80% Confidence	8.3%	8.4%	-	12.7%	27.1%
Error Bound at 80% Confidence	777	407	-	158	224
Error Ratio	0.38	0.38	-	0.64	1.26
<b>WMECO</b>					
Total Tracking Savings	315	-	-	37	27
Total Measured Savings	177	-	-	26	97
Realization Rate	56.0%	-	-	71.3%	361.3%
Relative Precision at 90% Confidence	0.0%	-	-	0.0%	0.0%
Error Bound at 90% Confidence	0	-	-	0	0
Relative Precision at 80% Confidence	0.0%	-	-	0.0%	0.0%
Error Bound at 80% Confidence	0	-	-	0	0
Error Ratio	0.00	-	-	0.00	0.00
<b>NSTAR</b>					
Total Tracking Savings	4,496	-	-	916	771
Total Measured Savings	5,561	-	-	858	578
Realization Rate	123.7%	-	-	93.6%	74.9%
Relative Precision at 90% Confidence	5.3%	-	-	19.2%	14.3%
Error Bound at 90% Confidence	294	-	-	165	83
Relative Precision at 80% Confidence	4.1%	-	-	15.0%	11.1%
Error Bound at 80% Confidence	229	-	-	129	64
Error Ratio	0.72	-	-	0.81	1.53
<b>Cape Light Compact</b>					
Total Tracking Savings	284	284	100.0%	60	60
Total Measured Savings	721	339	47.0%	63	108
Realization Rate	254.3%	119.5%	47.0%	103.6%	178.0%
Relative Precision at 90% Confidence	0.0%	0.0%	-	0.0%	0.0%
Error Bound at 90% Confidence	-	-	-	-	-
Relative Precision at 80% Confidence	0.0%	-	-	0.0%	0.0%
Error Bound at 80% Confidence	-	-	-	-	-
Error Ratio	0.00	0.00	-	0.00	0.00

### 4.3 Comparison to Prior Results

While this is the first state-wide evaluation of the Custom HVAC program, it is informative to compare these results to those of prior studies done by individual PA's. National Grid evaluated

their Custom HVAC program in 2005 and 2006. The combined 2005 and 2006 realization rate for annual MWh was found to be 81.1%, which is significantly lower than the findings in this study. Their combined summer kW rate was lower and combined winter kW rate was higher (72.2% and 104.9% respectively).

## 4.4 Implications for Future Studies

The results of this analysis can be used to inform future sample designs. During the design of this study, an error ratio of 0.60 was assumed for annual MWh savings and 1.20 was assumed for summer kW, based on limited historical information. These were chosen to be conservative, and turn out to be fairly accurate. Based on the findings of this study, the error ratios were slightly lower than anticipated: the annual MWh error ratio was 0.48 and the summer kW error ratio was 0.68. It turns out that the winter kW error ratio was as anticipated, at exactly 1.20. As a result, the precisions levels were slightly better than what was required.

On an individual PA basis, both National Grid and NSTAR results achieve the desired precision levels for annual MWh savings, and come reasonably close for summer kW.

## 4.5 Conclusions and Recommendations

Overall, the Custom HVAC program appears to be successfully providing energy and demand savings in the State of Massachusetts. Below are major findings and recommendations that apply statewide, as well as to the individual PAs.

### 4.5.1 Statewide

**Review tracking calculation methodologies.** Tracking calculation methodologies ranged from building simulations to single line calculations. Performance contractor proprietary software was also used for tracking estimates in a number of cases. Bin analyses, single line calculations, and proprietary software sometimes calculate on-peak energy savings and winter and summer peak demand savings using weighted averages or non-defined default multipliers. These different approaches and non-uniform averages and multipliers sometimes result in over or underestimation of peak savings values. Even though a TA analysis may apply the correct peak hours, these other undefined factors can sometimes contribute to the savings variances. It is recommended that evaluation calculations be performed with 8,760 hours spreadsheets. The exception is for eQUEST and DOE2 simulations which can be recreated with those programs. The use of 8,760 hour calculations provides the ability to calculate performance

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(baseline/existing and installed cases) to the unique weather or load profile for each hour. The use of TMY3 weather data as the standard in the hourly calculations provides the most current weather data for annualizing savings, and should be used for all savings calculations.

**Cross-check TA report with corresponding analysis files.** Analysis files (building simulation or spreadsheets) should be provided by the TA engineer with the final TA report, and the PAs should make sure that the provided analysis outputs match the report text and screening tool. There were a few instances across PAs, in which the savings values in the TA reports and analysis files did not match, causing difficulties in identifying how the tracking savings were developed.

#### 4.5.2 Cape Light Compact

There was one CLC sample site included in the 2009 Custom HVAC Impact Evaluation, which makes it difficult to propose recommendations regarding CLC's program. However, there are some observations that could be made from reviewing this sample site.

**Verify simulation model inputs.** This site produced an annual energy savings estimate that was 254% of the tracking estimate. There were several reasons for this large positive discrepancy, but the primary reason was that the chiller plant loads were significantly underestimated in the tracking analysis. Considering that this was a new construction project, and the tracking assumptions were based on the best information available at the time, it is reasonable to expect some differences between the tracking and evaluated chiller loads. However, there were a number of incorrect model inputs that were identified during the evaluation that contributed to the large increase in savings. These were inputs such as constant speed pumps and fans that were actually on variable frequency drives (VFD) and a fixed brine supply temperature that should have been allowed to modulate in the model. Correcting these model inputs would help improve the tracking estimates for future projects.

#### 4.5.3 National Grid

**Review measure life for retro-commissioning measures.** Two retro-commissioning sites in the sample derived their tracking savings by utilizing existing EMS controls to optimize the scheduling of supply fans, return fans and air handling units. Evaluators found that some fans at both of these locations were no longer operating based on the originally proposed schedules, but were running more hours than the pre-existing conditions. Since the evaluation took place about a year after implementation of these measures, savings for these fans were set to zero for

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a significant portion of their measure lifetimes (5 and 10 year measure life). It is first recommended that similar measures are given the same estimate of measure life. It is also recommended that National Grid considers giving this type of retro-commissioning measure something less than a 5 year lifetime since this type of measure isn't always sustainable over these 5 and 10 year lifetimes. A measure life of 2 to 3 years may be more appropriate if this measure continues to receive incentives.

**Review measures and categorize correctly.** It is recommended that all measure codes are reviewed to confirm that the measure is correctly categorized. It appears that one sample site should have been categorized as a process measure rather than HVAC. One other site included lighting occupancy sensor savings as part of the tracking savings. This site did install occupancy sensors to control room dampers in addition to lighting fixtures, but the HVAC savings associated with the sensors were not claimed in the tracking analysis.

**Do not use heating degree day calculations for C&I measures.** Heating degree day calculations were used to estimate savings from implementing longer heating set back hours at one location. Heating degree day calculations are a residential tool and is not applicable to C&I facilities. Heating degree day calculations cannot accurately estimate impacts of core areas that have high internal gains and minimal exterior wall exposures. Therefore, it is recommended that heating degree day calculations not be used as an acceptable calculation tool for future C&I HVAC projects.

**Update old versions of TA reports and analyses.** It is recommended that when revisiting an older eQUEST study to document savings in a more recent project, the analysis should be updated to the latest version of eQUEST to account of any differences in claimed savings between the versions of the modeling software. Also, it is important that any changes in building operation since the original study be included. There was one site in which the TA study was completed several years ago, but not implemented until 2009. In this case, the evaluator could not match the savings in the study with the eQUEST files provided with the application. It is expected that the difference is because an updated version of eQUEST is being used since the time of the original study.

**Consider interactivity of all measures for project savings.** It is important that the interactivity between all measures in a project be considered in the TA study. The total savings for the measures in one site were calculated as a cumulative total of the measures instead of an interactive total, which resulted in a lower realization rate.

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**Consider all secondary sources of energy savings/penalties.** It is recommended that all secondary sources of savings and/or penalties be considered. The measure analyzed at one site involved a reduction in exhaust airflow. The tracking study calculated fan savings, but did not consider cooling savings associated with the resulting reduction in ventilation air. At another site, the tracking study did not consider fan penalties associated with an increase in air handler discharge air temperature resulting from the implemented measures.

**Evaluators should record EMS schedules and set points when possible.** At one site, EMS data was not provided to evaluators, as promised. A lightning strike required the EMS to be reset, and the trend data was lost and no new trends were started. Despite not collecting any EMS trends, evaluators were able to estimate savings for this site by using a combination of power monitoring and EMS schedules and set points. For the evaluation, it is important to capture and record as much information from the EMS system and scheduling screens during site visits. This is the equivalent of spot measurements in an analysis. This should be standard practice for evaluators when relying on EMS data, or anytime schedules and set points are available using EMS screen shots.

#### 4.5.4 NSTAR

**Review tracking system inputs.** It is recommended that the PA reviews the tracking system inputs to ensure that they match the tracking study report text and analysis. At one site, the values from the tracking study for summer and winter peak demand reductions entered in the tracking system were switched (summer value entered as winter and winter value entered as summer) from the values stated in the report text.

**Require adequate savings documentation.** It is recommended that the PA ensures that the tracking study report text clearly describes the calculation of the summer and winter demand reduction along with the source of the demand reduction. At one site, the demand reductions claimed in the tracking study could not be matched by the eQUEST files provided with the application.

In addition, it is recommended that the PA ensures that the source of equipment performance for base and proposed equipment is clearly identified in the tracking study. The source of the chiller performance curves used for two sites in their respective eQUEST models were not provided with the application documents.

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#### 4.5.5 Western Massachusetts Electric Company

There was one WMECO sample site included in the 2009 Custom HVAC Impact Evaluation, which makes it difficult to propose recommendations regarding WMECO's program. However, there are some observations that could be made from reviewing this sample site.

**Consider more rigorous post-installation check-up.** This site produced an annual energy savings estimate that was 56% of the tracking estimate. This project included EMS upgrades to automatically control the free cooling system, VFDs on chilled water pumps, condenser water pumps, heating hot water pumps and auxiliary pumps. The reason for the decrease in savings was the result of the disabling of the EMS controls on the free cooling system, and the chilled and condenser water pumps operating at full speed. The savings for these project components were set to zero because they are currently operating no different than the pre-retrofit condition. The evaluation found that the EMS free cooling controls were disabled due to concerns of frequent cycling on the lag chiller. WMECO should try to identify non-performing measures such as this during a post-installation inspection. It could be that the customer may need more education on how to control these measures, or that the measure ultimately doesn't qualify for incentives.

**Ensure TA studies and supporting calculations are stored for future evaluations.** One other issue was that the evaluation team was not provided with the TA savings spreadsheets used to estimate the tracking savings for this project. For the measures that were operating correctly, heating hot water and auxiliary pumps, the evaluated summer and winter demand savings were significantly higher than the corresponding tracking estimates. Since the tracking savings calculations were not available, evaluators were unable to clearly identify where the differences in demand savings come from. It is recommended that WMECO obtain and keep all savings calculations from the vendors performing the calculations.

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## Appendix A: References

- [1] *The California Evaluation Framework*, prepared for Southern California Edison Company and the California Public Utility Commission, by the TecMarket Works Framework Team, June 2005, Chapters 12-13.
- [2] *Model Assisted Survey Sampling*, C. E. Sarndal, B. Swensson, and J. Wretman, Springer, 1992.

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## Appendix B: Site Reports