Rhode Island Commercial and Industrial Impact Evaluation of 2013-2015 Custom CDA Installations

National Grid

Final Report
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1 EXECUTIVE SUMMARY

This Executive Summary provides a high-level review of the results for the Rhode Island Commercial and Industrial (C&I) Impact Evaluation of 2013-2015 Comprehensive Design Approach (CDA) Installations. In this section, we state the study objectives, summarize the evaluation approach, and present key findings, conclusions, and recommendations.

CDA is an energy efficiency track within the custom commercial and industrial (C&I) new construction energy efficiency programs offered in Rhode Island. It is an integrated, whole-building, performance path-based approach that is ideally initiated at the beginning of the new building or major renovation design stage to yield cost-effective energy efficiency opportunities and significant energy use reductions relative to state building code and/or common practice. CDA projects are unique in their complexity and analytical difficulty as they analyze many measures simultaneously which requires hourly building simulation models to estimate savings from measures that tend to be highly interactive.

This evaluation was completed between 2016 and 2018. It has been seven years since the last CDA evaluation. While most realization rates from that effort and prior ones were fairly high, the CDA offering has grown and changed in ways that make it important to reassess its performance.

1.1 Overview of objectives and approach

The objective of this Impact Evaluation of Electric Custom CDA Installations for the program years 2013-2015 is to provide verification and re-estimation of energy and demand savings for a sample of statistically selected Custom CDA projects through site specific inspection, monitoring, and analysis. The results of this study will be used to determine the gross realization rates for Custom CDA energy efficiency projects implemented for future energy projects in this impact category.

A synopsis of the research approach is as follows:

DNV GL developed a stratified sampling design from program participation data provided by National Grid. The final evaluation sample design for this study was expected to achieve an electric energy savings realization rate result with ±24.8% relative precision at the 90% confidence interval for a combined RI and MA National Grid territory (MA+RI).

Site specific measurement and verification (M&V) plans were created for each sampled site. These plans were reviewed and approved by National Grid before data collection was initiated.

The data used to estimate evaluated savings was collected by the team according to the approved M&V plan. The evaluation collected and reviewed all provided program documentation and collected data associated with each sampled project. Data collection methods included interviews of facility personnel, interviews of equipment vendors, on-site monitoring of operating equipment, receipt of data collected by the customer, and receipt of utility meter consumption data.

The applicants for all sampled sites in this study used eQuest[1] to develop proposed and baseline energy consumption. Instead of recreating the entire model, the technical assistant (TA or applicant) developed model was used as a starting point and revised to fit the "as-built" or as found on-site conditions. The as-built model was then calibrated to electric billing data. Following National Grid's acceptance of the calibration

[1] eQuest is one of the DoE recommended energy simulation tools that comprehensively estimates energy consumption of buildings using DoE-2 energy code.

memo, the as-built model was created using TMY3 weather data. Finally, the energy savings measures were returned to the baseline conditions. Savings were calculated as the difference between the weather normalized and calibrated as-built model and the baseline model.

The evaluation created unique site reports for each sampled project. Each report includes a project description, a description of the tracking savings assumption and methodology, a description of the data collected by the evaluation, a description of the evaluation analysis completed, and a discussion of the evaluation results and reasons for the variance between tracking and evaluation estimates of savings. These reports are available in Appendix D.

1.2 Key findings and conclusions

The evaluation results were aggregated using the final adjusted case weights. The overall (MA+RI) realization rate is the ratio of the total measured savings to the total tracking savings, each of which is calculated by summing across National Grid territory in both MA and RI.

Table 1-1 and Table 1-2 summarize the overall results of this analysis at MA+RI, MA and RI levels individually. The results presented include realization rates (and associated precision levels) for annual 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.

Table 1-1: 2013-2015 RI and 2014 MA CDA custom electric annual energy (MWh) savings results

Results	MA+RI		MA only		RI only	
	Annual Energy	On-Peak Energy	Annual Energy	On-Peak Energy	Annual Energy	On-Peak Energy
	MWh	%	MWh	%	MWh	%
Total Tracking Savings	12,900	58%	11,667	56%	1,233	70%
Total Evaluated Savings	6,106	51%	5,279	51%	827	50%
Realization Rate	47.3%	88%	45.2%	91%	67.0%	71%
Error Ratio	0.47	0.83	0.49	0.86	0.35	0.59
Confidence Interval	90% Confidence					
Relative Precision	±18.0%	±38.9%	±20.2%	±43.3%	±30.1%	±51.0%
Error Bound	1,097	1,468	1,068	1,452	249	218

Note that the realization rate of RI (only) energy savings is higher than MA (only) savings but the difference is not statistically different based on the absolute precisions calculated for both the states individually. Essentially, the realization rates overlap when the precisions are included.

Table 1-2: 2013-2015 RI and 2014 MA CDA custom electric demand savings (kW) results

Results	MA+RI		MA only		RI only	
	Summer On-Peak	Winter On-Peak	Summer On-Peak	Winter On-Peak	Summer On-Peak	Winter On-Peak
	kW	kW	kW	kW	kW	kW
Total Tracking Savings	3,166	1,825	2,480	1,688	686	137
Total Evaluated Savings	1,560	461	1,135	365	425	97
Realization Rate	49.3%	25.3%	45.8%	21.6%	61.9%	70.7%
Error Ratio	0.68	0.78	0.65	0.63	0.78	1.33
Confidence Interval	80% Confidence					
Relative Precision	±23.2%	±29.1%	±24.9%	±28.0%	±53.0%	±90.2%
Error Bound	361.4	134.4	282.6	102.2	225.2	87.2

The electric annual energy savings realization rate was 47% with a relative precision of ±18% at the 90% confidence level. The relative precision target of ±20% was therefore achieved with an error ratio of 0.47 vs 0.30 planned. The error ratio is an estimate of the variance between the evaluated and tracking savings. The larger the error ratio, the larger the variance. One reason for this could be due to the greater focus on baseline verification in this evaluation as compared to the previous CDA impact evaluation.

The reduction in electric savings was mostly driven by the application of the lighting ISP from the MA code compliance study (P24)[2]. This study found that the standard practice for lighting in new buildings was 0.78 of allowed LPDs under IECC 2009 code. In Rhode Island, the LPD adjustment was also found to be reduced the site-level savings by approximately 20% for two sampled sites together.

Discussions with the National Grid revealed consistency across projects in the application of the prescriptive and mandatory sections of the MA and RI energy code, but some deviation in how ambiguous or non-code measures were handled. For example, National Grid refers all of their technical assistance providers to National Grid maintained guidelines to define ambiguous or non-code measure baselines. These guidelines rely on the mandatory and prescriptive code requirements, with some adjustments for what National Grid has found to be standard practice for some ambiguous code and non-code measures. In addition, some projects in the CDA sample used ASHRAE 90.1- Appendix G to define baselines, but National Grid did not uniformly apply it, the Energy Cost Budget method (Chapter 11 of 90.1), or the Total Building Performance method (Chapter 506/C407 of IECC 2009/2012) to define project baselines.

1.3 Recommendations

DNV GL makes the following recommendations based on the data collected, conclusions, results, and process of this impact evaluation.

Recommendation 1: Apply the realization rates results from this study (47% electric kWh) to adjust the gross savings claimed for CDA projects prospectively. National Grid should use the combined (MA+RI) realization results from this study for the program year 2019 and future planning of this impact category.

Recommendation 2: Adopt a baseline for LPD that is consistent with current industry standard

[2] Energy and Resource Solutions, Inc., P24 – Massachusetts Commercial New Construction Energy Code Compliance Follow-up Study, July 22, 2015

practice. As stated in the report, the realization rate from this study was based on applying a baseline LPD adjustment factor of 0.78 to apply to the allowed LPDs under IECC 2009 code based on the findings from a MA code compliance study (P24)[2]. A subsequent code compliance study (P70)[3] examining buildings permitted under IECC 2012 determined an LPD adjustment factor of 0.67. A code compliance study was also completed in RI in 2016[4] and the LPDs observed were 28% (unweighted) better than code (per IECC 2012) on average. As a result of these studies, National Grid in MA has proposed to immediately adopt a more stringent baseline for the CDA program. An in-progress study (P73B) has been commissioned to use this information and other data to recommend a final LPD adjustment factor which should be adopted by the programs. National Grid should adopt the 0.78 LPD factor until P73B study is completed or consider recommendation 3 below.

Recommendation 3: Re-examine and adjust the realization rate to apply to future CDA projects to account for the adoption of new baselines/ISPs as well as process improvements made by the program. National Grid should consider a small follow-up effort in RI to re-examine the realization rate from this study following agreement on the lighting ISP lighting power density (LPD) that will be used for projects beginning in 2019 or 2020, and after implementation of it and the other ISPs completed through this study. If these baselines are adopted by the program, the results from this study could be re-examined to estimate a new prospective realization rate, assuming the new baselines are in effect. We would recommend at least a full file review of all CDA projects to verify application of new baselines prior to using an updated prospective CDA realization rate.

Recommendation 4: Adopt the ISPs developed for parking garage exhaust fan, kitchen hood, and laboratory fume hood controls; and foil coil unit EC motors. MA CDA (P56) study produced four low-rigor ISP findings for fan coil unit EC motors, parking garage fan exhaust, kitchen ventilation controls, and laboratory fume hoods. The findings from these four ISP studies should be applied to appropriate future projects in RI, so that savings for these measures aren't overstated.

Recommendation 5: Improve the commissioning process to ensure ECM installation and intended function. Each project in the sample underwent one, and sometimes two, rounds of commissioning prior to the full incentive being paid to the applicant. However, the quality of commissioning was found to be an area needing improvement. In RI, the evaluation found the building operating schedules were significantly different from what was assumed during tracking analysis. DNV GL recommends that the programs take steps to improve the commissioning process to ensure that the claimed savings are being achieved. This can be done through the selection of preferred commissioning vendors, additional training, and guidance on what type of evidence is needed to confirm measure operation.

1.4 Considerations

The following considerations are specific to changes National Grid could make in the delivery of their energy efficiency programs.

1. Consider including a summary of the baseline selection in the project documentation. The program should document how the baseline was determined for unique custom projects in this impact category and provide clear statements on each decision made.

[3] MA C&I Energy Code Compliance and Baseline for IECC 2012 (P70), March 2018
[4] RI Commercial Energy Code Compliance Study-2016

2. Engineering firms providing TA studies for CDA projects should consider using other building simulation software, such as EnergyPlus specifically when unique HVAC measures like displacement ventilation (DV) or energy recovery ventilators (ERVs) are recommended in the building.
    a. EnergyPlus uses heat balance method to perform radiant and convective calculations at each surface and it models both radiation and thermal stratification through a 3-node stratification model which are critical elements to DV or ERVs. eQuest uses the transfer function method with custom weighting factors, essentially assumes all zones are fully mixed, which is not true in reality. These modeling differences could over/under-estimate savings compared to the as-built conditions.

1.5 Future research considerations

The following considerations are specific to the design and structure of future custom impact evaluations of National Grid' programs.

1. RI completed a CDA study recently and considering higher costs for this study, National Grid should consider following MA's timeline for this study and evaluate in RI when MA studies the next round of CDA projects.
2. Consider following MA's direction on evaluating any future CDA projects. Given the issues with commissioning, evaluators should consider documenting in the site M&V plan how they will independently validate the BAS data. BAS sensors sometimes do not report accurately to the BAS. In the future, the M&V plan should document the methods by which the evaluators will validate the BAS data so that it may better serve the evaluation.
3. Baseline review considerations: These considerations are specific to future baseline review efforts.
    a. Consider including a project file review task that inventories the measures that will be encountered during the evaluation.
    b. Consider including an anticipated baseline review methodology in the site-specific M&V plan. This methodology should include completion of the standard review guideline mentioned above and any additional site-specific questions.

2 INTRODUCTION

This document presents the final report for DNV GL's Impact Evaluation of 2013-2015 Comprehensive Design Approach (CDA) Installations. National Grid previously completed an impact evaluation of 2008-2009 electric custom CDA installations.[5]

CDA is an energy efficiency track within the custom commercial and industrial (C&I) new construction energy efficiency programs offered in Rhode Island. It is an integrated, whole-building, performance path-based approach that is ideally initiated at the beginning of the new building or major renovation design stage to yield cost-effective energy efficiency opportunities and significant energy use reductions relative to state building code and/or common practice. CDA projects are unique in their complexity and analytical difficulty as they analyze many measures simultaneously which requires hourly building simulation models to estimate savings from measures that tend to be highly interactive.

The project was completed between 2016 and 2018. It has been seven years since the last CDA evaluation. The prior study was electric only, and while most realization rates from that effort and prior ones were fairly high, the CDA offering has grown and changed in ways that make it important to reassess its performance.

2.1 Study objectives

The objective of this Impact Evaluation of Electric Custom CDA Installations for the program years 2013-2015 is to provide verification and re-estimation of energy and demand savings for a sample of statistically selected Custom CDA projects through site specific inspection, monitoring, and analysis. The results of this study will be used to determine the gross realization rates for Custom CDA energy efficiency projects implemented in 2019 and beyond.

2.2 Methods

DNV GL utilized the following approach for this impact evaluation:

Examined the 2013-2015 large C&I population to improve understanding of the relative impact of this category

Designed an efficient sampling plan for the selection of custom CDA projects for on-site visits to achieve the agreed relative precision targets using the error ratios determined in the previous CDA evaluations

Performed a full file review of all 2013-2015 Custom CDA projects to understand the composition of these projects by fuel type, measures installed, and measures incentivized.

Reviewed the TA studies, model files, and calculations used to develop the tracking savings for each sampled participant to develop site specific M&V plans

Performed comprehensive data collection at each sample site to support an independent analysis of achieved gross electric energy and demand savings realization rates

Established baselines for each sampled project based on the materials reviewed and additional data collected, as well as an LPD adjustment factor for lighting measures which was a product of P70[6], the code compliance study

Performed comprehensive data collection at each sample site to support an independent analysis of achieved gross energy and demand savings realization rates

[5] SBW Consulting and KEMA Inc. *Impact Evaluation of 2008 and 2009 Custom CDA Installations*, June 7, 2011.
[6] MA C&I Code Compliance Study, March 2018

Documented the evaluation activities completed in a comprehensive site-specific M&V report

Extrapolated the sample results to the population to estimate a combined MA and RI National Grid territory realization rates (RR) for the impact category.

3 METHODOLOGY

3.1 Population review

The population review task was completed early on in the study to identify the impact category's sampling strategy for both electric and gas. DNV GL reviewed the RI population data for the program years 2013 through 2015. Initial population data consists of a total 11 electric applications where 8 applications are parent / child applications, meaning the project was claimed in 2 pieces: ~80% savings claimed in the parent after the post inspection and ~20% claimed in the child after commissioning is completed. 4 (2 customer accounts) of these 11 applications have been removed from the population as they are yet to be commissioned and are therefore ineligible for evaluation, since the total savings claim has not been finalized. Therefore, 7 applications (or 5 customer accounts) have been used in the final population as shown in Table 3-1. DNV GL's data management team worked with National Grid to confirm that the electric projects identified are currently being tracked as Custom CDA and use the prior Custom CDA impact evaluation results.

Table 3-1: Population of 2013-2015 RI CDA projects

National Grid ID	Year	Total Gross (kWh)	notes
534507; 2508915	2012, 2014	368,011	parent, child
2521416; 3575541	2013, 2014	367,707	parent, child
2821013	2013	156,254	single application
2834588	2013	209,119	single application
4590647	2015	131,712	single application

3.2 Sample development

Evaluation sample designs strive to leverage error ratios from past evaluations of a similar nature, and some prior results informed the sampling parameters for this CDA study. Four years ago, an electric CDA study yielded a 0.23 error ratio, and this informed the selection of a more moderate 0.3 error ratio for CDA electric measures and energy savings. Citing the relatively small size of CDA in light of the overall large C&I energy efficiency portfolio and the higher cost of evaluating this type of comprehensive program, National Grid and DNV GL agreed to sample from combined Massachusetts (National Grid territory only) and Rhode Island population level rather than at the RI state-level. Likewise, the sample design did not set any specific precision targets, but reviewed several different sample scenarios to balance the number of sites with an acceptable level of precision. Following several discussions with the National Grid Study Manager and multiple iterations of sample designs, the final sample was set at an agreed-upon level, which would produce a result that could be applied to their CDA projects for future impact reporting. Note that the electric sample was designed for energy savings (kWh). Site specific and program aggregate demand impacts will be calculated as part of this study, and demand relative precision will be reported at the 80% confidence interval; however, the sample was not designed to meet any precision target for kW demand.

3.2.1 Sample targets

As mentioned above, the study was targeted to reasonable precisions for the combined population of MA and RI (National Grid territory only). Note that the electric sample was designed for energy savings (kWh). Site-

specific and program aggregate demand impacts were also calculated as part of this study, and demand relative precision is reported at the 80% confidence interval; however, the sample was not designed to meet any precision target for this variable.

3.2.2 Sample design

The final sample design for this project is shown in Table 3-2. Overall, the project was designed to achieve a combined MA and RI National Grid territory result with ±24.84% relative precision for electric energy (kWh) savings at the 90% confidence interval. Other scenarios with larger sample size were considered during this design phase but there was very little improvement in the estimated precision. For example, adding 1 sample point in RI (n=3) improved the precision by only 0.06% (i.e. ±24.78%) but there will be a significant cost increase for the study. Therefore, both National Grid and DNV GL decided to go with a sample size of 2.

Table 3-2: Sample design, anticipated relative precision of results

State	Accounts	Savings (kWh)	Sample Designed	Sample Achieved	Expected Relative Precision (90% Confidence)	Relative Precision Achieved (90% Confidence)
MA	19	11,667,024	3	4	±27.8%	±20.2%
RI	5	1,232,803	2	2	±26.5%	±30.1%
MA+RI	24	12,899,827	5	6	±24.8%	±18.0%

3.2.3 Sample stratification

The sample design utilized stratification by energy savings in order to achieve the sample targets with the fewest number of sample points. Table 3-3 shows the strata utilized for the electric sample, including the original sample size within each stratum, and the probability of selection.

Table 3-3: Final sample by strata

State	Stratum	Maximum (kWh)	Savings (kWh)	Population (N)	Sample Size (n)	Sample Weight
MA	1	546,897	4,166,729	13	1	13
	2	817,548	3,566,018	5	2	2.5
	3	3,934,277	3,934,277	1	1	1
RI	1	209,119	497,085	3	1	3
	2	368,011	735,718	2	1	2
MA+RI			12,899,827	24	6	

The sample frame for this impact evaluation was based on the projects tracked as CDA by National Grid through program years 2013- 2015. Due to the nature of this program offering, which is intended to improve whole building design from an energy efficiency standpoint, it is likely that there are both electric and gas savings present at most, if not all, sites.

3.3 Description of methodology

This section describes the general methodology used for both the full file reviews, baseline review, development of site evaluation plans, the execution of the plans, and the final process for producing program results. Each site report in Appendix D describes the site-specific methodology in detail.

3.3.1 Measurement and evaluation plans

Following sample selection and prior to beginning any site visits, DNV GL developed detailed measurement and evaluation plans for each sampled project. The plans included the following sections:

Project Description. A description of how the project saves energy.

Tracking Savings. A description of how the tracking savings were originally estimated, and their source, including:

- Model type used
- Identification of the key baseline model inputs
- Identification of the key proposed model inputs

Project Evaluation. A description of the methods to be used to evaluate the project, including but not limited to:

- How measure installation and current operation will be verified
- How building use and occupancy will be observed and/or assessed
- Identification of the tracking and expected evaluator baseline by measure
- The data to be collected by DNV GL
- Site staff interview questions
- The data to be provided by the site (e.g., building automation system [BAS] trends, production, pre-metering, etc.) and/or National Grid
- The expected evaluation analysis method to be used
- Other key parameters to be gathered through the evaluation and compared to those used in the original savings estimate

TA savings from all sites were estimated using the eQUEST building simulation software. To ensure consistency, evaluators used the same TA models as a starting point and used the same building simulation software as the TA for each site in the sample.

3.3.1.1 Site recruitment/interviews

National Grid provided a list of contacts to DNV GL along with approval to contact the customer. DNV GL called each site contact to discuss the site details and schedule a site visit. This discussion was used to improve our understanding of the site, the project, and the data available for the evaluation. Any new information received at this time was integrated into each site's M&V plan.

3.3.2 Data collection for verification, analysis, and reporting

Data collection included physical inspection, an interview with facility personnel, observation of site operating conditions and equipment, metering of equipment usage, and collection of facility provided data. In some cases, multiple facility interviews were completed to ensure an accurate understanding of operating practice.

The physical inspection focused on verifying measure installation and expected operation. For all but two projects, equipment was found to be installed and operating. In three cases, at least one measure included in the project was found to be not installed. This included two sites where static pressure reset controls were not installed, and another where occupancy sensors were not installed. Each site report includes the results of measure verification.

Instrumentation such as power recorders, TOU current loggers, and temperature loggers were installed to monitor the usage of operating equipment and conditions of the associated affected spaces. BAS trends were also collected at each site. Each site report includes a full description of the data collected and received.

3.3.3 M&V plan update

DNV GL submitted an updated site M&V plan to National Grid for every site after the completion of the primary site visit. This updated plan included the following information based on the site visit:

Any deviations to the plan that occurred during the visit or were expected to occur

All the measurement equipment installed and parameters measured

All data provided by the site at the time of the visit

All data expected to be provided by the site and the agreed deadline for receipt of the data

Site conditions observed during the visit and any potential issues identified with the measures being evaluated, including changes at the facility since installation that may impact project savings

The intention of the update was to keep National Grid current on the status of the site evaluation and communicate any anticipated or resultant deviations from the plan.

3.3.4 Baseline verification

Using site data, project documentation, and interviews at the facility, DNV GL assessed the reasonableness of the baseline for each project sampled. For measures that had an appropriate code baseline, evaluators applied the RI building code in effect at the time of the project's TA study or the application, whichever was earliest (called the "reference code").

For measures that did not have an appropriate code baseline or where the code may be ambiguous, DNV GL worked with National Grid to define and document the evaluation baseline for any measures. This included a section regarding lighting baseline, and the findings from a recent code compliance study, which found that current practice for non-residential new construction is better than code. The initial findings of the code compliance resulted in an LPD adjustment of 0.75 of applicable code LPD to be applied to each lighting baseline. However, prior to the finalization of this study, the code compliance team updated the adjustment factor using new customer participation information from National Grid. The new adjustment, which was applied to each site in this sample, was 0.78 of code LPD. Since this update occurred after each site's analysis models had been completed, DNV GL applied this factor to each site's evaluation savings estimate outside of the building simulation runs.

3.3.5 Analysis

DNV GL reviewed all data collected and utilized the data to complete an evaluation analysis for each sampled project.

3.3.5.1 Model calibration

Using information obtained through site visits and the data collected from each site, engineers completed as-built model calibrations against both electric and gas billing data, when available. This step is critical in ensuring that the evaluation models accurately reflect the actual performance of each building being evaluated. The general steps in this process are as follows:

1. Develop as-built model using original as-built model and adjusting the relevant model parameters to account for any differences between the tracking savings model assumptions and the observations from the site work and subsequent metering.
2. Calibrate the as-built model to local weather and utility billing data.
3. Normalize the as-built model to TMY3 weather data.
4. Convert the calibrated, normalized as-built model to baseline efficiency levels to obtain the baseline model by restoring the installed measures to their baseline conditions.

During the calibration step (#2 above), actual concurrent weather data was used in the evaluation models. For CDA projects that included electric and gas applications, engineers used the following calibration targets. As-built model files to within 15% for each month for electric billing data, and within 5% for annual consumption. Calibration was done by adjusting the as-built model using collected data and site observations. Calibrated models with detailed lists of parameters adjusted from collected data and their revised values were submitted to National Grid prior to proceeding with the remaining analysis and site reporting tasks in a calibration memo. There are three key areas where meter data was used in this step, including:

- Verification of equipment operation or non-operation
- Updating operating schedules
- Comparing modeled power to metered power for large equipment under high loads

Once the as-built model had been calibrated and reviewed by National Grid, evaluators continued on to steps #3 and #4 above.

3.3.5.2 Analysis of energy and demand savings

The last step of the site analysis involved normalizing the calibrated models to weather data. Typical Meteorological Year 3 (TMY3) data in closest proximity to each site was used to develop weather normalized savings estimates.

For each project, the analysis produced the following interactive savings estimates for all of measures installed collectively:

Annual kWh

Summer on-peak kW reduction

Winter on-peak kW reduction

Percent on-peak energy (kWh)

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.

Engineers submitted draft site reports to National Grid upon completion of each site evaluation. DNV GL utilized the end use summary, which is a standard eQuest model output, to support any possible measure specific findings. The eQuest model output provides a robust picture of the relative contribution of each major end use to the site savings and was the data source for reporting end-use savings. Incremental

measure savings analysis was not provided since not all TA models included measure level parametric runs to support this level of detail consistently across all sites that were evaluated.

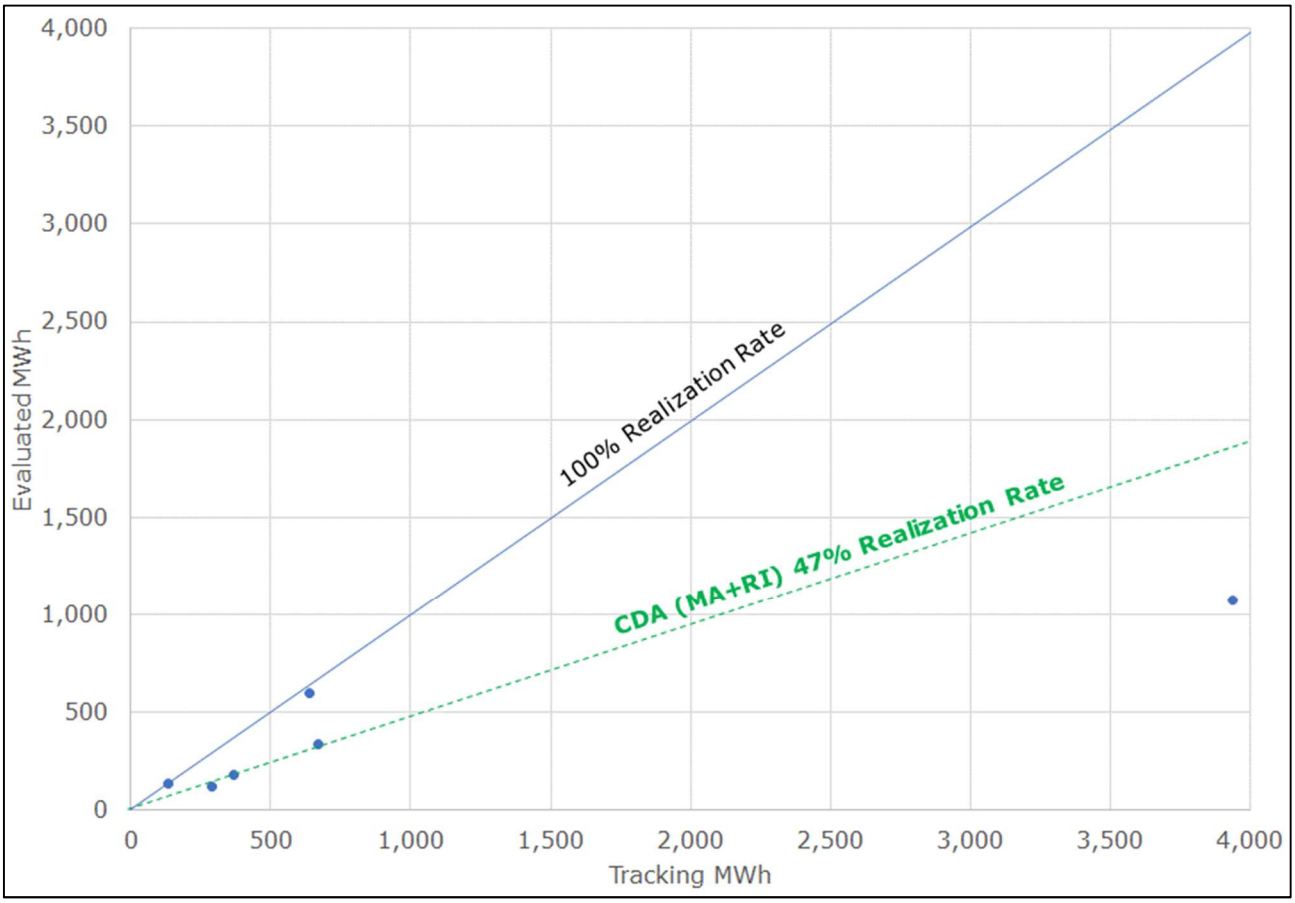
DNV GL responded to the comments received and submitted revised reports for comment. The final site reports are included in Appendix D . This report provides a concise overview of the evaluation methods and findings only.

4 FINDINGS

4.1 Site-level findings

Figure 4-1 presents a scatter plot of evaluated annual energy (MWh) savings plotted against the PA tracking savings. The data points shown are the actual unweighted values. The solid line represents a realization rate of 100%. The slope of the dashed green line is the combined RI and MA realization rate. Since the dashed line is below the 100% line, the realization rate is less than 100%. The scatter of the data around the dashed line indicates the variation savings between the tracking estimates and evaluated savings. Individual site results are shown in Appendix B.

Figure 4-1: Annual electric energy, evaluated savings vs. tracking savings (MA and RI)



4.2 Prospective realization rates

The site-level evaluation results were extrapolated to the population using the final sample case weights. The realization rates were estimated and then applied to National Grid's total tracking savings to determine their total measured savings. The overall (MA+RI) realization rate is the ratio of the total measured savings to the total tracking savings.

Table 4-1 summarizes the custom electric results of this analysis at state-level (National Grid only) and a combined National Grid territory of both states (MA+RI). Note that the realization rate for RI (only) energy savings is higher than MA (only) savings but the difference is not statistically different based on the absolute

precisions calculated for both the states individually. Essentially, the realization rates overlap when the precisions are included.

Table 4-1: 2013-2015 RI and 2014 MA CDA custom electric energy savings (MWh) results

Results	MA+RI		MA only		RI only	
	Annual Energy	On-Peak Energy	Annual Energy	On-Peak Energy	Annual Energy	On-Peak Energy
	MWh	%	MWh	%	MWh	%
Total Tracking Savings	12,900	58%	11,667	56%	1,233	70%
Total Evaluated Savings	6,106	51%	5,279	51%	827	50%
Realization Rate	47.3%	88%	45.2%	91%	67.0%	71%
Error Ratio	0.47	0.83	0.49	0.86	0.35	0.59
Confidence Interval	90% Confidence					
Relative Precision	±18.0%	±38.9%	±20.2%	±43.3%	±30.1%	±51.0%
Error Bound	1,097	1,468	1,068	1,452	249	218

The electric annual energy savings realization rate was 47% with a relative precision of ±18% at the 90% confidence level. The relative precision target of ±20% was therefore achieved with an error ratio of 0.47 vs 0.30 planned. The error ratio is an estimate of the variance between the evaluated and tracking savings. The larger the error ratio, the larger the variance. One reason for this could be due to the greater focus on baseline verification in this evaluation as compared to the previous CDA impact evaluation.

The reduction in electric savings was mostly driven by the application of the lighting ISP from the MA code compliance study (P24)[7]. This study found that the standard practice for lighting in new buildings was 0.78 of allowed LPDs under IECC 2009 code. In Rhode Island, the LPD adjustment has reduced the site-level savings by approximately 20% for two sampled sites together.

Discussions with the National Grid revealed consistency across projects in the application of the prescriptive and mandatory sections of the MA and RI energy code, but some deviation in how ambiguous or non-code measures were handled. For example, National Grid refers all of their technical assistance providers to National Grid maintained guidelines to define ambiguous or non-code measure baselines. These guidelines rely on the mandatory and prescriptive code requirements, with some adjustments for what National Grid has found to be standard practice for some ambiguous code and non-code measures. In addition, some projects in the CDA sample used ASHRAE 90.1- Appendix G to define baselines, but National Grid did not uniformly apply it, the Energy Cost Budget method (Chapter 11 of 90.1), or the Total Building Performance method (Chapter 506/C407 of IECC 2009/2012) to define project baselines.

[7] Energy and Resource Solutions, Inc., P24 – Massachusetts Commercial New Construction Energy Code Compliance Follow-up Study, July 22, 2015

Table 4-2: 2013-2015 RI and 2014 MA CDA custom electric demand savings (kW) results

Results	MA+RI		MA only		RI only	
	Summer On-Peak	Winter On-Peak	Summer On-Peak	Winter On-Peak	Summer On-Peak	Winter On-Peak
	kW	kW	kW	kW	kW	kW
Total Tracking Savings	3,166	1,825	2,480	1,688	686	137
Total Evaluated Savings	1,560	461	1,135	365	425	97
Realization Rate	49.3%	25.3%	45.8%	21.6%	61.9%	70.7%
Error Ratio	0.68	0.78	0.65	0.63	0.78	1.33
Confidence Interval	80% Confidence					
Relative Precision	±23.2%	±29.1%	±24.9%	±28.0%	±53.0%	±90.2%
Error Bound	361.4	134.4	282.6	102.2	225.2	87.2

4.3 Electric discrepancy analysis (RI only)

There are many reasons for the differences between evaluated and tracking savings. The individual site reports provide a detailed discussion of the savings variance and the discrepancies that drove each one. The following describe the discrepancy categories in RI sites:

Equipment efficiency: Differences between the as-found equipment system type, size, and efficiency as compared to TA proposed building models. An example of this is site 2521416, which both included equipment sizing and equipment efficiency differences between the proposed and evaluated as-built models. The evaluators used as-built drawings and nameplate data to correctly input heating and cooling capacities for each RTU as opposed to having eQUEST size them.

Baseline: Adjustments to the lighting baselines made by the evaluation. The evaluation adjusted the baseline efficiency in:

- Set baseline according to code requirements and adjustment of 78% baseline was implemented. Site 2521416 baseline has been updated to be 22% better than code based on MA code compliance study.

Operation: Differences between the as-found hours of operation compared to those assumed in the tracking analysis. Each site in the sample experienced various operational differences. This both increased and decreased savings at different projects. For example, for site 2521416, there was a reduction of 20% savings due to the adjustment of building occupancy, and in site 4590647, there was an increase in savings by 21% due to change in AHU schedules, adjustment of AHU minimum flows and removing humidity controls in post-retrofit case. In many cases, the proposed controls and sequences were not functioning as intended.

5 CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions, recommendations, considerations, and opportunities for future research.

5.1 Conclusions

This evaluation achieved its objective and provided the verification or re-estimation of electric energy and demand savings estimates for a sample of custom electric projects through site-specific inspection, monitoring, and analysis. Extrapolated realization rates were determined at the combined National Grid territory level in MA and RI.

The sample design for this study was expected to achieve a statewide electric energy savings realization rate result with ±24.8% relative precision at the 90% confidence interval. The actual evaluation achieved a relative precision of ±18.0% at the 90% confidence interval for electric energy savings.

5.2 Recommendations

DNV GL makes the following recommendations based on the data collected, conclusions, results, and process of this impact evaluation.

Recommendation 1: Apply the realization rates results from this study (47% electric kWh) to adjust the gross savings claimed for CDA projects prospectively. National Grid should use the combined (MA+RI) realization results from this study for the program year 2019 and future planning of this impact category.

Recommendation 2: Adopt a baseline for LPD that is consistent with current industry standard practice. As stated in the report, the realization rate from this study was based on applying a baseline LPD adjustment factor of 0.78 to apply to the allowed LPDs under IECC 2009 code based on the findings from a MA code compliance study (P24)[2]. A subsequent code compliance study (P70)[8] examining buildings permitted under IECC 2012 determined an LPD adjustment factor of 0.67. A code compliance study was also completed in RI[9] in 2016 and the LPDs observed were 28% (unweighted) better than code (IECC 2012) on average. As a result of these studies, National Grid in MA has proposed to immediately adopt a more stringent baseline for the CDA program. An in-progress study (P73B) has been commissioned to use this information and other data to recommend a final LPD adjustment factor which should be adopted by the programs. National Grid should adopt the 0.78 LPD factor until P73B study is completed or consider recommendation 3 below.

Recommendation 3: Re-examine and adjust the realization rate to apply to future CDA projects to account for the adoption of new baselines/ISPs as well as process improvements made by the program. National Grid should consider a small follow-up effort in RI to re-examine the realization rate from this study following agreement on the lighting ISP lighting power density (LPD) that will be used for projects beginning in 2019 or 2020, and after implementation of it and the other ISPs completed through this study. If these baselines are adopted by the program, the results from this study could be re-examined to estimate a new prospective realization rate, assuming the new baselines are in effect. We would recommend at least a full file review of all CDA projects to verify application of new baselines prior to using an updated prospective CDA realization rate.

Recommendation 4: Adopt the ISPs developed for parking garage exhaust fan, kitchen hood, and

[8] MA C&I Energy Code Compliance and Baseline for IECC 2012 (P70), March 2018
[9] RI Commercial Energy Code Compliance Study-2016

laboratory fume hood controls; and foil coil unit EC motors. MA CDA (P56) study produced four low-rigor ISP findings for fan coil unit EC motors, parking garage fan exhaust, kitchen ventilation controls, and laboratory fume hoods. The findings from these four ISP studies should be applied to appropriate future projects in RI, so that savings for these measures aren't overstated.

Recommendation 5: Improve the commissioning process to ensure ECM installation and intended function. Each project in the sample underwent one, and sometimes two, rounds of commissioning prior to the full incentive being paid to the applicant. However, the quality of commissioning was found to be an area needing improvement. In RI, the evaluation found the building operating schedules were significantly different from what was assumed during tracking analysis. DNV GL recommends that the programs take steps to improve the commissioning process to ensure that the claimed savings are being achieved. This can be done through the selection of preferred commissioning vendors, additional training, and guidance on what type of evidence is needed to confirm measure operation.

5.3 Considerations

The following considerations are specific to changes National Grid could make in the delivery of their energy efficiency programs.

1. Consider including a summary of the baseline selection in the project documentation. The program should document how the baseline was determined for unique custom projects in this impact category and provide clear statements on each decision made.
2. Engineering firms providing TA studies for CDA projects should consider using other building simulation software, such as EnergyPlus specifically when unique HVAC measures like displacement ventilation (DV) or energy recovery ventilators (ERVs) are recommended in the building.
    a. EnergyPlus uses heat balance method to perform radiant and convective calculations at each surface and it models both radiation and thermal stratification through a 3-node stratification model which are critical elements to DV or ERVs. eQuest uses the transfer function method with custom weighting factors, essentially assumes all zones are fully mixed which is not true in reality. These modeling differences could over/under-estimate savings compared to the as-built conditions.

5.4 Future research considerations

The following considerations are specific to the design and structure of future custom impact evaluations of National Grid' programs.

1. RI completed a CDA study recently and considering higher costs for this study, National Grid to consider following MA's timeline for this study and evaluate in RI when MA studies the next round of CDA projects.
2. Consider following MA's direction on evaluating any future CDA projects. Given the issues with commissioning, evaluators should consider documenting in the site M&V plan how they will independently validate the BAS data. BAS sensors sometimes do not report accurately to the BAS. In the future, the M&V plans should document the methods by which the evaluators will validate the BAS data so that it may better serve the evaluation.
3. Baseline review considerations: These considerations are specific to future baseline review efforts.
    a. Consider including a project file review task that inventories the measures that will be encountered during the evaluation.

b. Consider including an anticipated baseline review methodology in the site-specific M&V plan. This methodology should include completion of the standard review guideline mentioned above and any additional site-specific questions.

APPENDIX A. SUMMARIES OF SAMPLED PROJECTS

The following table provides a summary of the projects included in the final RI evaluation sample.

SITE ID	End Use Category	TA savings by end use	Evaluator savings by end use	Realization Rates by end use
	ELECTRIC	kWh	kWh	%
45906457	Space Cool	114,438	112,176	98%
	Space Heat	-4,401	-4,005	110%
	Vent. Fans	20,105	27,601	137%
	Pumps & Aux.	-12,198	-9,416	77%
	Ext. Usage	1,533	1,533	100%
	Area Lights	15,066	3,266	22%
	Total Electric*	134,543	131,153	97%
	GAS	Therms	Therms	%
	Space Heat	19,995	14,522	73%
	Hot Water	447	485	109%
	Pumps & Aux.	72	0	0%
	Total Gas*	20,513	15,007	73%
2521416-3575541	Space Cool	62,406	75,264	121%
	Space Heat	-876	-2,511	35%
	Vent. Fans	152,887	131,164	86%
	Pumps & Aux.	97	-390	-402%
	Ext. Usage	19,977	0	0
	Area Lights	229,557	-33,234	-14%
	Total Electric*	464,046	170,294	37%
	GAS	Therms	Therms	%
	Space Heat	4,539	3,201	71%
	Hot Water	343	706	206%
	Pumps & Aux.	0.9	-3	-293%
	Total Gas*	4,883	3,904	80%

APPENDIX B. SITE SAVINGS SUMMARY

The following table shows the tracked and evaluated electric savings for every site in the final sample.

		Tracking				Evaluated			
Program Administrator	Project ID (w/ Parent)	Annual Energy Savings (kWh)	% On-Peak Savings	Summer On-Peak Demand Savings (kW)	Winter On-Peak Demand Savings (kW)	Annual Energy Savings (kWh)	% On-Peak Savings	Summer On-Peak Demand Savings (kW)	Winter On-Peak Demand Savings (kW)
NGRID (RI)	2521416-3575541	367,707	100%	41.0	39.0	182,258	65%	2.9	49.3
NGRID (RI)	4590647	131,712	44%	40.0	9.7	131,155	55%	23.3	8.8
NGRID (MA)	2508881-903986	637,285	39%	192.2	121.6	594,710	85%	200.0	60.4
NGRID (MA)	2508878-816297	3,934,277	50%	593.7	442.2	1,074,107	50%	186.8	51.1
NGRID (MA)	3575521-917309	671,340	69%	263.0	291.1	335,271	55%	55.7	70.6
NGRID (MA)	3575485-1300233	290,359	61%	85.4	31.7	120,720	53%	36.5	2.2

The following table shows the tracked and evaluated gas savings for every site in the final sample.

		Tracking	Evaluated
Program Administrator	Project ID	Annual Energy Savings (Therms)	Annual Energy Savings (Therms)
NGRID (RI)	2521416-3575541	5,352	3,904
NGRID (RI)	4590647	19,086	15,007
NGRID (MA)	976238	205,368	263,250
NGRID (MA)	3549519	205,052	205,667

APPENDIX C. SITE VARIANCE SUMMARY

The following table provides a brief summary of the primary reasons for the difference between the tracked and evaluated electric savings.

Program Administrator	Project ID (w/Parent)	Energy RR	Primary reasons for savings variance
NGRID (RI)	2521416-3575541	46%	BASELINE LPD: Baseline LPDs were adjusted to 0.78 of code LPD values. OPERATION: Building occupancy – Weekend, summer, and evening occupancy was not included in the TA building simulation. Actual annual electric energy use was 45% higher. BAS – Cooling and heating set point temperatures overlap resulting in simultaneous heating and cooling in the winter. The outside air dampers are enabled on 3 off the 5 RTUs during the winter resulting in a minimum of 30% outside air that needs to be conditioned during unoccupied time. The systems operate as expected in the summer.
NGRID (RI)	4590647	100%	MODELING ERROR: LPD for as-built model was 0.89 then occupancy and daylighting were added in the TA model. The evaluation schedule included occupancy and daylighting to the 0.99 LPD. Fan Energy – both SF and RF energy in the TA model were the same and small for the AHUs. The fan kW/CFM was changed to match that found on the mechanical schedule. OPERATION: AHU-1 Fans Operation- In the TA model fans were scheduled off during unoccupied times with night cycling as needed. BAS and meter data show the fans are always on. Fan Minimum Flow- In the TA model the minimum flow for AHU-1 SF & Exhaust could vary as low as 30%. BAS data show that AHU-1 flows are at or above 80% through the evaluation period. AHU-2 exhaust flow was at or above 35% during that same period. Supply fan was turned off during unoccupied times in the TA model. Humidity Controls- The TA model assumed laboratory-type humidity control that does not exist in the building. The TA model used 55% maximum relative humidity in AHU-1.
NGRID (MA)	2508881-903986	93%	BASELINE LPD: Baseline LPDs were adjusted to 0.78 of code LPD values.
NGRID (MA)	2508878-816297	27%	BASELINE LPD: Baseline LPDs were adjusted to 0.78 of code LPD values.
NGRID (MA)	3575521-917309	50%	BASELINE LPD: Baseline LPDs were adjusted to 0.78 of code LPD values.
NGRID (MA)	3575485-1300233	42%	BASELINE: Static Pressure Reset – The evaluation determined static pressure reset to be code required and removed it from the study.

APPENDIX D. SITE REPORTS

This appendix includes the individual site reports documenting the tracking and evaluated savings for each sampled project.

Site ID: DNV_E003

Program Administrator	National Grid
Project ID(s)	2521416
Program Year	2013

Project Description

This new construction project proposed and installed five energy efficient measures in an elementary school as part of a custom Comprehensive Design Approach [CDA] program. This project includes both gas and electric measures. 11 other energy efficient (EE) measures were also completed at this facility but they did not pass National Grid's benefit cost test and they were not rebated. Therefore, not included in this evaluation.

The five incented measures were: condensing boilers for heat and domestic hot water, LED interior lighting, displacement ventilation throughout the building, and a VFD on Roof Top Unit (RTU)-1 supply fan.

Savings were calculated using a whole building analysis in eQuest (v3.64) for those five measures in both Tracking and this evaluation. The baseline was defined per requirements of National Grid's Design 200Plus baseline document as well as the Rhode Island State Energy Code IECC 2009 for the 5 incentivized measures only.

Evaluators updated the proposed tracking whole building model to as-found building conditions, operation, and calibrated it to the utility bills based on installed equipment nameplate information, metered data, BAS trends, and building operating schedules collected during the site visit. The baseline model was then built from the calibrated model to meet the IECC 2009 code standard.

Table 5-1 shows the tracking and evaluated gas and electric energy (kWh), demand (kW) savings for this project along with their realization rate. The reduction in electrical savings is related to a lower lighting power density baseline (75% of ASHRAE 90.1), equipment operating schedules and temperature control set-points discrepancies. The reduction in gas savings is due to the interactive effects in the evaluation model. The TA gas model used the IECC 2009 baseline for all measures except the boilers.

Table 5-1: Project Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Gas energy (Therms)	5,352	3,904	80%
Electric energy (kWh)	367,707	170,294	46%
% of Energy Savings on Peak	100%	64.8%	65%
Summer On-Peak Demand (kW)	41	46.07	112%
Winter On-Peak Demand (kW)	39	-0.80	-2%

The incented measures are detailed in Table 5-2 along with the measure-level savings and the whole building cumulative savings as documented by the in-PA's TA report.

Tracking Savings and TA methodology

This section provides a summary of the methodology used to estimate the tracking savings claimed for the project. Actual values used in the model are shown in Table 5-9 and in the Evaluation of Results section.

Table 5-2: Proposed Energy Efficiency Electric Measures

Measure #	Measure Name	Measure Description
ECM#8	Displacement Ventilation	Underfloor air distribution diffusers installed in office spaces and displacement diffusers throughout building.
ECM#9	Superior Lighting System	Average interior LPD not to exceed 0.615 W/ft^2. T5 and T8 lamps must be high efficient fluorescent fixtures or super T8.
ECM #15	VFD's	7.5 HP VFD installed on RTU 1 supply fan and 5 HP VFD on RTU 1 return fan.
Combined CDA Savings = 367,707[10]		

Table 5-3: Proposed Energy Efficiency Gas Measures

Measure #	Measure Name	Measure Description
ECM#5	High Efficiency Condensing Boilers	(2) Buderus SB615/185 18.2 HP with max efficiency of 95%.
ECM#6	High Efficiency Condensing DHW Heater	EVO HWD-299-2 (or equivalent) with max input of 300 kBtu/hr and output of 281 kBtu/hr (93.7%).
Combined CDA Savings= 5,352		

Tracking Calculation Methodology

The TA calculated tracking savings using the building energy modeling software, eQUEST v3.64. A baseline model was created; then custom measures were simulated together to account for interactive effects. The baseline model was created using building geometry as obtained from the plans, operating schedules (estimated) and the requirements of National Grid's Design 200Plus baseline document as well as the Rhode Island State Energy Code IECC 2009. Energy savings were considered as the difference in energy consumption between the baseline and proposed case.

Building Operation

The 102,795 ft2 two-story elementary building is made up of classrooms, a cafeteria and kitchen, a gymnasium, a media center and administrative offices.

The airside mechanical systems for the facility consist of (5) packaged roof top units (RTUs) serving individual thermal zones, (1) heating and ventilating unit (H&V), (1) make up air unit (MAU), and a dedicated exhaust serving the kitchen. Each of the (5) RTUs are 100% outside air (OA) units with enthalpy wheel energy recovery units. The RTUs supply between 4,690 and 12,665 CFM of outside air, between 320 and 960 MBH of heating, and between 218 and 632 MBH of cooling to the thermal zones. Each unit has direct expansion (DX) cooling and a gas-fired furnace for additional heat to supplement the preheat from the energy recovery wheel. The 100% OA MAU provides 3,870 CFM of fresh air to maintain pressurization in the kitchen with the kitchen hood exhausting a maximum of 4,850 CFM. The H&V unit is 1,200 CFM, 35% OA unit with an indirect gas-fired furnace to provide heating to the space. Air is delivered to the spaces using

[10] The original eQuest tracking model generated 371,658 kWh savings but savings due to Kitchen hood controls (3,951 kWh) were value engineered out of the project, hence 367,707 kWh.

under-floor air distribution in the main office spaces and displacement diffusers throughout the remainder of the thermal zones.

The hot water (HW) heating system consists of fin tube radiation (FTR) throughout perimeter classrooms and offices and unit heaters (UHs) in miscellaneous spaces throughout the remainder of the facility, such as in corridors and stairwells. The HW system is powered by (2) natural gas-fired, modulating condensing boilers. The boilers have a maximum efficiency of 98% when fully condensing and a 532 MBH heating output. The HW for the heating system is circulated by a 170 GPM, 75 ft. head pump. UHs range in capacity from 18 to 160 MBH and FTR is 540 Btu/h-ft.

Project Evaluation

This section briefly describes the evaluation savings analysis plan. It describes how the analysis used the data collected to evaluate annual energy savings.

The evaluators updated the TA's CDA (tracking) eQuest model with field-verified inputs and end-use metered data and finally calibrated the model to post utility bills. The evaluators verified the applicant's baseline model against National Grid's Design 200Plus baseline document as well as the Rhode Island State Energy Code IECC 2009 to make sure that the baseline model reflects the appropriate energy code.

This project consists of measures that are affected by seasonality, so onsite metering started mid-winter and ended in September. This allowed the evaluators to capture the building operation over a wide range of outside air temperatures and building occupancy. A site visit was performed on February 8, 2017 to perform a physical inspection, verify the installation of the measures, and install data loggers to monitor energy use.

Table 5-4 shows how the evaluators inspected and verified the equipment installation and operation of each measure during the site visits.

Table 5-4: Measure Verification

Measure	Verification Method	Verification Result
ECM#1 High efficiency lighting	Check the counts and fixture wattage of as-built lighting as well as visual inspection. Metered the lighting circuits in the breaker panels.	Confirmed the lights, occupancy sensors and daylight dimmers were installed in the perimeter zones. Used as-built drawings to estimate the average Lighting Power Density for the building. (The model used a single LPD rather than identifying the LPD for each zone.) Meter data show the power variation
ECM #2 Displacement Ventilation	Observe displacement diffuser location in affected spaces	Installed and operating
ECM #3 VFD on RTU-1	Visual inspection, power output and BAS trend	Verified the VFD was in place. Both power measurements and BAS air flow trends show a variation in operation which would not be present in a constant speed system.
ECM #4 Condensing boilers	Verify installation and manufacturers efficiency rating. Confirm supply water temperature varies with OA temperatures	The boilers were installed and the manufacturers specifications show 98% efficient. During operating times the measured supply water temperatures range between 130F to 168F which indicates the boilers operate as expected.
ECM #5 Condensing DHW boilers	Verify installation and manufacturers efficiency rating.	The boilers were installed and operating. The boiler efficiency per the manufacturers specifications is 94.7%.

Data Collection

This section outlines the installed metering equipment and data collected during the site visit. Table 5-5 shows the metering equipment installed, parameters metered, metering intervals and the duration of the metering.

Table 5-5: Evaluation Data Collection – Installed Equipment

Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Metering Interval
Boiler supply and return temperature	Hobo temperature probes	Feb 1st/April	1 min
DHW supply and return temperature	Hobo temperature probes	Feb 1st/April	1 min
Interior lighting hours of operation	Dent Time-of-use logger	Feb 1st/July	Hourly
RTU power and operation	Dent ELITEpro logger	Feb 1st/July	5 min
RTU Supply/Return temperature	Hobo temperature logger	Feb 1st/July	5 min
PPM CO_2	Hobo CO_2 logger	Feb 1st/July	5 min

Table 5-6 highlights the trended EMS and site data used in this evaluation. Evaluators were granted access to the EMS and could chose the time frame and interval.

Table 5-6: Evaluation Data Collection – Data Received

Parameter	Source	Duration	Interval
Boiler efficiency	BMS	Feb 1st/April	Hourly
DHW efficiency	BMS	Feb 1st/April	Hourly
Exterior lighting hours of operation/wattage	BMS/construction documents	Feb 1st/July	Hourly
RTU CFM	BMS	Feb 1st/July	Hourly
RTU Supply/Return temperature	BMS	Feb 1st/July	Hourly
Occupied/unoccupied schedules	BMS	Feb 1st/July	Hourly
PPM CO_2	BMS	Feb 1st/July	Hourly
Roof/Wall insulation	Construction documents	NA	NA
Window Glazing	Construction documents	NA	Hourly

Processing Site Data and Verification of Measure Performance

This section describes how the data listed in Table 5-5 and Figure 2: Metered hourly was used to update the as-built eQuest model based on the actual building characteristics. The building envelope values were assumed to match the building specifications as there is now effective way to measure the actual thermal conductivity of the walls, roof and windows. The manufacturer's specifications of the final HVAC configuration resulted in slightly different efficiencies' than sighted by the design engineers. There was a small change ERV effectiveness between the as-built and as-designed values. The as-built model reflects those changes.

Meter data was used to adjust schedules as shown below.

Lighting and Occupancy

Most of the fixtures in the building are T8 LED in some configuration. The BAS enables the lights at 5:30 a.m. and disables them around midnight, depending on the planned activities. Manual switches and/or occupancy sensors are used to control the lights, once enabled.

The building layout is such that each classroom has a long exterior wall with windows. Light shelves were installed to push the natural light deeper into the room. There are 4 rows of lights running parallel to the exterior wall and the bank closest to the windows are dimmable. All the fixtures are enabled through the BAS. Once enabled each room has a switch and ceiling mounted occupancy sensor to control all the fixtures.

The as-built construction documents and fixture specifications were used to find the building lighting power density. The average LPD was found to be 1 W/sqft. Occupancy sensor location and operation was also verified during site visits. Daylight harvesting was observed during site visits and confirmed with the Elite logger data collected at the power panel. The circuits were separated by room so dimming could be verified by the total power draw of the circuit.

Lighting logger data implied that the building was occupied well after classes officially ended at 2 p.m. Figure 2: Metered hourly shows the average time the lights were ON during the winter (Color blue spectrum in the figure below) weekday (WWD), Saturday and Sunday and summer (Color red spectrum) weekday and weekend. These data come from lighting loggers that were placed in 8 different classrooms to record the on time. Tables for the other zones can be seen in the appendix.

The TA models assumed the lights were off and the space was unoccupied except during class times and all summer. The occupancy schedules were updated to reflect this change.

Figure 2: Metered hourly averaged %Time ON in Classrooms

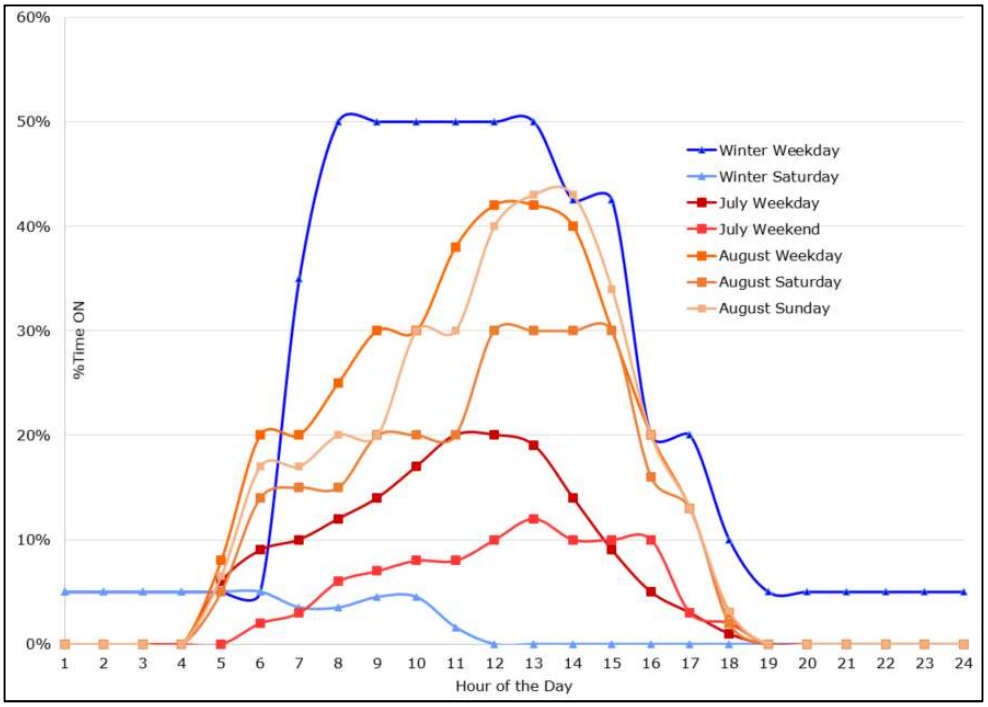
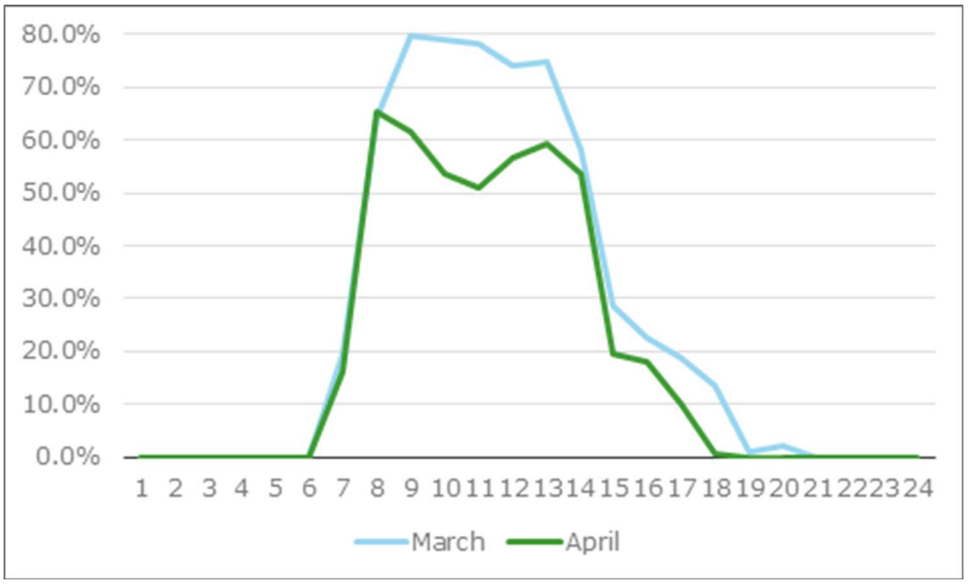


Figure 3: illustrates the average weekday hourly power fluctuations during March and April. The profiles are similar but the hourly power draw is significantly lower in April than in March. The power decline starts almost immediately in April while the decline starts later, closer to 8:30 a.m. in March. Since the activity in the room would be similar for each month the major change is the amount of natural light illuminating the space.

Figure 3: Classroom A213 Light Average Hourly Percent Power Draw – Winter



Space Conditions

There is a town operator who updates the BAS few times each year, as needed. The facility operators do not change the inputs but use the BAS as a troubleshooting and information tool.

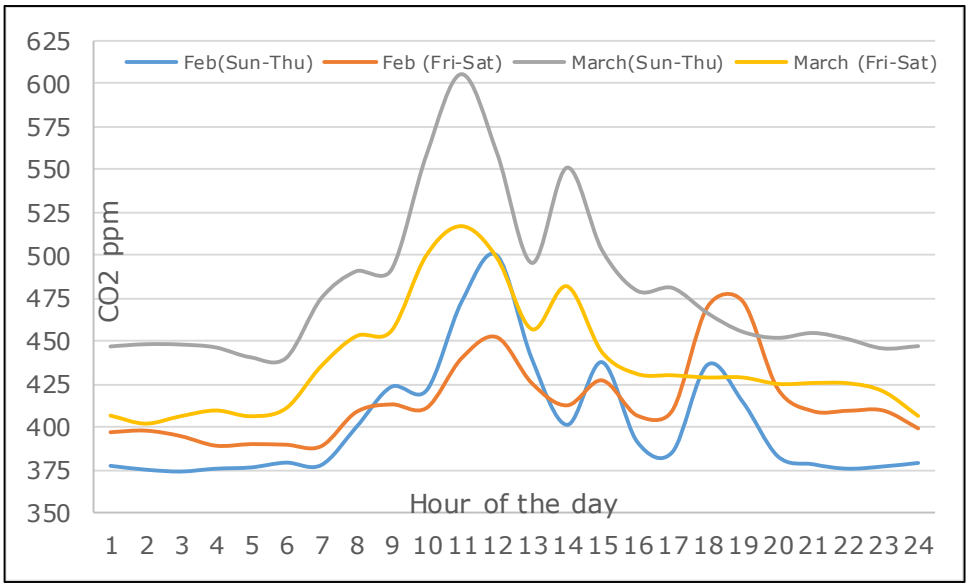
Table 5-7 shows the average hourly metered temperatures for cooling occupied and unoccupied, heating occupied and unoccupied states. The table also shows the set-points provided by the customer during interview and it is obvious the BAS is not operating as the facility operators think it does. Temperature tables for metered zones can be seen in the appendix.

Table 5-7: Cooling and Heating Set-points:

Set-points	Metered	Tracking
Cooling Occupied	70˚F	72˚F
Cooling Unoccupied	70˚F	76˚F
Heating Occupied	70˚F	70˚F
Heating Unoccupied	68˚F	66˚F

CO2 sensors installed in the cafeteria/dais and the gym are used to control the outside air dampers in addition to comparative enthalpy controls. Carbon dioxide and temperature data were used to determine the occupancy of the gym and cafeteria, which contains a dais. Figure 4 shows the additional occupancy that starts around 5 p.m. which can be attributed to the use of the stage for the winter shows. It was assumed that the same schedule was followed in December. The cafeteria/stage occupancy and equipment schedules were updated in the model to reflect the additional hours off occupancy.

Figure 4: CO2 Cafeteria/Stage Data in February and March



The outside air dampers should start opening as the carbon dioxide level reaches 600 parts per million. Figure 5 is a typical CO2 profile of an occupied day. The CO2 starts to ramp up with occupancy and peaks at 622 ppm between noon and 1 p.m. RTU-4 fresh air dampers start to open shortly after noon when the CO2 level reaches 600 ppm. The steep drop after 1 p.m. indicates that the space was vacated and dampers were open enough to purge the air quickly.

Figure 5: Typical CO2 PPM Profile on Occupied Days (Thursday)

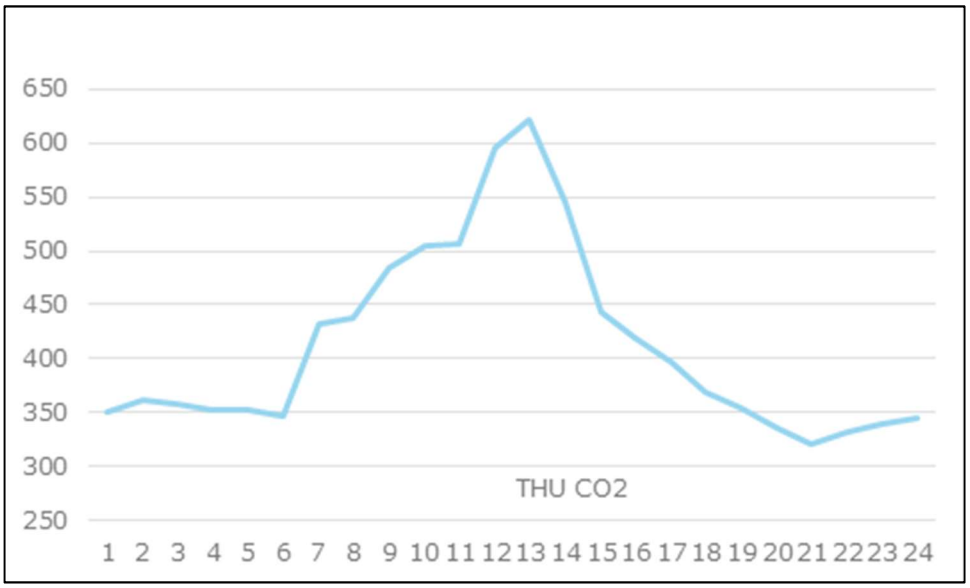


Figure 6 illustrates another inconsistency in BAS operation. Outside dampers were supposed open when CO2 reaches 600 ppm. Although there were no classes, the gym was occupied by about 10 am, and it appears that the gym was unoccupied by about 2 p.m. and the CO2 started to decline due to natural infiltration. Figure 6 shows that dampers did not open on April 24 at all even when CO2 levels were at 1974 ppm. At 6:30 a.m. on Tuesday morning dampers opened when the CO2 level was at 894 ppm. The steep drop

indicates that fresh air was introduced quickly. By 7 a.m. the CO2 level was 528 ppm and normal occupancy operation started.

Figure 6: April 24-25 Gymnasium CO2 When OA Dampers Did Not Open

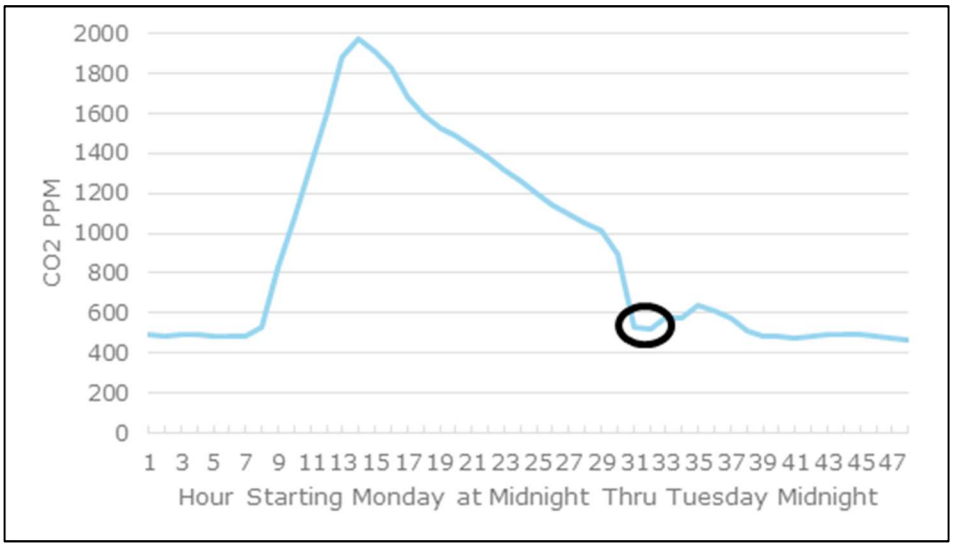
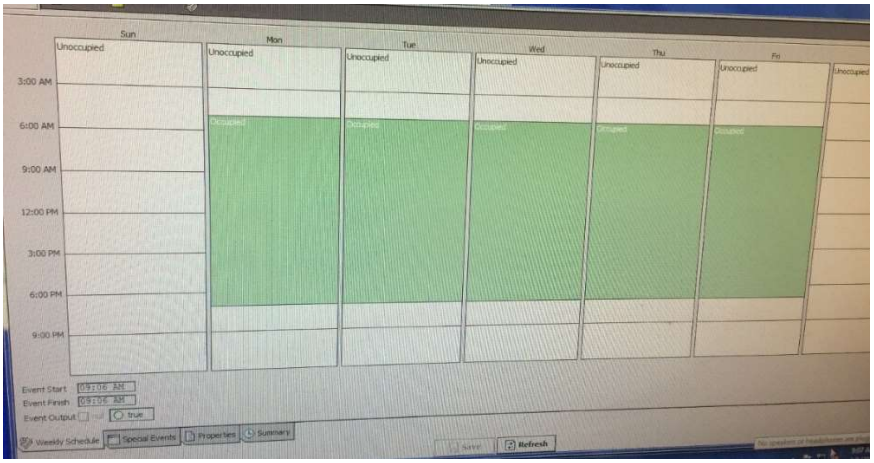


Figure 7 is a photo of the BAS occupancy schedule for this RTU. There is a Special Events tab that allows the user to change the occupancy status. This is done by the town BAS operator. Per our logger data, similar incidents to that shown in Figure 6 occurred during an entire week in February, and 6 single days between February 8 and May 5.

Figure 7: BAS Occupancy Schedule



Schedules

Figure 8 below shows the BAS schedules which were in-line with the metered data. But the schedules did not match the tracking model assumptions. New schedules were extracted from the meter data for occupancy, lighting, and miscellaneous equipment operation and updated in the evaluated model.

Figure 8. BAS Screenshot of the Building Occupancy by Location

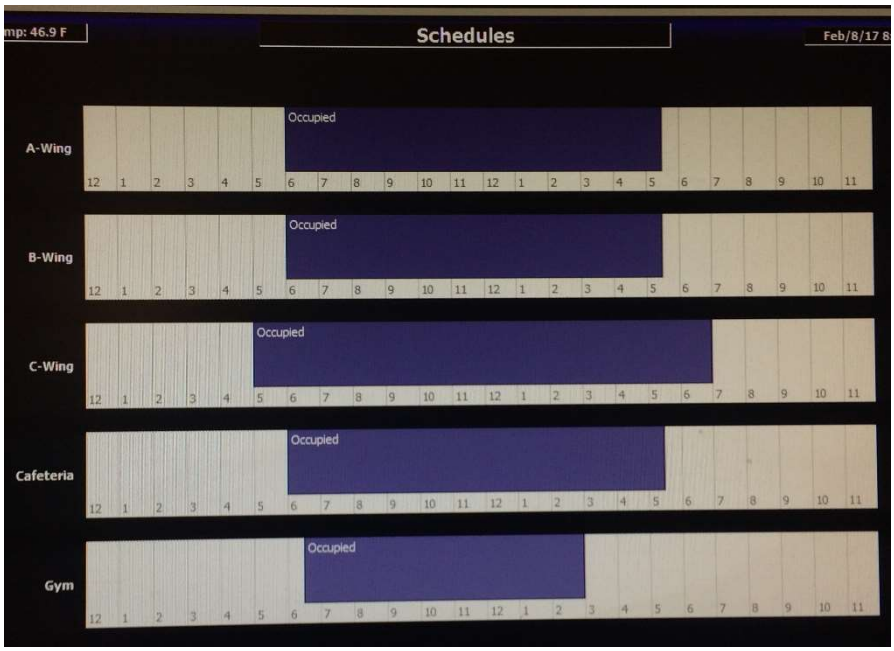
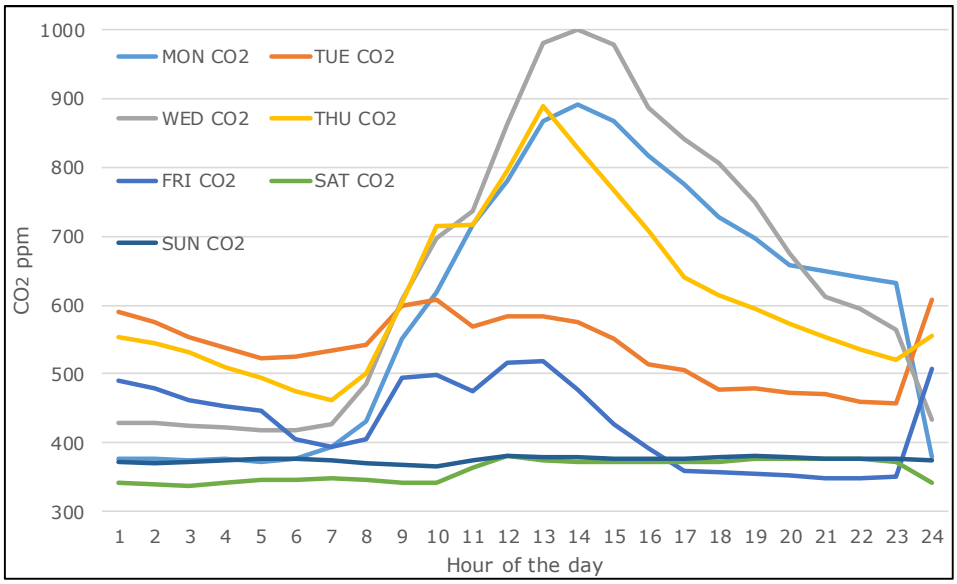


Figure 9: Winter Gym Schedule Based on CO2 Level



Additional zone graphs used for schedule updates are in the appendix.

Construction Documents

Photos of the construction drawings were used to verify light fixture locations, some HVAC equipment sizes and locations, pump power and envelope specifications. Efficiency ratings were extracted from the submittals for the boilers, roof top units, exhaust fans, make up air unit and heating & ventilations.

Calibration

The building model was updated to reflect as-found conditions using the data collected on site, then the evaluators calibrated the eQuest model to 2017 monthly utility data using Providence (RI) real-time weather data. Adjustments were made to parameters such as plug load and schedule, LPD and lighting schedules in zones with occupancy and daylighting controls.

Model Calibration

The evaluators used metered data, equipment cut sheets, as-built construction documents and information from the site contact to update the TA proposed model so that it reflected as-built conditions. The evaluators simulated the building model using local (Providence, RI) weather data calibrated the model to actual utility billing data from 2017

Table 5-8 describes the most significant adjustments made to the TA proposed model.

Table 5-8. Model Calibration Overview

Process Step	Tracking	As-Built/Evaluated
Lighting schedules		
Classrooms	During regular school weeks lighting levels were "always on" at some percentage. Weekend were 25% ON 1-24 hrs. There was no reduction for the light shelves and daylighting	Created Saturday Schedule to reflect logger information and Sunday Schedule was set as all off. Altered weekday schedules to reflect logger data. Emergency lighting was carried as a separate schedule.
Kitchen	Scheduled off weeks off like that of the student. Also, off on weekends and summer.	Lighting & MAU meter data show the kitchen is occupied during the weeks the kids are off, weekends, and summer months. Since the MAU is interlocked with the kitchen hood and dishwasher the KITC GAS Schedule was changed to reflect this. The occupancy and MISC EQ schedules were updated as well.
	Weekend lighting was at 20% both days	Data logger show light levels vary with the hours. New Saturday and Sunday schedules were created for the kitchen/cafeteria. The lights were on during the weeks the students were not there. Schedule was adjusted for this as well.
Cafeteria	Weekday lights off until 8 a.m. and on until 4 with only full on for 5 hours	Data logger show the lights come on full at 5 a.m. and off at 9 pm. The cafeteria is part of the main hallway. Saturday and Sunday schedules were added
Common area schedules	Hallways, stairwells, atriums and other common areas used the office lighting schedules	Logger data show a significant reduction in weekend lighting in the

Process Step	Tracking	As-Built/Evaluated
		common areas when compared to the office areas.
After school sport schedules added	None	School calendar indicates after school outdoor sports activities in Oct, Nov, Mar and Apr. Both gas and electric bills for these months show additional usage that cannot be accounted for by inside activity. Domestic hot water and sport lighting schedules were added.
Restrooms	On the same schedule as office lights	Created a restroom schedule based on logger data.
Space temperatures and airflows		
Classroom Cooling Temp	Unoccupied hours the temp was 76F Occupied hours Temp was 72F	Logger data show Unoccupied temp 69F Occupied temp 70F
Classroom Heating Temp	Unoccupied hours the temp was 66F Occupied hours Temp was 70F	Logger data show Unoccupied temp 68F Occupied temp 69F
Office heating temp schedule	Had weekday and weekend schedule	Occupied weekday temp – 72F Unoccupied weekday temp - 70F Added Sat and Sun schedules. Sat temp is 68F and Sun temp is 67F
Office Cooling Temp	Unoccupied hours the temp was 76F Occupied hours Temp was 72F Summer was set as a vacation week so always at minimal flow.	Always 72F
Classroom and office outside air flow	Unoccupied hours the flow was 0.001 Occupied 8 hours M-F the flow was 1 Summer was set as a vacation week so always at minimal flow.	Meter electric data combined with monthly gas and electric bills indicate the flow is always 1. The eQuest model utilizes the comparative enthalpy economizers to reduce the outside air Setting the OA to 1 allows the software to vary the OA by comparing return air and outside air conditions. (The BAS Sequence of Operation, SOP, indicates that the dampers be closed and fans off during unoccupied times)
Classroom and office minimum air flow	Occupied hours the air flow was 0.3 Unoccupied hours the air flow was 0.001	Meter electric data combined with monthly gas and electric bills indicate the flow is always 1. (The BAS Sequence of Operation, SOP,

Process Step	Tracking	As-Built/Evaluated
		indicates that the fans be off during unoccupied times)
Equipment Energy Use		
RTU efficiency	RTU/ERV combined efficiency 16 RTU capacities and airflows modeled per the construction drawings	RTU/ERV combined efficiency 14 RTU capacities and airflows modeled per the manufacturers as-built specifications.

Figure 10 shows the monthly electric usage comparison of our calibrated model and actual. The variation in monthly electric consumption is 7% or less and 3% for the annual consumption except for February and May. Figure 11 shows the monthly gas consumption comparison of our calibrated model with the actual. The variation in monthly gas consumption is 9% or less and 1% for the annual consumption except for October. Figure 12 and Figure 13 show the actual monthly consumption in 2015 to August of 2017 for comparison.

Figure 10: Model Calibration with Monthly Electric Energy Consumption

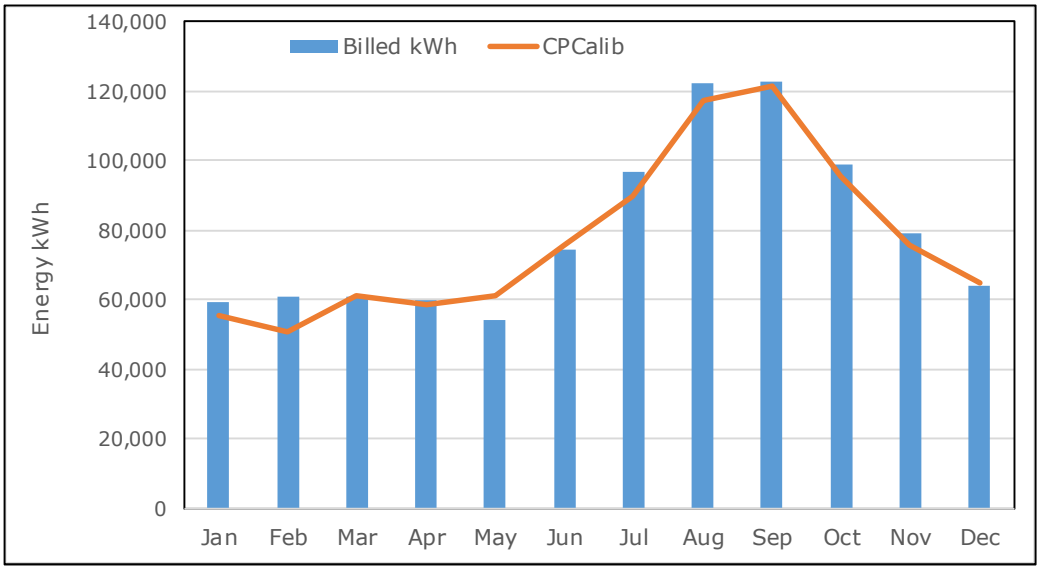


Figure 11: Model Calibration with Monthly Gas Consumption

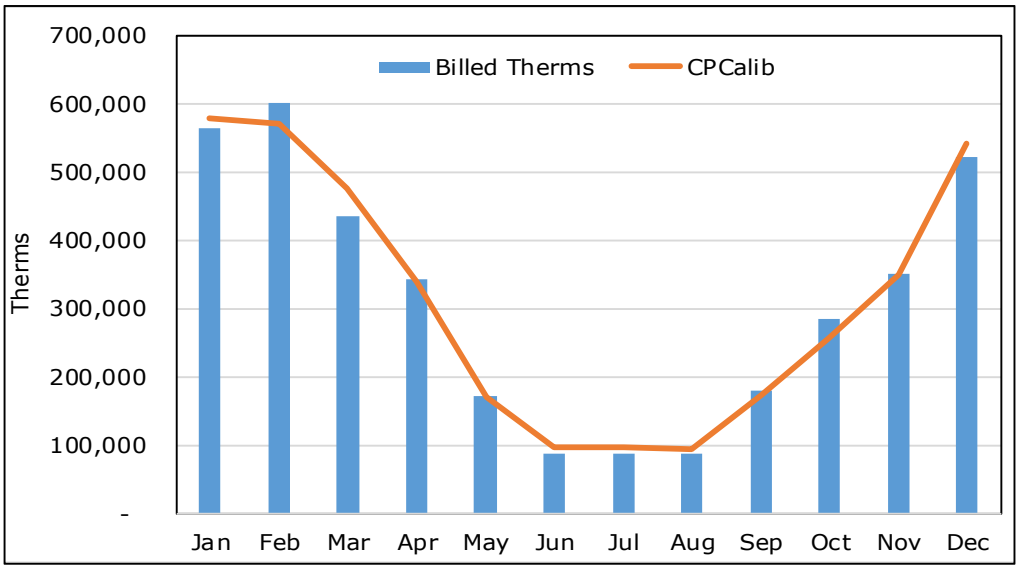


Figure 12: Actual Monthly Electric Consumption 2015-2017

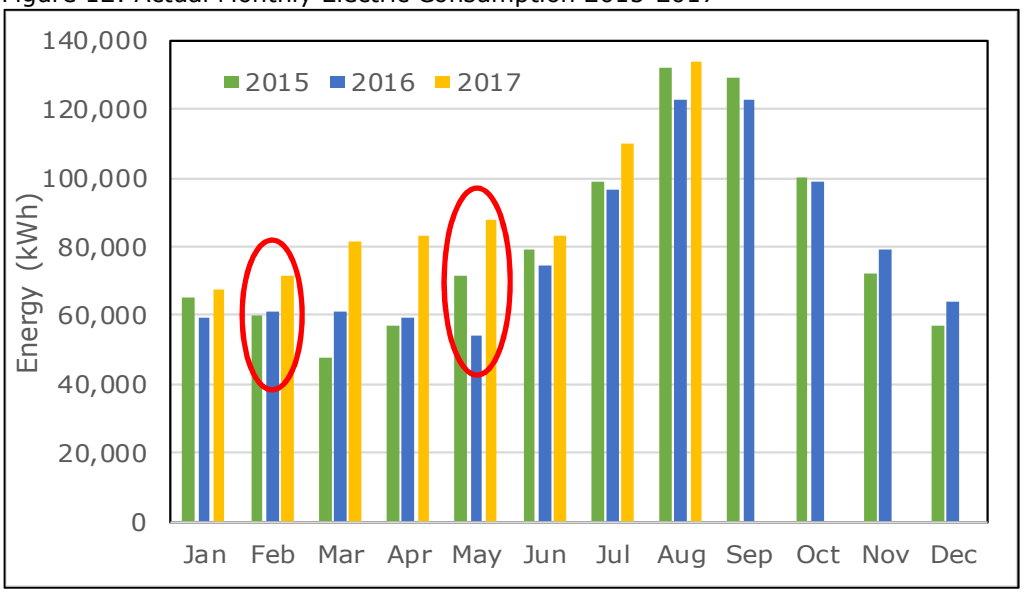
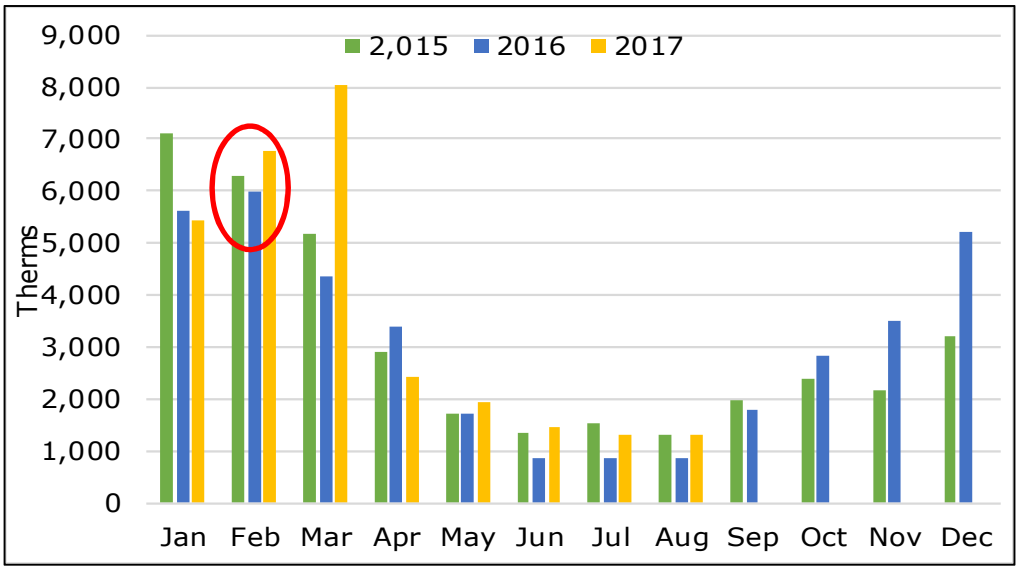


Figure 13: Actual Annual Monthly Gas Consumption 2015 -2017



Our calibrated model has low electric use in February while the February gas usage is 6% lower than actual. Classes are held 15 days in February compared to the normal 20 days in other months. The students have 1 week off for winter vacation and President's Day. This time is used for facility maintenance activities which are somewhat accounted for in the model but are not predictable between years. Several hours could be spent guessing where that additional electric energy is used.

The electric usage in the model is higher in May than the billed usage. May 2016 billed monthly electric usage is an anomaly as can be seen in Figure 12. Rather than adjust the model to meet May 2016 it was decided to maintain normal operations to predict the best savings.

Evaluation Savings Analysis

Once the model was calibrated, the 2017 weather file was replaced with the TMY3 weather file for the from the same weather station. This was done to create a weather normalized model that can be compared to the TA estimated savings.

The baseline model was derived from the calibrated model by setting key parameters to baseline values as defined by National Grid's Design 200Plus baseline document as well as the Rhode Island State Energy Code IECC 2009 for Climate Zone 5A. Whole building interactive savings were calculated as the difference between the baseline and as-found models. A comparison of the key parameters changed for each measure and for the baseline can be found in Table 5-9 in the following section.

Evaluation Results

This section will summarize the evaluation results determined in the analysis above. This section will include a summary table of savings by major end use and application.

Comparison of Baseline Assumptions

Table 5-9 and

Table 5-10 compare the key parameters used in the Tracking analysis with those used in the Evaluation analysis. The purpose of these tables is to show how different values changed.

Table 5-9: Comparison of Key Parameters in the Baseline Model

	BASELINE			
Reference	Parameter	Tracking Value(s)	Evaluation Value(s)	Notes
Building Envelope	Roof insulation – entirely above deck	U=0.044	U=0.044	IECC 2009 Table 502.2(1)
	Above-grade wall insulation	U=0.065	U=0.065	ECC 2009 Table 502.2(1)
	Vertical Windows	U-VALUE=0.472 SHGC = 0.40	U-VALUE=0.472 SHGC = 0.40	ICEE 2009 Table 502.3
	Skylights	U-value 0.325	U-value 0.325	ICEE 2009 Table 502.3
HVAC Efficiency	RTU-1, cooling mode	10.6 EER	10.6 EER	ICEE 2009 Table 503.3(2)
	All other RTUs, cooling mode	9.2 EER	9.2 EER	ICEE 2009 Table 503.3(2)
	All RTUs, heating mode	80% - gas fired	80% - gas fired	ICEE 2009 Table 503.3(4)
DCU (PTAC), cooling	Weight Efficiency	12.5 EER	12.5 EER	ICEE 2009 Table 503.3(3)
DCU Condensing units		10.1 EER, 11.2 IPLV	10.1 EER, 11.2 IPLV	ICEE 2009 Table 503.3(6)
	HV-1 heating mode	80% - gas fired	80% - gas fired	ICEE 2009 Table 503.3(4)
	MAU, heating mode	80% - gas fired	80% - gas fired	ICEE 2009 Table 503.3(4)
	Demand Controlled Ventilation	None	None	IECC 2009 Section 503.1. Required for spaces larger than 500 sqft and with average occupant load of 40 per 1000 sqft
Energy Recovery Ventilators on RTUs	Sensible Eff Latent Eff	RTU-1 – NO ERV Other RTU's have 0.5 0.5	RTU-1 – NO ERV Other RTU's have 0.5 0.5	IECC 2009 Section 503.2.6
Supply Fan BHP		RTU-1 – 6.1 RTU-2- 16.5 RTU-3 – 15.9 RTU-4 – 8.0 RTU-5 – 8.4 MAU – 4.3	RTU-1 – 6.1 RTU-2- 16.5 RTU-3 – 15.9 RTU-4 – 8.0 RTU-5 – 8.4 MAU – 4.3	IECC 2009, Tables 503.2.10(1) & (2), ASHRAE 90.1 Section G3.1.2.9
Exhaust Fan BHP		RTU-1 – 6.1 RTU-2- 16.5 RTU-3 – 15.9 RTU-4 – 8.0 RTU-5 – 8.4	RTU-1 – 6.1 RTU-2- 16.5 RTU-3 – 15.9 RTU-4 – 8.0 RTU-5 – 8.4	IECC 2009, Tables 503.2.10(1) & (2), ASHRAE 90.1 Section G3.1.2.9

Economizers			Required on all RTUs. High Limit shutoff 70F	IECC 2009 Table 503.1(1) SA, ASHRAE 90.1 Section G3.1.2.6, Table G3.1.2.6B
Boilers, space heat	Gas fired hot water boilers	80% eff	80% eff	ICEE 2009 Table 503.3(5)
Boilers, DHW	Gas-fired hot water boilers	80% eff	80% eff	IECC 2009 TABLE 504.2 HOT WATER SUPPLY BOILER
ECM #1 – High Efficiency Lighting & Controls	LPD Daylighting Occupancy Sensors	1.2	0.9	The evaluation baseline LPD value was adjusted to 75% of the code LPD calculated using ASHRAE 90.1-2007 as recommended by the Energy Code Compliance and Baseline Assessment Study, P70.
ECM #2 – Displacement Ventilation	Classroom occupancy, light and equipment fractional reductions. Office occupancy, light and equipment fractional reductions.	100% - No reductions	100% - No reductions	Per ASHRAE 90.1 User's Manual: Building Performance Rating Method, users area allowed to "substitute a thermodynamically similar component model" when the simulation tool can't explicitly model a building feature. Cooling, heating and supply air flows for all equipment are auto-sized in eQuest to simulation the increased loads of not utilizing displacement ventilation.
ECM #3 VFD on RTU	Fan Control	Constant	Constant	IECC 2009 Section 503.4.2

Comparison of As-Built Assumptions

Table 5-10 compares the key As-Built parameters used in the TA tracking analysis with those used in the evaluation analysis. It provides context for explaining the realization rates verified by this evaluation.

Table 5-10: Comparison of Key Parameters in the As-Built Model

Reference	Parameter	Tracking Value(s)	Evaluation Value(s)	Notes
Building Envelope	Roof insulation – entirely above deck	U=0.031	U=0.031	As-built and construction drawings were the same. The Evaluators did not confirm the actual values.
	Above-grade wall insulation	U=0.046	U=0.046	
	Vertical Windows	U-VALUE=0.317 SHGC = 0.58	U-VALUE=0.317 SHGC = 0.58	
	Skylights	U-VALUE=0.325	U-VALUE=0.325	
HVAC Efficiency	RTU-1, cooling mode	10.8 EER	10.6 EER	
	All other RTUs, cooling mode	9.8 EER	9.2 EER	
DCU Condensing units	Weighted Efficiency	10.1 EER, 11.2 IPLV	10.1 EER, 11.2 IPLV	
Demand Controlled Ventilation	C02 Zone Sensors	RTU- 4 Cafeteria RTU-5 Gym	RTU- 4 Cafeteria RTU-5 Gym	
Energy Recovery Ventilators on RTUs	Sensible Eff Latent Eff	RTU-1 0.76, 0.76 RTU-2- 0.76, 0.76 RTU-3- 0.76, 0.76 RTU-4 - 0.77, 0.77 RTU-5 - 0.77, 0.77	RTU-1 0.73, 0.68 RTU-2 0.7, 0.64 RTU-3 – 0.68, 0.64 RTU-4 – 0.74, 0.69 RTU-5 – 0.73, 0.68	
RTU Fan Power	Supply Fan BHP	RTU-1 – 5.4 RTU-2- 14.0 RTU-3 – 11.5 RTU-4 – 7.2 RTU-5 – 7.6 MAU – 1.4	RTU-1 – 4.8 RTU-2- 16.1 RTU-3 – 15.8 RTU-4 – 7.4 RTU-5 – 7.9 MAU – 1.4	
	Exhaust Fan BHP	RTU-1 – 3.73 RTU-2- 10.0 RTU-3 – 8.2 RTU-4 – 5.1 RTU-5 – 5.4	RTU-1 – 3.4 RTU-2- 12.7 RTU-3 – 12.4 RTU-4 – 7.5 RTU-5 – 6.0	
Outside Air	Economizers	Comparative Enthalpy on all RTUs with 100F high shut off limit	Comparative Enthalpy on all RTUs with 100F high shut off limit	
Boilers, space heat	Condensing gas-fired	98% efficient	98% efficient	
Boilers, DHW	Condensing gas-fired	94% efficient	94% efficient	

ECM #1 – Lighting	LPD Daylighting Occupancy Sensors	0.615 YES	1.0 YES Space lighting reduced	The TA model LPD includes occupancy sensor reduction. Our meter data show the hours of reduced power. The LPD was reduced per zone-type during those hours.
ECM #2 – Displacement Ventilation	Classroom occupancy, light and equipment fractional reductions. Office occupancy, light and equipment fractional reductions.	"CLAS OCC DV FRAC" = 0.6667 "OFFI OCC DV FRAC" = 0.75 "OFFI LIGHT DV FRAC" = 0.6667 "CLAS LIGHT DV FRAC" = 0.5 "OFFI EQUIP DV FRAC" = 0.6667 "CLAS EQUIP DV FRAC" = 0.5	"CLAS OCC DV FRAC" = 0.6667 "OFFI OCC DV FRAC" = 0.75 "OFFI LIGHT DV FRAC" = 0.6667 "CLAS LIGHT DV FRAC" = 0.5 "OFFI EQUIP DV FRAC" = 0.6667 "CLAS EQUIP DV FRAC" = 0.5	This is a DV work-around in eQuest. It is a method of redistributing the loads and simulating stratification of used air in the space. By moving a portion of these loads to the plenum (unconditioned air) the cooling load is reduced. This reduces the amount of energy the associated RTU must produce to maintain space temperature and the amount of air that must be supplied to each space.
		Equipment, light and occupancy loads were added to the plenum spaces	Equipment loads were added to the plenum spaces	
ECM #3 VFD on RTU-1	Fan Control	Variable Speed	Variable Speed	

End Use Analysis

This section provides a breakdown of the TA and evaluated project savings by end use and describes the key drivers behind the difference between TA and evaluated project savings. Table 5-11 shows the savings by end use for both the TA and evaluated building.

Table 5-11: Savings by End Use

End Use Category	TA savings by end use	Evaluator savings by end use	Realization Rates by end use
	Electrical (kWh)	Electrical (kWh)	Electric
Space Cool	62,406	75,264	121%
Heat Reject.	-	-	-
Refrigeration	-	-	-
Space Heat	(876)	(2,511)	-
HP Supp.	-	-	-
Hot Water	-	-	-
Vent. Fans	152,887	131,164	86%
Pumps & Aux.	97	(390)	-403%
Ext. Usage	19,977	0	-
Misc. Equip.			-
Task Lights	-	-	-
Area Lights	229,557	(33,234)	-14%
Total Electric*	464,046	170,294	37%
GAS	Gas (Therms)	Gas (Therms)	Gas
Space Cool	-	-	-
Heat Reject.	-	-	-
Refrigeration	-	-	-
Space Heat	4,539	3,201	71%
HP Supp.	-	-	-
Hot Water	343	706	205%
Vent. Fans	-	-	-
Pumps & Aux.	0.9	(3)	-293%
Ext. Usage	-	-	-
Misc. Equip.	-	-	-
Task Lights	-	-	-
Area Lights	-	-	-
Total Gas*	4,883	3,904	80%

*The difference of total savings between this number and the TA Tracking value comes from running the model for 2017 rather than the 2013 year. Additionally, two separate models were used by the TA to generate savings; one for the gas EEMS and one for the electric EEMS. Combining the two produced interactive effects that were not included in the TA's calculations.

Table 5-12: Discrepancy Summary

Discrepancy Category	Impact on Savings		Description of Discrepancy
	Gas	Electric	
Original Tracking Savings	100%	100%	

Baseline adjustment		-4%	Lighting Baseline – a baseline adjustment of 75% baseline was implemented during this evaluation (Baseline has been updated to be 25% better than code based on MA baseline framework study).
Equipment Efficiency			The 5 custom-built, installed RTUs had an ERV/RTU EER of 14.5. The construction drawings and TA model called for EERs between 16.3 and 17.7
Operational Profile	-10%	-20	Building occupancy – Weekend, summer, and evening occupancy was not included in the TA building simulation. Actual annual electric energy use was 45% higher.
Operation Failures	-10%	-30%	BAS – Cooling and heating set point temperatures overlap resulting in simultaneous heating and cooling in the winter. The outside air dampers are enabled on 3 off the 5 RTUs during the winter resulting in a minimum of 30% outside air that needs to be conditioned during unoccupied time. The systems operate as expected in the summer.
	80%	46%	

Ancillary Impacts

This section explains the ancillary impacts associated with each fuel based on the model output. Only electric measures were incentivized under the CDA program. A summary of the primary and ancillary fuels savings is presented in Table 5-13.

Table 5-13: Ancillary Impacts

Measure	Fuel		Source of ancillary impact
	Electric Savings (kWh)	Gas Savings (Therms)	
High Efficiency lighting	10,655	-125	The gas penalty comes from the additional mechanical heating that would have been supplied by the lighting in the space.
Total	10,655	-125	Total ancillary impact is calculated as the sum of electric penalties resulting from measures that were intended to only save electric energy.

Improvement Opportunities

This section will document any opportunities for program improvement identified during the evaluation.

1. Consider using a prescriptive schedule for schools. This school model assumed no afterschool or weekend activities. It did not include summer school hours for the classrooms and kitchens. The office hours were significantly lower than winter hours as well. What our data show is that this building is used almost daily. This was confirmed by the facility operators. Most of the proposed energy efficiency measures may have been incentivized had all operating hours been included.

2. For these measure types, DNV GL recommends National Grid to verify occupancy and equipment operating schedules, temperature controls set-points post-installation, as most savings discrepancy at this site was due to difference in set-backs and schedules difference from tracking assumptions.

Consider sharing these results with the site. The systems are not working as the facility operators think it is.

Appendix

Schedules

The tables below show the zone schedules used in the model. They are based on the meter data gathered for this evaluation.

OFFICE

	LIGHTING					Occupancy		MIN FLOW	MISC EQ
Hour of Day	WWD	WWE	SWD	SSAT	SSUN	WD	WE	OFFI WD	WD
1	0	0	0	0	0	0	0	0.001	0.15
2	0	0	0	0	0	0	0	0.001	0.15
3	0	0	0	0	0	0	0	0.001	0.15
4	0	0	0	0	0	0	0	0.001	0.15
5	0.35	0	0.02	0	0	0	0	0.001	0.15
6	0.75	0.06	0.2	0	0	0.2	0	0.001	0.15
7	0.9	0.06	0.44	0	0.02	0.85	0	0.001	0.6
8	0.9	0.12	0.69	0	0.09	1	0	0.001	1
9	0.9	0.12	0.69	0.06	0.1	1	0	0.3	1
10	0.9	0.16	0.69	0.06	0.1	1	0	0.3	1
11	0.9	0.16	0.66	0.06	0.065	0.65	0	0.3	1
12	0.9	0.16	0.62	0.12	0.06	1	0	0.3	0.8
13	0.85	0.16	0.6	0.12	0.1	1	0	0.3	1
14	0.85	0.16	0.6	0.1	0.075	1	0	0.3	1
15	0.85	0.08	0.47	0.175	0.05	0.3	0	0.3	1
16	0.85	0.05	0.37	0.1	0.04	0.1	0	0.3	0.6
17	0.85	0.05	0.3	0.06	0.05	0	0	0.001	0.6
18	0.5	0.05	0.09	0.04	0	0	0	0.001	0.15
19	0.3	0	0.045	0.01	0	0	0	0.001	0.15
20	0.3	0	0.02	0	0	0	0	0.001	0.15
21	0.2	0	0	0	0	0	0	0.001	0.15
22	0	0	0	0	0	0	0	0.001	0.15
23	0	0	0	0	0	0	0	0.001	0.15
24	0	0	0	0	0	0	0	0.001	0.15

	TEMPERATURES					
Hour of Day	WWD	WSAT	WSUN	SWD	SSAT	SSUN
1	71	71	69	71	72	71
2	71	71	69	71	72	71
3	70	71	69	71	72	71
4	70	71	69	71	72	71
5	70	70	69	71	71	71

6	71	70	69	71	71	71
7	71	70	69	71	71	71
8	72	70	69	72	71	71
9	73	70	69	72	71	71
10	73	70	69	72	72	71
11	74	70	69	72	72	71
12	74	70	69	73	72	71
13	74	70	69	73	72	71
14	74	70	69	73	72	71
15	74	70	69	73	72	71
16	74	70	69	72	72	71
17	74	70	69	72	72	71
18	74	70	69	72	72	71
19	73	70	69	72	72	71
20	73	70	69	72	71	71
21	72	70	69	72	71	71
22	72	70	69	72	71	71
23	72	69	69	72	71	71
24	71	71	69	72	72	71

CLASSROOM

Lighting

Hour of Day	WWD	WSAT	NO LIGHT	JULY WD	JULY WE	AUG WD	AUG SAT	AUG SUN
1	0.05	0.05	0	0.000	0.000	0.000	0.000	0.000
2	0.05	0.05	0	0.000	0.000	0.000	0.000	0.000
3	0.05	0.05	0	0.000	0.000	0.000	0.000	0.000
4	0.05	0.05	0	0.000	0.000	0.000	0.000	0.000
5	0.05	0.05	0	0.060	0.000	0.080	0.050	0.065
6	0.05	0.05	0	0.090	0.020	0.200	0.140	0.170
7	0.35	0.035	0	0.100	0.030	0.200	0.150	0.170
8	0.5	0.035	0	0.120	0.060	0.250	0.150	0.200
9	0.5	0.045	0	0.140	0.070	0.300	0.200	0.200
10	0.5	0.045	0	0.170	0.080	0.300	0.200	0.300
11	0.5	0.016	0	0.200	0.080	0.380	0.200	0.300
12	0.5	0	0	0.200	0.100	0.420	0.300	0.400
13	0.5	0	0	0.190	0.120	0.420	0.300	0.430
14	0.425	0	0	0.140	0.100	0.400	0.300	0.430
15	0.425	0	0	0.090	0.100	0.300	0.300	0.340
16	0.2	0	0	0.050	0.100	0.200	0.160	0.200

17	0.2	0	0	0.030	0.030	0.130	0.130	0.130
18	0.1	0	0	0.010	0.020	0.030	0.020	0.032
19	0.05	0	0	0.000	0.000	0.000	0.000	0.000
20	0.05	0	0	0.000	0.000	0.000	0.000	0.000
21	0.05	0	0	0.000	0.000	0.000	0.000	0.000
22	0.05	0	0	0.000	0.000	0.000	0.000	0.000
23	0.05	0	0	0.000	0.000	0.000	0.000	0.000
24	0.05	0	0	0.000	0.000	0.000	0.000	0.000

Occupancy				Space Set Point Temps			
WD	WE	SWD	FAN	WWD	WWE	SWD2	SWE
0	0	0	1	68	68	70	70
0	0	0	1	68	68	70	70
0	0	0	1	68	68	70	70
0	0	0	1	68	68	70	70
0	0	0	1	69	68	70	70
0	0	0	1	70	68	70	70
0.65	0	0	1	70	68	70	70
1	0	0.65	1	70	68	70	70
1	0	0.65	1	70	68	70	70
1	0	0.65	1	70	68	70	70
0.65	0	0.65	1	70	68	70	70
1	0	0.25	1	70	68	70	70
1	0	0.25	1	70	68	70	70
1	0	0.25	1	70	68	70	70
0.2	0	0	1	70	68	70	70
0	0	0	1	70	68	70	70
0	0	0	1	70	68	70	70
0	0	0	1	70	68	70	70
0	0	0	1	70	68	70	70
0	0	0	1	70	68	70	70
0	0	0	1	70	68	70	70
0	0	0	1	69	68	70	70
0	0	0	1	68	68	70	70
0	0	0	1	68	68	70	70

KITCHEN SCHEDULES

LIGHTING

HOUR	WWD	WWE	SWD	SSAT	SSUN
1	0	0	0	0	0

2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0.7	0.07	0.13	0	0
6	0.95	0.2	0.6	0	0
7	0.98	0.35	0.98	0	0.080
8	1	0.2	0.98	0	0.100
9	1	0.2	0.98	0.100	0.100
10	1	0.2	0.98	0.100	0.100
11	1	0.16	0.98	0.100	0.100
12	1	0.175	0.98	0.100	0.130
13	0.98	0.1	0.980	0.020	0.100
14	0.97	0	0.800	0	0.100
15	0.96	0	0.470	0	0.020
16	0.96	0	0.405	0	0.010
17	0.96	0	0.405	0	0
18	0.96	0	0.405	0	0
19	0.96	0	0.405	0	0
20	0.96	0	0.405	0	0
21	0.93	0	0.405	0	0
22	0.25	0	0.405	0	0
23	0	0	0	0	0
24	0	0	0	0	0

Occupancy

HOUR	WD	WE	WWE
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0.35	0	0
7	1	0.2	0.2
8	1	0.2	0.2
9	1	0.2	0.2
10	1	0.2	0.2
11	1	0.2	0.2
12	1	0.2	0.2
13	0.35	0	0
14	0	0	0
15	0	0	0

16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0

	KITC GAS		HOOD EXHAUST		KITCHEN FAN	
HOUR	ON WD	WE	WD BASE	WE3	WD	WE2
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	1	0	0	0	0	0
7	1	1	1	0.2	1	1
8	1	1	1	0.2	1	1
9	1	1	1	0.2	1	1
10	1	0	1	0.2	1	1
11	1	0	1	0.2	1	1
12	1	0	1	0.2	1	1
13	0.4	0	1	0	1	0
14	0	0	1	0	1	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0

CAFETERIA

LIGHTING

Hour of Day	WWD	WSAT	WSUN	SWD	SSAT	SSUN
1	0.1	0.07	0.53	0.09	0	0.11
2	0.1	0.07	0.53	0.09	0	0.11
3	0.1	0.07	0.53	0.09	0	0.11
4	0.15	0.07	0.53	0.09	0	0.11
5	0.7	0.1	0.53	0.27	0	0.11
6	1	0.25	0.65	1	0	0.11
7	1	0.55	0.82	1	0.2	0.2
8	1	0.65	0.82	1	0.22	0.2
9	1	0.65	0.82	1	0.3	0.27
10	1	0.4	0.73	1	0.22	0.33
11	1	0.4	0.73	1	0.12	0.33
12	1	0.4	0.67	1	0.11	0.3
13	1	0.4	0.67	1	0.11	0.3
14	1	0.4	0.6	1	0.01	0.26
15	1	0.45	0.6	1	0	0.33
16	1	0.45	0.6	1	0.11	0.33
17	1	0.53	0.55	1	0.11	0.33
18	1	0.53	0.53	1	0.11	0.33
19	1	0.53	0.53	1	0.11	0.42
20	1	0.53	0.53	1	0.11	0.44
21	1	0.53	0.53	1	0.11	0.44
22	1	0.53	0.53	1	0.11	0.44
23	0.3	0.53	0.53	0.98	0.11	0.44
24	0	0.53	0.53	0.02	0.11	0.44

	Occupancy		Equip	
HOUR	WD	WE	UnO cc wk	OCC WD
1	0	0	0.15	0.15
2	0	0	0.15	0.15
3	0	0	0.15	0.15
4	0	0	0.15	0.15
5	0	0	0.15	0.15
6	0	0	0.15	0.15
7	0.1	0	0.15	0.6
8	0.75	0	0.15	1
9	0.1	0	0.15	1
10	0.25	0	0.15	1
11	0.75	0	0.15	1
12	0.25	0	0.15	1
13	0.1	0	0.15	1

14	0.1	0	0.15	0.6
15	0.1	0	0.15	0.6
16	0	0	0.15	0.6
17	0	0	0.15	0.15
18	0	0	0.15	0.15
19	0	0	0.15	0.15
20	0	0	0.15	0.15
21	0	0	0.15	0.15
22	0	0	0.15	0.15
23	0	0	0.15	0.15
24	0	0	0.15	0.15

COMMON AREAS

LIGHTING

Hour of Day	WWD	WWE	SWD	SWE
1	0	0	0.13	0.14
2	0	0	0.13	0.14
3	0	0	0.13	0.14
4	0.1	0	0.13	0.14
5	0.7	0.05	0.4	0.14
6	1	0.2	1	0.14
7	1	0.2	1	0.28
8	1	0.2	1	0.28
9	1	0.2	1	0.35
10	1	0.2	1	0.35
11	1	0.15	1	0.3
12	1	0.15	1	0.3
13	1	0.05	1	0.27
14	1	0	1	0.26
15	1	0	1	0.24
16	1	0	1	0.23
17	1	0	1	0.22
18	1	0	1	0.23
19	1	0	1	0.15
20	1	0	1	0.14
21	0.9	0	1	0.14
22	0.25	0	0.9	0.14
23	0	0	0.13	0.14

24	0	0	0.13	0.14

RESTROOOMS

Hour of Day	WWD	WWE	SWD	SWE
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0.3	0	0.075	0
6	0.3	0.05	0.3	0
7	0.4	0.05	0.14	0.035
8	0.75	0.05	0.34	0.035
9	0.85	0.2	0.6	0.1
10	0.85	0.125	0.6	0.1
11	0.85	0.05	0.64	0.05
12	0.85	0.05	0.62	0.02
13	0.85	0	0.6	0.02
14	0.75	0	0.6	0
15	0.65	0	0.44	0
16	0.55	0	0.3	0
17	0.5	0	0.3	0
18	0.25	0	0.2	0
19	0.125	0	0.13	0
20	0.125	0	0.05	0
21	0.125	0	0.04	0
22	0	0	0.1	0
23	0	0	0	0
24	0	0	0	0

Occupancy

HOUR	WD	WE	SWD
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0.65	0	0
8	1	0	0.65
9	1	0	0.65

10	1	0	0.65
11	0.65	0	0.65
12	1	0	0.25
13	1	0	0.25
14	1	0	0.25
15	0.2	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0

Restroom occupancy was zero for weekends and unoccupied times.

BAS TREND DATA

Power meters were installed on all RTUs and the MAU in anticipation of comparing the hourly power draw with the airflows, supply and return temperatures, ERV temperatures, etc. The facility operators were under the impression that the BAS was continuously trending this information. Only 1 week of operation is available so below is the RTU data used to confirm the RTU efficiency.

The tables below show the air flow and power draw for the RTUs. The outdoor daytime temperatures this week were in the mid-70's and the humidity was high. The grayed area on Thursday is the highest outside air temperatures and humidity that occurred while the building was occupied. The humidity was between 85 to 100% between 9 a.m. and 3 p.m.

Week operating data:

Table 5-14: RTU-4 BAS Trend Data Used in Model Calibration (RTU-3 is similar)

Sunday	10-Sep		Monday	11-Sep		Tuesday	12-Sep		Wednesday	13-Sep		Thursday	14-Sep			Friday	15-Sep	
CFM	kW	kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	cooling BTU/h	CFM	kW	CFM
	12.19		3089	12	0.00374	3093	11.90	0.00385	3048	6.97	0.00229	3081	12.72	0.00413		888	5.10	
	11.37		3069	9	0.00309	3083	12.02	0.00390	3118	7.71	0.00247	3068	12.14	0.00396		879	5.11	
	11.50		3052	6	0.00196	3078	11.81	0.00384	3071	7.53	0.00245	3063	12.89	0.00421		863	5.11	
	11.51		3092	6	0.00179	3076	12.24	0.00398	3102	7.53	0.00243	3073	12.19	0.00397		844	5.11	
	10.89		3087	7	0.00240	3063	11.78	0.00385	3053	7.69	0.00252	3092	13.02	0.00421		858	5.11	
3129	11.52	0.0037	7800	10	0.00124	7683	19.37	0.00252	7528	22.42	0.00298	7581	26.91	0.00355		852	5.10	
3085	10.84	0.0035	9353	10	0.00108	9248	21.38	0.00231	9189	20.10	0.00219	9097	25.68	0.00282		898	5.08	
3088	11.38	0.0037	9336	10	0.00108	9231	20.87	0.00226	9175	20.80	0.00227	9074	28.11	0.00310	404,843	669	5.08	
3068	11.96	0.0039	9328	10	0.00107	9174	23.96	0.00261	9167	23.15	0.00253	9074	28.51	0.00314	410,574			
3052	11.76	0.0039	9247	10	0.00107	9185	24.56	0.00267	9123	26.86	0.00294	9097	28.24	0.00310	406,591			
3082	11.48	0.0037	9229	17	0.00180	9096	27.98	0.00308	9075	30.41	0.00335	9097	29.74	0.00327	428,318			
3067	12.18	0.0040	9205	20	0.00217	9068	29.14	0.00321	9076	30.12	0.00332	9088	30.58	0.00337	440,413			
3084	12.01	0.0039	9200	24	0.00266	9066	27.20	0.00300	9120	27.18	0.00298	9073	30.75	0.00339	442,789			
3095	12.54	0.0041	9199	21	0.00226	9124	28.04	0.00307	9110	26.57	0.00292	9094	30.63	0.00337	441,002			
3065	12.15	0.0040	9204	23	0.00254	9110	26.55	0.00291	9103	28.93	0.00318	9094	28.62	0.00315	412,166			
3067	12.10	0.0039	9171	23	0.00254	2785	26.15	0.00939	9118	29.25	0.00321	9101	28.49	0.00313				
3101	11.94	0.0039	7651	20	0.00261	673	0.00	-	9117	26.73	0.00293	7565	21.57	0.00285				
3066	12.23	0.0040	3084	12	0.00401	664	0.00	-	9112	24.14	0.00265	3103	13.43	0.00433				
3095	11.87	0.0038	3068	12	0.00380	2756	18.42	0.00668	7603	19.01	0.00250	3113	13.25	0.00426				
3077	12.01	0.0039	3092	12	0.00397	7493	18.43	0.00246	3073	12.72	0.00414	3109	13.13	0.00422				
3071	11.83	0.0039	3053	12	0.00401	3103	7.73	0.00249	3093	12.30	0.00398	3092	13.05	0.00422				
3092	11.43	0.0037	3081	12	0.00400	3079	8.19	0.00266	3056	12.37	0.00405	3098	12.88	0.00416				
3088	12.02	0.0039	3096	12	0.00375	3094	6.05	0.00195	3116	12.35	0.00396	3079	13.69	0.00445				
3087	11.34	0.0037	3108	12	0.00376	3117	12.00	0.00385	3094	3.72	0.00120	3054	12.43	0.00407				

Table 5-15. RTU-1 BAS Trend and Elite Logger Data used for Model Calibration

	Monday	11-Sep		Tuesday	12-Sep		Wednesday	13-Sep		Thursday	14-Sep			Friday
kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	Cooling BTU/h	CFM
	7,521	6.51	0.00087	7,446	6.48	0.00087	7,212	9.86	0.00137	7,353	15.56	0.00212		7,394
	7,525	6.50	0.00086	7,451	6.50	0.00087	7,200	12.79	0.00178	7,354	15.59	0.00212		7,401
	7,518	6.51	0.00087	7,458	9.21	0.00123	7,184	12.54	0.00175	7,361	15.54	0.00211		7,383
	7,515	6.51	0.00087	7,445	11.19	0.00150	7,193	12.27	0.00171	7,367	15.48	0.00210		7,381
0.00086	7,519	6.52	0.00087	7,445	10.48	0.00141	7,205	12.72	0.00176	7,370	15.48	0.00210		7,383
0.00087	7,514	6.56	0.00087	7,452	11.83	0.00159	7,239	12.97	0.00179	7,360	15.52	0.00211		7,385
0.00086	7,506	6.52	0.00087	7,449	9.89	0.00133	7,411	10.59	0.00143	7,363	15.55	0.00211		7,408
0.00086	7,502	6.49	0.00087	7,427	7.59	0.00102	7,398	11.23	0.00152	7,354	15.61	0.00212	226,308	7,363
0.00086	7,510	6.46	0.00086	7,406	6.98	0.00094	7,393	10.47	0.00142	7,342	15.65	0.00213	226,985	7,355
0.00123	7,482	9.78	0.00131	7,410	11.55	0.00156	7,374	11.93	0.00162	7,335	15.61	0.00213	226,393	
0.00153	7,467	11.99	0.00161	7,371	12.96	0.00176	7,340	15.67	0.00213	7,331	15.58	0.00213	225,891	
0.00162	7,450	12.75	0.00171	7,334	14.37	0.00196	7,329	15.83	0.00216	7,340	15.60	0.00213	226,264	
0.00167	7,431	13.24	0.00178	7,341	13.67	0.00186	7,348	14.68	0.00200	7,312	15.63	0.00214	226,689	
0.00172	7,441	12.92	0.00174	7,347	12.61	0.00172	7,327	14.68	0.00200	7,324	15.60	0.00213	226,205	
0.00171	7,424	12.04	0.00162	7,363	12.36	0.00168	7,326	14.17	0.00193	7,339	15.55	0.00212	225,499	
0.00169	7,431	11.82	0.00159	7,365	12.47	0.00169	7,342	13.38	0.00182	7,343	15.63	0.00213		
0.00158	7,435	11.45	0.00154	7,351	11.95	0.00163	7,316	13.36	0.00183	7,334	15.69	0.00214		
0.00148	7,445	10.50	0.00141	7,383	10.44	0.00141	7,344	14.18	0.00193	7,349	15.61	0.00212		
0.00148	7,443	9.71	0.00131	7,342	10.61	0.00145	7,361	13.10	0.00178	7,359	15.64	0.00213		
0.00172	7,444	10.82	0.00145	7,330	8.56	0.00117	7,374	12.90	0.00175	7,351	15.66	0.00213		
0.00168	7,449	12.09	0.00162	7,346	9.17	0.00125	7,386	13.54	0.00183	7,353	15.69	0.00213		
0.00180	7,448	8.97	0.00120	7,221	8.97	0.00124	7,381	13.31	0.00180	7,373	15.65	0.00212		
0.00180	7,433	8.95	0.00120	7,212	8.88	0.00123	7,366	14.71	0.00200	7,379	15.63	0.00212		
	7,489	11.67	0.00156	7,463	8.13	0.00109	7,212	8.86	0.00123	7,362	15.52	0.00211		

Table 5-16. RTU-2 BAS Trend and Elite Logger Data Used for Model Calibration

Monday	11-Sep			Tuesday	12-Sep			Wednesday	13-Sep			Thursday	14-Sep			Friday
kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	CFM	kW	kW/CFM	Cooling BTU/h	CFM
	12298	23	0.00188	12294		-	12250	27.31	0.00223	12289	37.10	0.00302		12289
	12297	23	0.00189	12296		-	12232	30.70	0.00251	12282	37.21	0.00303		12279
	12293	23	0.00189	12296		-	12262	30.86	0.00252	12282	37.13	0.00302		12285
	12297	23	0.00189	12297		-	12255	33.40	0.00273	12285	37.07	0.00302		12279
-	12297	23	0.00190	12297		-	12240	30.14	0.00246	12284	37.08	0.00302		12288
-	12297	23	0.00190	12295		-	9301	28.68	0.00308	12292	37.14	0.00302		9329
-	12297	23	0.00189	12294		-	12296	27.88	0.00227	12285	37.29	0.00304		9330
-	12297	23	0.00189	12295		-	9325	19.78	0.00212	12274	37.67	0.00307	546,147	12288
-	12297	23	0.00187	12294		-	439	0.03	0.00007	12283	37.72	0.00307	546,948	12292
-	12290	23	0.00186	12289		-	438	0.07	0.00015	12284	37.80	0.00308	548,063	
-	12294	34	0.00274	12286		-	441	2.58	0.00585	12265	37.76	0.00308	547,486	
-	12290	40	0.00323	12274		-	440	0.06	0.00013	12276	37.76	0.00308	547,588	
-	12295	44	0.00356	12283		-	3393	13.97	0.00412	12268	37.86	0.00309	549,027	
-	12293	42	0.00344	12274		-	12270	37.12	0.00303	12267	37.73	0.00308	547,073	
-	12289	39	0.00321	12281		-	12269	37.26	0.00304	12281	37.65	0.00307	545,872	
-	12286	39	0.00320	12291		-	12274	37.19	0.00303	12261	37.59	0.00307		
-	12288	37	0.00305	12280		-	12274	37.08	0.00302	12271	37.70	0.00307		
-	12288	35	0.00282	12287		-	12275	36.96	0.00301	12276	37.56	0.00306		
-	12290	30	0.00244	12278		-	12287	36.91	0.00300	12283	37.61	0.00306		
	12294	29	0.00234	12264		-	12288	36.88	0.00300	12283	37.67	0.00307		
	12296	28	0.00231	12243		-	12288	36.84	0.00300	12274	37.74	0.00307		
	12297	28	0.00230	12221		-	12282	36.88	0.00300	12279	37.70	0.00307		
	12293	28	0.00227	12246		-	12292	36.95	0.00301	12282	37.65	0.00307		
	12298	23	0.00188	12297		-	12235	26.84	0.00219	12294	36.99	0.00301		

Site ID: DNV_E007

Program Administrator	National Grid
Project ID(s)	4590647
Program Year	2014

Project Description

This new construction project installed seven energy efficient measures in an elementary school as part of a custom Comprehensive Design Approach [CDA] program. This project includes both gas and electric measures.

The seven incented measures were: high efficiency lighting and controls, high efficiency chillers, condensing boilers for heat and domestic hot water, building envelope improvements, variable flow fume hoods, and energy recovery ventilators. Chilled beams were proposed for an incentive but did not pass National Grid's benefit cost test so was not incentivized. Since they were installed in the building both the as-built and baseline models included chilled beams in the evaluated model.

Savings were calculated using a whole building analysis in eQuest (v3.64) for those seven measures in the Tracking and eQuest (v3.65 – Windows 10 upgrade) for this evaluation. The baseline was defined per requirement of the current building energy IECC-2012 and ASHRAE 90.1 2010. The campus is also equipped with some renewable energy sources such as Solar Panels and Wind Turbines.

Table 5-17 shows the tracking and evaluated gas and electric energy (kWh), demand (kW) savings for this project along with their realization rates. The slight decrease in gas savings comes from humidity requirements that were assumed in the TA model but do not exist.

Table 5-17: Project Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Gas energy (Therms)	19,086	15,007	79%
Electric energy (kWh)	131,712	131,155	100%
% of Energy Savings on Peak	44%	55%	125%
Summer On-Peak Demand (kW)	40.0	8.79	22%
Winter On-Peak Demand (kW)	9.71	23.27	240%

The incented measures are detailed in Table 5-2 along with the measure-level savings and the whole building cumulative savings as documented by the in-PA's TA report.

Tracking Savings AND TA METHODOLOY

This section provides a summary of the methodology used to estimate the tracking savings claimed for the project. Actual values used in the model are shown in Table 5-28 and Table 5-29, the Evaluation Results section.

Table 5-18: Proposed Energy Efficiency Electric Measures

Measure #	Measure Name	Measure Description
EEM#1	Automatic Lighting Controls	Interior fixtures are a combination of LED and T8 technologies with occupancy sensors in classrooms, offices, and restrooms. Daylighting controls were installed in most the perimeter zones and sequence ballasts on and off as the daylight levels change.
EEM#2	High efficiency air-cooled chillers	Two 48.5-ton air cooled scroll chillers with EER of 9.7 and IPLV of 15.1 were installed. These chillers serve both chilled water loops during the cooling season only.
EEM#3	High efficiency condensing boilers	Two condensing boilers with 89% full load efficiency at 150ºF supply temperature and a

		30-degree loop differential serve both AHUs and baseboard on the perimeter zones.
EEM#4	High efficiency condensing domestic hot water heater	One condensing hot water heater with a full load efficiency of 96% provides 140°F hot water to a 260-gallon storage tank.
EEM#5	Envelope optimization	The building walls and roof were insulated above code in the new walls. Glazing assemblies with SHGC =0.27, VLT of 64% and an overall u-factor of 0.43 or less.
EEM#6	Variable Air Volume Fume Hood Exhaust System	Two-position, VAV and CV fume hood exhaust valves were installed in the laboratories to reduce the exhaust air flow during unoccupied times.
EEM#7	Energy Recovery Wheels on AHUs 1 and 2	Enthalpy wheels were installed on both AHU exhausts. These are the primary source of heat to the space with heating coils as back up. An additional sensible only ERV was installed on AHU-2 for reheating the dehumidified air going into the zones served by chilled beams.
Combined CDA Savings = 131,712 kWh and 19,086 Therms		

Tracking Calculation Methodology

The TA calculated tracking savings using the building energy modeling software, eQUEST v3.64. A baseline model was created then custom measures were evaluated using parametric runs. Each measure was analyzed by generating an hourly simulation of the building energy consumption. The baseline model was created using building geometry as obtained from the plans, estimated operating schedules and the requirements of Rhode Island State Energy Code IECC 2012 and ASHRAE 90.1-2010 Appendix G. Energy savings were considered as the difference in energy consumption between the baseline and proposed case.

Savings from each measure were appraised by the National Grid Cost/Benefit Screening test. The measures that passed were combined into the baseline model to get the actual interactive savings.

Building Operation

Of this 38,564 ft^2 high school laboratory building, 10,600 ft^2 was existing and the remaining 27,964 ft^2 was added as new construction. The existing part of the building is primarily made up of classrooms while the newly constructed portion consists of lab space, common areas, corridors and restrooms.

Classes start before Labor Day and finish at the end of May. Classes are M-Sat although Mondays typically have a late start and no class twice a month. There are days off for the standard US holidays and there are no multiple week breaks during the school year.

There are 6 labs with variable flow fume hoods.

There is a building automation system controlling the HVAC systems. There are utility meters in the building monitoring the building energy consumption and in some cases, the equipment consumption. The utility data used to calibrate the eQuest model for this evaluation came from the Building Automation System (BAS) trends for operating HVAC, DHW equipment and customer owned sub-meters, as there were no National Grid meters attached to this building.

Two condensing boilers provide hot water to the air handler heating coils and the baseboard heat in the perimeter zones of the building.

The chilled water system consists of two air-cooled chillers and 3 variable volume glycol pumps. The chilled water system provides chilled water to the air handling unit cooling coils and to a secondary heat exchanger. The system operates during the cooling season (typically April through November). The secondary loop at 58°F serves the chilled beams. The primary loop provides 44°F water to the cooling coils in the air handlers. The "water" is 30% propylene glycol for freeze protection when the chillers are not in operation.

There is an air handler for each side of the building. Both AHUs are 100% outside air and both have enthalpy wheels for heat recovery. Supply, return and exhaust fans are all on variable frequency drives. Fan speed control is adjusted to maintain duct pressure.

AHU-1 serves the new section of the building with labs, classrooms and offices. It operates 24 hours a day. Discharge air temperature set point resets based on outside air temperatures such that when the OAT is 80°F or above the discharge temperature is 55°F. When OAT is below 55°F the discharge temperature is 58°F. At OAT between the two the discharge temperature varies linearly between 55°F and 58°F.

Two exhaust fans work in tandem to serve AHU-1. They exhaust from the laboratory side of the building and operate 24 hours a day.

AHU-2 serves the classrooms with chilled beams so has an additional sensible only ERV which is used to reheat the discharge air temperature after dehumidification. This reduces the condensation on the chilled beams. The AHU supply air temperature is 58°F.

A 2.6 kW photovoltaic array and 250W wind turbine contribute to the electrical use in the building. A geothermal loop with a 5-ton ground source heat pump was designed to supplement the secondary chilled water loop and serve baseboard heat in the greenhouse. Per the facility manager, this system works intermittently. A small array of solar hot water tubes provides a very small portion of hot water to the domestic storage tank.

Project Evaluation

This section briefly describes the evaluation savings analysis plan. It describes how the analysis used the data collected to evaluate annual energy savings.

The evaluators updated the TA's CDA eQuest model with field-verified inputs and end-use metered data and finally calibrated the model to post project completion utility bills. The evaluators verified the applicant's baseline model against the Rhode Island State Energy Code IECC 2012 and ASHRAE 90.1-2010 Appendix G.

This project consists of measures that are affected by seasonality, so onsite metering started mid-winter and ended in September. This allowed the evaluators to capture the building operation over a wide range of outside air temperatures and building occupancy. A site visit was performed on March 8, 2017 to perform a physical inspection, verify the installation of the measures, and install data loggers to monitor energy use.

Table 5-4 shows how the evaluators inspected and verified the equipment installation and operation of each measure during the site visits.

Table 5-19: Measure Verification

Measure Name	Verification Method	Verification Result
High Efficiency Lighting and Controls	Check the counts and fixture wattage of as-built lighting as well as visual inspection	Installed and operating
High Efficiency Air Cooled Chillers	Visual inspection of name plate data, check temperatures and flows to verify operation	Installed and operating
High Efficiency Condensing Boilers	Visual inspection of name plate data, check temperatures and flows to verify operation	Installed and operating
High Efficiency Domestic Hot Water Heaters	Visual inspection of name plate data, check temperatures and flows to verify operation	Installed and operating
Envelope Optimization	As-built construction documents as well as inspection of windows	Verified with construction drawings and commissioning report
Variable Volume Laboratory Exhaust	Visual inspection and AHU name plate data	Installed and operating
Enthalpy Recovery Wheels on Lab AHU's	Visual inspection and AHU name plate data	Installed and operating

Data Collection

This section outlines the installed metering equipment and data collected during the site visit. Table 5-20 shows the metering equipment installed, parameters metered, metering intervals and the duration of the metering.

Table 5-20: Evaluation Data Collection - Installed Equipment

Parameter	M&V Equipment Brand and Model	Quantity	Metering Start/Stop Dates	Metering Interval
Lighting hours of operation	Dent time-of-use logger	19	March 15th, 2017/September 27, 2017	Hourly average
Chiller power and hours of operation	Dent ELITEpro logger	2	March 8th, 2017/ September 27, 2017	5 min average
AHU power and hours of operation	Dent ELITEpro logger	2	March 8th, 2017/ September 27, 2017	5 min average
Space temperature	Hobo temperature logger	8	March 15th, 2017/ September 27, 2017	5 min average

Table 5-21 highlights the trended BAS and site data used in this evaluation.

Table 5-21: Evaluation Data Collection – Data Received

Parameter	Source	Duration	Interval
Roof insulation	Construction documents and CX report	NA	NA
Wall insulation	Construction documents and CX report	NA	NA
Window specifications	Construction documents and CX report	NA	NA
Space Temperatures	BMS	3/27-9/27, 2017	15 minute
ERV Temperatures and wheel speed	BMS	3/27-9/27, 2017	15 minute
AHU Flows [CFM]	BMS	3/27-9/27, 2017	15 minute
Whole Building Electricity Use, kW	BMS	2015-2016	15 minute
Geothermal Heat Production, BTU	BMS	2015-2016	15 minute
Whole Building Geothermal Use	BMS	2015-2016	15 minute
DHW, NG (ccf)	BMS	2015-2016	15 minute
Non-DHW, NG (ccf)	BMS	2015-2016	15 minute
HVAC Boilers, NG (ccf)	BMS	2015-2016	15 minute
PV Production, kW	BMS	2015-2016	15 minute
Wind Turbine Production, kW	BMS	2015-2016	15 minute
DHW, gal	BMS	2015-2016	15 minute
Non-DHW, gal	BMS	2015-2016	15 minute
HVAC Make Up Water, gal	BMS	2015-2016	15 minute
Total Water Use, gal	BMS	2015-2016	15 minute

Processing Site Data and Verification of Measure Performance

This section describes how the data listed in Table 5-22 was processed so that it could be incorporated into the energy model for savings analysis. BAS whole building and gas trends were used to update the as-built eQuest model based on the actual building characteristics. Building occupancy and lighting operation were very different than anticipated. The as-built model reflects those changes.

Meter and BAS trend data was used to adjust schedules and HVAC operation as shown below.

Lighting and Occupancy

Most of the fixtures in the building are a combination of LED and fluorescent in some configuration. Per the construction drawings, the overall LPD is 0.99 w/sqft which meets the energy efficiency code. Controls

include occupancy sensors, multi-level switching and perimeter daylight controls that are designed to control the outer 8' of fixtures with a/b switched ballasts. The lighting loggers measure the percentage of operation during each hour. The tables below show the schedules used in the eQuest model based on the logger data.

WWD = Winter Weekday
WSAT = Winter Saturday
WSUN = Winter Sunday
SWK = Summer Week
SWD = Summer Weekday
SSAT = Summer Saturday
SSUN = Summer Sunday

Table 5-22: Classroom Lighting Operation - Percent Time On

HOUR	WWD	WSAT	WSUN	SWK
1	0.0%	1.5%	0.0%	0.0%
2	0.0%	2.0%	0.0%	0.0%
3	0.0%	2.0%	0.0%	0.0%
4	0.0%	2.0%	0.0%	0.0%
5	5.0%	2.0%	0.0%	0.0%
6	10.0%	6.0%	0.0%	0.0%
7	35.0%	40.0%	0.0%	0.0%
8	50.0%	40.0%	0.0%	0.0%
9	40.0%	40.0%	1.0%	0.0%
10	40.0%	20.0%	1.0%	0.8%
11	40.0%	4.0%	1.0%	6.0%
12	40.0%	2.5%	0.0%	6.0%
1	40.0%	2.5%	0.0%	6.0%
2	20.0%	2.5%	0.0%	3.0%
3	10.0%	3.5%	3.0%	1.0%
4	10.0%	3.5%	10.0%	1.0%
5	8.0%	1.0%	10.0%	1.8%
6	7.0%	0.0%	1.0%	12.1%
7	5.0%	0.0%	3.5%	19.3%
8	1.0%	0.0%	3.5%	4.9%
9	1.0%	0.0%	0.0%	0.7%
10	0.0%	0.0%	0.0%	0.1%
11	0.0%	0.0%	0.0%	0.0%
12	0.0%	1.5%	0.0%	0.0%

Table 5-23: Lab Lighting Operation - Percent Time On

HOUR	WWD	WSAT	WSUN	SWD	SSAT	SSUN
1	1%	2%	0%	0%	0%	0%
2	1%	2%	0%	0%	0%	0%
3	1%	2%	0%	0%	0%	0%
4	1%	2%	0%	0%	0%	0%
5	10%	7%	9%	0%	0%	0%
6	35%	24%	35%	0%	0%	0%
7	40%	24%	25%	2%	0%	3%
8	35%	30%	6%	16%	8%	25%
9	26%	35%	6%	13%	4%	18%
10	31%	18%	6%	2%	0%	2%
11	25%	9%	5%	4%	0%	0%
12	28%	7%	1%	4%	0%	0%
1	28%	7%	0%	6%	0%	0%
2	15%	5%	1%	6%	0%	0%
3	12%	5%	3%	5%	0%	0%
4	12%	2%	0%	4%	3%	0%
5	5%	0%	0%	2%	0%	0%
6	5%	0%	0%	0%	0%	0%
7	5%	0%	0%	0%	0%	0%
8	5%	0%	0%	0%	0%	0%
9	5%	0%	0%	0%	0%	0%
10	5%	0%	0%	0%	0%	0%
11	3%	0%	0%	0%	0%	0%
12	1%	3%	0%	0%	0%	0%

Table 5-24: Restroom Lighting Operation - Percent Time On

Hour	WWD	WSAT	WSUN	SWD2	SWE
1	0%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%
6	3%	2%	2%	0%	0%
7	45%	50%	1%	0%	0%
8	75%	70%	5%	4%	0%
9	70%	70%	9%	9%	0%
10	70%	40%	8%	6%	0%
11	60%	12%	3%	9%	0%
12	55%	12%	12%	10%	0%
13	55%	5%	12%	12%	0%
14	55%	5%	5%	12%	0%
15	20%	8%	5%	12%	0%
16	27%	0%	3%	12%	0%
17	20%	0%	3%	6%	0%
18	20%	4%	6%	4%	0%
19	30%	0%	25%	3%	0%
20	40%	0%	25%	1%	0%
21	10%	0%	1%	0%	0%
22	0%	2%	1%	0%	0%
23	0%	0%	0%	0%	0%
24	0%	0%	0%	0%	0%

Table 5-25: Mechanical Room Lighting Operation - Percent Time On

HOUR	WWD	WSAT	WSUN	SWD	SSAT	SSUN
1	2.5%	10.0%	0.0%	4.5%	0.0%	0.2%
2	2.5%	10.0%	0.0%	4.5%	0.0%	0.0%
3	2.5%	10.0%	0.0%	4.5%	0.0%	0.0%
4	2.5%	10.0%	0.0%	4.5%	0.0%	0.0%
5	2.5%	10.0%	0.0%	4.5%	0.0%	0.0%
6	6.0%	10.0%	0.0%	4.5%	0.0%	0.0%
7	10.0%	10.0%	0.0%	4.5%	0.0%	0.0%
8	10.0%	0.0%	0.0%	5.5%	0.0%	0.0%
9	10.0%	0.0%	0.0%	7.0%	0.0%	0.0%
10	10.0%	0.0%	0.0%	7.0%	0.0%	0.0%
11	10.0%	0.0%	0.0%	8.0%	0.0%	0.0%
12	10.0%	0.0%	0.0%	12.0%	0.0%	0.0%
13	6.0%	0.0%	0.0%	12.0%	0.0%	0.0%
14	4.5%	0.0%	0.0%	10.0%	0.0%	0.0%
15	4.5%	0.0%	0.0%	9.0%	0.0%	0.0%
16	4.5%	0.0%	0.0%	6.8%	0.0%	0.0%
17	4.5%	0.0%	0.0%	6.8%	0.0%	0.0%
18	4.5%	0.0%	0.0%	6.8%	0.0%	0.0%
19	4.5%	0.0%	0.0%	6.8%	0.0%	0.0%
20	4.5%	0.0%	0.0%	6.8%	0.0%	1.0%
21	4.5%	0.0%	0.0%	6.8%	0.0%	0.0%
22	6.5%	0.0%	0.0%	6.8%	0.0%	0.0%
23	6.5%	0.0%	0.0%	6.8%	0.0%	0.0%
24	2.5%	10.0%	0.0%	6.8%	0.0%	0.0%

The areas not listed had no significant change from the schedule used in the TA model. Since these values included occupancy and daylighting no additional reduction was needed. The baseline lighting schedules were created from these schedules. Most of the classrooms and labs had both daylighting and occupancy sensors so the percent time ON was increased by 20% during occupied hours. For zones with occupancy sensors only, i.e. restrooms, the percent time on was increased by 10% during occupied hours.

ASHRAE 90.1-2010 Building-type LPD defines the baseline for schools to be 0.99. Since this building LPD was 0.99 the savings comes from the controls only.

AHU Fan Operation

The sequence of operations (SOO) states that the exhaust fan shall always operate and the speed should vary to maintain duct static pressure. BAS data suggests that AHU-1 is operating constantly while AHU-2 operates during occupied times.

Figure 14 shows the percentage of flow for AHU-1 and the building exhaust as tracked by the BAS during the evaluation period. While allowed to vary the low-flow limit is about 80%. This low flow limit was reflected in the as-built evaluation models.

Figure 14: Air Flow of AHU-1 and Exhaust Fans During the Monitoring Period

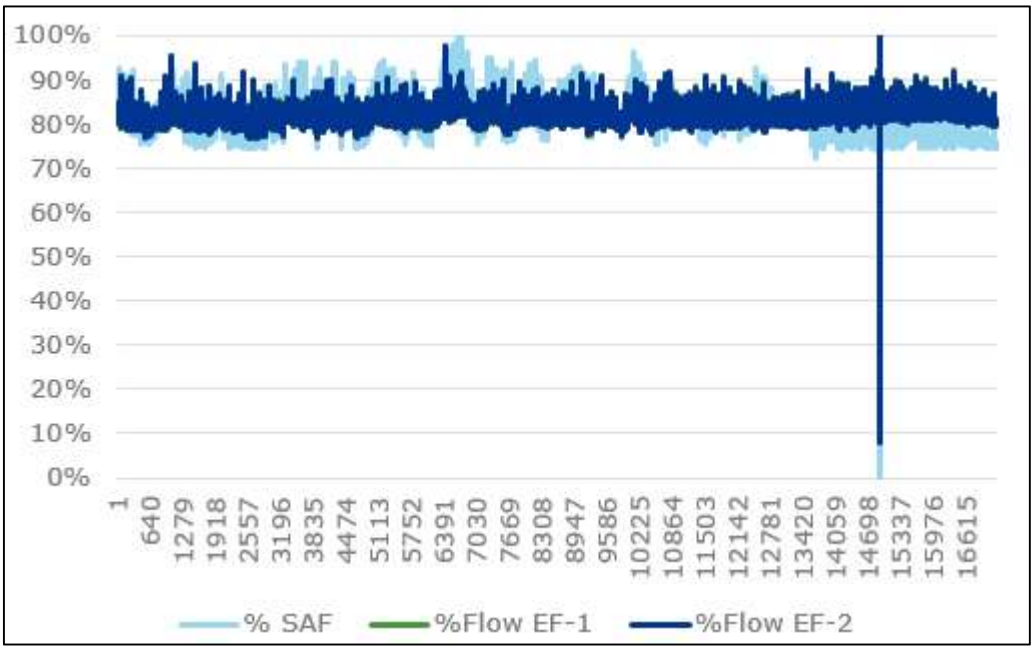


Figure 15 and Figure 17 show AHU-2 average percent supply air flows as tracked by the BAS during April and July, respectively. The SOO indicates that this fan shall operate with building occupancy. It does ramp up and down but per the graphs it is never entirely off. To model this fan, a flow schedule was used to set the minimum flow to 0.01 during unoccupied hours. The fan is always on in the model and the flow can vary like the graphs below.

Figure 15: AHU-2 Average Percent Supply Fan Air Flow in April

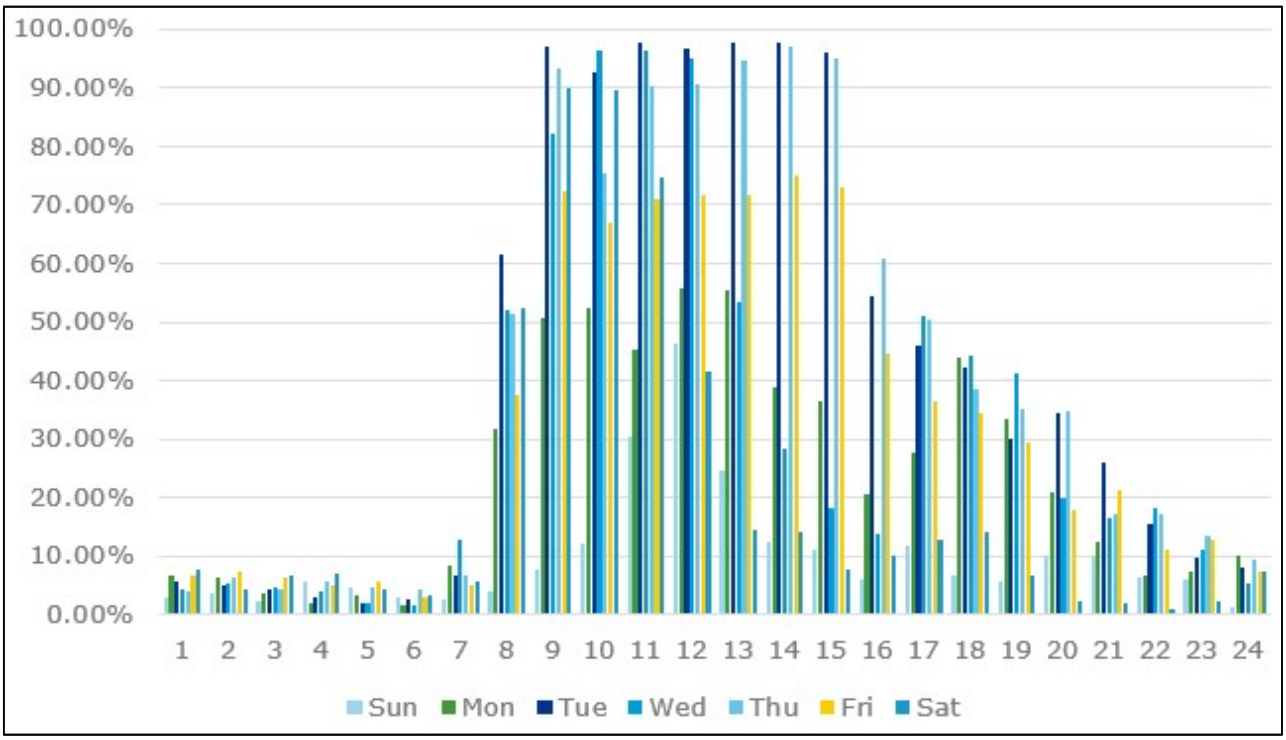
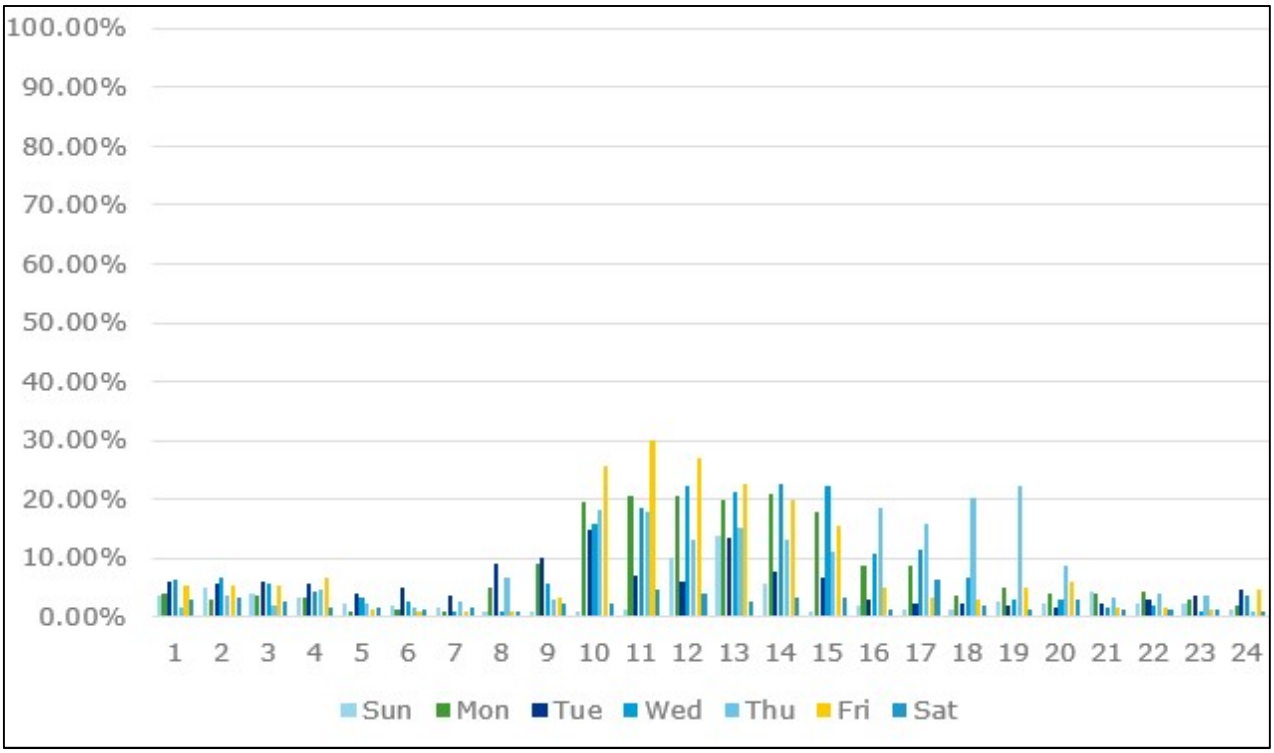


Figure 16: AHU-2 Average Percent Supply Air Flow in July



The exhaust fan profile shows that minimum flow is about 35%. A flow schedule was created in the model for AHU-2 exhaust fan which set the minimum flow to 35%.

Figure 17: AHU-2 Average Percent Exhaust Air Flow in April

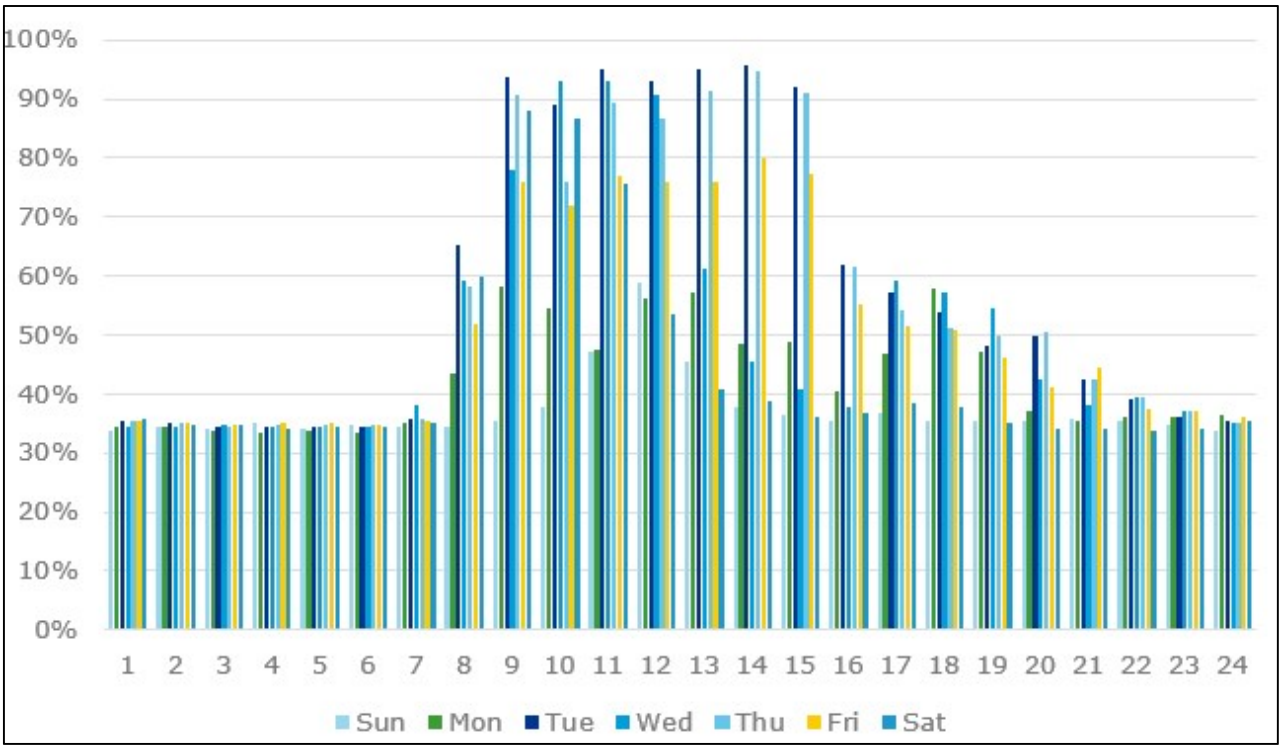
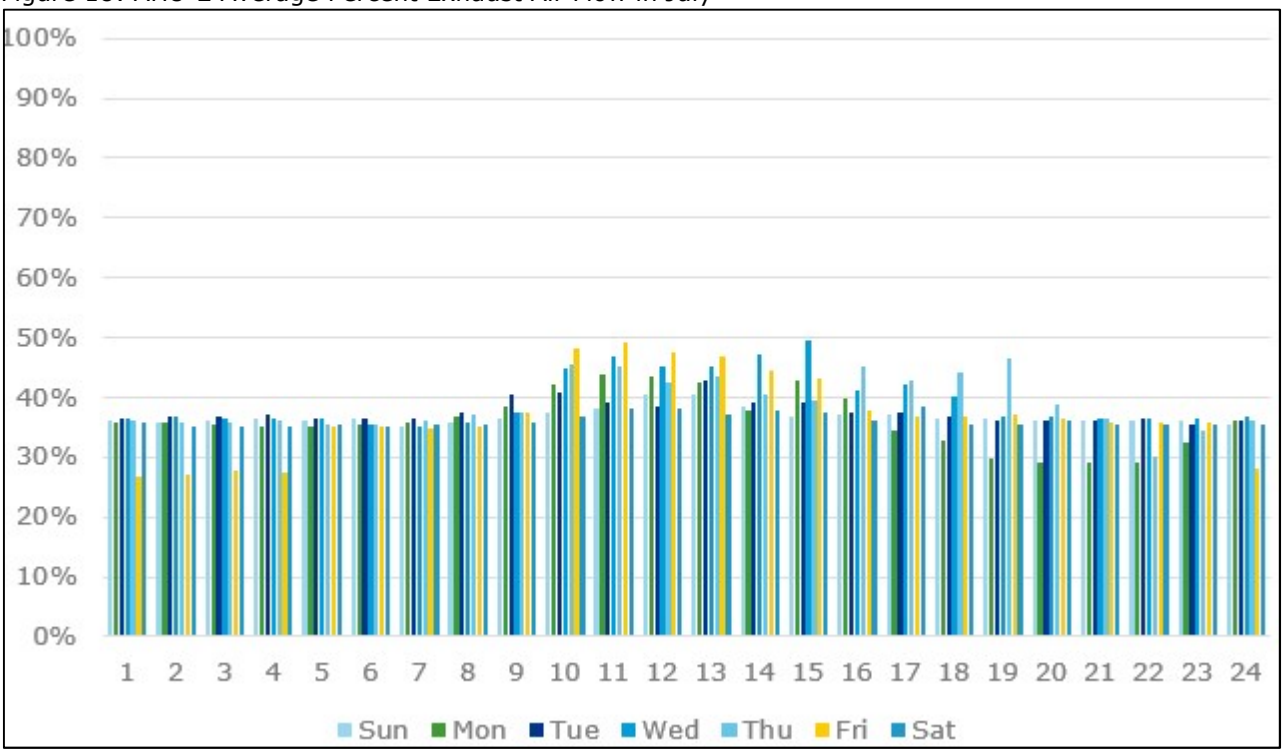


Figure 18: AHU-2 Average Percent Exhaust Air Flow in July



The baseline for these systems is package VAV with reheat and hot-water fossil fuel boiler. One system per floor. Because both the AHUs in this building serve 1st and 2nd floors, 4 systems were modeled in the

baseline. Two for each AHU, 1 per floor. Each of these units was operating with the same flow limits as the as-built units.

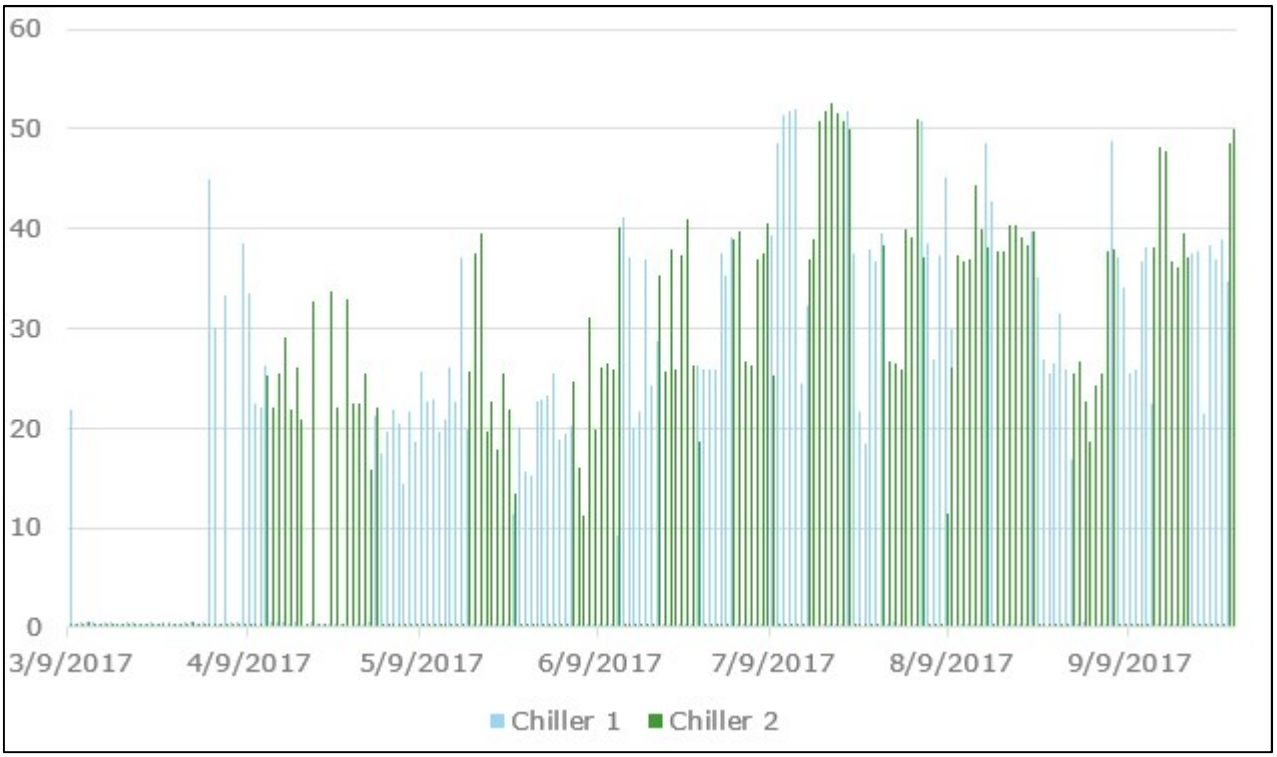
Chiller Evaluation

The TA eQuest model showed simultaneous heating and cooling. Chillers came on whenever cooling was called for in the TA eQuest model. Per the facility mangers the chillers only operate during the cooling season.

Figure 19 confirms the facility managers claim. It shows the chiller energy use during the evaluation period. It started on April 9 and the meters were removed before the chillers were turned off. The calibration model shows that it operates through November.

The chiller operation was modeled to operate when outside air temperatures were above 57°F rather than scheduled on/off. This allows the model to turn the chillers on and off when cooling is called for in the building and the outside air temperature is above 57°F.

Figure 19: Chiller Electric Usage During the Evaluation Period



As stated above, the baseline is packaged direct expansion units so no chillers are modeled in the baseline. Cooling is available and used year-round in the baseline.

Boiler Evaluation

Two condensing boilers were installed to provide supplemental space heating and reheats. Natural gas usage for the boilers is tracked by the BAS. Figure 20 is the trended usage for 2016 year. The spikes in the heating season occur on Monday mornings during the warm up. One spike in April is probably due to maintenance or testing as the BAS trend shows "normal" consumption levels before and after that spike. The other spikes are anomalies in the trend data. If the 15-minute interval reading is not recorded in the trend the next

reading includes the missed record. The spike in September is a good example of this. It appears that there is no gas consumed for several hours then a spike occurs. This spike is the total gas consumed for that period of "no use".

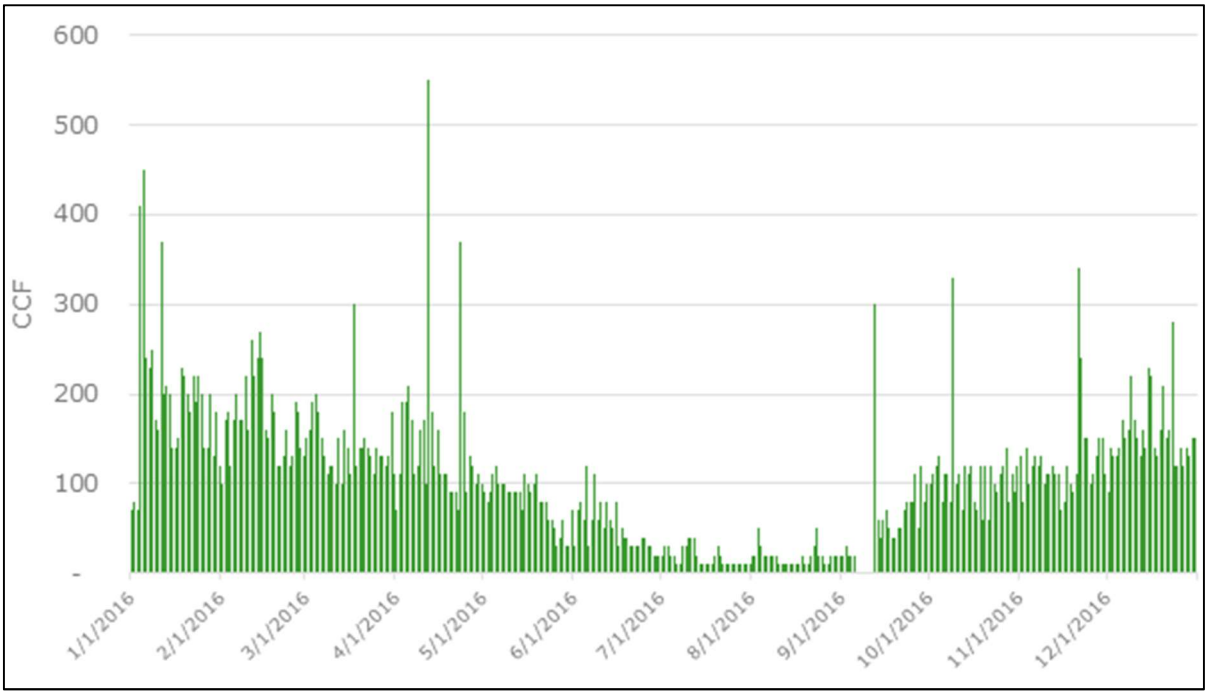
The figure shows that hot water is available through the cooling season for reheats. The boilers operate year 'round in the evaluation model. There are 2 condensing boilers, 1500 MBTU capacity each. Boiler efficiency is 87% at 180ºF and 91.5% at 130ºF supply water temperatures. Variable volume hot water pumps operate in a lead/lag configuration.

Table 5-26: Hot water loop reset schedule

Outside Air Temperature	Loop Operating Temperature
30ºF or less	180
30ºF to 70ºF	180-130 (varies linearly over range)
Above 70ºF	130

The evaluation model follows this configuration. All the hot water coils were modeled with 2-way valves.

Figure 20: Boiler Natural Gas Usage, CCF, for the Year



The baseline boilers are the same as the TA baseline, hot water boilers 80% efficient, auto-sized to represent 50% of the peak load with reset schedules matching ASHRAE 90.1-2010 Appendix G requirements. The hot water loop is modeled with 180ºF supply temperature and 50-degree loop temperature differential. The loop reset temperature varies linearly between 180ºF and 150ºF for outside temperatures between 20ºF and 50ºF, respectively. The loop pump is modeled as constant volume with a 3-way valve on the hot water coils.

Variable Air Volume Lab Exhaust Evaluation

Eight variable air volume fume hoods were installed in 6 labs and lab-prep rooms in the building. The system is designed to reduce the exhaust air during unoccupied hours. The total unoccupied minimum air flow is about 14% of the total general building exhaust connected to AHU-1. The air flow reduction per fume hood can be seen in Table 5-27. When all the fume hoods are operating in Unoccupied mode the total reduction in the general exhaust is 15%. During occupied mode, the exhaust air flow should increase.

Table 5-27: Fume Hood Flow, CFM

Room #	# of Fume hoods	Occ. Minimum Air Flow cfm	Unocc. Minimum Air Flow, cfm
104	1	1200	550
201	1	1200	550
203	1	1200	550
204	2	1200	550
205	1	400	400
206	2	1200	550
Total Air Flow, CFM		6400	3150
		Difference	3250
		Total General Exhaust Air Flow	22,000
		% difference	15%

The two graphs below show the average percent flow in April from both general exhaust fans. There is not a 15% increase in the general exhaust during occupied hours. It appears that this measure is not operating as anticipated. The airflow changes made in the TA model were not incorporated in the evaluation model.

Figure 21: Exhaust Fan 1 Average Hourly Percent Flow by Day in April

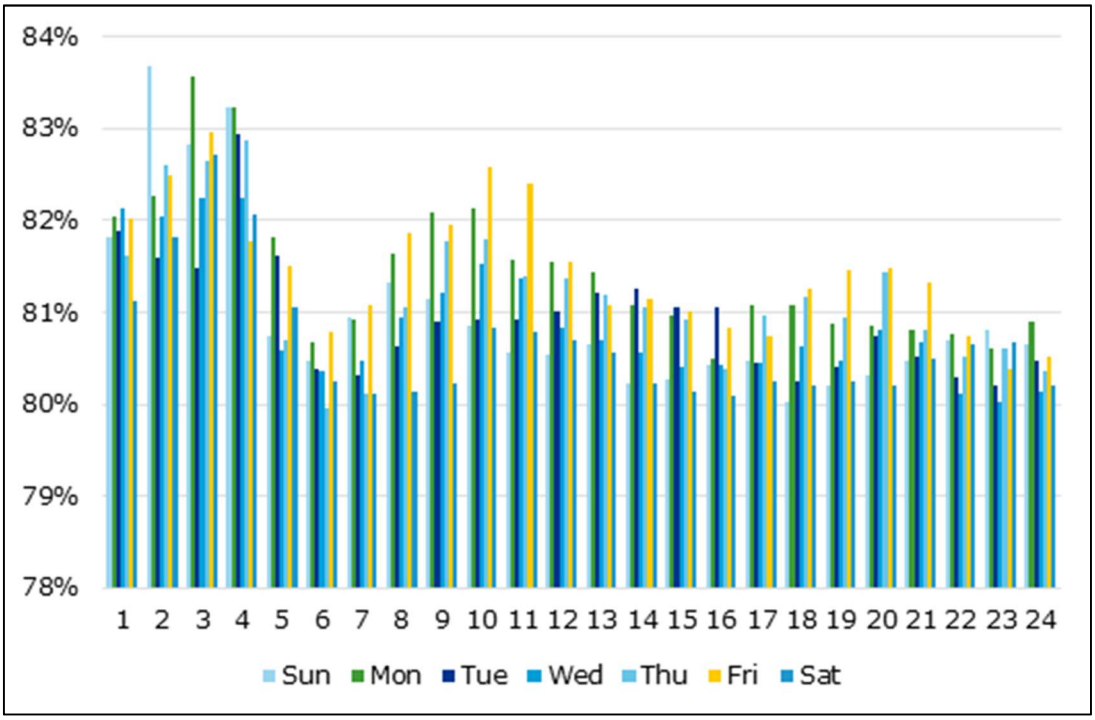
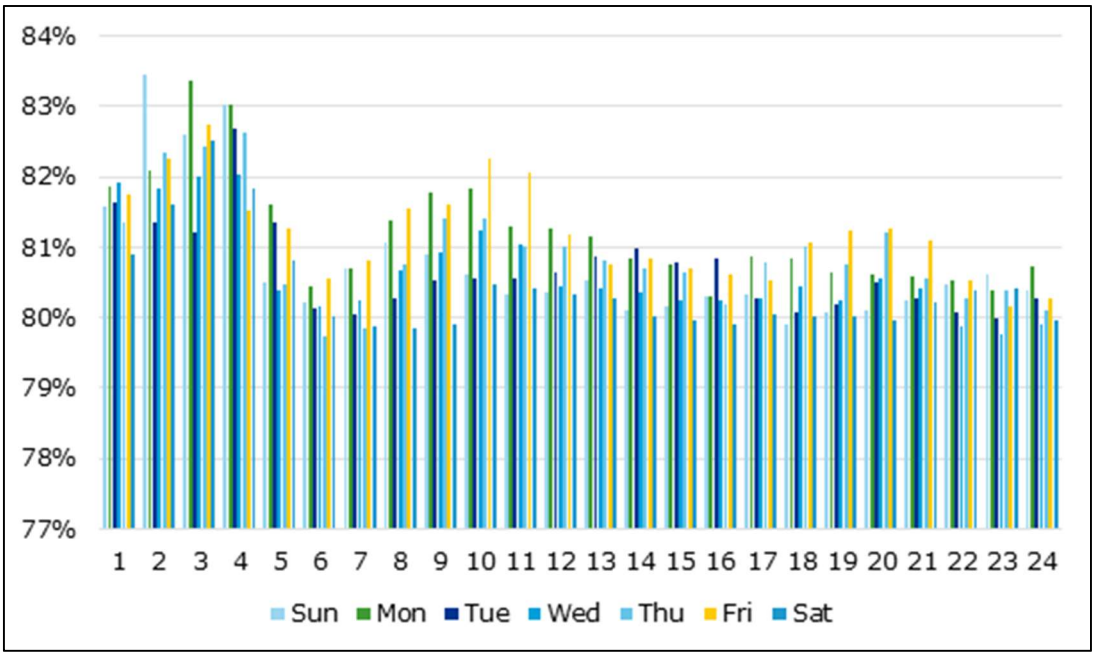


Figure 22: Exhaust Fan 2 Average Hourly Percent Flow by Day in April



ERVs on AHUs 1 & 2 Evaluation

The 100% outside air, 22,000 cfm AHU-1 was designed with a 74% sensible / 75.7% latent effectiveness enthalpy recovery wheel to transfer energy and moisture between the outside air and exhaust air streams. Similarly, the 100% outside air, 8,000 cfm AHU-2 which provides primary air to the chilled beams was designed with a 74% sensible / 74% latent effectiveness enthalpy recovery wheel as well as a sensible only wheel for reheating the dehumidified air during the peak dehumidification loads. Both units utilize differential enthalpy to control the energy recovery wheels, ERWs.

The BAS provided ERW return, exhaust, supply and outside temperatures and humidity's for the period beginning in April 1, 2017 and ending September 27, 2017. These were used to determine the effectiveness of the heat wheels using the following formula:

$$Eff = W_{sa}\,(T_2-T_1)/W_{min}\,(T_3-T_1)$$

Where,

Eff = Sensible heat recovery effectiveness

T_1 = Outside air temperature before heat wheel

T_2 = Supply air discharge temperature after heat wheel

T_3 = AHU return air temperature

W_{sa} = Supply airflow

W_{min} = Minimum of exhaust and supply airflow

Since these are 100% outside air AHUs, the exhaust airflow was equal to the supply airflow, which condenses the formula to:

Eff = (T2-T1)/(T3-T1)

The BAS outside air humidity data were inconsistent so the latent effectiveness could not be calculated with any confidence. AHU-1 sensible heat wheel effectiveness averages about 71% during the heating season up to about 50ºF outside air temperature. The temperature data also indicates that the heat wheel operates during occupied hours and whenever there is a difference in outside and inside conditions.

The ERV sensible effectiveness was changed to 71% and the latent effectiveness was not changed. The baseline ERV effectiveness was 50% per ASHRAE 90.1-2010. The ERV was modeled within the packaged VAV unit with hot water preheat coils, the same as the TA model.

Construction Documents

The construction documents were used to measure space-type LPD and equipment energy use. The controls sequence of operation was referenced for operating temperatures and schedules and equipment operation such as airflows, boiler set points, and loop temperatures.

Calibration

The building model was updated to reflect as-found conditions using the data collected on site, then the evaluators simulated the building model with 2016 weather data from the Providence, RI T.F. Green S weather station and compared modeled consumption to 2016 monthly utility data. Adjustments were made to parameters such as and lighting schedules in zones with occupancy and daylighting controls. The chillers were turned off during heating season. Figure 23 shows the monthly electric usage comparison of the calibrated model (green line), the TA model (blue line) and the BAS trended usage (blue columns). Except for October, the variation in monthly consumption is below 10% of the BAS measured monthly usage, which is the threshold set during the planning of this study. The variation in the annual consumption is 3% for the evaluation model.

October data showed some anomalies for which the customer could not recall any incidents that would cause exceptionally high usage. National Grid approved the use of the calibrated model on January 12, 2018.

Figure 23: Electricity Usage Calibration

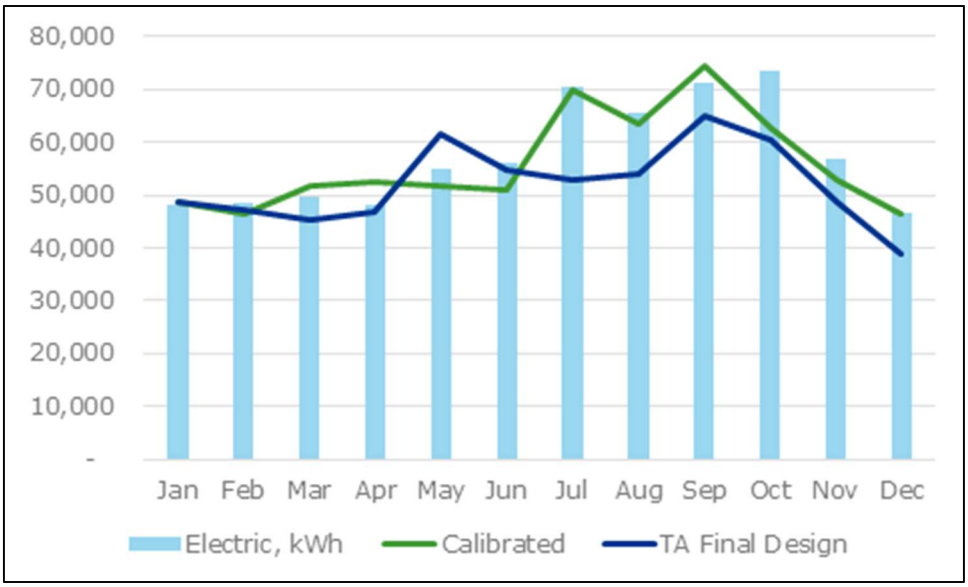
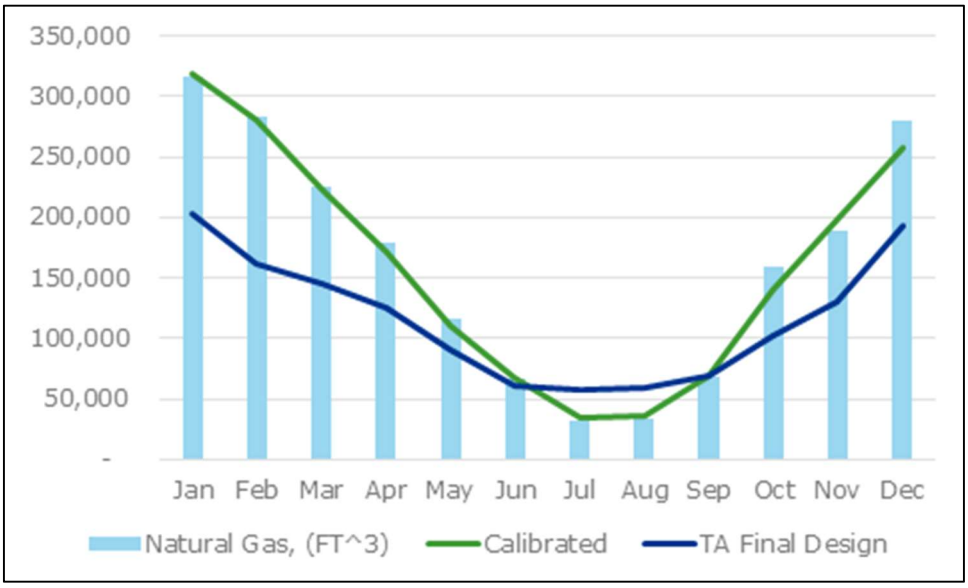


Figure 24 shows the monthly gas usage comparison. The largest difference between the monthly usage in the calibrated model and the BAS trend was 10% and 2% of the annual usage, except in October. Per the note above, this calibration model was approved by National Grid on January 12, 2018.

Figure 24: Natural Gas Usage Calibration



Evaluation Savings Analysis

Once the model was calibrated, the 2016 weather file was replaced with the TMY3 weather file from the same weather station. This was done to create a weather normalized model that can be compared to the TA estimated savings.

The baseline model was derived from the calibrated model by setting key parameters to baseline values as defined by the Rhode Island State Energy Code IECC 2012 for Climate Zone 5A. Whole building interactive

savings were calculated as the difference between the baseline and as-found models. A comparison of the key parameters changed for each measure and for the baseline can be found in Table 5-28 of the following section.

Evaluation Results

This section will summarize the evaluation results determined in the analysis above. This section will include a summary table of savings by major end use and application.

Comparison of Baseline Assumptions

Table 5-28 and Table 5-29 compare the key parameters used in the Tracking analysis with those used in the Evaluation analysis. The purpose of these tables is to show how different values changed.

Table 5-28: Comparison of Key Parameters in the Baseline Model

BASELINE				
Reference	Parameter	Tracking Value(s)	Evaluation Value(s)	Notes
Hot water loop	Loop Delta T	50°F	50°F	ASHRAE 90.1 2010 Section G3.1.3.3 states that hot-water design supply temperature shall be modeled as 180°F and design return temperature is 130°F
Space Temperatures	Heating Occ.	70°F	74°F	
	Heating Unocc.	65°F	61°F	
Lighting	Schedules	1 schedule for all zones	Multiple schedules based on zone type	Created from logger data
Schedules	Month and day	Dates set based on 2013 year	Dates set based on 2016 year	
Loop Pumps	1 HW Pump	2 HW Pumps		

Electric Generators	Solar Electric	No electric generators	PV-Module	
AHU-1				
AHU-1 Minimum air Flow		1	0.8	
1st PVAV Return-kW/flow		0.001064	0.001142	
2nd PVAV kW/cfm		Return & supply the same 0.001071	Supply = 0.001064 Return =0.001142	Probably an oversight in TA model
Reheat Delta		18°F	32°F	
Zone min-flow ratio		No zone minimum flows	Used same flows as as-built model	These values are associated with the fume hood savings. The fume hoods existing in these zones in the baseline too.
Assigned flows		No zone assigned flows	Used same flows as as-built model	
ERV OA-Static EXH-Static		0	0.8	
AHU-2				
AHU-2 Fan Schedule	Unoccupied Hours	Off	On	Trend data show the AHU fan operating at irregular hours which made it difficult to schedule. Left it on and allowed the flow to go very low.
1st Office PVAV Supply and Return Fan		0.000857 kW/cfm for both	0.001364 0.000783	Probably an oversight in TA model
2nd Office PVAV Supply and Return Fan		0.000843 kW/cfm for both	0.001364 0.000783	
ERV OA-Static EXH-Static		0	0.7	

Comparison of As-Built Assumptions

Table 5-29 compares the key As-Built parameters used in the TA tracking analysis with those used in the evaluation analysis. It provides context for explaining the realization rates verified by this evaluation.

Table 5-29: Comparison of Key Parameters in the As-Built Model

Reference	Parameter	Tracking Value(s)	Evaluation Value(s)	Notes
Hot water loop	Loop Delta T	50°F	50°F	
Space Temperatures	Heating Occ.	70°F	74°F	
	Heating Unocc.	65°F	61°F	
Lighting Schedules	Schedules	1 schedule for all zones	Multiple schedules based on zone type	Created from logger data
	Month and day	Dates set based on 2013 year	Dates set based on 2016 year	
	DAYLIGHTING	YES	NO	Daylighting and occupancy are accounted for in the new lighting schedules derived from logger data
Loop Pumps	# of pumps	1 HW Pump 2 CHW Pumps	2 HW Pumps 3 CHW Pumps	Existing
Loop Operation	Chilled water Loop-Operation	Chilled water loop Always on	Snap Snap -T = 57°F Outdoor temperature	Stops chiller from operating during the winter months.
	Hot water Loop-Operation	Hot water loop STANDBY	DEMAND	Standby – loop is active when a fan is operating. The coil may not be calling for heat. Demand – loop is active when a coil load exists.
Boiler	EIR	1.148	1.204	Per boiler spec.
Electric Generators	Solar Electric	No electric generators	PV-Module	
All heating systems	Max Supply Temp	90°F	105°F	
AHU-1				
Airflow	Supply Return-kW/flow	0.001352 0.00119	0.001406 0.001142	Per construction drawings
	Return Flow CFM	20,000	22,000	
Humidity	Max-Humidity	55%	No humidity control	No humidity requirement specification found.
Minimum Flow		1	0.8	
Zone Flows	min-flow	No zone minimum flows	Used same flows as as-built model	These values are associated with the fume hood savings. The fume hoods existing in these zones in the baseline too.
	Assigned flows	No zone assigned flows	Used same flows as as-built model	
Baseboard	Baseboard-ctrl	Thermostat	Out-door reset	
	Baseboard-rating	Defined in perimeter zones	Let eQuest define zone baseboard	
Zone Exhaust	Exhaust kW/Flow	0.000119	0.001142	Mechanical schedule
ERV OA-Static	EXH-Static	0	0.8	
AHU-2				

AHU-2 Fan Schedule	Unoccupied Hours	Off	On	Trend data show the AHU fan operating at irregular hours which made it difficult to schedule. Left it on and allowed the flow to go very low.
1st Office PVAV Supply and Return Fan		0.000857 kW/cfm for both	0.001364 0.000783	Probably an oversight in TA model
2nd Office PVAV Supply and Return Fan		0.000843 kW/cfm for both	0.001364 0.000783	
Capacity		eQuest sizes the cooling and heating coil capacities	Cooling and heating capacities defined	From mechanical schedule
ERV OA-Static	EXH-Static	0	0.7	

End Use Analysis

This section provides a breakdown of the TA and evaluated project savings by end use and describes the key drivers behind the difference between TA and evaluated project savings. Table 5-30 shows the savings by end use for both the TA and evaluated building.

Table 5-30: Savings by End Use

End Use Category	TA savings by end use	Evaluator savings by end use	Realization Rates by end use
ELECTRIC	kWh	kWh	%
Space Cool	114,438	112,176	98%
Heat Reject.	-	-	
Refrigeration	-	-	
Space Heat	(4,401)	(4,005)	
HP Supp.	-	-	
Hot Water	-	-	
Vent. Fans	20,105	27,601	137%
Pumps & Aux.	(12,198)	(9,416)	77%
Ext. Usage	1,533	1,533	
Misc. Equip.			
Task Lights	-	-	
Area Lights	15,066	3,266	22%
Total Electric*	134,542	131,153	97%
GAS	Therms	Therms	%
Space Cool	-	-	
Heat Reject.	-	-	
Refrigeration	-	-	
Space Heat	19,995	14,522	73%
HP Supp.	-	-	
Hot Water	447	485	108%
Vent. Fans	-	-	
Pumps & Aux.	72	-	0%
Ext. Usage	-	-	
Misc. Equip.	-	-	
Task Lights	-	-	
Area Lights	-	-	
Total Gas*	20,513	15,007	73%

*The difference of total savings between this number and the TA Tracking value comes from running the model for 2016 rather than the 2013 year.

A significant portion of the reduction in both cooling and heating savings can be attributed to removing the humidity control. A 55% RH maximum control was included in the TA model that does not exist in the building. The chillers and boilers were modeled with "DEMAND" control in the model. This allowed for mechanical cooling during the winter months. As shown above, the chillers are off during the heating season. Hot water is available for reheats all year.

The fans in this building are almost always operating. The supply fan on AHU-2 can go off during unoccupied times if the space temperatures are satisfied. The minimum flow from the exhaust fan associated with AHU-

2 is about 35%. AHU-1 supply and exhaust fans operate at 80% and higher. The additional fan savings comes from more run hours on the fans and higher minimum flows that the TA model assumed.

In the TA, final report on page 7 the lighting power density is stated to be 0.99W/sqft. This is the IECC 2012 baseline LPD. The TA proposed model used 0.89 and the eQuest "Daylighting" command to account for the controls. This reduced the entire building LPD when the occupancy sensors were installed in classroom, restrooms and some labs. Daylighting was in perimeter spaces only. Most of those spaces had occupancy sensors as well.

A spot check of the actual LPD per space type is shown in the table below. For the evaluation model 0.99 LPD was used along with schedules created from lighting logger operation data. These data accounted for both occupancy and daylighting. The same LPD was used in the baseline model. The fraction of operating hours operating schedule was increased by 10% in spaces with occupancy sensors and 10% in spaces with daylighting and 20% in spaces with both.

Table 5-31: Lighting LPD by Zone-Type

Zone-Type	LPD
Classroom	1.635
RR	0.893
Corridors	1.431
Meeting	1.055
Lab	1.134
Storage	1.071
Office	0.995
Weighted Bldg. LPD	1.0

Table 5-32 is the discrepancy summary table that describes major differences between the TA model and evaluation model.

Table 5-32: Discrepancy Summary

Discrepancy Category	Impact on Savings		Description of Discrepancy
	Gas	Electric	
Original Tracking Savings	100%	100%	
Modeling Error		-21%	LPD for as-built model was 0.89 then occupancy and daylighting were added in the TA model. The evaluation schedule included occupancy and daylighting to the 0.99 LPD. Fan Energy – both SF and RF energy in the TA model were the same and small for the AHUs. The fan kW/CFM was changed to match that found on the mechanical schedule.
Operational Profile	-39%	21%	AHU-1 Fans Operation- In the TA model fans were scheduled off during unoccupied times with night cycling as needed. BAS and meter data show the fans are always on. Fan Minimum Flow- In the TA model the minimum flow for AHU-1 SF & Exhaust could vary as low as 30%. BAS data show that AHU-1 flows are at or above 80% through the evaluation period. AHU-2 exhaust flow was at or above 35% during that same period. Supply fan was turned off during unoccupied times in the TA model. Humidity Controls- The TA model assumed laboratory-type humidity control that does not exist in the building. The TA model used 55% maximum relative humidity in AHU-1.
	79%	100%	

Improvement Opportunities

This section will document any opportunities for program improvement identified during the evaluation.

APPENDIX E. FAN COIL UNIT EC MOTORS ISP REPORT

ISP Study Target Application: Fan Coil Unit Motors for Systems Designed from 2012 through 2014

ISP Report Finalization Date: 08/03/2017

1. Research Summary

This ISP research report summarizes the methods, findings, and conclusions of a low rigor ISP study for electrically-commutated (EC) motors used in fan coil units (FCU) serving laboratory, hospital, large residential, office and school buildings designed in the 2012-2014 period. This ISP study was triggered by a need to establish baselines for projects included in the Comprehensive Design Approach (CDA) impact evaluation (P56). Table F-1 summarizes the seven affected P56 sites (the P56 evaluation sample includes seven projects at six locations) with fan coil unit EC motors and the ex-ante baselines applied by the PAs and recommended by this ISP research.

This ISP research included a combination of secondary research and eight interviews with credible and well-informed respondents, including mechanical system designers and energy consultants.

P56 Evaluation Baseline Recommendation

The P56 projects impacted by this research (see Table F-1) all utilized EC motors in design case fan coil units and were evaluated against permanent split capacitor (PSC) motors in the baseline.

All respondents that were interviewed indicated that a significant amount (minimum 25%, maximum 75%) of PSC motors were still being specified for fan coil units over the past 3-5 years. Additionally, the respondents that primarily used EC motors in the past 3-5 years were generally more aware of utility incentive programs, citing energy savings and upfront costs as important considerations. Therefore, we recommend that PSC motors be considered "standard efficiency" technologies for designs utilizing fan coil units between 2012 and 2014. All of the sampled P56 projects were modeled by the Program Administrators' Technical Assistance (TA) providers as having baseline fan coil units with PSC motors. This baseline is consistent with the "standard efficiency" technology identified by interviewees.

The DNV GL team observed that many of the sampled P56 project TA energy models included baseline FCUs operating continuously. The evaluators consulted with the P56 Baseline Advisory Group (BAG) and reviewed IECC and ASHRAE 90.1 to derive the baseline FCU motor control strategy. According to IECC 2009 Table 506.5.1(3) (note i) and ASHRAE 90.1-2007 Table 11.3.2A (note i), when modeling building energy savings for constant volume fan coil units, the baseline FCUs should be controlled in the same manner as the proposed design. The evaluators recommend that the ex post baseline FCU controls be updated to reflect the recommendations in Section 506 of IECC 2009 and Chapter 11 of ASHRAE 90.1 and that for constant volume FCUs, the baseline motor controls be similar to the as-built systems.

One exception to this baseline is systems where the proposed FCUs are variable air volume systems, which are not addressed in code, and per several interviewees, were not standard practice during the P56 timeframe. Based on the available information, the evaluators recommend that the ex post baseline for VAV FCUs be constant volume FCUs with PSC motors that cycle based on heating and cooling loads, unless continuous airflow is required for application specific purposes. In the case of Project E in Table F-1, continuous baseline operation is considered allowable because continuous circulation air is required for the laboratory function.

Additional information regarding the evaluation baseline recommendations can be found in Section 4.

Table F-1: P56 CDA Impact Evaluation – Fan Coil Unit Motor Measure Details

CDA Project	Bldg. Type and Location	Design Year & Applicable Code	Measure Description	Ex Ante Baseline	Evaluation Ex Post Baseline
Fan Coil Units A BR+A 487,000/753,000 kWh	Mixed-use office/residential building in Boston, MA	2009 IECC and ASHRAE 90.1-2007 w/ amendment 1	FCU ECMs (131 total fan coils ranging in size from 290-1,350 CFM installed with EC motors as one measure, and cycling controls as a second measure)	FCUs with constant speed PSC fan motors run continuously to supply outdoor air for ventilation.	The evaluators recommend that the baseline FCUs be modeled as having controls similar to the as-built units, but with PSC motors rather than EC motors. See site report for CS9571 for additional details.
Fan Coil Units B A&L 66,000/4,500,000 kWh	Hospital in Worcester, MA	IECC 2009 and ASHRAE 90.1-2007 w/ amendment 1	47 FCUs with EC motors serving IT, mechanical and electrical equipment rooms	Constant speed PSC fan motors run continuously	FCUs with PSC motors that cycle to maintain temperature set points during operating hours, similar to the installed EC motors
Fan Coil Units C Atelier ten UK/218,000 kWh 1/9 measures	Academic Dormitory Hall in Cambridge, MA	IECC 2009 and ASHRAE 90.1-2007 w/ amendment 1	Fan coil units are installed with EC motors, fan controls are such that baseboard takes precedence over FCU to conserve fan energy	Fans are installed with PSC motors and run continuously at 100% speed.	FCUs with PSC motors that cycle to maintain temperature set points during operating hours, similar to the installed EC motors

CDA Project	Bldg. Type and Location	Design Year & Applicable Code	Measure Description	Ex Ante Baseline	Evaluation Ex Post Baseline
Fan Coil Units D DMI 53,000/780,000 kWh	High School in Leominster, MA	IECC 2009	9 FCUs are installed with EC motors. Unit sizes range from 750 to 1,250 CFM	FCUs installed with PSC motors and run continuously during occupied hours	FCUs with PSC motors that cycle to maintain temperature set points during operating hours, similar to the installed EC motors
Fan Coil Units E B2Q 48,000/850,000 kWh	Chemical Engineering Lab in Cambridge, MA	IECC 2009 and ASHRAE 90.1-2007 w/ amendment 1	142 FCUs are installed with EC motors and fan speed modulation to maintain space temperature set points when the heating/cooling valves are fully open	FCUs installed with PSC motors that run continuously at 100% speed	Same as ex ante - FCUs with PSC motors that run continuously, similar to the installed EC motors
Fan Coil Units F&G (App. No.'s 976238 and 3549519) A&L 23,000/1,600,000 kWh	Pharmaceutical Research Lab in Boston, MA	IECC 2009 and ASHRAE 90.1-2007 w/ amendment 1	200-250 EC motors for the whole building.	PSC motors running @75% speed for 5,000 hrs./yr	FCUs with PSC motors that cycle to maintain temperature set points during operating hours, similar to the installed EC motors

Additional ISP Findings

In addition to asking ISP interviewees about fan coil unit motors used during the CDA-applicable period (2012-2014), the ISP researchers asked interviewees about more recent (2016/2017) system design practices.

For projects designed more recently, the ISP interviewees were consistent in stating that EC motors are becoming more common practice, which is consistent with recent updates to the MA Energy Code. IECC 2015, which went into effect in MA in 2017, requires fractional horsepower motors to be EC motors with efficiencies >70%. Interviewees added that certain applications, specifically those with high pressure drops, may still require the use of PSC motors; however, this is not addressed by code. This use of PSC motors was not observed in P56.

Details regarding the findings of this ISP research, including more additional observations regarding ISP for EC motors in FCUs outside of the P56 project scope, are included in Section 4 and Appendix F2 of this report.

2. Background Information

Fan coil units typically utilize factional horsepower motors to power its fans. Older motor technologies for fractional horsepower sized motors are known to operate at relatively poor motor efficiencies. The commonly used fan coil unit motor types include:

- Permanent Split Capacitor (PSC)
- Electrically Commutated (EC)

During the period of interest (2012-2014), the Massachusetts building code referred to IECC 2009 and the 2009 IMC to define the minimum mechanical system requirements for new buildings. Neither IECC 2009 nor 2009 IMC includes any mention of fan power limitations or specific control requirements for sizes under 5 hp as found in fan coil units. Additionally, ASHRAE 90.1 2007 does not have fan power requirements or fan coil unit control requirements for systems of this size. The footnotes in Section 506 of IECC 2009 and Chapter 11 of ASHRAE 90.1-2007 include recommendations for fan coil unit controls, but not motor efficiency or type. This ISP study seeks to determine the standard practice for fan coil unit motors for new construction laboratory, hospital, large residential, commercial, and school buildings designed between 2012-2014.

IECC 2009

There is no mention of electrically-commutated motors in IECC 2009.

Fan Power Limitation Table 503.2.10.1(1) and Fan Power Limitation Pressure Drop Adjustment Table 503.1.10.1(2) apply to fans above 5 hp not found in fan coil units

3. Method

The measure baseline is the equipment that was commonly designed in the sectors and time period identified in Section 1, absent program intervention.

This ISP research included interviews with eight engineering firms that are familiar with the design of fan coil units in HVAC applications. In addition, secondary research was performed to identify the codes and existing standard practice research for these systems. The results of this research have been triangulated across multiple primary data sources and supplemented with the secondary data, and they are summarized in this report. The method generally follows the low rigor protocol described in the Baseline Framework.[11]

The primary data collection included questions regarding the following:

- Design practice at the time of the CDA project design (2012-2014) and in the future (2015 and beyond)
- Factors (e.g., building type) influencing the system design
- The influence of Energy Efficiency Service providers on system design

[11] See Section 6.2 of *MA Commercial/Industrial Baseline Framework*, Final Report, DNV GL and ERS, February 2, 2017, for discussion on high and low rigor approaches for non-site-specific ISP methods.

A preponderance of evidence standard was applied in the final recommendation of baseline.[12]

4. Findings and Recommendations

The findings and recommendations for this research are presented in the following two sections. The first section describes the baselines recommended for the seven P56 sites described in Table F-1, while the second section includes general ISP recommendations for fan coil unit motor selections. Appendix F2 provides detailed primary and secondary research findings.

Rationale for P56 Project ISP Recommendations

The P56 projects impacted by this research (see Table F-1) all used EC motors in fan coil unit designs. For all buildings types, both the secondary research and primary data collection indicated that between 2012 and 2014 use of PSC motors in fan coil units was common. All of the projects included in the P56 evaluation sample were modeled by the TAs to have baseline fan coil unit systems with PSC motors (see Table F-1). This baseline is consistent with the "standard efficiency" technologies identified in our ISP interviews and described in secondary research (see Appendix F2). Based on the available information, the evaluators recommend that the ex post baseline for the seven P56 evaluation projects be PSC motors, similar to the ex-ante baseline. The evaluators also recommend that the baseline PSC motor efficiency/power demand be determined based on the following references (listed in order of priority):

1. Review of project files to determine if a specific alternative FCU model or motor was included in the original building design and document by the Energy Efficiency Service providers and/or Teas'
2. Review manufacturer's literature for the installed FCUs to determine if a PSC-equipped alternative was offered; include baseline motors with power draw/efficiency equivalent to the manufacturer's specified alternative.
3. Use industry standard efficiencies, which have been shown to be in the range of 35%-50% efficiency for PSC motors and 70%+ for EC motors[13].

The DNV GL team observed that many of the sampled P56 project TA energy models included baseline FCUs operating continuously. The mandatory provisions of IECC 2009 and ASHRAE 90.1-2007, which were the code references applicable to the sampled P56 projects, do not include FCU motor control requirements, making the baseline control strategy for these systems ambiguous. In the absence of mandatory code requirements for motor controls, the evaluators consulted with the P56 Baseline Advisory Group (BAG) and reviewed the alternative compliance paths of the IECC and ASHRAE 90.1 to derive the baseline FCU motor control strategy. According to IECC 2009 Table 506.5.1(3) (note i) and ASHRAE 90.1-2007 Table 11.3.2A (note i), when modeling building energy savings for constant volume fan coil units, the baseline FCUs should be controlled in the same manner as the proposed design. The evaluators recommend that the ex post baseline FCU controls be updated to reflect the recommendation in Section 506 of IECC 2009 and Chapter 11 of ASHRAE 90.1 and that for constant volume FCUs, the baseline motor controls be similar to the as-built systems. One exception to this baseline is systems where the proposed FCUs are variable air volume systems, which are not addressed in code, and per several interviewees, were not standard practice during

[12] As per the 2017 Massachusetts Commercial/Industrial Baseline Framework: "Preponderance of evidence" means that "the greater weight of evidence" favors one condition or the other. The quality of evidence is more important than the volume of it." For further discussion on this methodology, see *Early Retirement Using Preponderance of Evidence*, v1.0, July 16, 2014. Prepared for the California Public Utilities Commission.

[13] See 2013 U.S. Department of Energy study, Page 16: *Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment* - https://energy.gov/sites/prod/files/2014/02/f8/Motor%20Energy%20Savings%20Potential%20Report%202013-12-4.pdf

the P56 timeframe. Based on the available information, the evaluators recommend that the ex post baseline for VAV FCUs be constant volume FCUs with PSC motors that cycle based on heating and cooling loads.

Additional Findings

While the catalyst for this ISP research was to characterize the baselines for the P56 evaluation projects, it also presented an opportunity to gather insights beyond the P56 project scope to inform future ISP for fan coil unit motors.

New construction projects in Massachusetts are required to comply with the Massachusetts Building Energy Code ("the Code") to define baseline. Until mid-2014, the applicable version of the MA Energy Code referenced IECC 2009 (and the 2009 IMC) as well as ASHRAE 90.1-2007 to define project baselines. This was the version of code that was applicable for all of the projects in the P56 evaluation sample. On July 1st, 2014, the Code was updated to reference IECC 2012 (and the 2012 IMC) as well as ASHRAE 90.1-2010. This code was in effect through December 31, 2016. The Code was again updated on January 1, 2017 and now references IECC 2015 (and IMC 2015) as well as ASHRAE 90.1-2013. With recent changes in code, the minimum requirements for fractional horsepower motors has become more stringent:

- IECC 2009/IMC 2009 and ASHRAE 90.1-2007 does not mention EC motors or requirements for fractional horsepower motors. Fan coils are listed in the standard HVAC design table has having constant speed, cycling fan controls.
- IECC 2012/IMC 2015 had similar fractional motor requirements to IECC 2009/IMC 2009
- Starting with ASHRAE 90.1-2013 and IECC 2015, which became applicable in Massachusetts on 1/12017, the code required that fractional horsepower motors must be electronically commutated with a minimum efficiency of 70% as rated in accordance with DOE 10 CFR 431.

The majority of interview responses indicated an increase in EC motor usage since 2012, with a significant portion of the FCU motor market now (as of early 2017) being made up of EC motors. In addition, the use of EC motors in applications with fractional horsepower motors has recently become a requirement in multiple code documents (e.g. IECC 2015, ASHRAE 90.1 2013). This information offers a preponderance of evidence that projects designed in 2017 and beyond are included EC motors as the baseline for FCUs. However, the baseline for projects designed between 2014 and 2017 is less clear as the most recent code requirements were not yet in effect and interview respondents indicated that the market was still transitioning in this period.

While respondents were consistent in stating that EC motors were standard in 2017, two respondents mentioned that using the variable-speed capability of EC motors was still not standard practice, indicating a potential opportunity for energy efficiency measures through improved FCU motor controls.

Detailed Results of Primary and Secondary Research

Summary of Primary Research

A summary of the interview questions and answers are included in Table F2-1, and key observations from this research are highlighted below.

- Respondents generally agreed that PSC motors were commonly used for fan coil units installed between 2012 and 2014:
    - Five respondents stated that at least 50% of fan motors were PSC 3-5 years ago.

- Three respondents stated that they switched to EC motors 3-5 years ago, but also added that PSC motors were commonly used at that point.
- All MEP firms stated that EC motors are primarily used today, some of which also cited the new code requirement. Two of those firms cited the need to still use PSC motors in applications with high pressure drop requirements.
- Most of the interviewees were MEP design engineers with experience in system design and limited knowledge of whether utility incentives were received for their designs. Feedback regarding the influence of energy efficiency programs was split with half the respondents indicating that incentives were typically not pursued for EC motors. Of the respondents stating that incentives were not influencing their decisions, the majority indicated that upfront material costs were an important factor.

- Respondents were also consistent regarding the design of systems installed today (2016/2017):
  - All eight respondents stated that EC motors account for the vast majority of projects installed today.
  - One respondent mentioned that PSC motors are still used in high pressure applications. This respondent did not mention specific code exceptions that allow this practice.
  - Two respondents discussed utilizing the variable speed capability of EC motors as a potential energy efficiency practice.

Table F2-1: Primary Data Sources

Company	# of systems designed/installed/analyzed over the last 5 years	Type of system installed 2012-2014	Influence of energy efficiency programs on design	Type of systems installed today
MEP Firm A	Respondent indicated they had experience with system installation over the last five years; did not provide a number.	Approximately 25% PSC, 75% EC, with EC becoming increasingly more common in the past 3-5 years.	Yes.	EC motors are much more commonly installed today.
MEP Firm B	50+	Primarily EC motors but still many PSC motors.	Cost and energy savings are considerations and EE programs do influence design.	Primarily EC motors since it is now code required. PSC still used for high pressure applications.
MEP Firm C	Respondent indicated they had experience with system installation over the last five years; did not provide a number.	Switched to EC motors about 3-5 years ago.	None.	EC motors.
MEP Firm D	20-25	80% PSC, 20% EC. Considered 'premium' design.	Did not know but installation/operating cost is a factor.	90% EC, 10% PSC. Nearly all FCUs have EC motors.
MEP Firm E	12	80% PSC, 20% EC. EC motors were just transitioning 3-5 years ago.	Incentives not a major factor but a consideration. Energy savings are important.	90% EC, 10% PSC. Still some PSC motors for specific applications.
MEP Firm F	Respondent indicated they had experience with system installation over the last five years; did not provide a number.	Mostly PSC motors 3-5 years ago. EC more common in labs/universities that need finer variable speed controls.	Generally, no, across all states in the northeastern US.	Moving towards EC motors but PSC motors still used in some applications, esp. when no need for variable speed control.
MEP Firm G	Respondent indicated they had experience with system installation over the last five years; did not provide a number.	50% PSC, 50% EC. EC motors used as much as possible.	Only 10-15% of projects w/ EC motors; however, energy savings and upfront cost are considerations.	More EC motors are being used today.
Modeling Firm A	15	50% PSC, 50% EC. Often dropped in value engineering.	Yes, influenced by incentives.	Variable speed capability of EC motors being utilized more often.

Summary of Secondary Research

A summary of the secondary research resources is included in Table F2-2. The secondary research provided information on the requirements in other jurisdictions and recent developments in the IECC, ASHRAE 90.1, IMC, and MA Energy Code.

The secondary sources indicated that EC motors did not become standard practice until codes were updated to reflect ASHRAE 90.1-2013 or IECC 2015. There are no EC motor requirements prior to these documents.

IECC 2015 and ASHRAE 90.1 2013 require the use of EC motors with a minimum efficiency of 70% for fractional horsepower motors. Exceptions to this requirement include fan motors used for heating-only applications and fans/motors that comply with additional efficiency specifications (IECC 2015 Tables C-403.2.3 or C403.2.12, see Table F2-2).

APPENDIX F. PARKING GARAGE EXHAUST FAN CONTROL ISP REPORT

1. Research Summary

This ISP research report summarizes the methods, findings, and conclusions of a low rigor ISP study for garage exhaust fan controls installed in enclosed parking garages designed from 2012 through 2014. This ISP study was triggered by a need to establish baselines of specific measures for projects included in the Comprehensive Design Approach (CDA) impact evaluation (P56). Table 1 summarizes the garage exhaust fan control systems installed at the two affected P56 sites (the P56 evaluation sample includes three projects at two locations) and the ex-ante baselines applied by the PAs and recommended by this ISP research. All of the systems were installed in enclosed parking garages that required mechanical ventilation; the ISP research summarized in this report targeted similar enclosed parking garages designed from 2012-2014.

This ISP research included a combination of secondary research and eight interviews with credible and well-informed respondents, including mechanical system designers and energy consultants.

P56 Evaluation Baseline Recommendation

The P56 projects impacted by this research (see Table 1) all had exhaust flow rates of 16,000 CFM/fan or greater, and total system CFMs in excess of 30,000 CFM. For larger garage exhaust systems like these, both the secondary research and primary data collection indicated that between 2012 and 2014 constant speed operation 24/7, time-of-day/cycling fan control, and CO sensors with VSDs all were common. While the majority of respondents specified variable flow systems at the time, three of the eight specified less efficient constant-on or cycling controls at least half the time, one of them doing so all the time, and several others referred to their own practice as "high efficiency". Therefore, we recommend that constant speed fans running 24/7, cycling via a time-clock, or with CO controls be considered "standard efficiency" technologies for enclosed parking garage exhaust systems designed between 2012 and 2014.

All of the projects included in the P56 evaluation sample modeled the baseline garage exhaust fans as running at constant speed when the garage was "occupied" and off or cycling when the garage was "unoccupied". This baseline is consistent with one of the two "standard efficiency" technologies identified by interviewees and described in secondary research. Based on this research, the DNV GL team recommends maintaining the ex-ante baseline fan control strategies for the ex post evaluation of the three P56 projects.

Table 1. P56 CDA Impact Evaluation – Garage Exhaust Fan Measure Details

CDA Project	Bldg. Type and Location	Design Year & Applicable Code	Measure Description	Ex Ante Baseline	Evaluation Ex Post Baseline
Garage Exhaust A	Mixed-use office/retail high-rise in Boston, MA	2014 ASHRAE 90.1-2007 and 2009 IECC/IMC	3 x 16,500+ CFM garage exhaust fans, each with a VFD and CO sensors and temperature sensors to control fan speed	Constant speed fans running at 100% speed from 5 am to midnight and off during all other hours	Same as ex ante
Garage Exhaust B & C (two projects covering adjacent buildings with identical garage fan system designs)	Mixed-use lab/office buildings in Boston, MA	2013 ASHRAE 90.1-2007 and 2009 IECC/IMC	3 x 20 hp supply fans and 3 x 10 hp exhaust fans (one supply and exhaust fan per parking level), each with a VFD and CO sensors to control fan speed. Fans rated to supply between 35,000 and 41,000 cfm per fan and exhaust 18,000 to 20,000 CFM per fan at 100% flow.	Constant speed fans running at 100% speed during occupied hours and running 25% of the time during unoccupied hours	Same as ex ante

Additional ISP Findings

In addition to asking ISP interviewees about garage fan controls designed during the CDA-applicable period (2012-2014), the ISP researchers asked interviewees about more recent (2016/2017) system design practices.

For projects designed more recently, the ISP interviewees were consistent in stating that they were installing VSDs with emissions sensors (CO or CO+NOx, as required by Code) regardless of system size. This shift in practice exceeds energy codes, which, starting with ASHRAE 90.1-2010 (incorporated in MA Energy Code on 7/1/2014) required such controls on large garage exhaust fans, but not on smaller systems. The responses from interviewees and shifts in code both suggest that VSDs with emissions sensors be considered standard practice for garage exhaust fan projects of all sizes moving forward.

Details regarding the findings of this ISP research, including more additional observations regarding ISP for garage exhaust fans outside of the P56 project scope, are included in Section 4 and Appendix G2 of this report.

2. Background Information

Garage exhaust fan systems are installed in enclosed parking garages to ensure that the indoor air quality in the garage is maintained at a level that is safe for human occupants. These systems are, in their simplest form, comprised of an exhaust fan, controller (on/off switch, CO controls, etc.), and grilles or ductwork to vent exhaust air out of the building. Distinct exhaust fan control configurations include, but are not limited to, the following:

- No controls: fans run at constant speed to maintain the minimum ventilation rate 24/7
- CO sensors with cycling constant-speed fans
- CO sensors control variable speed drives (VSDs) on fans
- CO and NOx sensors control VSDs on fans
- Occupancy sensor controls cycle fans
- Time clock-based on-off control of fans

During the period of interest (2012–2014), the Massachusetts building code referred to IECC 2009 and the 2009 IMC to define the minimum mechanical system requirements for new buildings. The 2009 IMC set minimum ventilation standards for parking garages and allowed for the installation of intermittent fan cycling via automated controls but did not require it. It was left to the designer to select the appropriate design for a particular application. This ISP study seeks to determine the standard practice for garage exhaust fan controls for new construction enclosed parking garages designed between 2012 and 2014. In addition, where possible, this research also explored standard practice for garage exhaust applications and design periods beyond the P56 projects summarized in table 1.

2009 IMC Section 404: Enclosed Parking Garages

404.1 Enclosed parking garages. Mechanical ventilation systems for enclosed parking garages shall be permitted to operate intermittently where the system is arranged to operate automatically upon detection of vehicle operation or the presence of occupants by *approved* automatic detection devices.

404.2 Minimum ventilation. Automatic operation of the system shall not reduce the ventilation airflow rate below 0.05 cfm per square foot of the floor area and the system shall be capable of producing a ventilation airflow rate of 0.75 cfm per square foot of floor area.

3. Method

The measure baseline is the equipment that was commonly designed in the sectors and time period identified in Section 1, absent program intervention.

This ISP research included interviews with eight engineering firms that are familiar with the design of garage exhaust systems. In addition, secondary research was performed to identify the codes and existing standard practice research for these systems. The results of this research have been triangulated across multiple primary data sources and supplemented with the secondary data, and they are summarized in this report. The method generally follows the low rigor protocol described in the Baseline Framework.[14]

The primary data collection included questions regarding the following:

- Design practice at the time of the CDA project design (2012-2014) and in the future (2015 and beyond)
- Factors (e.g., building type) influencing the system design

[14] See Section 6.2 of *MA Commercial/Industrial Baseline Framework*, Final Report, DNV GL and ERS, February 2, 2017, for discussion on high and low rigor approaches for non-site-specific ISP methods.

- The influence of Energy Efficiency Service providers on system design

A preponderance of evidence standard was applied in the final recommendation of baseline.[15]

4. Findings and Recommendations

The findings and recommendations for this research are presented in the following two sections. The first section describes the baselines recommended for the two P56 sites described in table 1, while the second section includes general ISP recommendations for garage exhaust fan controls. Appendix G2 provides detailed primary and secondary research findings.

Rationale for P56 Project ISP Recommendations

The P56 projects impacted by this research (see Table 1) all had exhaust flow rates of 16,000 cfm/fan or greater, and total system CFMs in excess of 30,000 CFM. For larger garage exhaust systems like these, both the secondary research and primary data collection indicated that between 2012 and 2014 constant speed operation 24/7, time-of-day/cycling fan control, and CO sensors with VSDs all were common; however, many of the designers specifying systems with VSDs believed that their systems represented "high efficiency" practices relative to the existing standards (LEED)[16] and energy codes, indicating that either constant speed fans running 24/7 or cycling via a time-clock or CO controls be considered "standard efficiency" technologies for enclosed parking garage exhaust systems designed between 2012 and 2014.

All of the projects included in the P56 evaluation sample modeled the baseline garage exhaust fan systems as constant speed fans running when the garage was "occupied" and off when the garage was "unoccupied". This baseline is consistent with one of the two "standard efficiency" technologies identified in our ISP interviews and described in secondary research. Based on the available information, we recommend that the ex post baseline for the three P56 evaluation projects be constant speed garage exhaust fans with cycling/time of day controls, similar to the ex-ante baseline.

Additional Findings

While the catalyst for this ISP research was to characterize the baselines for the P56 evaluation projects, it also presented an opportunity to gather insights beyond the P56 project scope to inform future ISP for garage exhaust fans.

New construction projects in Massachusetts are required to comply with the Massachusetts Building Energy Code ("the Code") to define baseline. Until mid-2014, the applicable version of the MA Energy Code referenced IECC 2009 (and the 2009 IMC) as well as ASHRAE 90.1-2007 to define project baselines. This was the version of code that was applicable for all of the projects in the P56 evaluation sample. On July 1st, 2014, the Code was updated to reference IECC 2012 (and the 2012 IMC) as well as ASHRAE 90.1-2010. This code was in effect through December 31, 2016. The Code was again updated on January 1, 2017 and now references IECC 2015 (and IMC 2015) as well as ASHRAE 90.1-2013. With each change in code, the minimum requirements for garage exhaust fans have become more stringent:

[15] As per the 2017 Massachusetts Commercial/Industrial Baseline Framework: "Preponderance of evidence" means that "the greater weight of evidence" favors one condition or the other. The quality of evidence is more important than the volume of it." For further discussion on this methodology, see *Early Retirement Using Preponderance of Evidence*, v1.0, July 16, 2014. Prepared for the California Public Utilities Commission.

[16] Article 37 of the Boston city zoning code requires that all buildings be "LEED Certifiable". http://www.cityofboston.gov/images_documents/Article%2037%20Green%20Buildings%20LEED_tcm3-2760.pdf

- IECC 2009/IMC 2009 and ASHRAE 90.1-2007 allowed for CO controls and variable flow control on exhaust fans, but did not require it.
- Starting with ASHRAE 90.1-2010, which became applicable in Massachusetts on 7/1/2014, the code required that garage exhaust systems > 30,000 cfm have CO controls and VSDs.
- The 2015 IECC, which went into effect in Massachusetts on 1/1/2017, is even more aggressive, lowering the minimum cfm for VSD controls to 22,500 cfm and requiring NOx sensors in addition to CO sensors.

The latest versions of the MA Energy Code require that large enclosed garage exhaust fan systems be controlled via VSDs with emissions sensors (CO only or CO + NOx). This control strategy was consistent with the one that interviewees are currently employing in their designs; all eight of the interviewees indicated that they specified VSDs with emissions sensors on the garage fans that they are designed recently (2016-2017). None of the respondents indicated that system size was a factor in their design practices, suggesting that although code does not require VSDs on smaller systems, designers may be specifying them regardless of the code requirements. There is a preponderance of evidence that VSDs on garage exhaust fans are now (2017) ISP and the evaluation review team recommends that the PAs consider removing this measure from their new construction incentive offerings in the future, especially for large systems and perhaps also for smaller systems as well.[17]

[17] National Grid already appears to have removed this measure starting with their 2015 new construction program.

Detailed Results of Primary and Secondary Research

Summary of Primary Research

A summary of the interview questions and answers are included in Table G2-1, and key observations from this research are highlighted below.

- Respondents were mixed regarding the type of garage exhaust fan control installed between 2012 and 2014:
  - Three respondents stated that at least 50% of the systems were constant volume systems and that the market was still installing constant volume exhaust systems (regardless of system size) 3–5 years ago.
  - One respondent stated that they saw a mix of garage fan controls but thought that systems with modulating airflow were generally still considered high efficiency in 2012–2014; this is less true today as changes in code have mandated that exhaust systems (especially large systems) have modulating control.
  - Four respondents stated that they mostly (or entirely) installed variable volume systems with CO sensors and VSDs on exhaust fans 3–5 years ago; however, at least two of these respondents stated that they were designing their systems to be LEED certifiable and found that CO-based VSD controls were a low-cost way to achieve energy savings.
  - Most of the interviewees were MEP design engineers with experience in system design. However, they had limited knowledge of whether utility incentives were received for their designs. In general, they felt that their designs did not change as a result of utility incentives, but they did feel that they were designing to high efficiency standards such as LEED.
- Respondents were more consistent regarding the design of systems installed today (2016/2017):
  - All eight respondents stated that variable speed exhausts with VSDs and CO control are common in design today, in part due to changing energy codes that require such controls for garage exhaust fans.
  - Two respondents stated that it is common to see both CO and NOx sensors included in designed today. This ensures that emissions from conventional gasoline engines as well as exhaust from diesel engines can be monitored and the garage exhaust fans can be modulated accordingly.
  - Of the eight respondents who stated that VSDs with emissions controls were common today, none of them indicated that their design practices by system size.

Table G2-1: Primary Data Sources

Primary Data Collection Firm Type	Number of Systems Designed/ Installed/ Analyzed over the Last 5 Years	Type of System Installed 2012–2014	Influence of Energy Efficiency Programs on Design	Type of Systems Installed Today
MEP Firm A	Respondent did not answer this question	Most systems designed 3-5 years ago were exhaust fans running 24/7 at constant speed.	Did not know if they received incentives for any past projects but thought they might be receiving some now for CO sensor w/VSD systems.	Now most systems have CO sensors and VSDs on exhaust fans to modulate the flow of exhaust air.
MEP Firm B	10+	Constant volume systems were common in the market 5 years ago, but they were still installing a lot of variable speed systems with CO controls because they were designing a lot of projects for LEED.	He did not think there were differences in the way they designed systems for projects that did/did not receive utility incentives.	Today's IMC requires that garage exhaust systems have CO + NOx sensors and VFDs to reduce airflow to the minimum allowable value (0.75 cfm/sq. ft.).
MEP Firm C	8+	They saw about 50% constant volume and 50% variable volume garage exhaust systems.	Did not ask.	Now it is nearly all variable volume systems – CO sensors (and sometimes also CO_2 sensors) that control VSDs on exhaust fans.
MEP Firm D	20+	For the last 5+ years, all enclosed garage exhaust systems have been designed with CO sensors and VSDs. Garage exhaust fan controls mean big energy savings relative to LEED's 24/7 constant volume baseline, which is a significant reason that they install them in their projects, most of which are built in Boston and need to be LEED-ready as per city ordinance.	Did not know.	Currently designing with CO and NOx sensors and VFDs on fans, as required by the IMC. Five years ago they were designing with CO sensors and VFDs, but no NOx. Ten years ago everything was 24/7 constant volume.
MEP Firm E	Respondent indicated they had experience with system installation over the last 5 years; did not provide a number.	For at least the last 5 years, they have been installing garage exhaust systems with CO controls and VFDs.	Respondent felt that they received incentives for variable speed exhaust fan controls fairly consistently – perhaps 60%–75% of the time.	All VFDs with CO sensors

Primary Data Collection Firm Type	Number of Systems Designed/ Installed/ Analyzed over the Last 5 Years	Type of System Installed 2012–2014	Influence of Energy Efficiency Programs on Design	Type of Systems Installed Today
MEP Firm F	Respondent indicated they had experience with system installation over the last 5 years; did not provide a number.	For the last 10+ years, they have been installing garage exhaust fan systems with CO sensors and VSDs on fans.	Respondent thought that they received incentives "most of the time" but was not sure and stated that they did not design the systems any differently for systems with vs. without incentives.	All CO sensors with VSDs
Modeling Firm A	Respondent indicated they had experience with system installation over the last 5 years; did not provide a number.	Firm does mostly energy modeling and sees a combination of variable speed, multi-fans, staging, and cycling fan systems with CO and/or time-of-day fan controls.	They were seeing incentives for modulating flow systems in new construction 3–5 years ago, but that is less common now.	It is more typical now than it was 3–5 years ago to see modulating controls on the garage exhaust fans, especially since changes to energy codes (ASHRAE 90.1-2010) require variable flow for large garage exhaust systems.

Summary of Secondary Research

A summary of the secondary research resources is included in table G2-2. The secondary research provided information on the requirements in other jurisdictions and recent developments in the IECC, ASHRAE 90.1, IMC, and MA Energy Code.

With some exceptions, the secondary sources indicated that exhaust fan controls did not become standard practice until codes were updated to reflect ASHRAE 90.1-2010 or IECC 2015. The exceptions to this were codes in Washington, Oregon, and California, all of which specified CO sensors as standard practice for large (> 8,000 cfm) exhaust fans as early as 2011.

Energy codes in place from 2012–2014 did not require variable flow garage exhaust systems. However, recent changes to the MA energy code, including the adoption of ASHRAE 90.1-2010 (effective in MA as of 7/1/2014) and IECC 2015 (the basis of MA code effective 1/1/2017), require variable speed garage exhaust fans and controls, making CO and NOx sensors controlling VSDs on exhaust fans standard practice.

Table G2-2: List of Secondary Sources

Resource Name	Publishing Organization	Major Findings of Document Review	Link to Resource
2009 International Mechanical Code (Applicable in MA until 7/1/2014)	International Code Council (ICC)	The 2009 IMC is a companion reference to the 2009 IECC, which is the basis of the MA Energy Code applicable at the time of these projects. Section 404 of the 2009 IMC includes language pertaining to parking garage exhaust. Section 404.1 states that garage ventilation system flow is permitted to vary as long as there are approved automatic detection devices in place; however, variable flow is not required by the IMC.	https://law.resource.org/pub/us/code/ibr/icc.imc.2009.pdf
2013 CA Building Efficiency Standards for Garage Exhaust (published in Sept. 2011)	California State-wide Codes and Standards Team	CO controls with variable flow are required for systems > 10,000 cfm. For systems less than this, or where < 20% of vehicles are gas-powered, baseline is constant speed fan. See Table 14 on page 26 of this document for a listing of CO control measure baselines from various states and programs.	http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Covered_Processes/2013_CASE_ASHRAE8-GarageExhaust_09.30.2011.pdf
2006 White Paper on Parking Garage Ventilation	American Fan Company	Systems with CO control were available as far back as 2006; no information on market share or rate of adoption.	https://www.americanfan.com/images/literature/PGV0806ParkingGarageCatalog.pdf
2015 IMC changes related to parking garage exhaust systems (Applicable in MA starting on 1/1/2017)	INTEC Controls	Provides an overview of the IMC (2003, 2006, 2009, 2012/2013, and 2015) as it relates to parking garage exhaust systems. Notably, before the 2012/2013 update, intermittent control was permitted but not required. The 2012/2013 update allowed for additional intermittent control strategies with occ and/or CO + NOx sensors. The 2015 IMC revision removes occ sensors from the list of permissible control devices.	http://inteccontrols.com/pdfs/IMC_2015_Changes_for_Parking_Garages.pdf
2015 white paper	Honeywell Analytics	Includes information on CO PPM values for controls programming. Also, provides details on the various sensor types for controls and recommended arrangement of fan and sensors.	http://www.honeywellanalytics.com/~/media/honeywell-analytics/documents/english/apn069_parkinggarage_web_1-8-15.pdf?la=en

Resource Name	Publishing Organization	Major Findings of Document Review	Link to Resource
2015 IECC (Applicable in MA starting on 1/1/2017)	ICC	**C403.2.6.2 Enclosed parking garage ventilation control** Enclosed parking garages used for storing or handling aut mobiles operating under their own power shall employ co tamination-sensing devices and automatic contro configured to stage fans or modulate fan average airflow rat to 50 percent or less of design capacity, or intermittentl operate fans less than 20 percent of the occupied time or required to maintain acceptable contaminant levels in acco dance with *International Mechanical Code* provisions. Fai ure of contamination sensing devices shall cause the exhau fans to operate continuously at design airflow. **Exceptions:** 1. Garages with a total exhaust capacity less tha 22,500 cfm (10 620 L/s) with ventilation systen that do not utilize heating or mechanical cooling. 2. Garages that have a garage area to ventilation sy tem motor nameplate power ratio that exceeds 112 cfm/hp (710 L/s/kW) and do not utilize heating mechanical cooling. Parking garage exhaust controls not required in IECC 2012; introduced in IECC 2015.	2015 IECC Section C403.2.6.2
2010 ASHRAE 90.1 (Applicable in MA starting on 7/1/2014)	ASHRAE	**6.4.3.4.5 Enclosed Parking Garage Ventilatio** Enclosed parking garage *ventilation systems* shall automat cally detect contaminant levels and stage fans or modulate fa airflow rates to 50% or less of *design capacity* provide acceptable contaminant levels are maintained. **Exceptions:** a. Garages less than 30,000 ft^2 with *ventilation system* that do not utilize *mechanical cooling* or *mechanic heating* b. Garages that have a garage area to *ventilation syste motor nameplate hp* ratio that exceeds 1500 ft^2/h and do not utilize *mechanical cooling* or *mechanic heating*. c. Where not permitted by the *authority having juris diction*. Parking garage exhaust controls not required in 90.1-2007; introduced in 90.1-2010.	ASHRAE 90.1-2010 Section 6.4.3.4.5
National Grid baseline guidelines (2012/2013 & 2014 versions)	National Grid implementation team	Page 4 of 13 of the 2012/2013 guidelines state that the baseline is cycling garage fans (no reference provided). Line item 28 of the 2014 guidelines consider garage fans controls to be standard practice as per ASHRAE 90.1-2010 6.4.3.4.5, which requires variable airflow exhaust systems for parking garages.	2014 version available at https://www.nationalgridus.com/media/trade/2014-baseline-document-for-ma-and-ri.pdf

APPENDIX G. KITCHEN HOOD CONTROLS ISP REPORT

ISP Study Target Application: Commercial Kitchen Hood Controls Designed from 2012 through 2014

ISP Report Finalization Date: May 30, 2017 (Final report)

1. Research Summary

This ISP research report summarizes the methods, findings, and conclusions of a low rigor ISP study for kitchen hood controls installed in commercial kitchens designed from 2012 through 2014. This ISP study was triggered by a need to establish baselines of specific measures for projects included in the Comprehensive Design Approach (CDA) impact evaluation (P56).

Table 1 summarizes the kitchen hood control systems installed at the two affected P56 sites, the ex-ante baselines applied by the PAs and the baseline recommended by this ISP research. Both systems were installed as part of major renovations and both incorporated variable speed fan controls and 100% outside-air (OA) makeup air units (MAUs) with heating capability and one also had cooling capability.

This ISP research included a combination of secondary research and eight interviews with credible and well-informed respondents, including mechanical system designers and energy consultants.

P56 Evaluation Baseline Recommendation

The two P56 projects impacted by this research (see Table 1) incorporated kitchen hood controls in major renovations. In both cases, fan speed controls were installed to operate the kitchen hood exhaust fan according to the cooking intensity based on effluent opacity and temperature. MAU fans were intertied with the exhaust fans to provide air volumes commensurate with exhaust flow. MAUs had the capability of tempering the makeup air, one providing only heating and the other providing both heating and cooling, as needed.

Both projects modeled the baseline kitchen ventilation systems as running the exhaust fans and MAU fans at full speed during the hours that cooking was taking place and off otherwise. These baselines are consistent with the most common "standard practice" technologies identified by interviewees and were also found among secondary research sources. Based on this research, the DNV GL team recommends maintaining the ex-ante baseline equipment and fan control strategies for the ex-post evaluation of both P56 projects, updating the fan schedules to reflect logged post-installation data.

Table 1: P56 CDA Impact Evaluation – Kitchen Hood Control Measure Details

CDA Project	Bldg. Type and Location	Design Year & Applicable Code	Measure Description	Ex Ante Baseline	Evaluation Ex Post Baseline
Kitchen Hood A	Mixed-use (admin & dormitory) building on college campus Boston, MA	2014 ASHRAE 90.1-2007 and 2009 IECC/IMC	Single kitchen hood with Variable Volume (VV) exhaust fan controlled by exhaust conditions; Single VV MAU with heat/cool capabilities provides 100% OA makeup and is controlled to match exhaust fan operation	Exhaust and MAU fans running at full speed during kitchen cooking hours as estimated by TA and otherwise off; OA tempered to meet space set points	Same as ex ante except operating schedule determined from logged data
Kitchen Hood B	High school 40 miles outside of Boston, MA	2013 ASHRAE 90.1-2007 and 2009 IECC/IMC	Single kitchen hood with VV exhaust fan controlled by exhaust conditions; 4 VV unit ventilators (UVs) with heating capability provide 100% OA makeup and are controlled to match exhaust fan operation	Exhaust and UV fans running at full speed during kitchen cooking hours as estimated by school personnel and otherwise off; OA heated to meet space set points	Same as ex ante except operating schedule determined from logged data

Additional ISP Findings

In addition to asking ISP interviewees about kitchen hood controls designed during the CDA-applicable period (2012-2014), the ISP researchers asked interviewees about more recent (2016-2017) system design practices.

The ISP interviewees were generally consistent in stating their kitchen ventilation design practices have not changed significantly over the past several years and that specifications are driven primarily by customer preferences and budgets. In one instance, a statement was made that earlier implementations of exhaust/makeup air flow controls based on cooking intensity were problematic and that customers avoided such systems for that reason. Not all the respondents were familiar with whether their projects had received Program Administrator incentives and those who were familiar stated that Program Administrator incentives

were generally obtained if available, but that they did not believe that they had a significant influence on system design. However, it should be noted that the respondents were primarily designers who may not be knowledgeable about the customer's decision-making process, including whether incentives influenced the customer to request that the designer include a particular kitchen ventilation system type.

Details regarding the findings of this ISP research, including more additional observations regarding ISP for kitchen hood controls outside of the P56 project scope, are included in Section 4 and Appendix H2 of this report.

2. Background Information

This ISP research report summarizes the methods, findings, and conclusions of a low-rigor ISP study for commercial kitchen hood controls in secondary schools and college dormitories installed in the 2012-2014 period. This ISP study was triggered by a need to establish baselines at specific sites selected in an ex-post evaluation (P56) and applies primarily to electric projects and may have ancillary natural gas savings (if applicable).

Exhaust hoods are installed in all commercial kitchens, primarily to remove cooking equipment effluents (smoke, grease and combustion products) from the building and secondarily, to maintain space conditions within acceptable comfort bounds. These systems are, in their simplest form, comprised of exhaust fan(s), a makeup air system providing ventilation air from some combination of potential sources, controls (on/off switch, temperature/smoke detectors modulating VSDs on fans, etc.) and hoods/ductwork to capture and vent exhaust air out of the building. Sources of makeup air include, but are not limited to:

- Dedicated makeup air units providing conditioned or unconditioned 100% outside air and serving only the kitchen
- Transfer fans or pressure differentials drawing air from adjacent spaces
- Conditioned air from central air handling units (AHUs) with or without economizers
- Some combination of these sources

Distinct methods of controlling kitchen ventilation systems include, but are not limited to:

- No controls; fans run constant speed, maintaining a worst-case ventilation rate 24/7
- On/Off controls allowing manual- or automatically-timed scheduled use of fans operating at constant or variable speeds
- Effluent opacity and/or temperature sensors that trigger start/stop and/or fan speed adjustments (balancing flow rates among exhaust and makeup air equipment) in response to effluent loading
- Sensors (generally temperature) that trigger ventilation adjustments in response to space conditions in the kitchen (this functionality is secondary to removal of cooking effluents)

During the period of interest (2012-2014), the Massachusetts building code referred to IECC 2009 and the 2009 IMC to define the minimum mechanical system requirements for new buildings. The 2009 IMC set minimum ventilation standards for commercial kitchens, requiring:

- Exhaust fans to be interlocked with the cooking appliances they serve
- Powered makeup air is to be interlocked with exhaust fans
- Minimum exhaust flow rates (cfm per linear foot of hood perimeter) specified for each of four duty ratings of cooking appliances

In addition, variable exhaust and makeup air flow rates are allowed, but not required, when associated cooking appliances are operating at less than full capacity. It is left to the designer to select the appropriate controls and makeup air sources for a particular application.

3. Method

The measure baseline is the equipment that was commonly installed in the sectors and time period identified in Section 1, absent program intervention.

This low-rigor ISP research included interviews with eight engineering firms familiar with the design of commercial kitchen hood control systems as its primary source of information. One respondent provided general kitchen hood control design information but did not respond to questions regarding design strategy frequencies in the baseline period.

Secondary research was performed to identify codes and existing standard practices both within Massachusetts and in jurisdictions outside Massachusetts. The overall results of this research were obtained by triangulating across multiple primary data sources supplemented with secondary data and are summarized in this report.[18]

The primary data collection instrument included questions regarding:

- Design practice at the time of the CDA project installations, today, and in the future
- Factors (e.g. kitchen size) influencing system design
- The influence of Energy Efficiency Service provider programs on system design

A preponderance-of-evidence standard has been applied in the final ISP baseline selection.[19]

4. Findings and Recommendations

Additional findings and recommendations from this research are presented in the following three sections. The first section provides the rationale for recommending the baselines described in Table 1 for the two relevant CDA sites, while the second section includes more generalized ISP findings and recommendations for kitchen hood controls. Appendix H2 provides detailed primary and secondary research findings and Appendix H3 provides a summary of the ASHRAE 90.1-2010 requirements for kitchen hoods.

Rationale for P56 Project ISP Recommendations

Both P56 projects incorporating kitchen hood control measures are simple in nature and have only minor functional differences. In essence, energy savings stem from fan speed reductions afforded by VSDs on the exhaust and MAU fans. In addition to fan power savings, energy associated with tempering makeup air is also reduced in proportion to the air flow reductions resulting from reduced fan speeds. No other differences between the installed equipment and baseline equipment cases would be expected because equipment specifications need to ensure maximum potential system loads can be met regardless of the controls that are installed. Therefore, the baseline- and installed-case equipment should be identical with the exception of VSDs controlled based on cooking intensity. This conclusion is supported by our primary research finding

[18] See Section 6.2 of *MA Commercial/Industrial Baseline Framework*, Final Report, DNV GL and ERS, February 2, 2017, for discussion on high and low rigor approaches for non-site-specific ISP methods.

[19] As per the 2017 Massachusetts Commercial/Industrial Baseline Framework: "Preponderance of evidence" means that "the greater weight of evidence" favors one condition or the other. The quality of evidence is more important than the volume of it." For further discussion on this methodology, see *Early Retirement Using Preponderance of Evidence*, v1.0, July 16, 2014. Prepared for the California Public Utilities Commission.

that, during the 2012-2014-time frame, five of the eight respondents indicated they employed constant volume exhaust systems with either manual or scheduled on/off controls in their system designs.

Additional Findings

Based on responses obtained by our primary research, the most prevalent systems designed by the responding interviewees in the 2012-2014-time period incorporated constant volume fans that were operated according to kitchen schedules. Some evidence was provided that indicated kitchens with greater varieties of cooking equipment will tend to have greater and more complex exhaust loads. There was no specific indication as to specific design impacts in such cases, but that controls would be implemented which address exhaust flow requirements of individual or closely-spaced kitchen equipment. Makeup air sources would also be expected to have more sophisticated controls to match the total makeup airflow to the total exhaust airflow. It was also stated that kitchens with variable cooking loads (e.g. office cafeterias) are more likely to have VAV systems installed than those with relatively constant loads.

Respondents were also queried as to the types of makeup air sources they specified, with an equal number of responses each for:

- Conditioned 100% outside air MAUs
- Transfer fans pulling makeup air from adjacent spaces
- Central air handling units with economizers.

While any combination of these sources could potentially be employed to meet the makeup air requirements, they all have the common traits of providing conditioned air delivered by mechanical means. At the same time, they have differences in terms of whether the energy consumed in tempering the air they provide is primarily for its use as makeup air in the kitchen. No further information from the interviews is available to either delineate or quantify the relative contributions of the respective sources.

ASHRAE 90.1-2010 was adopted by IECC 2012 which was included in Massachusetts building codes on July 1, 2014, and specifies that for kitchen exhaust systems with total capacities greater than 5,000 cfm, at least 50% of makeup air must be either unheated or heated to no more than 60°F and either uncooled or cooled by non-mechanical means. Scheduling and flow rates should coincide with hood exhausts and no direct-replacement air (i.e. air delivered by a MAU directly into the hood) should be considered to offset the makeup air provided to the kitchen space.

ASHRAE 90.1-2010 further demands more requirements for kitchen hood exhaust systems, which would require that conditioned makeup air must not exceed the greater of:

- The quantity of conditioned makeup air flow that would meet the kitchen space conditioning needs
- The exhaust air rated design flow minus any transfer air

Also, for kitchens with total exhaust volumes exceeding 5,000 cfm, at least one of the following three conditions are to be met:

- At least 50% of the makeup air must be from air that would otherwise be exfiltrated or exhausted
- Demand-controlled ventilation must be in effect on at least 75% of exhaust air and be able to reduce exhaust air flow to 50% or less of rated flow

- Employ energy recovery rated at not less than 40% effectiveness on at least 50% of exhaust flow

For timeframes beyond this P56 evaluation, the Mass Save document *2017 Baseline Document: Energy Code Base Case Overview,* January 31, 2017, addresses kitchen ventilation baseline requirements. The baselines for kitchen ventilation recommended in this document are in alignment with IECC 2015 Section C403.2.8 and ASHRAE 2013 Section 6.5.7.1, which define the minimum requirements for kitchen hood exhaust controls as per the 2017 Massachusetts Building Energy Code.

Detailed Results of Primary and Secondary Research

Summary of Primary Research

A summary of interview questions and answers are included in Table H2-1 and key observations from this research are highlighted below:

- Responses among the respondents were somewhat mixed regarding the type of kitchen hood exhaust controls installed between 2012 and 2014:
  - Five of the respondents indicated they employed constant volume exhaust systems with either manual or scheduled on/off controls in their system designs. These are effectively equivalent control strategies in terms of estimating energy consumption in that the fans do not run continuously but do operate whenever the associated cooking appliances are in use. Based on estimated frequency-of-specification percentages provided by the respondents, these control schemes accounted for 57% of specified systems during the 2012-2014-time period. Systems specified to operate similarly with respect to scheduling but employing variable volume fans accounted for 26% of the specified systems, while systems specified to operate continuously accounted for the remaining 17% with variable volume systems accounting for less than half of those.
  - With respect to makeup air sources, three options were indicated as equally likely to have been specified:
    - 100% conditioned OA dedicated makeup air units
    - Transfer fans pulling air from adjacent spaces
    - Central AHUs with economizers

    To identify a single makeup air source as ISP, the commonalities and differences among these three strategies were considered. Important common characteristics are the provision of conditioned air and likely delivery of that air by mechanical means. Differences include the primary reason for conditioning the air (transfer air and central AHU air will have been conditioned to satisfy loads in other spaces, so the energy involved in tempering that air is essentially scavenged when it's used for makeup air) and the fact that delivery of transfer air may depend on a negative pressure differential in the kitchen rather than a fan. Another important consideration is that these sources are not mutually exclusive and, indeed, are often specified in combination. There is insufficient information to disaggregate the relative contributions of the identified sources. It is our judgment that a reasonable designation of an ISP baseline makeup air source is a central AHU with an economizer. Its schedule should follow that of the kitchen hood exhaust in terms of schedule and volume and the air should be conditioned to the same set points as would be specified for air serving a space adjacent to the kitchen.
  - Makeup air controls were identified by all respondents as being tied to the kitchen hood exhaust fans.
  - Based on our findings, it is our judgment that the ISP baseline for commercial kitchen ventilation systems in the 2012-2014-time frame should be:
    - Constant volume kitchen hood exhaust fans that operate according to kitchen cooking schedules

    Factors driving kitchen hood control specifications were noted mostly as customer preferences, costs and kitchen size (and thus system complexity). Although multiple respondents indicated they obtain incentives when variable volume systems with heat/optical sensors controlling variable volume exhaust rates are implemented, no one indicated incentives had an influence on design and multiple respondents specifically stated that to be the case.

    Indications are that some early implementations of heat- and smoke-controlled variable volume systems were problematic and that some customers avoid them as a result. At the same time,

there was recognition that kitchen hood controls have been trending toward variable volume systems increasing in the fraction of new installations.

Table H2-1: Primary Data Sources

Primary Data Collection Firm Type	# of systems designed/installed/analyzed over the last 5 years	Type of system installed 2012-2014	Influence of energy efficiency programs on design[20]	Type of systems installed today
MEP Firm A	No data	Little experience in the 2012-2014-time frame; Response suggests DCV is still not the prevalent installed system control type but standard practice is moving in that direction.	Program existence considered to provide little, if any, influence on system design.	Did not provide specifics, but indicated customer preference and system costs are most important drivers of system design
MEP Firm B	Count not provided	• Controls: 50/50 mix of CV with manual on/off control and automated VAV with heat & opacity sensors driving exhaust and makeup air fan speeds • Makeup Air: 50/50 mix of 100% OA dedicated MAUs and central AHUs (no breakdown regarding with/without economizers)	No influence on system design, although he stated they apply for incentives when available for VAV systems but not CV systems	Mostly VAV systems with integrated exhaust and makeup air fans controlled by hood temperature and opacity sensors
MEP Firm C	Count not provided	• Controls: 100% constant volume exhaust fans, 75% on 24/7 and 25% had manual on/off control • Makeup Air: MAUs were stated to be a combination of all sources listed and are balanced with exhaust fans	Respondent indicated they always apply for incentives when variable speed systems controlled by heat/optical sensors are installed, but it's not clear the existence of incentives drives the decision to install such systems	Mostly VAV systems
MEP Firm D	Count not provided	• Controls: 50% constant volume exhaust fans with manual on/off control and 50% scheduled VAV with optical/heat sensor controls • Makeup Air: 30 – 40% dedicated MAU (possibly heated) with remainder conditioned air from adjacent space (no mention of fans)	Did not know	Mostly VAV systems over time frame of interest with some increase in recent years, but not a large change
MEP Firm E	Count not provided	• Controls: 90% timeclocks on CV systems, 10% scheduled with VAV controls • Makeup Air: Dedicated 100% conditioned OA MAU and/or transfer fans pulling from adjacent space (no percentages provided)	Did not remember	No changes.
MEP Firm F	Count not provided	• Controls: 90% manual on/off CV systems, 10% VAV controls on 24/7 • Makeup Air: Dedicated 100% conditioned OA, transfer fans pulling from adjacent space, central AHUs with or without economizers, or combinations of the above (no percentages provided)	Incentives have been received, but they have no influence on system design	Similar today to 3 – 5 years ago, but noticing an increase in VAV systems

[20] It is unknown as to the extent of the respondent's knowledge about the decision-making process. To be meaningful, a survey of decision makers or other knowledgeable parties is needed.

Primary Data Collection Firm Type	# of systems designed/installed/analyzed over the last 5 years	Type of system installed 2012-2014	Influence of energy efficiency programs on design[20]	Type of systems installed today
MEP Firm G	Count not provided	• Controls: 33% timeclock on CV; 50% manual on/off VAV; 17% sensor-controlled 24/7 VAV • Makeup Air: 33% unconditioned 100% OA; 17% transfer fans pulling from adjacent spaces; 50% from central AHU with economizer	No incentives received – no response to influence of incentives on design	No response
Modeling Firm A	Count not provided	• Controls: 30% manual on/off CV; 30% timeclock on CV; 20% manual on/off on VAV; 20% sensor-controlled 24/7 VAV • Makeup Air: Respondent indicated transfer fans and central AHU air were used, but did not specifically exclude other sources nor were relative contributions quantified	Incentives received for automated VAV controlled systems but they have no influence on system design	No changes in design over last 3 – 5 years

Additional Findings and Observations from Primary Research

The interview script used in collecting primary information provided an opportunity for respondents to indicate all the design strategies they employed in the 2012-2014-time frame. A list of strategies most likely to have been specified for each of three interacting kitchen ventilation system components (i.e. kitchen hood controls, makeup air sources and makeup air controls) was provided and respondents were asked to identify each component strategy they had used.

- For kitchen hood controls, respondents estimated the percentage of systems for which they specified each of the listed strategies. This allowed determination of each strategy's weighted average likelihood of occurrence. No data was collected to further refine the results by system capacities or other indicators of energy considerations. One of the respondents provided no information for this component.
- With respect to makeup air sources, data consisted of a combination of estimated percentages of occurrence and simple "yes/no" responses, relegating the analysis of the responses to a simple count of positive responses. Each respondent was asked to identify as many of the technologies as they had installed in the given time frame. Three of the eight respondents provided no information for this component. The three strategies identified as occurring most often and with equal likelihood of occurrence were:
    - 100% conditioned OA provided by dedicated makeup air units
    - Transfer fans pulling air from adjacent spaces
    - Central AHUs with economizers

  Each of these strategies was identified by three of the respondents.
- As was the case for makeup air *sources*, the responses for makeup air *controls* were mixed in terms of quantification as opposed to "yes/no" responses. Only four interviewees provided responses for this component of design, all indicating makeup air controls were tied to the hood exhaust controls. The only exception was a single response indicating makeup air had been specified to be controlled based on kitchen space conditions.
- No percentages were provided so it is impossible to apportion individual contributions to a single combination that typifies baseline makeup air sources. All three of the sources listed

above generally share the common energy-consuming traits of providing conditioned air and using fans to deliver it to the kitchen. Taking into account: (1) transfer air, if used, will likely have been tempered to address conditions in an adjacent space so its tempering energy is essentially scavenged; (2) the indication that economizers are assumed for central AHU air; and (3) dedicated makeup air is reportedly conditioned, conditioned makeup air from an economized central AHU is assumed to be a reasonable estimate for a generalized makeup air baseline. As far as the scheduling of makeup air is concerned, seven of the eight respondents indicated the makeup air controls are interlocked and volumes are balanced with exhaust air from the hoods.

- Most of the interviewees were mechanical design engineers with experience in commercial kitchen ventilation system design. Only two of the eight respondents indicated they applied for incentives, and they indicated they did it for all systems for which they specified variable volume controls. In general, of those responding, none felt that the availability of PA incentives influenced their designs; customer preference and system complexity were most often cited as key drivers of system design.

Summary of Secondary Research

A summary of the secondary research resources is presented in table H2-2. The secondary research provided information on requirements in other jurisdictions, recent developments in the IECC, ASHRAE 90.1 and IMC, as well indications of trends in kitchen hood design.

Secondary sources indicated significant changes to codes affecting kitchen exhaust hood design beginning with ASHRAE 90.1-2010. Other codes (IECC and California's Title 24) have adopted these changes with minor differences.

Energy codes still do not require variable speed kitchen hood exhaust fans; however, it is designated in ASHRAE 90.1-2010 as one of three options that can be employed to satisfy code requirements for whole kitchen systems with exhaust flow rates in excess of 5,000 cfm. Beyond changes directly impacting energy consumption of the kitchen hoods themselves, changes in ASHRAE 90.1-2010 impose energy consumption considerations on makeup air for those hoods in terms of flow rates and allowable tempering of that air. These considerations should be accounted for in baselines for projects subject to these requirements.

Table H2-2: List of secondary sources

Resource name	Publishing organization	Major findings of document review	Weblink to resource
2009 International Mechanical Code	International Code Council (ICC)	2009 IMC is a companion reference to the 2009 IECC, which is the basis of the MA Energy Code applicable at the time of these projects. Sections 506 and 507 of the 2009 IMC include language pertaining to commercial kitchen exhaust hood capacity requirements, with Section 507.2.1.1 requiring Type I hood exhaust fans to be interlocked with the vented appliance via heat sensor or other approved means. Section 508 addresses makeup air, stating that mechanically-provided makeup air must be interlocked with the exhaust fan and the makeup air capacity must not reduce the effectiveness of the exhaust fan. Variable flow is not addressed.	https://law.resource.org/pub/us/code/ibr/icc.imc.2009.pdf
2013 CA Building Efficiency Standards for Kitchen	California State-wide Codes and	The following efficiency measures are specified in California Title 24 Building Energy Efficiency Standards:	http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Covered_Processes/2013_C

Resource name	Publishing organization	Major findings of document review	Weblink to resource
Ventilation (originally published in 9/2011, incorporated into T24 7/2014	Standards Team	(1) Short-circuit hoods limited to ≤ 10% of exhaust fan capacity; (2) For systems with total exhaust requirements > 5000 cfm hoods must meet UL Standard 710 flow rates (see Appendix H3 in this document) (3) Makeup air (MUA) from mechanically cooled/heated sources cannot exceed the greater of: a. The space heat/cool load b. Exhaust cfm minus transfer air cfm (4) For systems with total exhaust requirements > 5000 cfm, at least one of the following 4 options must be incorporated: a. Replacement air that would have otherwise been exhausted ≥ 50% of MUA b. Demand-controlled ventilation (DCV) on ≥ 75% of exhaust cfm + at least one of the following: i. Modulation of air flow rates ii. Failsafe control on sensor failure iii. Allow full-flow override iv. Capability to reduce MUA & EXH flows to the greater of: 50% of design cfm or the ventilation required by Section 121, c. Energy recovery device listed at ≥ 40% effectiveness & treating ≥ 50% of exhaust d. ≥ 75% of MUA not heated > 60°F and not mechanically cooled	ASE_ASHRAE5-KitchenVent_09.30.2011.pdf
ASHRAE/IES Standard 90.1 - 2010	ASHRAE	The following efficiency measures are specified in ASHRAE/IES 90.1 – 2010 Section 6.5.7.1: (1) Short-circuit hoods limited to ≤ 10% of exhaust fan capacity; (2) Conditioned supply air provided to any space with a kitchen hood cannot exceed the greater of: a. The space heat/cool load b. Exhaust cfm minus transfer air cfm (3) For systems with total exhaust requirements > 5000 cfm hoods must meet UL Standard 710 flow rates (see Appendix H3 in this document) (4) Systems with total exhaust requirements > 5000 cfm, will have one of the following: a. ≥ 50% of replacement air will come from air that would have otherwise exfiltrated or been exhausted	ASHRAE 90.1 – 2010 Section 6.5.7.1

Resource name	Publishing organization	Major findings of document review	Weblink to resource
		b. Demand ventilation (DCV) on ≥ 75% of exhaust cfm with capabilities to reduce makeup & exhaust air flows at least 50% in response to appliance operation while maintaining full capture and containment of smoke, effluent and combustion products during cooking and idle c. Energy recovery device listed at ≥ 40% effectiveness & treating ≥ 50% of exhaust	
2006 White Paper on Commercial Kitchen Ventilation Best Practices	Food Consultants Society International -North America	Demand ventilation control systems are mentioned as available and having the potential to become mainstream in CKV system specifications	http://www.fishnick.com/publications/ventilation/FCSI_CKV_White_Paper.pdf
2013 ASHRAE Journal technical article	ASHRAE	Makes the case for Demand Control Ventilation becoming standard practice for CKVs in response to ASHRAE/IES Standard 90.1-2010	http://www.fishnick.com/publications/ventilation/ASHRAE-Future_of_DCV.pdf
2015 IECC	ICC	New section for 2015 IECC addressing commercial kitchen ventilation to provide compatibility with ASHRAE/IES 90.1 – 2010 standards	2015 IECC Section C403.2.7 and Table 403.2.7 (this table is equivalent to Table 6.5.7.1.3 in AHSRAE 90.1 – 2010 as provided in Appendix H3)
Kitchen Ventilation Systems – Application & Design Guide - 2005	Greenheck	2005 Guide suggests demand-controlled ventilation as the best approach to CKV system controls: (1) Manual control with 2-speed exhaust & supply fans (2) Automated control with 2-speed EF & SF + temp sensor (3) Automated VSD EF & SF with temperature sensor (4) Automated VSD EF & SF with temperature & opacity sensors	http://www.greenheck.com/media/pdf/otherinfo/KVSApplDesign_catalog.pdf
NGrid baseline guidelines (2014 version)	National grid implementation team	Page 13 of 20 of the 2014 guidelines state that: For systems with total exhaust ≤ 5000 cfm the baseline is: Constant volume with automatic on/off control and no dedicated makeup unless required by IMC 2009 501.3 or NFPA-96 2008 Section 8.3 For systems with total exhaust > 5000 cfm the baseline is: Each hood has an exhaust rate complying with Table 6.5.7.1.3 of ASHRAE 90.1-2010; [see Appendix H3 of this document] and one of the following: (1) ≥ 50% of all replacement air is transfer air	https://www.nationalgridus.com/media/trade/2014-baseline-document-for-ma-and-ri.pdf

Resource name	Publishing organization	Major findings of document review	Weblink to resource
		(2) DCV on ≥ 75% of exhaust air (3) Energy recovery with ≥ 40% effectiveness on ≥ 50% of total exhaust airflow	

ASHRAE 90.1-2010 Allowable kitchen hood maximum flow

Table 6.5.7.1.3 Maximum Net Exhaust Flow Rate, CFM per Linear Foot of Hood Length

Type of Hood	Light Duty Equipment	Medium Duty Equipment	Heavy Duty Equipment	Extra Heavy Duty Equipment
Wall mounted canopy	140	210	280	385
Single island	280	350	420	490
Double island (per side)	175	210	280	385
Eyebrow	175	175	Not allowed	Not allowed
Backshelf/Pass-over	210	210	280	Not allowed

NOTE: Table 6.5.7.1.3 was originally presented as Addendum ax to ASHRAE 90.1-2007 with accompanying text as follows:

6.5.7.1.3 If a kitchen/dining facility has a total kitchen hood exhaust airflow rate greater than 5,000 cfm then each hood shall have an exhaust rate that complies with Table 6.5.7.1.3. If a single hood, or hood section, is installed over appliances with different duty ratings, then the maximum allowable flow rate for the hood or hood section shall not exceed the Table 6.5.7.1.3 values for the highest appliance duty rating under the hood or hood section. Refer to ASHRAE Standard 154 for definitions of hood type, appliance duty, and net exhaust flow rate

Exception:

At least 75% of all the replacement air is transfer air that would otherwise be exhausted.

This addendum was incorporated into ASHRAE 90.1-2010.

APPENDIX H. LABRORATORY FUME HOOD CONTROLS ISP REPORT

ISP Study Target Application: Laboratory Fume Hood Controls

ISP Report Finalization Date: July 22, 2017

1. Research Summary

This ISP research report summarizes the methods, findings, and conclusions of a low rigor ISP study for fume hood controls installed in laboratories designed from 2012 through 2014. This ISP study was triggered by a need to establish baselines of specific measures for projects included in the Comprehensive Design Approach (CDA) impact evaluation (P56). Table 1 summarizes the fume hood control systems installed at the two affected P56 and the ex-ante baselines applied by the PAs and recommended by this ISP research. One fume hood control system was installed in a hospital laboratory. The second fume hood control system was installed in a university science lab.

This ISP research included a combination of secondary research and ten interviews with respondents that have direct experience with the installation, design, and operation of fume hood control systems. These respondents included fume hood installation vendors, mechanical system designers, and energy consultants.

Concurrent with this ISP research, the evaluators reviewed the P56 project baselines and verified them with site staff. In performing this review, the P56 DNV GL team determined that the baselines for the two P56 projects were existing conditions – both facilities had previously installed variable air volume (VAV) systems serving their labs that were no longer operating optimally, but had been, and could have continued to, meet the ventilation needs of their labs. The measures included in the two P56 projects included upgrades that allowed the facilities to improve the operation and energy efficiency of these systems.

The remainder of this ISP report presents the baselines for the two P56 projects along with additional findings regarding standard practice for laboratory fume hood exhaust system designs.

P56 Evaluation Baseline Recommendation

Based on a review of the on-site conditions, the ex post (evaluated) P56 project baselines were determined to be the existing fume hood systems and the baseline for both P56 projects were defined as the operation of these existing fume hood systems. The existing systems for both projects had some VAV capacity in the past, but at the time that they were upgraded through the CDA program they were comprised of a mixture of constant volume and variable air volume fume hoods. Site staff indicated that they had been operating the systems in this fashion for some time and could have continued to do so. Part of the operational degradation of the existing systems was due to failure of controls over time and equipment being placed into constant volume operation. Part of the energy savings is achieved by bringing these baseline systems back to full VAV operation and calibrating the entire fume hood system to the lab required air flow.

Table 1 summarizes the ex-ante baseline and recommended ex-post baseline for each project. The evaluators found the ex-ante baselines to be appropriate.

Table 1: P56 CDA Impact Evaluation – Fume Hood Controls Measure Details

CDA Project	Bldg. Type and Location	Design Year & Applicable Code	Measure Description	Ex-Ante Baseline	Evaluation Ex-Post Baseline
Hospital	Medical laboratories in Worcester, MA	2014 ASHRAE 90.1-2007 and 2009 IECC/IMC	Install variable flow fume hood in labs, which will reduce the amount of conditioned air exhausted from the space, thus reducing the amount of make-up air and fan energy.	Unquantified number of VAV fume hoods in existing fume hood system. Modeling assigned to 4 zones and two air handling units with a total supply capacity of 342,591 CFM.	Same as ex-ante
University	Science laboratories in Cambridge, MA	2014 ASHRAE 90.1-2007 and 2009 IECC/IMC	Installation of variable flow controls.	The tracking baseline was the existing fume hood system. This included an unspecified number of both variable volume (VAV) and constant volume (CV) fume hoods. Variable volume fume hoods utilized Phoenix control valves, which varied hood exhaust flow based on the sash position. Many of these valves were over 20 years old and some (quantity unspecified) had failed, defaulting to 100% flow 24/7. Constant volume fume hoods, which did not utilize control valves, ran at full exhaust capacity 24/7.	Same as ex-ante

ISP Findings

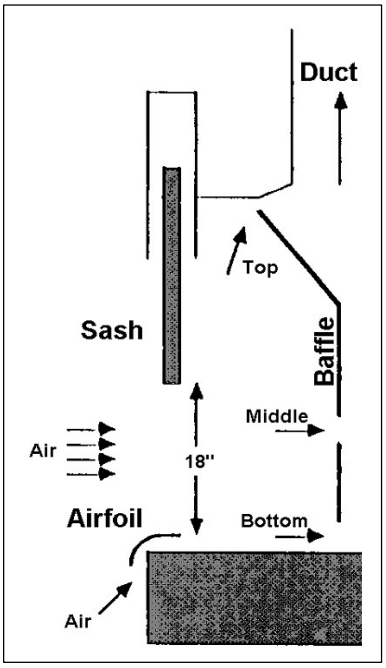
While the catalyst for this ISP research was to characterize the baselines for the P56 evaluation projects, it also presented an opportunity to gather insights beyond the P56 project scope to inform future ISP for laboratory fume hood controls. In addition to asking ISP interviewees about laboratory fume hood controls designed under the CDA-specific applications, the ISP researchers also asked interviewees about more

general and recent system design practices. These findings apply to both true new construction as well as major renovations. Findings from this research include:

- VAV systems are standard practice - The survey results found that constant volume systems are very rare and are only considered for special functions such as radiological applications. Nine of ten respondents stated that some type of variable flow control is implemented with fume hood systems. Therefore, variable air volume systems are considered the standard for fume hoods.
- More complex fume hood control types are highly varied - The ISP interviewee responses indicated that there was limited uniformity in the laboratory fume hood controls specified and installed at the time of the CDA project designs (2012-2014) and at the time of this research in early 2017.
- Controls and system design are typically site-specific – Interviewees were consistent in stating that fume hood operation and controls are commonly site-specific or application-specific and must be customized for the operation of the facility.
- Safety is the top priority in system design - There is a wide range of possible use for laboratory fume hoods including levels of toxicity and hazardous materials. Both secondary research and interviewee responses indicated that fume hood operation and controls must be designed to meet the safety criteria posed by these conditions.
- Recirculating fume hoods are gaining traction in certain markets – Several of the interviewees stated that recirculating fume hoods are applicable for certain low use/low toxicity applications. These units would result in significant energy savings and reduce annual maintenance costs.
- Proximity and face velocity sensors still represent high efficiency practice – While several of the interviewees indicated that they have used these control types in their system designs, these designers felt that these control strategies were not typical and represented higher efficiency (and cost) designs.

Details regarding the findings of this ISP research, including more additional observations regarding ISP for laboratory fume hood controls outside of the P56 project scope, are included in Section 4 and Appendix I2 of this report.

2. Background Information



Laboratory fume hoods are a type of ventilation system that serve to exhaust chemical fumes, vapors, gasses, dust, mist, and aerosol. In addition, fume hoods also serve as physical barrier to reactions and ambient laboratory environments, offering a measure of protection against inhalation exposure, chemical spills, run-away reactions, and fires.

A typical fume hood has a box like structure with a moveable sash window. Experimental procedures are performed within the hood which is consistently and safely ventilated, usually by means of an extract blower and ductwork. Chemical fumes are exhausted and diluted many times over into the atmosphere.

When environmental concerns are of importance, an extract treatment system, often referred to as a scrubber is installed to remove most of the vapors from the exhaust air stream.

Fume hoods function by maintaining a negative pressure in the interior of the hood to prevent any contaminant from escaping while drawing air in through the hood opening at a consistent rate. A suitable hood face velocity (the speed at which air is drawn into the hood) is of importance to the safe and effective operation of a fume hood. While excessive face velocities can often result in turbulence and reduce containment, insufficient velocities can also compromise hood performance.

During the period of interest (2012-2014), the Massachusetts building code referred to IECC 2009 and the 2009 IMC to define the minimum mechanical system requirements for new buildings. IECC 2009 [Section 503.2.6] and ASHRAE 90.1-2007 [Section 6.5.7.2] state that laboratory fume hood systems must include at least one of the following features:

a. *VAV hood exhaust and room supply systems capable of reducing exhaust and makeup air volume to 50% or less of design values.*

b. *Direct makeup (auxiliary) air supply equal to at least 75% of the exhaust rate within specified space temperature and humidification parameters.*

c. *Heat recovery systems to precondition makeup air for fume hood exhaust.*

The ASHRAE minimum exhaust rate for these parameters is 15,000 CFM. The minimum threshold drops to 5,000 CFM in the 2009 IECC.

3. Method

Two P56 CDA projects included laboratory fume hood control measures, although the projects were found to be retrofits of existing systems. This ISP study seeks to determine the standard practice for fume hood controls for new construction university and medical laboratory buildings designed between 2012-2014. This ISP also compares the P56 CDA laboratory fume hood projects with the IECC 2009 and ASHRAE 90.1-2007 requirements mentioned above Both Method

This low rigor ISP research included interviews with eight engineering firms that have reviewed the installation and operation of laboratory fume hoods. Two firms that install, test, and maintain laboratory fume hoods were also interviewed. In addition, secondary research was performed to identify the codes and

existing standard practice research for these systems. The results of this research have been triangulated across multiple primary data sources and supplemented with the secondary data, and they are summarized in this report. The method generally follows the low rigor protocol described in the Baseline Framework.[21]

The primary data collection included questions regarding the following:

- Design practice at the time of the CDA project design (2012-2014) and in the future (2015 and beyond)
- Factors (e.g., building type) influencing the system design
- The influence of Energy Efficiency Service providers on system design

4. Findings and Recommendations

The findings and recommendations for this research are presented in the following two sections. Section 4.1 describes the baselines recommended for the two P56 sites described in table 1, while Section 4.2 includes general ISP recommendations for laboratory fume hood controls. Appendix I2 provides detailed primary and secondary research findings.

Rationale for P56 Project ISP Recommendations

Based on the review of the on-site conditions, the ex post (evaluated) P56 project baselines were determined to be the existing fume hood systems, similar to the ex-ante project baselines. The existing systems for both projects had some VAV capacity in the past, but at the time that they were upgraded through the CDA program they were comprised of a mixture of constant volume and variable air volume fume hoods. Site staff at both locations stated that the systems had been operated under these suboptimal conditions for some time and would have continued to operate in this fashion if not for the system upgrade. Part of the operational degradation of the existing systems was due to failure of controls over time and equipment being placed into constant volume operation. Part of the energy savings is achieved by bringing the baseline systems back to full VAV operation and calibrating the entire fume hood system to lab required air flow.

While not required to align with ISP given their retrofit baselines, the operation of the existing systems for both P56 projects was consistent with responses provided in interviews that inform the ISP of laboratory fume hood controls installed in new buildings. Interview respondents indicated that at the time of the CDA project designs most fume hood systems were VAV, with a small portion of them being CV systems. The existing equipment baselines for both projects referenced some form of VAV controls. Individual components and controls had failed in the field and full VAV operation was no longer possible, meaning that likewise some portion of the baseline P56 systems were operating as constant volume systems.

Additional Findings

While the catalyst for this ISP research was to characterize the baselines for the P56 evaluation projects, it also presented an opportunity to gather insights beyond the P56 project scope to inform future ISP for laboratory fume hood controls. Notable findings from this ISP research are highlighted below.

- Code requirements for fume hood controls – Both the IECC and ASHRAE 90.1 include provisions regarding fume hood systems that require VAV systems for all fume hood systems above a certain CFM. However, these "requirements" are not mandatory. If a facility can

[21] See Section 6.2 of *MA Commercial/Industrial Baseline Framework*, Final Report, DNV GL and ERS, February 2, 2017, for discussion on high and low rigor approaches for non-site-specific ISP methods.

illustrate that installing a VAV system will jeopardize the safety of the occupants, then it may be precluded from the IECC and ASHRAE 90.1 requirements.

- Lab fume hood system design practices emphasize safety and are highly varied - The interviewees were consistent in stating that, except for the inclusion of variable air volume (VAV) systems, there is limited uniformity in the type of laboratory fume hood controls that they specify. VAV is an end-result and the equipment and steps needed to achieve VAV operation vary from site-to-site and even between individual contractors. There are no mandatory controls specified for fume hood operation to achieve VAV operation. The key design variables are safety based. The standards are recommended best practices but are still voluntary. There are minimum and maximum face velocities, for example, but how those minimums are set and maintained are still dependent upon the facility, installers, and maintainers. There is no mandate for a specific control. Comments by Installation Firm A and MEP Firm F clearly show that personal preference affects control implementation and this would not be possible with fixed installation requirements. There is no uniformity even across what would appear to be common requirements like static pressure and face velocity sensors. A comment by a respondent for Installation Firm B stated that, "If you have to maintain building pressure requirements then you have to monitor something".
- VAV is commonly installed - 90% of the respondents stated that some form of VAV control has been standard for over 5-years. None of the respondents anticipated forthcoming new technologies or applications that would replace the basic VAV approach to system design.
- Minimize controls complexity - While interviewees indicated that VAV system design was common, they also stated a preference to keep systems as simple as possible. More complex controls require more complex maintenance which adds to annual operating costs. And, when controls fail, the systems are likely to revert to full constant volume operation to maintain user safety.
- Future energy efficiency opportunities – Interviewees indicated that controls such as face velocity sensors and proximity sensors are not standard practice and do have merits and potential. However, their applicability is not universal. These controls are more applicable in large medical and research facilities with routine lab schedules and personnel familiar with their necessity and operation. These controls are less successful in smaller labs where there is greater personnel change and less sophisticated maintainers.

  Several interviewees also stated that recirculating hoods may be an option for some very basic lab hoods such as in schools, colleges, and some basic R&D functions.

Based on the research performed here, it is recommended that laboratory fume hood measure continue to be reviewed and analyzed as a custom measure. Variable air volume systems are, and will continue to be, the preferred baseline for most systems. Savings are achieved by optimizing air flow within this type of system design while maintaining user safety.

Detailed Results of Primary and Secondary Research

Summary of Primary Research

A summary of the interview questions and answers are included in Table I2-1, and key observations from this research are highlighted below.

- All 10 of the respondents stated that little has changes in fume hood operating controls from the 2012-2014 period to 2017. The fume hood controls are site specific. All anticipated savings from fume hood controls is from reducing exhaust flow CFM while maintaining required safe operation:
  - Nine of the ten respondents said that some form of variable air flow has been the standard configuration for over 5 years.
  - One respondent stated that constant volume may still be required and is preferential on some specialized systems especially in radiological and hazardous applications.
  - One respondent referred to "low flow fume hoods" as an option. The others did not.
  - Sash position sensors were the most common fume hood control being installed.
  - Face velocity sensors were the second most common control.
  - Proximity sensors are not commonly installed and were considered by respondents to represent "high efficiency" practice.
  - Static pressure sensors [duct and room] are required to maintain proper building pressurization.

Table I2-1: Primary Data Sources

Primary Data Collection Firm Type	Number of Systems Designed/ Installed/ Analyzed over the Last 5 Years	Type of System Installed 2012–2014	Influence of Energy Efficiency Programs on Design	Type of Systems Installed Today vs 2012-2014
MEP Firm A	Did not provide	Universities and labs are (and over the last 3-5 years have been) variable airflow systems with Phoenix controls. VAV systems with airflow modulated based on sash position. Schools more typically have filtered recirculation systems. Did not indicate whether they included VAV. He felt that generally these practices were standard for the industry (they do both design and commissioning. As Cx agents they review a lot of other people's work).	Did not know	No – he felt that the design of these systems is generally slow to change and that the practices today are similar to what they were 3-5 years ago. He did indicate that recirculation systems seemed to be gaining traction, especially for facilities with generally low particulate/hazardous exhaust loads (e.g. schools).

Primary Data Collection Firm Type	Number of Systems Designed/ Installed/ Analyzed over the Last 5 Years	Type of System Installed 2012–2014	Influence of Energy Efficiency Programs on Design	Type of Systems Installed Today vs 2012-2014
MEP Firm B	25-30	Today - Type of system varies by lab type. Biology labs will typically have VAV systems, but not variable flow fume hoods. This is because biology labs are typically wide open spaces with high constant outdoor air demands as per codes and standards. This differs from Chemistry labs, which are usually much smaller spaces with many hoods. In Chemistry labs, they see smaller spaces with high intermittent exhaust rates, so they more often design these with variable flow hoods. 3-5 years ago, they designed chemistry labs more like biology labs because the two were laid out more similarly. It was less likely that chemistry labs would have variable flow hoods back then. Biology lab hasn't changed in the last 3-5 years.	Did not know	VAV system as a minimum depending upon site.
MEP Firm D	20+	10-15 years ago they were designing constant volume lab systems, then they moved to variable air volume with strobic fans. Then about 5-7 years ago they started to integrate the strobic fans to use VFDs with sash position sensors and less often also proximity sensors. In all cases the systems are designed to maintain minimum safe flow rates (example given of 100 fpm when in use and 50 fpm when not in use).	Did not know	VAV with 100 fpm safe minimum. Additional controls expanded as needed.
MEP Firm E	Did not provide	Full spectrum. 5% CV "not typical" - if small dedicated. 95% manifolded with VFD to maintain s.p. in exhaust.	Did not know	Same as 2012-2014 response
MEP Firm F	Did not provide	2 position valve "mostly" VAV; didn't mention any others.	Did not know	"No – they have been doing the same thing for at least 5 years. Some changes in airflows. We're designing at 100 fpm, now selecting 20-80 fpm. Hood manufacturers have proven they can capture exhaust at lower rate w/baffles "getting closer to standard leading edge"
MEP Firm G	Did not provide	Mostly VAV exhaust with sash position or velocity some presence sensors also (< 40% of projects) Low face velocity hoods not in NC, just retrofit.	Did not know	VAV has been standard. Enhancements have included adding presence sensors, on guy added an alarm (on EMS). Next = Combo sash and education.
MEP Firm H	20	"Low flow fume hoods, occupancy based flow reductions, time clock reductions"	Did not know	"Low flow fume hoods, occupancy based flow reductions, time clock flow reductions". "24/7 operation vs occupancy based controls"

Primary Data Collection Firm Type	Number of Systems Designed/ Installed/ Analyzed over the Last 5 Years	Type of System Installed 2012–2014	Influence of Energy Efficiency Programs on Design	Type of Systems Installed Today vs 2012-2014
Installation Firm A	30+	Controls are mostly specific with the facility and type of work done. We also do specialty lab work including radiologic labs [recent industrial project]. There are common controls, most being sash position and velocity sensors. VAV controls and static pressure sensors are also common especially when maintaining building pressures.	Did not know	Nothing major. More a function of changing project types than technology changes.
Installation Firm B	Did not provide	Static pressure, face velocity, sash position, proximity sensors, temperatures, CFM were installed the most.	Did not know	No. Some control prices have come down, but testing and calibration still required. Project scope still hostage to cost.

Summary of Secondary Research

A summary of the secondary research resources is included in table I2-2. The secondary research provided information on the requirements in other jurisdictions and recent developments in the IECC, ASHRAE 90.1, industry standards, and MA Energy Code.

Table I2-2: List of Secondary Sources

Resource Name	Publishing Organization	Major Findings of Document Review	Link to Resource
2009 International Mechanical Code (Applicable in MA until 7/1/2014)	International Code Council (ICC)	The 2009 IMC is a companion reference to the 2009 IECC, which is the basis of the MA Energy Code applicable at the time of these projects. No direct fume hood reference	https://law.resource.org/pub/us/code/ibr/icc.imc.2009.pdf
ANSI/AIHA Z9.5-2003	American National Standards for Laboratory Ventilation	Provides industry standards for safe fume hood operation, estimates safe air-flow parameters, and identifies toxicity, and other safety /operational functions. No specific controls are specified or mandated. Compliance is voluntary. "The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether he or she has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processors, or procedures not conforming to the standards."	http://www.lab-ehs.com/staticmedia/js/ueditor_new/jsp/upload/20140303/80991393813268031.pdf
US OSHA, 29 CFR Part 1910.1450	*Occupational Safety and Health Administration*	Defines exposure, toxicity, remediation, building pressures by space type and substance, safe lab use protocols, and other safety requirements. No specific controls are recommended or mandated.	https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=10106&p_table=STANDARDS

Resource Name	Publishing Organization	Major Findings of Document Review	Link to Resource
Standard NFPA 45-2000	National Fire Protection Association	Defines contaminants and safe fume hood operation. No specific control requirements.	
ANSI/ASHRAE 110-1995	ASHRAE	Establishes the protocols for testing and balancing fume hoods for safe operation. No specific control recommendations.	http://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards?mode=code&code=45
Standard SEFA 1.2-2002	Scientific Equipment Furniture Association	Provides standards for safe hood operation, face velocities, testing procedures, room balancing, and other operational, and safety consideration. These are best practices. No controls are specified.	http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Application_Notes/LC-125-LabGuidelinesStandards.pdf
National Grid baseline guidelines (2012/2013 & 2014 versions)	National Grid implementation team	Page 7 of 24 of the 2014 guidelines. Baseline: Systems ≤ 5,000 cfm: constant volume exhaust with constant volume supply/makeup air systems. Potential High Performance Practices - Automatically controlled exhaust volume based on sash position or occupancy; VFD on exhaust fans. Baseline - Systems > 5,000 cfm must include at least one of the following:(1) VAV system capable of reducing exhaust and makeup flow rates and/or incorporate energy recovery should meet equation in 6.5.7.2(2) Zones capable of reducing flow rates by 50% of design rates, or min to maintain pressure requirements (3) Makeup air supply ≥ 75% of exhaust flow rate, heated ≤ 2F below room set point, cooled ≤ 3F above set point, no humidification added, and no simultaneous H/C (ASHRAE 90.1 2010 6.5.7.2) Potential High Performance Practices - Exceed requirements of ASHRAE 90.1 2010 6.5.7.2	2014 version available at https://www.nationalgridus.com/media/trade/2014-baseline-document-for-ma-and-ri.pdf