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Ameren Missouri Program Year 2020 Annual EM&V Report

Volume 3: Business Portfolio Appendices

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Appendix A. Additional Methodology Detail

Respondent-Level Free Ridership Methodology

This section outlines our approach for calculating respondent-level free ridership (FR) values for the BizSavers® programs, based on responses to questions in the participant online survey/interviews. The approach estimates program influence on project efficiency and applies an adjustment to reflect program influence on the quantity and timing of installed equipment.

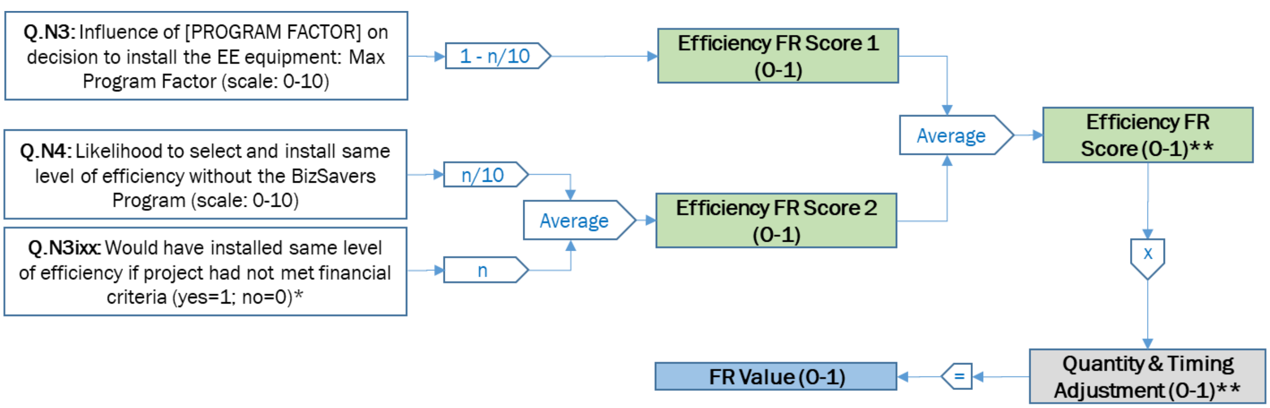
The approach is identical to that used in PY2019, except for the addition of a more-detailed review of additional survey responses, including open-ended responses, for projects that (1) have inconsistent Efficiency FR Scores and account for 1% or more of sampled savings (at the program level); and (2) account for 5% or more of sampled savings (at the program level).

We used the following calculations:

- FR Value = [(Efficiency Score 1 + Efficiency Score 2) ÷ 2] x Quantity and Timing Adjustment Factor
- NTG Value = 1 – FR Value

Figure 1 presents a diagram of the FR algorithm used for this evaluation.

Figure 1. Overview of Respondent-Level Free-Ridership Algorithm



*Asked only of those who rated importance of financial criteria >7 and indicated that the incentive caused the project to meet their financial criteria.
** We conducted an additional review of open-ended and other closed-ended responses for (1) projects with inconsistent responses to efficiency and/or quantity & timing questions, respectively, that account for at least 1% of sampled program savings; and (2) projects accounting for at least 5% of sampled program savings.

The following subsections describe the questions and algorithms used to estimate respondent-level FR values.

Program Influence on Project Efficiency

The participant online surveys/interviews included a series of questions to determine the influence of the program on the efficiency level of the incented project. Based on these questions, we developed two FR efficiency scores for each respondent, which were then averaged to calculate the respondent's overall

Efficiency FR Score. FR scores can range from 0 to 1, where 0 means no FR (i.e., full credit for the program) and 1 means full FR (i.e., no credit for the program).

The overall Efficiency FR Score is the average of the following two sub-scores:

- **Efficiency FR Score 1 (ES1) – Rating of program factors.** Respondents were asked to rate (on a scale of 0 to 10) the importance of several program and non-program factors on their decision to select energy-efficient equipment rather than a less efficient alternative.[1] The Efficiency FR Score 1 is based on the maximum rating given to any of the program factors and was calculated as:

  1 – (Maximum Program Factor Rating ÷ 10)

- **Efficiency FR Score 2 (ES2) – Counterfactual.** Average of ES2a and ES2b:
  - **ES2a. Likelihood to install same level of efficiency without the BizSavers Program:** Respondents were asked to rate (on a scale of 0 to 10) the likelihood that they would have installed equipment with the same level of efficiency without the program. This score was calculated as:

    Likelihood to install without the program ÷ 10

  - **ES2b. Would participant have selected the same energy-efficient equipment if it hadn't met their financial criteria:** This question was only asked of respondents who rated the importance of financial criteria greater than 7 and indicated that the incentive caused the project to meet or exceed their financial criteria. For all other respondents, the Efficiency FR Score 2 only uses the first measurement of the counterfactual (i.e., ES2a). This score was calculated as:

    Yes = 1; No = 0

Quantity and Timing Adjustment Factor

In addition to influencing the efficiency of a project, the program can affect the quantity and timing of the installed energy-efficient equipment.[2] Because decisions about measure quantity and installation timing are often correlated, we calculated a combined "Quantity and Timing Adjustment Factor." This factor ranges from 0 to 1, where a lower value means a greater quantity and timing adjustment (i.e., more credit to the program). As shown in Figure 1, the Quantity and Timing Adjustment Factor is multiplied by the Efficiency FR Score to derive the FR Value.

To develop the Quantity and Timing Adjustment Factor, the survey first asked respondents how much of the installed energy-efficient equipment would have been installed at the same time without the program. Only the quantity that would not have been installed at the same time was eligible to receive the quantity and timing credit.

[1] Several factors asked about in the survey can be considered either a program factor or a non-program factor, depending on the response to a follow-up question: previous experience with this type of equipment, financial criteria, and expected energy savings.
[2] For some measures, the concept of quantity may not be applicable. For projects with those measures, we will skip questions about quantity and set the quantity adjustment factor to 1.0, i.e., no FR adjustment is applied.

Respondents were then asked if they would have installed the remaining quantity later and, if so, how much later. The response, expressed as the number of months the program accelerated the project, was translated into a timing adjustment, using the following formula:[3]

Timing Adjustment = 1 – (# Months Accelerated – 6) ÷ 42

Substituting the midpoint of the response for # Months Accelerated results in the following adjustments:

- Same time: 1.0
- Up to 6 months later: 1.0
- 7–12 months later: 0.93
- 1–2 years later: 0.71
- 2–3 years later: 0.43
- 3–4 years later: 0.14
- More than 4 years later: 0.0
- Don't know/Refused: Average of valid responses from other respondents

The timing adjustment can range from 0 to 1. A smaller adjustment value means a greater reduction in FR, because the program resulted in a greater acceleration of the project.

The Quantity and Timing Adjustment Factor is then calculated by multiplying the percentage of the project that would not have been installed at the same time without the program by the timing adjustment and adding this product to the percentage of the project that would have been installed at the same time without the program. We used the following formula for this calculation:

Quantity and Timing Adjustment Factor =

*(% Not Installed at Same Time * Timing Adjustment) + % Installed at Same Time*

If the respondent did not provide valid responses to the initial quantity question (i.e., an "unsure" response to the question: "*Without the incentives from Ameren Missouri's BizSavers program, would you have installed the same quantity of energy-efficient equipment in <INSTALLDATE> or would you have installed less?"*), we used the following rules to assign a Quantity and Timing Adjustment Factor:

- If the respondent indicated that the availability of the BizSavers program somewhat or significantly changed either the quantity or the timing of their project, we assigned a Quantity and Timing Adjustment Factor equal to the average of valid responses from other respondents.
- If the respondent indicated that the availability of the BizSavers program changed neither the quantity nor the timing of their project, we assigned a Quantity and Timing Adjustment Factor of 1.0 (i.e., no reduction in FR).

[3] The timing adjustment is capped at 1.0, i.e., if the *# Months Accelerated* is 6 months or less, the adjustment is equal to 1.0 and no adjustment is applied.

Additional Response Review

To increase the confidence in the FR scores of sampled projects, we conducted an additional review of survey responses for three types of projects:

- Sampled projects with inconsistent responses about the program's influence on the efficiency of their project, defined as those with Efficiency FR Scores of (ES1<0.3 AND ES2>0.7) or (ES1>0.7 AND ES2<0.3), where ES1 is based on the maximum program factor (N3) and ES2 is based on the response to the counterfactual questions (N4 and N3ixx). This analysis is limited to inconsistent responses for sampled projects that account for 1% or more of sampled savings (separately estimated for Standard and Custom projects).
- Sampled projects with inconsistent responses about the program's influence on the quantity and timing of their project, defined as those who (a) indicated the program had at least a moderate influence on quantity (i.e., a response of 2 or 3 to CF1b) or timing (i.e., a response of 2 or 3 to CF1c) but had a Q&T Adjustment of 1.0 or (b) indicated the program had no influence on quantity and timing (CF1b AND CF1c equal to 1) but had a Q&T Adjustment of less than 1.0. This analysis is limited to inconsistent responses for sampled projects that account for 1% or more of sampled savings (separately estimated for Standard and Custom projects).
- Sampled projects that account for 5% or more of sampled savings (also separately estimated for Standard and Custom projects).

Two consultants independently reviewed supplemental information collected in the survey to inform the project-level FR scores. We used a two-step process:

1. We relied on the quantitative questions about changes to plans for efficiency, quantity, and timing (CF1a-c) to develop Preliminary Attribution Ratings for both efficiency and timing/quantity.

2. The Preliminary Attribution Ratings were modified, if needed, based on responses to the additional counterfactual question (N7), as well as several open-ended questions: the consistency check question (CC1a), the introduction question (V1), and the follow-up questions about changes to plans for efficiency, quantity, and timing questions (CF2a-c).

The output of this analysis consisted of two categorical Attribution Ratings for each respondent included in this analysis: an efficiency attribution rating and a quantity/timing (Q&T) attribution rating. Each rating can take one of four values: high (H), medium (M), low (L), or indeterminate (?) program attribution. Based on these Attribution Ratings, the project-level Efficiency FR Scores (ES) and Quantity and Timing Adjustment Factors were revised as follows:

- **Efficiency Score (ES):** The Efficiency Attribution Rating determined the weights used to combine the ES1 and ES2 scores to calculate the project's overall ES. The status quo was a simple average (i.e., both scores have a weight of 0.5). For projects with a "high" efficiency attribution rating, a larger weight was applied to ES1 (always a lower level of FR), while for projects with a "low" efficiency attribution rating, a larger weight was applied to ES2. For projects where the supplemental information was inconclusive—as well as projects with a "medium" efficiency attribution rating—the status quo (i.e., weights of 0.5 each) was applied. ES Weights are provided in Table 1.

Table 1. Efficiency Score Weights

Efficiency Attribution Rating	ES1 Weight	ES2 Weight
High	0.67	0.33
Medium	0.50	0.50
Low	0.33	0.67
Indeterminate	0.50	0.50

- **Quantity & Timing Adjustment Factor:** The Q&T Attribution Rating determined how, if at all, to modify the Q&T Adjustment Factor applied to a project. This analysis differed for respondents who reported in Q. N5b that they would have installed the same quantity of efficient equipment at the same time (i.e., % Install = 100%) and those who reported a quantity of less than 100% (i.e., % Install < 100%).
  - **Respondents with % Install = 100%:** We assigned a revised Q&T Adjustment Factor based on the assigned Q&T Attribution Rating. The factors were calculated based on average Q&T Adjustments conditioned on CF1b and CF1c responses: A respondent with a "high" Q&T Attribution Rating was assigned the average Q&T Adjustment Factor of all respondents who provided responses of "Changed significantly" to both CF1b and CF1c. A respondent with a "medium" Q&T Attribution Rating was assigned the average Q&T Adjustment Factor of all respondents who provided a response of "Changed somewhat" or "Changed significantly" to at least one of CF1b or CF1c. A respondent with a "low" or "indeterminate" Q&T Attribution Rating kept a Q&T Adjustment Factor of 1.0 (i.e., no adjustment). Q&T Adjustment Factors are provided in Table 2.

Table 2. Q&T Adjustment Factors

Q&T Attribution Rating	Q&T Adjustment Factor
High	0.41
Medium	0.58
Low	1.00
Indeterminate	1.00

  - **Respondents with % Install < 100%:** We reviewed their responses to the quantity and timing battery, and the resulting Q&T Adjustment Factor, for consistency with the supplemental information. If needed, we assigned a new Q&T Adjustment Factor, using the rating methodology described above.

The two consultants compared results and discussed any instances where they assigned different attribution ratings until consensus was reached.

Lighting EUL Analysis

To address stakeholder comments on business lighting Effective Useful Life (EUL) values used in the PY2019 evaluation (which were based on a memorandum prepared by the program implementer[4]), we conducted two research activities during PY2020:

- Calculation of EULs based on rated equipment lifetime and estimated annual HOU for installed lighting products in the program-tracking data; and
- Review of technical reference manuals (TRMs), to provide additional context by comparing the TRC memo EUL values with EUL values used in other jurisdictions for similar lighting measures.

Based on these research activities, we developed EUL recommendations, by lighting category, for the PY2020 program evaluation and future TRM updates. The memorandum embedded below describes the methodology and findings of these activities and presents the EUL values used in the PY2020 ex post evaluation of energy-efficient lighting measures implemented through Ameren Missouri's business programs.

Ameren Missouri
BizSavers Lighting E

[4] Lockheed Martin, Memo: "Ameren Missouri MEEIA 2019-21 Energy, PCDR, and EUL Methodology," January 30, 2019. At the time of the memo, the program implementation team was part of Lockheed Martin; the implementation team now works under the name TRC.

Appendix B. Desk Review and Onsite Reports: Custom Incentive Program

Site ID: 8000 (Enduse: HVAC)

Project Description

This project installed four new air handling units (AHUs) and two dedicated outdoor air system (DOAS) units in a manufacturing facility that had added process equipment, expanded some building areas, and required a lower cooling space temperature for the manufacturing process.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8000 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
New AHUs, DOAS - Cooling	HVAC	616,141	561.11
New AHUs, DOAS - HVAC	HVAC	703,449	312.32
	Total	**1,319,590**	**873.43**

Data Collection

During the site visit on January 6, 2020 with the Trade Ally, field staff collected photographic nameplate data of the new AHUs and DOAS units and data from the existing plant and HVAC chillers. Field staff obtained screenshots of the equipment graphics on the building management system (BMS) for current operating conditions and setpoints. After the site visit, the trade ally provided trend data for the AHUs.

Analysis

The ex ante savings were estimated using building simulation models in the IES VE modeling software. The platform and native building model were not available to the evaluation team, so the evaluation team examined available model documentation, including the inputs document, modeled outputs, and savings.

The evaluation team used installed equipment model numbers and manufacturer's specifications to verify the values used for the modeling. The equipment matched the submittals with one exception: the fan motor size on AHU-11 was 15 hp on the model nameplate and only 14 hp in the submittal. The evaluation team confirmed that the ex ante modeling files used the correct motor size, as the other 38,000 CFM units were also 15 hp.

Site 8000 Equipment Verification

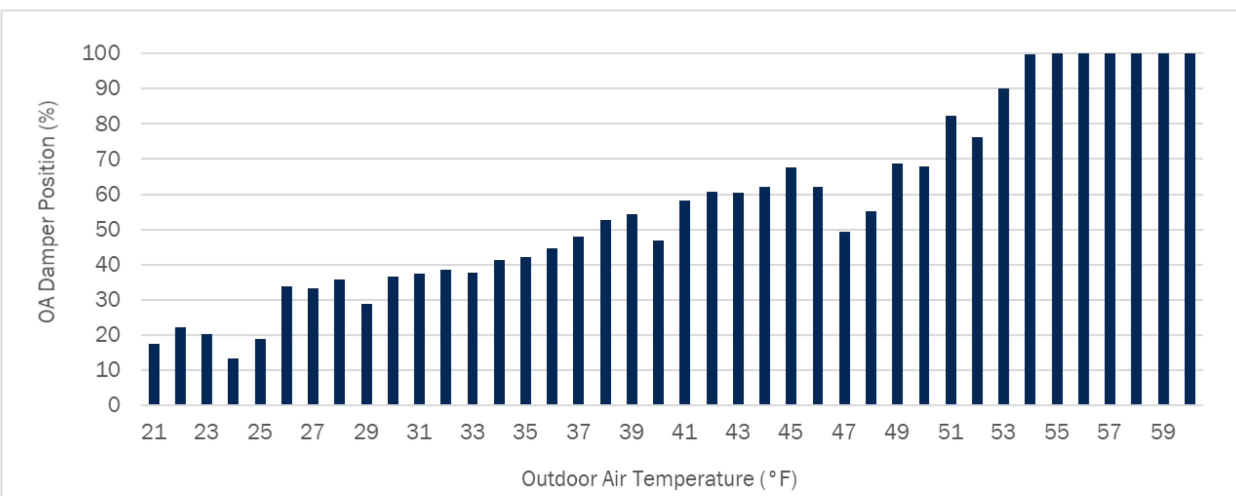
Unit	Baseline	New Equipment Verification				
	System	Nameplate Model	CFM	Supply Fans	Capacity Cool (Tons)	Capacity Heat (MBH)
AHU9	Existing	CSAA080UBL00	38,000	15 hp x 4	80	-

Unit	Baseline	New Equipment Verification				
	System	Nameplate Model	CFM	Supply Fans	Capacity Cool (Tons)	Capacity Heat (MBH)
AHU11	Existing	CSAA080UBL00	38,000	15 hp x 4	80	-
AHU12	ASHRAE 90.1	CSAA080UBL00	38,000	15 hp x 4	80	-
AHU13	ASHRAE 90.1	CSAA021UBL00	8,000	5 hp x 2	21	16.5,38 kW reheat
DOAS2	Existing	CSAA057UBL00	25,000	20 hp x 2	57	Electric Heat 238kW
DOAS1	Existing	CSAA057UBL00	25,000	20 hp x 2	57	Electric Heat 238kW

The ex ante building simulation model used an existing equipment baseline for the manufacturing area and an ASHRAE 90.1 baseline for the new recreation area applicable, which conformed to the local adopted building code.

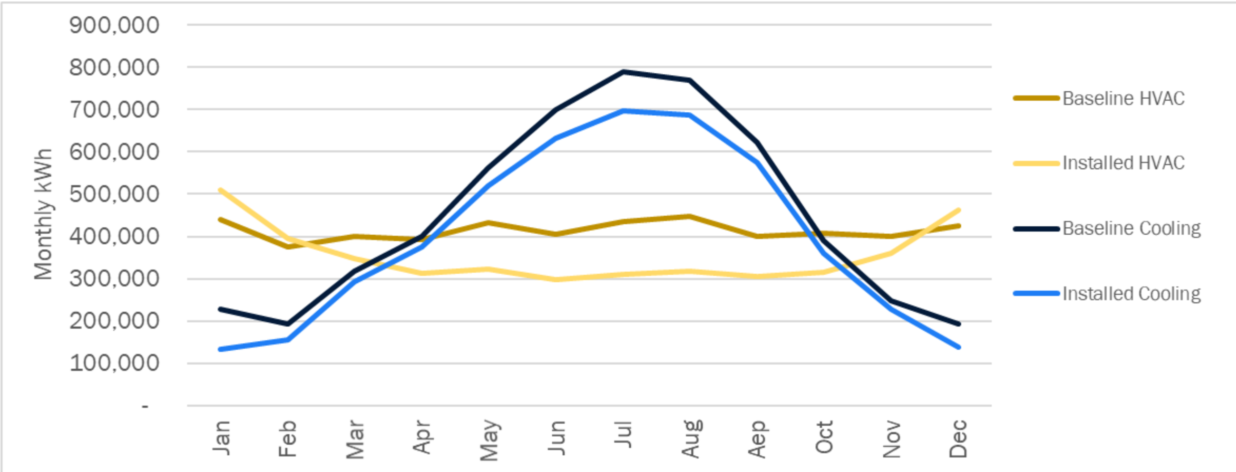
The evaluation team used the BMS trend data to verify the AHUs with economizers. The figure below shows the outdoor air damper position for AHU9 compared to the outdoor dry bulb temperature for the month of February 2020. Before the project implementation, the outdoor air volume was limited, which required the return air to be conditioned by the DX rooftop cooling units. The large year-round heat load in the manufacturing plant, is now conditioned with outdoor air from AHU9 when in economizer mode, and outdoor air supplied by the new DOAS units when the AHUs are not in economizer mode. When the AHUs go to economizer mode, the DOAS mixes return air with outdoor air to maintain the discharge air temperature of 52°F.

Site 8000 AHU Economizer – AHU-9 OA Damper Position (Trend Data, February 2020)



The figure below shows the modeled monthly energy usage for the baseline and proposed model for the Cooling and HVAC Enduses.

Site 8000 Simulation Models Monthly Usage (Typical Weather Year)



Based on the verification of installed equipment, validation of existing equipment, review of equipment operations, and review of the simulation model inputs and outputs, the evaluation team accepted the ex ante modeled savings.

Results

The ex post savings are 100% of the ex ante savings for energy usage and demand savings.

Site 8000 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
New AHUs, DOAS - Cooling	616,141	616,141	100%	561.11	561.11	100%
New AHUs, DOAS - HVAC	703,449	703,449	100%	312.32	312.32	100%
Total	**1,319,590**	**1,319,590**	**100%**	**873.43**	**873.43**	**100%**

Reasons for Discrepancies

- N/A – the equipment is installed and operating as proposed and modeled.

Other Findings and Recommendations

- The project was modeled in the IES Virtual Environment building energy simulation software, which is well suited for building design and estimating energy measure savings. However, the modeling files are not always available with the project documents. The program should revise guidelines requiring participants submitting savings based on building simulation to include submission of the native software file with any associated templates, an editable file format for model inputs, and an editable file format of the model outputs.

Site ID: 8001 (Enduse: HVAC)

Project Description

This project replaced the direct expansion (DX) cooling units with two water-cooled chillers at a six-story office building. The project also added variable frequency drives (VFD) and installed cooling coils to four air handler units; and installed an enthalpy wheel energy recovery unit to capture heat from exhaust air and to assist with building pressurization.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8001 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Water-Cooled Chiller	HVAC	191,967	174.82
HVAC Controls / EMS	HVAC	727,364	322.94
Total		**919,331**	**497.76**

Data Collection

During the site visit on December 1, 2020 with the facility building engineer, the field engineer collected photo documentation of the model nameplates for the two new chillers, cooling tower, water pumps with drives, and the energy recovery unit. The field engineer also reviewed the four air handlers for the current VFD drive speed and operation and obtained baseline operating conditions for the previous equipment and controls, which included schedules and building occupancy. Screenshots collected of the building management system computer displaying the air handling units, the chillers, and cooling towers provided information on setpoints and current operating trends. The field engineer collected the energy management system's logic diagram to establish the change to operating schedule for the optimized startup routine. The trended data spanned the previous seven days for the air handler supply fan speed, chiller enable status, and indoor temperatures.

The field engineer discussed the occupancy schedules and determined that the current occupancy included 70% of building tenants currently working from home.

Analysis

The ex post analysis verified the inputs used for the Ex Ante Trane Trace building energy modeling and adjusted ex ante savings based on billing data, weather data, and building occupancy trends over the pre- and post-installation periods.

For the baseline energy model review, the ASHRAE 90.1 performance rating method indicates a minimally efficient water-cooled packaged unit for the installed water-cooled chillers. The energy model accurately portrays the collected chiller nameplate capacities of 140 tons for each of the two chillers. On the airside, the new energy recovery unit was sized correctly in the energy model, along with VFDs on air handlers.

The evaluation team utilized the IPMVP Option C, Whole Building Analysis to estimate the project savings based on the pre- and post-installation period weather data, utility billing data, and building occupancy. The evaluation team applied the following linear regression algorithm to derive monthly consumption estimates.

$$kWh = Pre/Post\ flag \times Coef_{Pre/Post} + CDD\ flag \times Coef_{CDD} + HDD\ flag \times Coef_{HDD} + Work\text{-}at\text{-}Home\ flag \times Coef_{Work\text{-}at\text{-}Home} + Intercept$$

The inputs to the regression are listed in the table below.

Site 8001 Billing-Weather Data Regression Variables

Coefficient	Predictor Variables	Source
Pre/Post	Binary flag for pre and post periods	Months Pre and Post, exclusive of July 2020
CDD	Cooling Degree Days	NOAA Lambert STL weather above 60°F
HDD	Heating Degree Days	NOAA Lambert STL weather below 63°F
Work-at-Home	Months with >50% tenants working at home due to COVID-19 protocols.	Site contact
Intercept	Constant value	Regression output

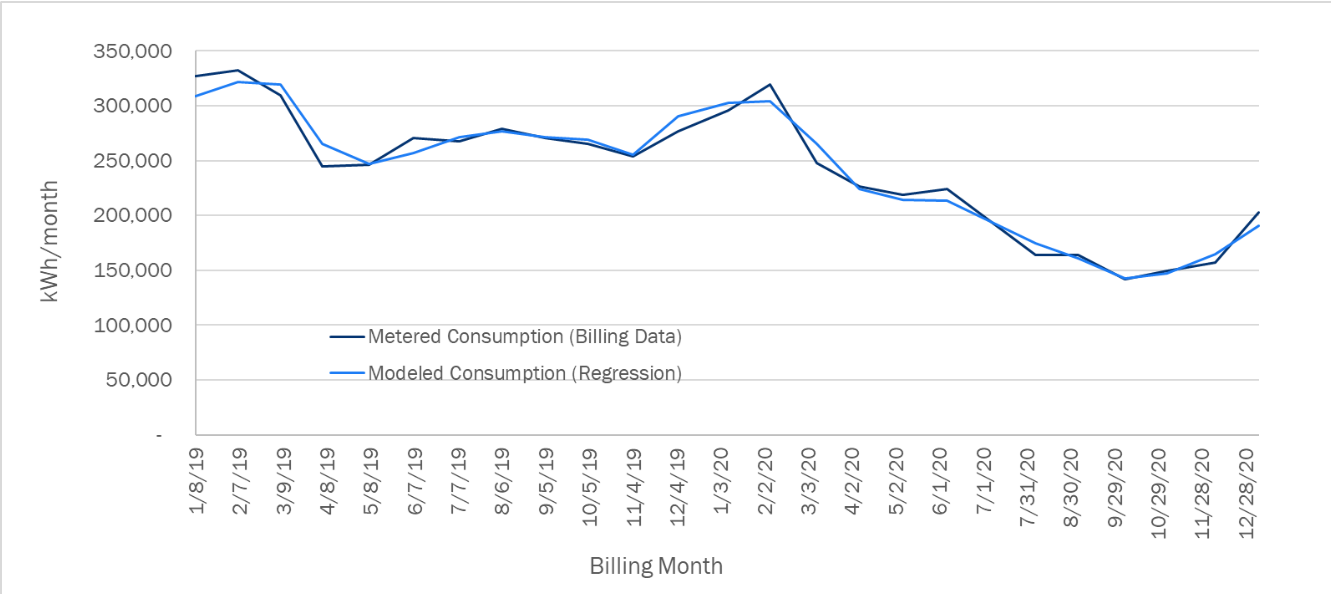
Coefficients used in the linear regression model are reported in the table below along with their statistical significance. All coefficients used had a p-value less than 0.05. The regression equation for the post period model had a good fit with an R-square value 0.97. The evaluation team tested the work-at-home coefficient for months outside the known start of the work-at-home period, resulting in estimates with poor statistical significance, i.e., P-values much larger than the 0.05 significance threshold.

Site 8001 Billing-Weather Data Regression Variables (observations = 23)

Term	Coefficients	P-value (exponential)	t-stat
Intercept	210,337	1.58 E-14	21
Pre/Post	(73,759)	1.36 E-08	-9
CDD	114	2.81 E-05	5
HDD	118	6.62 E-08	9
Work-at-Home	(36,514)	5.09 E-05	-5

The following figure illustrates the results of the regression analysis in comparison to the actual billed energy consumed over the pre- and post-installation period. The figure below shows the pre- and post- periods with TMY3 data, CDD, and HDD, which excludes the COVID-19 work-at-home energy savings.

Site 8001 Billing Data, Weather Data with Regression Model



The ex post analysis calculates future monthly energy savings by inserting TMY3 normalized weather data into the developed linear regression algorithm (to reflect a typical weather year) and by setting the work-at-home flag to zero (to reflect a typical, non-COVID occupancy year). Therefore, the ex post analysis calculated future annual consumption when COVID-19 restrictions are lifted, and occupancy rates return to historical normals at the site.

Results

The ex post savings are 96% of the ex ante energy and peak demand savings.

Site 8001 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Water-Cooled Chiller	191,967	184,821	96%	174.82	168.31	96%
HVAC Controls/ EMS	727,364	700,286	96%	322.94	310.92	96%
Total	**919,331**	**885,107**	**96%**	**497.76**	**479.23**	**96%**

Reasons for Discrepancies

- N/A – the measure is installed and operating as described in the ex ante analysis.

Other Findings and Recommendations

- N/A

Site ID: 8002 (Enduse: HVAC)

Project Description

This project, completed at a low-rise office building, replaced pneumatic controls for a parallel fan terminal variable air volume (VAV) rooftop unit (RTU) system with direct digital controls (DDC). The project eliminated two pneumatic control compressors and implemented night setbacks, demand control ventilation, optimum start, supply air reset, and fan pressure optimization.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8002 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
HVAC Controls/ EMS	HVAC	623,748	276.93
	Total	**623,748**	**276.93**

Data Collection

During the site visit on December 2, 2020 with the trade ally, the field engineer collected photographic documentation on the new digital zone thermostats, new VAV box actuators, and the existing RTU nameplates. The building management system (BMS) computer was accessed remotely to obtain screenshots of the new control system, system diagrams of the equipment with the setpoints, setback schedules and trend logs with up to seven days of CO_2 levels that trigger the demand control ventilation. The trade ally, who also performed the work, indicated two of the RTU's are enabled to run 24/7 along with pneumatic control lines to the fan terminal boxes, enabling the fans to run 24/7.

Following the site visit, the evaluation team verified key inputs, baselines, and weather data in the ex ante Trane Trace building model. The following are key items that generated savings in the as-built model:

- Weather: The model used St. Louis NOAA weather; the building is within 20 miles of the weather station.
- Thermostat settings: 75° Fahrenheit cooling and 71° Fahrenheit heating for occupied periods.
- Internal loads: Default low-rise office building with one workstation per person and recessed fluorescent lighting aligned with the evaluation team's site visit observations.
- Building construction: The model used face brick exterior walls which aligned with the field observations.
- Lighting schedule: The lighting schedule (see table below), obtained during the site visit, is appropriate for an office building, with occupancy peaking during regular business hours.
- Pre-inspection photos: Evidence of pneumatic controls.
- Post-inspection photos: New DDC controls, CO_2 sensors, and BMS control screens.
- Invoice: Dated August 26, 2020 and describes replacing pneumatic control with Distech BAS control system. Demand control ventilation of four RTUs, also confirmed with the BMS programming screenshots.

- Model inputs: The baseline model had no optimum start, no DCV, and no reset. The alternative model included optimum start, CO_2-based DCV, proportional air control, and supply air reset.

Site 8002 Lighting Schedule

Midnight to 6am	6am to 7am	7am to 8am	8am to 5pm	5pm to 6pm	6pm to 7pm	7pm to Midnight
10%	40%	80%	95%	40%	20%	10%

Analysis

Due to a change in the facility ownership (and resulting change in the electric account number), the evaluation team was unable to collect consumption data and perform IPMVP Option C, Whole Building Analysis with a weather billing regression, which is the preferred approach to evaluating a project of this complexity (e.g., multiple HVAC improvements and building controls with wide-ranging interactive effects). As a result, the evaluation team verified the ex ante energy models align with the implemented measures and field observations. The evaluation team confirmed that the difference in the annual energy usage of the two models (baseline and alternate) has a high certainty to occur.

Results

The ex post savings are 100% of the ex ante energy savings and peak demand savings.

Site 8002 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
HVAC Controls/ EMS	623,748	623,748	100%	276.93	276.93	100%
Total	**623,748**	**623,748**	**100%**	**276.93**	**276.93**	**100%**

Reasons for Discrepancies

- N/A

Other Findings and Recommendations

- N/A

Site ID: 8003 (Enduse: HVAC)

Project Description

This project reduced excess air flow to one of the building wings at a large museum by resheaving the motor pulley for the constant volume supply fans to reduce supply air flow. The reduction in air flow saves energy by reducing the fan energy requirements to move the air and the heating and cooling system requirements to condition the excess air.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8003 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
HVAC Controls – Reduce supply fan air flow	HVAC	498,316	221.24
Total		**498,316**	**221.24**

Data Collection

Field staff met with the facility engineer on December 1, 2020, collected photographic data of the new supply fan pulley and pictures of nameplates from the chiller plant equipment, and obtained screenshots of the building management system for the impacted air handlers. Field staff also verified the absence of an equipment schedule, as the equipment operates continuously with the same setpoints to maintain specific conditions that protect the museum exhibits.

The air handlers did not have flow meters, nor variable speed supply fan motors to profile the outside air flow and return air flow. Field staff collected one-time measurements for outdoor air damper position, mixed air temperature, return air temperature, humidity, and space temperatures.

During the site visit, field staff also noted that COVID-19-related local government mandates requiring closing operations to the public significantly impacts operations and energy consumption during the post-installation period. The site contact confirmed that the facility intends to resume normal operations once the operation restrictions are lifted.

Analysis

The ex post analysis developed three initial estimates of the savings due to the atypical post-installation operations observed due to COVID-19.

IPMVP Option C, Whole Building Analysis

The first method utilized 29 months of facility energy consumption data (from June 2018 through December 2020) and the following equation, based on the variables with statistical significance.

$$kWh = Pre/Post\ flag \times Coef_{Pre/Post} + CDD \times Coef_{CDD} + Days\ Closed \times Coef_{DaysClosedt} + CDD * Pre/Post\ flag \times Coef_{PrePost} + Intercept$$

Site 8003 Billing-Weather Data Regression Variables

Coefficient	Predictor Variables	Source
Pre/Post	Binary flag for pre and post periods	Dates of pre and post TAB reports
CDD	Cooling Degree Days	NOAA Lambert STL
Pre/Post * CDD	Pre/Post relationship to CDD	Significance testing
Days Closed	Days/month closed for pandemic	Mandated closing schedules
Intercept	Constant value	Regression output

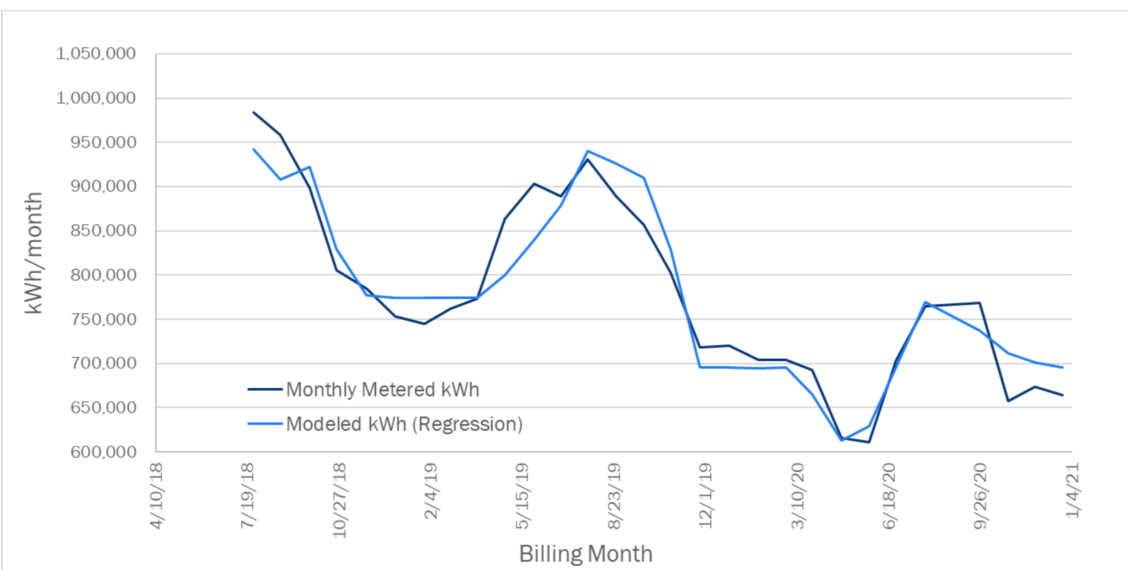
The linear regression model used the variables in the following table, along with their statistical significance. All coefficients used had a p-value less than 0.05 and a significant t-stat. The regression equation for the post period model had a good fit with an R-square value 0.9.

Site 8003 Billing-Weather Data Regression Variables

R Square	0.90		
Observations	29		
	Coefficients	**P-value**	**t Stat**
Intercept	773,780	0.0000	58.68
Pre/Post	(78,888)	0.0003	-4.27
CDD	262	0.0000	7.59
CLOSED	(2,847)	0.0020	-3.46
cdd *p	(158)	0.0086	-2.86

The figure below illustrates the relationship of the billed energy data and weather data to the regression model.

Site 8003 Billing Data, Weather Data with Regression Model



The consumption data and modeled consumption show a reduction in the monthly facility energy consumption. This reduction is a combination of the savings achieved by the energy efficiency project and reduced operations due to COVID-19 restrictions.

IPMVP Option A, Retrofit Isolation using Previous Site Analysis

The ex post work also leveraged previous evaluation work on a different wing at the same facility, completed three years prior. The chiller plant provides chilled water to both wings, and the air handlers are similar with constant volume air supplied to the museum exhibits. The prior analysis determined a value of 19.2 for the fan and chiller energy consumption per CFM of supply air flow (kWh/CFM). The evaluation team applied this kWh/CFM estimate to the measured air flow reduction (36,365 CFM) from the project's testing and balancing reports to estimate chiller savings from the reduced airflow.

IPMVP Option C, Simulation with IGES Modeling Software

Lastly, the ex post work reviewed the ex ante model developed in the IGES modeling software. The evaluation team verified that the model included measured air flow reduction of 36,365 CFM. The evaluation team also verified that the one-time measurements for discharge air temperature, mixed air temperature, humidity, space temperatures were included in the applicable weather bin period of the model.

Results

The table below shows the estimated savings for each of the three ex post methods.

EM&V Method	Annual Energy Savings (kWh)
IPMVP Option C, Whole Facility	807,414
IPMVP Option A, Retrofit Isolation using Previous Site Analysis	696,715
IPMVP Option D, Simulation with IGES Modeling Software	498,316

The Option D, Building Simulation used to estimate the ex ante savings, utilized inputs from the entire building, including those beyond the evaluation boundary, and calibrated the loads to billing data. This method was the most rigorous and, since it represents the most recent pre-pandemic operation, it is also most likely to resemble the post-pandemic operation compared to the other two methods. Also, the Option D modeling methods are consistent with the verified inputs collected during the site visit and validating the testing and balancing prior reports for the air flow reduction.

The results of the Option D method, and final evaluation results, are presented in the following table.

Site 8003 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
HVAC Controls - reduce air flow	498,316	498,316	100%	221.24	221.24	100%
Total	**498,316**	**498,316**	**100%**	**221.24**	**221.24**	**100%**

Reasons for Discrepancies

- N/A - The evaluated ex post savings are consistent with the estimated ex ante savings.

Site ID: 8007 (Enduse: HVAC)

Project Description

This project, completed at a public service facility, replaced a 1,300-ton water-cooled chiller operating at 4,160 volts with a variable speed chiller operating at 480 volts and converted the chiller plant from a primary-secondary to a variable primary flow. Savings are achieved by the higher efficiency of the new chiller operating at part loads (IPLV).

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8007 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
Water-Cooled Chiller	Cooling	387,384	352.78
Total		**387,384**	**352.78**

Data Collection

The evaluation boundary for this analysis is the new 1,300-ton chiller. The measures for the pump energy savings when converting to variable primary flow were not sampled for the evaluation, but the evaluation team referenced the Trane Trace modeling for the pumps to examine the chiller plant load profile.

The evaluation team reviewed the project documents for the project narrative, Trane Trace pump modeling, ex ante savings calculation, 1,300-ton York chiller specifications for part load and full load, invoices for model verification, and chiller consumption calculation.

Upon requests for clarification, the program implementer provided a revised savings estimate for the chiller replacement, as the original ex ante estimate compared the full load chiller rated kW/ton performance for the baseline chiller to the part load chiller rated kW/ton performance of the installed chiller.

Analysis

The evaluation team adjusted the load ratings to compare chillers with ratings that were tested under the same conditions of the AHRI 550/590 standard test with 44°F leaving chilled water at 2.4 GPM/ton flow, 85°F entering condenser water temperature at 3.0 GPM/ton flow. This was completed per ASHRAE 90.1 2013, section 6.4.1.2.1. The ex ante analysis has completed these adjustments using a similar method.

Full Load Value (kW/ton), adjusted for non-standard conditions: $FL_{adj} = FL / K_{adj}$

Part Load Value (kW/ton), adjusted for non-standard conditions: $PLV_{adj} = IPLV / K_{adj}$

Where:

Variable	Formula/Definition	Source
Load (Full), (IPLV)	Full Load, Integrated Part Load	Manufacturer
$Load_{adj}$ (Full),(IPLV)	FL, IPLV adjusted for nonstandard test conditions	ASHRAE 90.1
K_{adj}	A x B; Adjustment factor to AHRI 550/590 test conditions	ASHRAE 90.1
A	0.00000014592*POWER(lift,4)-0.0000346496*POWER(lift,3)+0.00314196*POWER(lift,2)-0.147199*lift+3.9302	ASHRAE 90.1
B	0.0015 x LvgEvap + 0.934	ASHRAE 90.1
Lift	Leaving CW – Leaving CHW	ASHRAE 90.1
Leaving CW	Full load condenser leaving water temp, F	Manufacturer
Leaving CHW	Full load evaporator leaving water temp, F	Manufacturer

The provided NPLV(IPLV) test conditions for the installed chiller were compared to the AHRI 550/590 test conditions in the following table. Adjustments are not indicated in the ASHRAE 90.1 2013, section 6.4.1.2.1 section for the evaporator flow and the condenser water flow, both of which were lower than the test conditions. The lower evaporator flow, results in additional time for heat transfer to the water, with the lower leaving evaporator water temperature of 42˚ F compared to the standard of 44˚ F. The AHRI Standard 550/590 Errata 2018, provides the note to the evaporator water flow, "rated weather flow is determined by the water temperatures at the rated capacity," and the 2.4 GPM per ton is for reference only. This is similar for the condenser water flow, that is determined by the water temperature at rated capacity. From this, the ex post did not deviate from the ASHRAE adjustment K factor method. The ex ante method included a normalization for the lower condenser water flow.

Site 8007 AHRI Standard Test Conditions and Chiller NPLV/IPLV Conditions

Factor	AHRI 550/590 Test Conditions	Chiller NPLV Test Conditions
Leaving Condenser Water Temperature (F)	94.3	94.64
Leaving Evaporator Water Temperature (F)	44.0	42.00
Entering Condenser Water Temperature (F)	85.0	85.00
Entering Chiller Water Temperature (F)	54.0	56.81
Evaporator flow (GPM)	3,120	2,100
Condenser flow (GPM)	3,900	3,750

The results of the Full Load and Part Load adjustment for the installed chiller to enable comparison to ASHRAE ratings are listed in the following table.

Site 8007 ASHRAE Method Load Adjust to Standard Conditions

	Ex Ante -Adjusted	Ex Post – Adjusted	Non - Standard Test
K_{adj}	0.953	0.951	1.0000
FL (kw/ton)	0.606	0.607	0.356

	Ex Ante -Adjusted	Ex Post – Adjusted	Non - Standard Test
NPLV (kw/ton)	0.3735	0.374	0.577

The ex ante project documents indicated the measure was binned to "New/Replace on Fail" baseline, which is determined by ASHRAE 90.1 prescriptive chiller minimum efficiencies for both full and part load, with an option of meeting either Path A or Path B. The standard requires that both the Full Load and Part Load minimums be met for either Path A or Path B. The following table compares the adjusted full load chiller values for the installed chiller to the ASHRAE 90.1 2013 guideline for minimum efficiency requirements. IPLV and NPLV express the same chiller specification with IPLV the rating and NPLV the tested rating.

Site 8007 ASHRAE Method Load Adjust to Standard Condition

	Ex Ante Adjusted	Ex Post Adjusted	Path A	Path B
FL (kw/ton)	0.6060	0.6072	0.560	0.585
IPLV (kw/ton)	0.3735	0.3742	0.500	0.380

In the previous table, neither the ex ante nor the ex post adjusted efficiency values meet the minimum efficiency requirements for Path A or Path B. The non-adjusted chiller rating is less than or equal to the Path B ratings pair but does not compare two chillers with ratings from the same AHRI test conditions.

Communication with the program implementer indicated that the program considered the existing chiller efficiency represented by the Path A Part Load value of 0.5 kW/ton and the new installed chiller by Path B Part Load value of 0.380 kW/ton. This method is unconventional for New/Replace on Fail equipment baselines.

The evaluation reviewed previous site visit work in the area and identified projects where the participant had recommissioned their end of life equipment with new controls and variable frequency drives. Based, on this local practice, the ex post utilized an early replacement baseline for the analysis rather than a replace-on-fail baseline. As the original chiller had been removed when operational, and the actual kW/ton rating not known to the evaluation team, the evaluation team used the ASHRAE 90.1 Part A IPLV value of 0.500 kW/ton as the baseline from which to estimate savings.

The evaluation team determined the annual hours of use from the project documentation of the two chiller plant pump simulation model and applied the annual ton-hours to a three chiller plant, with the variable speed chiller operating as a trim chiller. The results are listed in the following table.

Site 8007 Chiller Annual Usage and Savings

	kW/ton	Hours	Tons	Annual kWh
Baseline	0.500	2,348	1,300	1,526,109
Installed	0.3742	2,348	1,300	1,142,158
			Savings (kWh)	**383,951**

Results

The Ex Post savings are 99% of the Ex Ante savings for both peak and demand savings.

Site 8007 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Water-Cooled Chiller	387,384	383,951	99%	352.78	349.66	99%
Total	**387,384**	**383,951**	**99%**	**352.78**	**349.66**	**99%**

Reasons for Discrepancies

- The ex post followed the Part Load adjustment method for chillers not tested at the complete AHRI test conditions, with a similar method as the ex ante, but followed the ASHRAE 90.1 2013 method.
- The ex post savings estimate set the annual hours of use to 2,348 hours based on the Pump Model Trane Trace Study completed within the project documents. The ex ante savings were based on one-third of 8760 annual hours. The ex post was informed by the project narrative, which stated two chillers are always running, with the third required for some days. As the new chiller is variable speed, the ex post considered the part load hours provided in the Pump Model Trane Trace Study.

Other Findings and Recommendations

- The ex ante binned the measure as New/Replace on Fail, which normally equates to either a Codes & Standards or Common Practice baseline, but mixed two baseline methods in this project. The ex ante analysis sourced the ASHRAE 90.1 Standard for kW/ton data, but applied a Path A, IPLV value to represent a common practice baseline selection and a Path B, IPLV value to qualify the installed chiller. Adherence to a Codes & Standards Baseline would require both the baseline and installed chiller to consistently reference to either Path A or Path B (not both) and to meet or exceed both the Full Load and Part Load kW/ton thresholds defined for that compliance path. The evaluation team recommends the program implementer determine baseline selection methods that align with the program design and provide guidance to program participants by updating program guidelines.

Site ID: 8008 (Enduse: HVAC)

Project Description

A high school building received a retro-commissioning study and implemented twenty of the energy conservation measures (ECMs) with programming revisions of the building management system (BMS). The ECMs included occupied scheduling updates to ten air handling units (AHU) and rooftop units (RTU), along with static pressure reset for the supply fans. The project also optimized programming on the chiller plant to reduce the plant operating hours during unoccupied periods and pumps and fans for lower average flow and speed. Energy savings are achieved for improved overall efficiency of the facilities' cooling equipment. The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8003 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
BMS Programming including equipment	HVAC	329,232	299.83

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
schedules, static pressure reset, and minimum flows			
Total		329,232	299.83

Data Collection

Field evaluation staff met with the facility director and the trade ally on December 3, 2020, and collected photographic documents of the chiller nameplates, three air handling units, and one rooftop unit; screenshots of the equipment graphics in the BMS; historical trend data for cooling equipment; and building schedules.

Facility operations and occupancy rates and schedules have been affected by COVID-19. The site contact provided the current operations with both in-person and virtual classes for students and identified a temporary change in the building schedule to provide an additional hour of an air purge at the end of the school day.

The ex post engineer aggregated the ex ante worksheets for each ECM and the historical summer trend data for the chiller, chilled water pumps, condenser water pumps, and cooling tower fans.

Analysis

The ex ante savings estimates are based on weather-bin calculations for each ECM, measured from the baseline operations supported by the BMS trended data.

The ex post analysis reviewed the ex ante calculations and verified the inputs used for the weather bin estimates. The implemented measures, with the ex ante savings and ex post review of data are listed in the table below.

Site 8003 Verification of Ex Ante Weather Bin Analysis

Unit	Baseline (kWh)	Installed (kWh)	Savings (kWh)	Ex Post Verification Notes
AHU-1	67,224	61,117	6,107	Schedule implemented; Verified by Supply Fan status trend data
AHU-2	68,819	49,052	19,767	Schedule implemented; Verified by Supply Fan status trend data
AHU-3	73,313	63,517	9,796	Schedule implemented; Verified by Supply Fan status trend data
AHU-4	20,407	18,047	2,360	Schedule implemented; Verified by Supply Fan status trend data
AHU-5	6,876	6,701	175	Schedule implemented; Verified by Supply Fan status trend data
RTU-6	52,853	47,206	5,647	Schedule implemented; Verified by Supply Fan status trend data
AHU-7	6,876	5,056	1,820	Schedule implemented; Verified by Supply Fan status trend data
AHU-9	24,352	22,467	1,885	Schedule implemented; Verified by Supply Fan status trend data
AHU-10	21,797	21,291	506	Schedule implemented; Verified by a one-day trend
AHU-12	20,519	14,937	5,582	Schedule implemented; Verified by Supply Fan status trend data
AHU-13/14	144,484	119,413	25,071	Schedule implemented; Verified by Supply Fan status trend data
AHU-16	42,411	41,357	1,054	Schedule implemented; Verified by Supply Fan status trend data
AHU-17	37,689	22,346	15,343	Schedule implemented; Verified by Supply Fan status trend data
AHU-18	8,196	4,617	3,579	Schedule implemented; Verified by Supply Fan status trend data
Music Rm	12,229	11,263	966	Schedule implemented; Verified by AHU-enabled trend
FCU's	41,563	37,499	4,064	Verified 14 FCU for start/stop trend data
CH Off	181,006	84,676	96,330	Partially verified; Scheduled for zero weekends; Chiller run time averaged eight hours on Saturdays.
CT Off WB	47,407	13,230	34,177	Wet bulb programming completed
CW Pump	104,014	78,254	25,045	Verified one pump off, or two pumps at 30% speed
CHW	289,434	219,476	69,958	Partially verified pump trends, some weekend run time

The chiller plant measure, which intended to schedule the chiller plant off on weekends and evenings, was partially implemented, as the post trend data indicated an average of eight operating hours on Saturdays. However, other measures overachieved savings. For example, the music room had a tighter schedule than the other classrooms.

The ex post analysis estimated savings using IPMVP Option C, Whole Building Analysis, and utilized the following equation, based on the variables with statistical significance:

$$kWh = Pre/Post\ flag \times Coef_{Pre/Post} + CDD \times Coef_{CDD} + Virtual\ Class \times Coef_{Virutal} + Intercept$$

Site 8003 Billing-Weather Data Regression Variables

Coefficient	Predictor Variables	Source
Pre/Post	Binary flag for pre and post periods	Dates of substantial completion
CDD	Cooling Degree Days	NOAA Lambert STL
Virtual Class	Month affected by Covid-19 pandemic	Site contact; online school calendar
Intercept	Constant value	Regression output

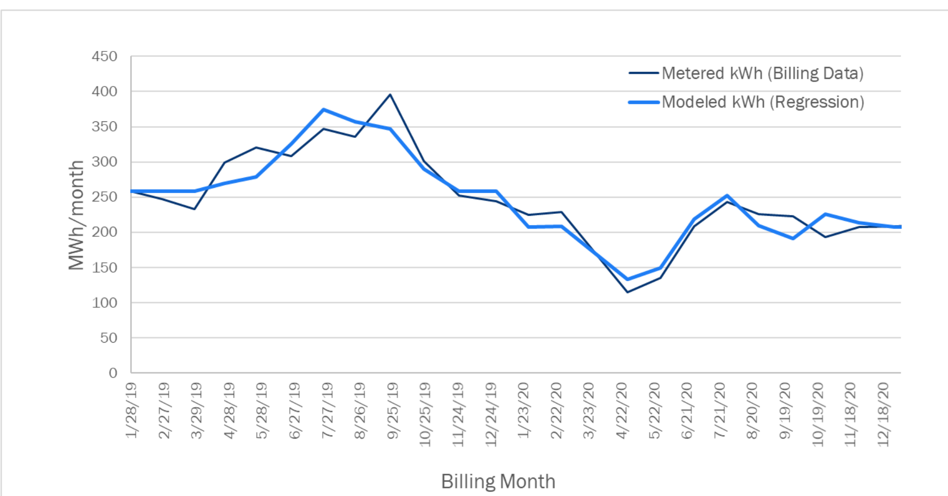
The linear regression model used the variables in the following table along with their statistical significance. All coefficients used had a p-value less than 0.05 and a significant t-stat. The regression equation for the post period model had a good fit with an R-square value 0.85. The heating degree days (HDD) was determined to not have significance in estimating the monthly energy usage in the regression model. Likewise, a variable for summer and holiday breaks did not have significance.

Site 8003 Billing-Weather Data Regression Variables

R-Square	0.85		
Observations	24		
Term	**Coefficients**	**P-value**	**t - stat**
Intercept	258,456	0.0000	26.76
Pre/Post	(50,473)	0.0024	-3.47
CDD	273	0.0000	6.51
COVID-19 Pandemic	(80,821)	0.0003	-4.40

The following figure illustrates the relationship of the metered monthly energy consumption data and weather data to the modeled monthly energy consumption based on the ex post regression model. The inclusion of the COVID-19 variable isolates the reduction in energy from closings, reduced hours, reduced visitors.

Site 8003 Billing Data, Weather Data with Regression Model



To estimate annual energy savings in a typical (i.e., typical weather and without the COVID-19-effected schedule changes), the ex post analysis used the regression with TMY3 weather data and the COVID-19 variable coefficient set to zero.

Results

The IPMVP Option C, Whole Building Analysis method estimated savings of 605,680 kWh across all the measures implemented with this project. To isolate the ex post savings associated with the project's cooling measures (selected through the sample design), the ex post savings were apportioned by the expected savings, resulting in 396,056 kWh, which is 120% of the ex ante energy and peak demand savings.

Site 8003 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Cooling Only HVAC	329,232	396,056	120%	299.83	360.68	120%
Total	**329,232**	**396,056**	**120%**	**299.83**	**360.68**	**120%**

Reasons for Discrepancies

- N/A

Other Findings and Recommendations

- N/A

Site ID: 8009 (Enduse: HVAC)

Project Description

This project, implemented at a public safety building that operates 24 hours per day, reduced cooling and fan energy consumption by reducing the volume of exhaust air and programmed the building management system (BMS) to adjust their air handler's discharge air temperature during the night.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8009 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
Temperature Setback Fans	HVAC	21,930	9.74
Temperature Setback Chiller	Cooling	22,526	20.51
Exhaust CFM Reduction	Cooling	268,989	244.96
	Total	**313,445**	**275.21**

Data Collection

During the site visit on November 30, 2020 with the facility manager, the field engineer collected photo documentation for the chiller plant nameplates; collected screenshots of the BMS system for the chiller plant, air handlers, exhaust fans, heat recovery units, and setpoints; and downloaded trend data for the supply fans, exhaust fans, and chiller plant.

The site contact explained that, due to concerns with odors in the restrooms and living spaces after the project was implemented, the facility had partially returned to the original operating conditions. There were no indications of returning to the previous decreased exhaust air, as the odor issues had been fixed with the increase in outside air.

The field engineer collected the system limit of seven trended days for each unit to determine the current (i.e., post-installation) airflow for each exhaust fan and supply fan. The data types collected align with the data tracked from the original air balancing completed within the project and shown in the following table.

Site 8009 Air Balancing, Before & After – Ex Ante Methods

Unit	Air Flow (CFM)		
	Before	After	Saved
EF-1A	23,150	13,175	9,975
EF-1B	25,350	13,545	11,805
EF-2A	26,125	13,231	12,894
EF-2B	24,725	13,450	11,275
		Subtotal	**45,950**
SF-1C	24,735	8,815	15,920
SF-1D	24,828	8,938	15,890
SF-2C	24,301	11,111	13,190
SF-2D	24,644	11,234	13,410
		Subtotal	**58,410**

Analysis

The collected data for the exhaust fans and supply fans was available for most points in the BMS computer from an air flow meter, measuring CFM. For points where the meter was not functioning, the evaluation team used fan speed to estimate the air flow from the full speed air flow. The units in the table "SF, EF" are components of the larger air handler "AHU" and integrated enthalpy air economizers.

Site 8009 Verified Exhaust and Supply Air Flow Savings

	Fan Speed (%)	VFD (Hz)	Air Flow (CFM)	Air Flow Baseline (CFM)	Ex Post Savings (CFM)
EF-1A	-	36	17,652	23,150	5,498
EF-1B	-	36	17,652	25,350	7,698

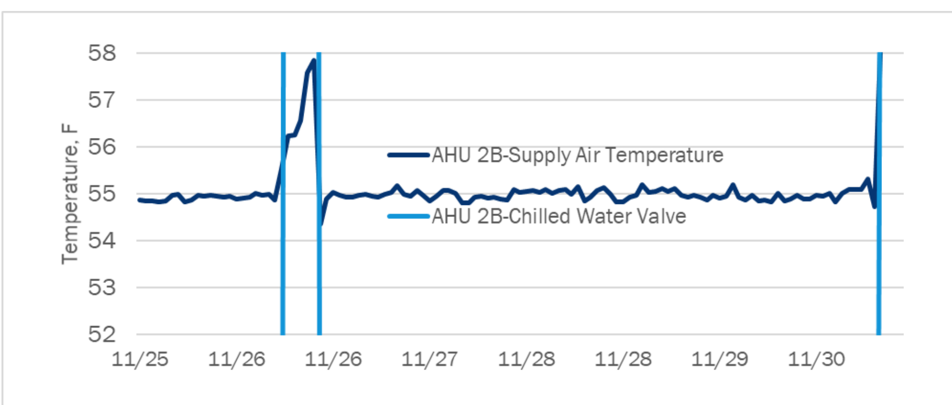
	Fan Speed (%)	VFD (Hz)	Air Flow (CFM)	Air Flow Baseline (CFM)	Ex Post Savings (CFM)
EF-2A	33	-	13,754	26,125	12,371
EF-2B	33	-	14,935	24,725	9,790
				Total	**35,357**
AHU-2A	54	32	15,851	-	-
AHU-2B	54	31	14,935	-	-
AHU-1A	61	37	19,283	-	-
AHU-1B	61	38	19,283	-	-
SF-1C	-	48	20,000	24,735	4,735
SF-1D	-	49	20,000	24,828	4,828
SF-2C	54	46	15,851	24,301	8,450
SF-2D	54	45	15,028	24,644	9,616
				Total	**27,629**

The current operating conditions of the exhaust fans indicate that the facility added 11,593 CFM of exhaust air back to the system after the project was completed. The current levels represent 75% of the original airflow reduction. There were no indications of returning to the previous levels of decreased exhaust air, as the additional supply air to replace the increased exhaust air rates had fixed the odor issues.

The evaluation team converted the trended CFM rates to units of kWh based on the latent and sensible cooling of the air and annualized the energy savings performance for the facility's 24/7 operation.

The evaluation team analyzed the AHU1 and AHU2 trend datasets to verify the additional measure for nighttime setback for cooling savings. Although the need to enable the chillers is not frequent in the heating season, it did occur twice over a seven-day period, as shown on the following figure. When the chilled water valve opened for cooling, the program went to a two-degree night discharge temperature setback.

Site 8009 Algorithm Inputs



Results

The total ex post savings were 79% of the ex ante savings based on the data collected during the site visit in December.

Site 8009 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Temperature Setback Fans	21,930	21,930	100%	9.74	9.74	100%
Temperature Setback Chiller	22,526	22,526	100%	20.51	20.51	100%
Exhaust CFM Reduction	268,989	202568	75%	244.96	184.48	75%
Total	**313,445**	**247,024**	**79%**	**275.21**	**214.73**	**78%**

Reasons for Discrepancies

- The project was implemented as planned; however, due to odor issues, the site partially reversed the exhaust fan reduction to increase the amount of fresh air into the building. The partial reversion (to 75% of the original airflow reduction) reduced the savings achieved by the airflow reduction measure.

Other Findings and Recommendations

- N/A

Site ID: 8010 (Enduse: HVAC)

Project Description

This project, completed at a community recreation center, replaced four rooftop units (RTUs) that were original to the 1999 constructed building with efficient RTUs and upgraded the building controls to the new RTUs. The new RTUs achieve energy savings over the existing units due to their higher efficiency performance (IEER) and variable speed supply fans.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8010 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
Install new RTU1, RTU2, RTU3, RTU4	Cooling	152,752	139.11
Install new RTU1, RTU2, RTU3, RTU4	HVAC	104,855	46.55
	Total	**257,607**	**185.66**

Data Collection

During the site visit with the Facility Director on December 2, 2020, the field engineer collected photographic documentation of the model nameplates for the new RTUs, photos of the zones conditioned by the units, new wall thermostats, and the new controls to the units. The field engineer also downloaded trend data from the building management system (BMS) computer.

Due to COVID-19, the facility has reduced the normal operations for this municipal recreation facility. To understand typical operations, the field engineer collected information on the previous equipment operation and on the current reduced operating hours.

Analysis

The ex ante analysis estimated savings using a Trane Trace model with inputs to develop the loads and specify the baseline and efficient equipment scenarios. The ex post analysis leveraged these existing Trane Trace building simulation models to verify the savings. The evaluation team confirmed that the EER values for each of the four new rooftop units aligned with the manufacturer specifications. Since the existing RTUs were working, and since it is not uncommon for municipal agencies to prolong equipment life through ongoing maintenance, the evaluation team accepted that—despite the age of the existing equipment—the existing equipment (EER=9.3) can be considered as the baseline.

The evaluation team reviewed the Trane Trace output file to bin the model components to the appropriate Cooling and HVAC enduses. For the cooling enduses (shown in the following table), the ex ante and ex post pre and post models were identical.

Site 8010 Pre/Post Simulation Model – Cooling Enduse (Ex Ante and Ex Post)

Unit	Baseline		Installed		Savings
	Cooling	Heat Rejection	Cooling	Heat Rejection	
RTU1	78,247	4,511	36,303	2,840	43,616
RTU2	98,561	4,786	62,180	3,712	37,454
RTU3	109,992	6,238	62,072	4,722	49,436
RTU4	56,738	2,953	35,194	2,250	22,246
Total	**343,538**	**18,489**	**195,749**	**13,525**	**152,753**

Part of the pool equipment loads and equipment usage were included in the ex ante models, and the ex post initially included all components to consider the tradeoffs in the model. The pool space dehumidification unit is a Dectron brand unit, installed in the year 2017, with DX cooling. This unit also rejects condenser heat to outdoor air during the summer but rejects heat to a heater exchanger in the winter to heat the pool water.

The ex ante installed model included scheduling of the heat reclamation unit, which saved electric energy in the model, but also increased the amount of natural gas required for the pool water heater. The ex post analysis set the evaluation boundary to include the four new rooftop units and the zones controlled. Since the scheduling change to reduce the runtime of the heat reclamation unit results in some fuel switching (and increased gas consumption), the ex post analysis moved the pool zone outside the evaluation boundary and did not include any energy impacts of changes made to the pool units. When the evaluation boundary is set to the total building with all fuel sources, there is a negative net savings as summarized in the following table.

Site 8010 Pool Space Conditioning and Pool Water Heating (with equivalent gas usage)

	Pre		Post	
	Ex Ante	Ex Post	Ex Ante	Ex Post
Pool Space Cooling	-	46,401	-	52,232
Pool Space Cooling	-	6,892	-	7,868
Pool Space HVAC	11,691	11,691	12,435	12,435
Pool Space HVAC	2,061	2,061	2,061	2,061
Pool Space HVAC	158,767	158,767	102,987	102,987
Pool Space HVAC	29,544	29,544	20,857	20,857
Pool Space HVAC	100,433	100,433	100,433	100,433
Pool Water Heating (therms)	-	5,603	-	16,374
Pool Water Heating (kWh equivalent)	-	164,168	-	479,758
Total	**302,496**	**525,560**	**238,772**	**795,004**

For the HVAC Enduse, the evaluation team aggregated the model output values into the following table and compared the ex ante and ex post. The ex post included all HVAC energy, including both cooling and heating operation. The ex post savings for HVAC was 21,171 kWh less than the ex ante for HVAC Enduse, due to the inclusion of all fan energy, both heating and cooling, and to the exclusion of the pool zone from the evaluation boundary. Also, the ex ante pre and post model, included the value of "energy recovered – therms" in the electric energy for the pool unit as a kWh unit value.

Site 8010 Pre/Post Simulation Model – HVAC Enduse

Unit	Function	Pre		Post	
		Ex Ante	Ex Post	Ex Ante	Ex Post
RTU1	Cooling Fan	40,264	40,264	27,369	27,369
	Heating Fan	-	25,971	-	16,492
	Return Fan	7,742	7,742	5,425	5,425
RTU2	Cooling Fan	21,485	21,485	19,858	19,858
	Heating Fan	-	35,015	-	20,672
	Exhaust Fan	2,446	2,446	2,541	2,541
	Return Fan	2,923	2,923	2,354	2,354
RTU3	Cooling Fan	23,007	23,007	21,021	21,021
	Heating Fan	48,862	48,862	30,017	30,017
	Exhaust Fan	-	763		778
	Return Fan	4,057	4,057	3,552	3,552
RTU4	Cooling Fan	16,651	16,651	14,523	14,523

Unit	Function	Pre		Post	
		Ex Ante	Ex Post	Ex Ante	Ex Post
	Heating Fan	-	43,774	-	25,027
	Exhaust Fan	465	465	535	535
	Return Fan	3,982	3,982	3,557	3,557
Pool Unit	All Fans	290,805	Outside evaluation boundary	226,337	Outside evaluation boundary
	Therms recovered	11,691	Not electric energy	12,434	Not electric energy
Total		**474,380**	**277,406**	**369,525**	**193,722**
Ex Ante Total Savings HVAC (kWH)					**104,855**
Ex Post Total Savings HVAC (kWH)					**83,684**

Results

The ex post total savings were 92% of the ex ante energy savings, and 95% of the peak demand savings.

The ex post savings were equal to the ex ante savings for the Cooling Enduse. The ex post savings were greater than the ex ante savings for the HVAC Enduse. But the ex post did not include net effects of the pool zone, with electric savings and additional natural gas usage for pool water heating from the loss of heat reclamation by the reduced run hours of the Dectron unit.

Site 8010 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Packaged rooftop units	152,752	152,753	100%	139.11	139.11	100%
Packaged rooftop units	104,855	83,684	80%	46.55	37.15	80%
Total	**257,607**	**236,437**	**92%**	**185.66**	**176.26**	**95%**

Reasons for Discrepancies

- Exclusion of the pool system in the ex post pre- and post-simulation models, which saved electricity for the dehumidification unit, while causing less winter heat reclamation which required the natural gas pool heater to operate longer.
- The ex ante model only included the HVAC proportion of savings in the pool zone, but excluded the cooling energy difference for the same equipment.

Other Findings and Recommendations

- This project involved the replacement of 20-year old HVAC equipment and considered existing 20-year old units as the baseline for this study. While the ex post found this designation acceptable, due to the existing equipment being operational and at a municipal facility (where is it common to extend maintenance for years before purchasing new HVAC equipment), Ameren Missouri should consider adopting or clarifying guidelines regarding when existing conditions are acceptable as the baseline for equipment that is already older than its normal EUL.

Site ID: 8011 (Enduse: HVAC)

Project Description

This project replaced ten rooftop HVAC units with five new makeup air (MAU) units to provide constant volume air flow to the factory area at a manufacturing facility.

The table below describes the energy efficiency measure and ex ante gross savings claimed for this project.

Site 8011 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Packaged / Rooftop Unit	HVAC	240,930	219.41
	Total	**240,930**	**219.41**

Data Collection

During the site visit with the facility engineer on December 4, 2020, the field engineer collected photographic documentation for the nameplates of the five new rooftop MAU units and the ten decommissioned RTUs (which were electrically disconnected but still located on the roof). The engineer accessed the unit controller for one MAU and captured screenshots of the heating run hours and cooling run hours since the July 2020 installation. The site contact provided operating schedules and space humidity requirements and described the inability of the existing system to provide adequate outside air to flush the odors from the plant manufacturing processes. The manufacturing plant's process requirements were changed to provide 100% outdoor air to the factory, as compared to the maximum economizer damper position of the replaced rooftop units.

Analysis

The ex post analysis leveraged the ex ante analysis by updating the inputs to the ex ante weather bin engineering analysis workbook and completed additional engineering calculations to capture the savings of the new efficient makeup air units when the MAU is in heating or economizer mode. The ex post adjustments to the original savings estimates include: (1) updated efficiency value for the baseline equipment, and (2) inclusion of fan motor savings when the MAUs are in heating and economizer mode.

The following table compares the ex ante and ex post values for key savings calculation inputs and shows the source of the ex post values.

Site 8011 Bin Analysis workbook inputs

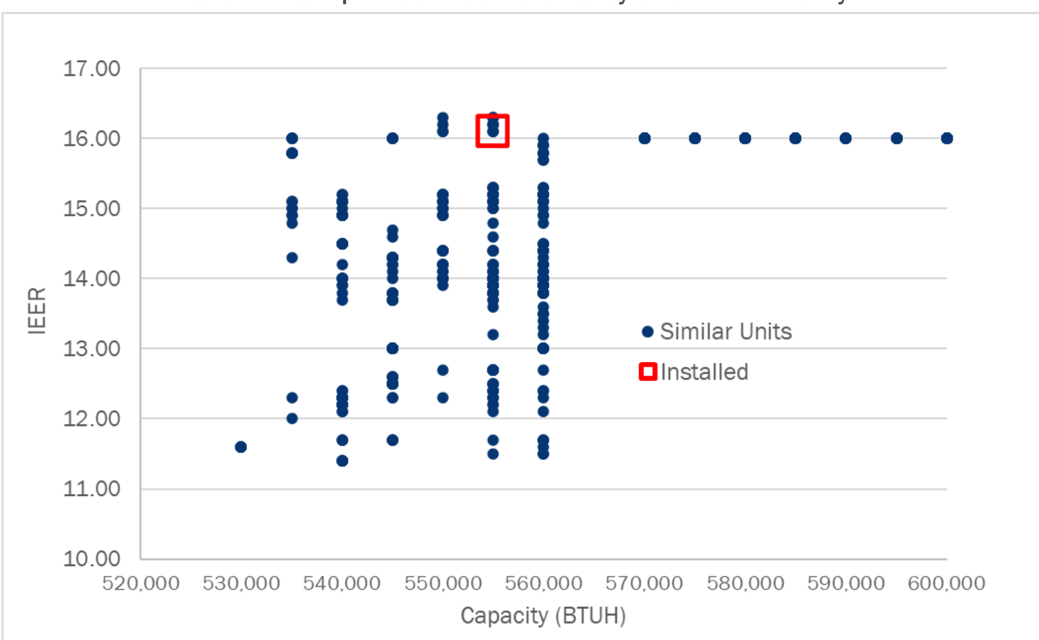
Factor	Ex Ante Value	Ex Post Value	Ex Post Source
Baseline IEER	10.1	11.4	AHRI listed products
Installed IEER	16.1	16.1	Model nameplate
Operating months	8	12	Site contact
Humidity set point	50%	40%	Weather bin

Baseline Equipment Specification

Neither the ex ante nor ex post analyses considered the existing units as the baseline, as they were near the end of their useful life (manufactured in 2007). The ex post analysis revised the baseline efficiency for the MAU unit after determining that the local building code prescriptive method was not applicable to a process cooling load. Instead, the ex post analysis determined an equivalent minimally-efficient unit based on the specifications of equipment available in the market.

The IECC 2015 Energy Efficiency code is enforced in the county where the facility replaced their HVAC equipment. The prescriptive efficiency for units installed to condition space for comfort has an EER rating of 9.9 and IEER of 11.4. As the HVAC equipment is providing conditioned air primarily for the process and not space comfort, the ex post analysis identified an alternate baseline through analysis of the AHRI equipment directory. The AHRI directory lists over 700 models and submodels of similar units to the installed 555,000 BTUH unit. The IEER efficiency of the installed unit model, along with the efficiency of comparable units by size, are shown on the following figure.

Site 8011 Comparable Baseline Units by Size and Efficiency



The evaluation team used this dataset of current production HVAC units (ranging from 520 MBTUH to 600 MBTUH) to identify a comparable minimally-efficient baseline unit with an IEER of 11.4. The ex post savings estimate established the 550 MBTUH unit with an IEER of 11.4 as the baseline.

Humidity Setpoint Adjustments

The ex post analysis adjusted the humidity input in the savings calculator from 50% (ex ante) to 40% (ex post). The dew point is controlled in the manufacturing process at 49°Fahrenheit.

Additional Fan Savings

During the collection of data from the unit controller, the total cooling, heating, and run hours were obtained, and modeled to estimate the heating, cooling and economizer set points. These endpoints were modeled with local weather data, to determine the values for the savings workbook bin analysis.

Site 8011 Metered Data July to December

MAU Status	Run Hour Meter (hours)	Implied Setpoint (°F)
Heat On	611	35
Economizer On	493	54
Economizer Off		35
Cooling On	2,205	54

The installed units have a very efficient IEER in the AHRI database for unitary equipment sized from 520–600 MBTUH. This efficiency is obtained by running efficiently at part loads of 25%, 50%, 75% and full load at 100%. The ex ante bin analysis considered the weather bins when the unit operates in cooling mode but does not capture the supply fan motor savings when in economizer mode and in heating mode. The equipment IEER includes the motor efficiency but can be expressed as savings only when included in the full-year model for the non-cooling weather bins. The specifications list the supply fan motors as ECM type, with 5.3-hp motors.

To estimate these fan savings, the ex post savings considered the difference in operating efficiency of a baseline induction motor compared to the installed ECM motors.

Site 8011 Bin Analysis and ECM Motor Savings

HVAC weather bin analysis		
Baseline (kWh)	Installed (kWh)	Savings (kWh)
748,909	530,284	218,625
ECM Motor Savings		
Hours excluded in bin analysis	3104	
Motor hp	5.3	
ECM Savings Factor	.27	
Active RTU	4	
Backup RTU	1	
Savings (kWh)		13,388
	Measure total savings	**232,013**

Results

The ex post savings considered both the cooling-only savings from the weather bin analysis and the full year ECM motor savings, resulting in annual energy savings of 232,013 kWh. These results represent a 96% realization rate for energy savings and 93% realization rate for the peak demand savings. The peak demand savings realization rate is lower as the additional energy savings for the ECM motor operate with the HVAC enduse profile.

Site 8011 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Makeup air units - Cooling	**240,930**	**218,625**	**96%**	219.41	199.10	93%
ECM supply fan motor - HVAC		**13,388**			5.94	
Total	**240,930**	**232,013**	**96%**	**219.41**	**205.04**	**93%**

Reasons for Discrepancies

- Baseline efficiency for the ex ante savings was a value that would not have been available to the program participant nor is applicable to a manufacturing facility. The ex post baseline efficiency of 11.4 reflects a minimum-efficient unit commercially available; coincidentally, this baseline aligns with the local building code for the prescriptive efficiency in the IECC 2015. The increased efficiency value for the baseline unit reduced total savings.
- Ex post included the additional HVAC savings for the ECM fan motors, not captured in the weather bin calculator tool; the addition of these fan-only savings increased total savings.

Other Findings and Recommendations

- Recommend updating the program weather bin analysis workbook to include additional energy conservation measure types and enduses.

Site ID: 8014 (Enduse: HVAC)

Project Description

This project retrofitted 50 variable air volume fan terminal unit (VAV/FTU) box controllers, programmed new minimum airflow setpoints, and installed digital wall thermostats to balance the conditioned air flow to the first- and second-floor common areas at a multi-story senior living facility. The project saves both fan and cooling energy by reducing the airflow and air conditioning requirements.

The following table describes the energy efficiency measures and ex ante gross savings claimed for this project. The estimated savings represent about 4% of annual facility consumption.

Site 8014 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
HVAC Controls / EMS	HVAC	88,905	39.47
	Total	**88,905**	**39.47**

Data Collection

Field staff met with the project trade ally's controls technician on December 8, 2020. Field staff obtained photographic documentation for rooftop units (RTU 6 and 7) and collected screenshots of the building control system for the current operating conditions of the RTUs and the previous seven days of stored history. The RTUs operate continuously to supply air to the common area, but all the VAV boxes had not been controlled for the last few years, with the air flow setpoint defaulted to 100% open. Data downloaded from the control system for the VAV boxes and the FTU boxes indicated that, in the post-installation condition, none of the boxes were opening to 100% and were modulating based on minimum air flow and space temperature setpoints.

The team also collected three years of facility consumption data covering both the pre-installation (baseline) period and the post-installation period. Although the pre- and post-installation periods spanned through the COVID-19 pandemic period, the facility continued operating without changes in building occupancy or daily usage, so the facility consumption data reflects normal operation.

Analysis

The new controls for the VAV and FTU boxes enabled the facility to program new setpoints and lower the outside air and the return air load on RTU-6 and RTU-7.

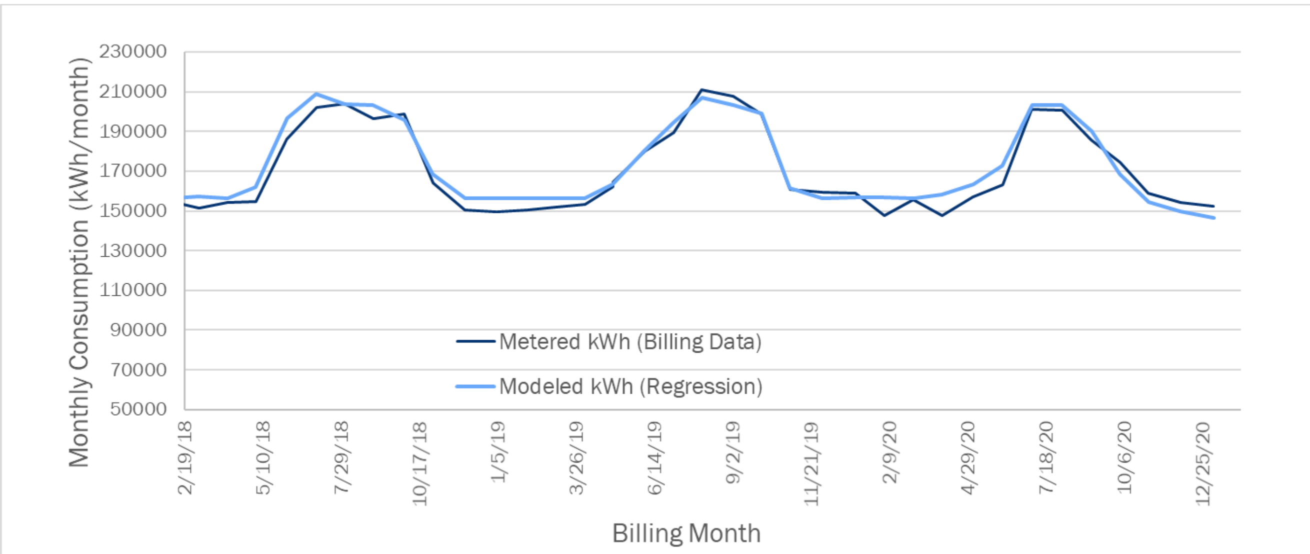
Ex ante project documentation indicates that the ex ante savings estimates are based only on a reduction in the RTU fan motor consumption and do not include associated savings on the cooling equipment. The project documentation indicates that the ex ante analysis assumes 16% of the building's baseline consumption is for ventilation and estimates restoring the VAV function to the two RTUs (for which the fans run continuously) will reduce ventilation consumption by 80%. The ex ante analysis includes some conservative adjustments to avoid overstating savings.

The ex post analysis used the IPMVP Option C, Whole Facility approach and performed a linear regression equation of the sites' billing energy data and local weather conditions to estimate the savings for both the fan motor energy and cooling compressor energy. The significant coefficients of the linear regression equation were the flag for the pre and post period, along with the cooling degree days. The HDD coefficient was not used in the final model, as the P-value was not significant.

Site 8014 Billing energy data and weather linear regression statistics

R Square	0.87		
Observations	37		
	Coefficients	**P-value**	**t Stat**
Intercept	156,451	0.0000	72.68
Pre/Post	(9,875)	0.0253	-2.34
CDD	113	0.0000	13.03

Site 8014 Billing energy data, weather data and regression model



The evaluation team estimated the annual energy savings by applying the linear regression model, built on current weather data and billing data, TMY3 typical year weather data and applied the factor for the HVAC Enduse to the energy savings to estimate summer peak demand savings. The HVAC Enduse factor best represents the demand savings for this project, as the savings was driven by both year-round fan motor savings and cooling savings.

Results

The ex post savings are 133% of the ex ante savings for both energy and peak demand.

Site 8014 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
HVAC Controls / EMS	88,905	118,503	133%	39.47	52.61	133%
Total	**88,905**	**118,503**	**133%**	**39.47**	**52.62**	**133%**

Reasons for Discrepancies

- By analyzing whole-facility consumption data, the ex post savings considered the effect of the new VAV and FTU box controllers and new setpoints, which achieved both fan motor savings and cooling savings, on the complete building HVAC. The ex ante savings estimate considered only the fan motor savings.

Other Findings and Recommendations

- N/A

Site ID: 8015 (Enduse: HVAC)

Project Description

A high school replaced a building's direct expansion (DX) cooling units with 119 variable refrigerant flow (VRF) split units with heat recovery. These units provide efficient simultaneous heating and cooling to satisfy zonal conditioning requirements. The project also installed a dedicated outdoor air supply (DOAS) unit with efficient fans and natural gas heat for fresh air requirements. The heating for fresh air was not in the project scope but did include the HVAC savings for the efficient direct drive fan operation. Additional measures of efficient lighting and window replacements implemented at the site are excluded from the ex post analysis because they fall outside the scope of the sample frame.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8015 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Variable refrigerant DX units	Cooling	47,683	43.42
Variable refrigerant DX units/DOAS	HVAC	26,068	11.57
	Total	**73,751**	**55.00**

Data Collection

The evaluation team conducted a site visit with the Site Director on December 9, 2020. The field engineer captured photo documentation of the new variable refrigerant cooling units with heat recovery, the dedicated outdoor air supply (DOAS), and nameplate model data of each unit. The current school operating schedules were collected along with the new equipment operating schedules. At the time of the site visit, the building management computer system (BMS) was not set up with a front front-end user interface, so the field engineering could not access the system for additional data collection.

The Trane Trace simulation model used as the source of ex ante savings was accessed for the baseline model and efficient model that excludes the window replacement measures.

Analysis

The ex post analysis leveraged the existing Trane Trace simulation models for review and revisions to ex ante assumptions with field collected data. The equipment and plant specifications aligned with the field-verified equipment nameplate and efficiency data. The evaluation team made one adjustment to the models by disaggregating the fan motor from the compressor, to evaluate savings separately for these motors.

Additionally, the evaluation team reviewed weather inputs for the models. While the weather data used in the ex ante is appropriate for the calibration and model construction, it is not representative of typical weather. The ex post analysis adjusted the baseline and efficient models with St. Louis Lambert Airport NOAA typical meteorological year (TMY3) weather data.

The evaluation team constructed a linear regression analysis between monthly billing consumption and weather data to verify the overall project savings. The analysis showed that monthly billing consumption over months with virtual school classes, combined with partially completed window replacements (window replacements were completed in phases) resulted in a low correlation between weather and consumption. Therefore, the ex post analysis relied on the results of the energy models with field-verified adjustments.

Site 8015 Baseline – Efficient Simulation Models for Ex Ante and Ex Post

	Baseline Simulation Model (kWh)		As-Installed Simulation Model (kWh)		Savings (kWh)	
	Ex Ante	Ex Post	Ex Ante	Ex Post	Ex Ante	Ex Post
Cooling	78,579	83,778	30,896	31,407	47,683	52,371
HVAC	51,035	49,230	24,967	23,824	26,068	25,406
Total	**129,614**	**133,008**	**55,863**	**55,231**	**73,751**	**77,778**

Results

The realization rate for electric energy savings is 105% and 107% for peak demand savings.

Site 8015 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Variable refrigerant DX units	47,683	52,371	110%	43.42	47.69	110%
Variable refrigerant DX units/DOAS	26,068	25,406	97%	11.57	11.28	97%
Total	**73,751**	**77,778**	**105%**	**55.00**	**58.97**	**107%**

Reasons for Discrepancies

- Ex post disaggregated equipment power in the Trane Trace simulation model as listed on the VRV model nameplate for fans and compressor. The ex post reran the energy models with TMY3 weather data to reflect typical annual energy savings.

Other Findings and Recommendations

- The evaluation team recommends that ex ante analyses utilize TMY3 weather data when possible. Use of TMY3 data in place of current-year weather improves the certainty of energy savings in future years.

Site ID: 8016 (Enduse: HVAC)

Project Description

This project replaced existing cooling control valves with smart control valves on three air handling units (AHUs) at a large sporting complex. The project saves energy by operating the chilled water pumps, condenser water pumps, and water-cooled chillers in more efficient operating ranges.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8016 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Cooling-Only HVAC Equipment	Cooling	69,565	63.35
	Total	**69,565**	**63.35**

Data Collection

The ex post method is based on the desk review of the available project documentation. Evaluation staff aggregated and reviewed documents from this project and from previous energy efficiency projects at the same site.

The ex ante savings estimate utilized the Energy Valve Savings Estimator tool provided by the manufacturer of the new air handler cooling coil control valves. The new smart control valves have a self-contained processor to monitor valve position, water flow, and temperature, to react quickly to optimize the outgoing water temperature based on the incoming water temperature and flow. The Energy Valve Savings Estimator tool has inputs from the user based on the equipment and operating conditions.

Analysis

The ex post updated the Energy Valve Savings Estimator tool to include the entire chiller plant and process feeds to another building. The approach was determined from a review of the tool, which considers all the equipment on the water side, and assumes the drop in the supply and return temperature is effective at all the AHUs on the secondary loop. This project replaced the valves on three AHUs (out of 14 total AHUs), which contribute to 20% of the chiller loop load based on coil cooling capacity.

The table below shows compares the ex ante and ex post inputs to the Estimator tool and provides the source of the ex post values.

Site 8016 Savings Estimator Workbook Inputs

Estimator Input	Ex Ante	Ex Post	Units	Ex Post Source
Evaluation Boundary	Air Handler Coil Cooling Load	Chiller Plant Capacity		Email from Energy Valve manufacturer
Chilled Water plant Load	903	2400	tons	Mechanical drawing
Number of chillers	1	2	number	Ex Ante narrative
Operating hours/day	12	12	hours/day	Ex Ante Report
Operating days/week	7	7	days/week	Ex Ante Report
Chiller IPLV	0.8	0.8	IPLV	Ex Ante Report
Actual secondary head	150	150	ft	Ex Ante Report
Min flow	30	30	Percent	Ex Ante Report
Tower fans	0.46	0.46	kW/ton	Ex Ante Report
Load profile 1.0	156	156	Hours	Ex Ante Report
Load profile 0.8	1248	1248	Hours	Ex Ante Report
Load profile 0.6	936	936	Hours	Ex Ante Report
Load profile 0.4	468	468	Hours	Ex Ante Report
Load profile 0.2	312	312	Hours	Ex Ante Report
Load profile 0.1	0	0	Hours	Ex Ante Report
Total hours	3120	3120	Hours	Ex Ante Report

The table below shows the results from the Savings Estimator tool using the ex post inputs, including the total chiller plant savings (including pump and chiller energy) for both an 8-degree delta T and to a 14-degree delta T. The ex post savings are calculated as the difference between the two delta T scenarios, to reflect the improvement from the 8-degree delta T to the 14-degree delta T.

The table also indicates the proportion of cooling load (20%) estimated to be carried by the three AHUs, and the final project ex post savings as 20% of the modeled total chiller plant savings. The project to replace the cooling coil water valves in three handlers, which carry 20% of the plant load, results in annual savings of 47,160 kWh.

Site 8016 Chiller Plant Savings & Installed Proportion

Savings Estimator (kWh)			Mechanical Drawing (MBH)	
Delta T (F)	Pump Energy	Chiller Energy	AHU	Coil Capacity
8	298,374	739,017	Site	27,188
14	168,976	636,583	AHU 1,2,11	6,943

Savings Estimator (kWh)			Mechanical Drawing (MBH)	
Delta T (F)	Pump Energy	Chiller Energy	AHU	Coil Capacity
Component Savings	129,398	102,434	Total	34,131
Total Chiller Plant Savings (kWh)		**231,832**	Proportion	**20%**
Project Savings (kWh)				**47,160**

The evaluation team consulted with the manufacturer of the installed energy valves to determine the evaluation boundary of the chiller plant cooling output used by the ex post savings method compared to the ex ante method's usage of the air handler cooling coil rating. The manufacturer's representative supported the ex post's analysis that the maximum achievable savings is the tons of chilled water produced, rather than the sum of the air handler cooling coil BTUs (when the chiller plan capacity is less than the sum of the cooling coils).

Results

The ex post savings is 68% of the ex ante energy and peak demand savings.

Site 8016 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Cooling equipment-install energy valve on AHUs	69,565	47,160	68%	63.35	42.95	68%
Total	**69,565**	**47,160**	**68%**	**63.35**	**42.95**	**68%**

Reasons for Discrepancies

- The ex ante analysis overestimated the savings by applying a portion of the capacity of the equipment controlled by the energy valves to the energy valve savings estimator tool. The valve manufacturer stated that the savings is limited to the actual tons of cooling leaving the chilled water plant.

Other Findings and Recommendations

- When multiple energy efficiency projects are completed at the same facility, the implementation team must take care not to overstate or double-count savings. The implementation team should review the total savings of all three projects at the same site to determine if the remaining work for valve replacements produces incremental savings.
- The implementation team should determine whether additional work at the project site will increase the number of chillers required to meet the site load from two 1300-ton chillers to three 1300-ton chillers.

Site ID: 8017 (Enduse: HVAC)

Project Description

This project, completed at a high school, replaced two existing constant volume rooftop air handling units (AHU) supplied from existing chilled water and hot water systems with new AHUs and implemented controls to improve system efficiency. Savings are achieved with the new controls interface to the AHUs by programming supply air temperature resets, cycling fans for occupied and unoccupied periods, and an enthalpy economizer.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8017 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
Rooftop AHU HRT5-Gym	HVAC	63,079	28.01
Rooftop AHU HHRT7	HVAC	2,318	1.03
	Total	**65,397**	**29.04**

Data Collection

The evaluation team collected the project documents, including the Trane Trace simulation model used to develop ex ante savings, simulation inputs and outputs, project invoices, and manufacturer specification data sheets. The evaluation team collected project documents from a previously-completed project that included planning documents for the evaluated project.

Analysis

The evaluation team verified existing Trane Trace simulation models and inputs for the baseline and alternative models in the Trane Trace 700 software. The evaluation team confirmed that the building description inputs and rooms match in both models.

The energy efficiency ratio (EER) of the new AHUs did not change, as the chilled water and hot water sources are the same prior to and following the efficiency improvements. Through the detailed review of the models, the evaluation team verified the Trane Trace models are accurate and acceptable for use in ex post analysis.

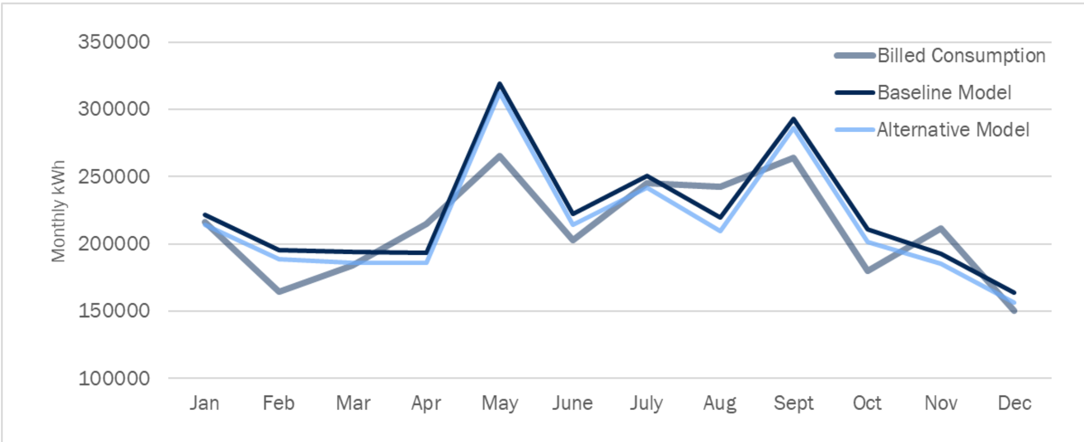
The savings are primarily from improvements to the system controls, including Supply Air Temperature Reset of +5°F for cooling and -5°F for heating, return fan programmed as Cycling with All Loads, and the enthalpy economizer replacing the dry bulb economizer. The new control methods are listed in the following table.

Site 8017 Inputs with Changes from Base to Proposed Model Simulations

Factor	Baseline Model	Proposed Model
System	VAV	VAV
Supply Air Temperature Reset	No	+5°F cooling -5°F Heating
Return Air Fan Control	Constant Fan Model	Cycling with All Loads
Economizer Type	Dry Bulb	Enthalpy

The evaluation team aggregated the baseline model and alternative model outputs from the Trane Trace simulation with the monthly billing energy data to verify the baseline model calibration, and then to verify the savings in the alternative model. The figure below shows the Trane Trace outputs for the baseline model, and alternative model compared to the monthly billing data.

Site 8017 Monthly Energy Usage - Billed, Baseline, and Alternative Model



The following table shows the modeled output with changes between each run.

Site 8017 Annual Energy Usage for Each Model with Savings

Equipment	Baseline (kWh)	Proposed Model (kWh)	Savings (kWh)
HHRT5: Supply Fan	93,106	30,027	63,079
HHRT7: Supply Fan	3,110	1,468	1,642
HHRT7: Return Fan	1,331	655	675

Results

The ex post savings are 100% of the Ex Ante energy savings and peak demand savings.

Site 8017 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Packaged/ Rooftop Unit	63,079	63,079	100%	28.01	28.01	100%
Packaged/ Rooftop Unit	2,318	2,318	100%	1.03	1.03	100%
Total	**65,397**	**65,397**	**100%**	**29.04**	**29.04**	**100%**

Reasons for Discrepancies

- N/A – the measure is installed and operating as planned.

Other Findings and Recommendations

- N/A

Site ID: 8018 (Enduse: HVAC)

Project Description

This project, completed at a two-story office building, replaced a 20-ton rooftop unit (RTU) and a 25-ton RTU with higher efficiency models that include enthalpy economizing and supply fan motors with variable frequency drives (VFDs). As a normal replacement, savings are estimated from the ASHRAE 90.1 2013 prescriptive unitary air conditioning unit baseline. Savings are achieved by the improved efficiency of the new RTUs compared to code-compliant models and through reduced cooling load when ambient conditions support enthalpy economizing.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8018 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
New rooftop units, 20-ton, 25-ton	HVAC	17,677	16.10
	Total	**17,677**	**16.10**

Data Collection

During the site visit on December 9, 2020 with the property manager, the field engineer collected photo documentation for the model nameplates of the two new RTUs, the new building system controller, and new air box actuator controls. At the time of the visit, the facility did not have a computer with a front-end user interface, or remote access to the interface, for the building management system (BMS). Consequently, the field engineer collected occupancy and operational schedules for the equipment from the property manager. The property manager provided the typical schedule for occupied and unoccupied equipment usage, along with describing the condition of the fan terminal units that previously operated 24 hours a day, seven days a week. The fan terminal units are measures implemented under this project, but not sampled for evaluation and are excluded in results.

Analysis

The ex post analysis leveraged the ex ante's weather bin calculator with inputs for schedules, baseline equipment, new equipment, economizer setpoints, and load information. All the inputs align with the site visit observations, with one exception: the baseline equipment efficiency did not align with the prescriptive tables in the ASHRAE 90.1 Standard. The building code for the county is the International Energy Conservation Code (IECC) 2015, which references the ASHRAE 90.1 2013 standard.[5,6] The code requires a minimum integrated

[5] International Code Council (2016). 2015 International Energy Conservation Code, Chapter 4 Commercial Energy Efficiency retrievable at: https://codes.iccsafe.org/content/IECC2015
[6] American Society of Heating, Refrigerating and Air-Conditioning Engineers (2013). ANSI/ASHRAE/IES Standard 90.1-2013, Energy Standard for Buildings Except Low-Rise Residential Buildings

energy efficiency ratio (IEER) of 11.6 for a 240,000 BTU unitary air conditioner with or without electric heat. The ex ante analysis applied an IEER of 11.4.

The efficient RTU model also included the option of enthalpy economizers, which provide a higher dry bulb temperature range for enabling outside air to flow inside with less run time on the compressors. The weather bin calculator utilized the dry bulb temperature as a substitute for the enthalpy by raising the cutoff point from 60° Fahrenheit to 67° Fahrenheit. The ex post analysis determined that this binning included too many hours when the enthalpy exceeded the changeover setpoint: 28 BTU/lbm of dry air. The change did not affect the savings results due to the size of the weather bins in the calculator tool, which utilize a four-degree bin range and make it difficult to observe effects of slight changes to setpoints.

Site 8018 Weather Bin Inputs

Factor	Source	Ex Ante Value	Ex Post Value
Baseline IEER – 240,000 BTUH	ASHRAE 90.1 2013	11.4	11.6
Baseline IEER – 300,000 BTUH	ASHRAE 90.1 2013	11.4	11.6
Enthalpy changeover setpoint	h <=28 BTU/lb m	67	66

Results

Following revision of the baseline IEER value from 11.4 (ex ante) to 11.6 (ex post), the weather bin analysis showed an annual energy savings of 15,569 kWh and peak demand savings of 14.18 kW, and an achieved realization rate of 88% for both energy and demand savings.

Site 8018 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
New rooftop units	17,677	15,569	88%	16.10	14.18	88%
Total	**17,677**	**15,569**	**88%**	**16.10**	**14.18**	**88%**

Reasons for Discrepancies

- Ex post applied the ASHRAE 90.1 2013 prescriptive baseline for unitary air conditioners without gas heat of 11.6, in contrast to the value of 11.4 applied in the ex ante analysis.

Other Findings and Recommendations

- The ex ante weather bin analysis utilizes four-degree temperature ranges. The evaluation team recommends updating to the weather bin calculator tool to utilize smaller temperature bins (e.g., one- to two-degree ranges), affording greater granularity on the effects of small changes in setpoints, loads and occupied periods, as exhibited in this project.

Site ID: 8040 (Enduse: HVAC)

Project Description

The project replaced fifteen air handling units (AHUs) with six new AHUs and new air ducts, installed new condenser water pumps and chilled water pumps, and implemented new building controls at a six-story office building. The air duct work included converting dual duct constant volume (CV) systems to variable air volume (VAV) systems, and the controls strategies include supply air temperature resets and optimized lighting scheduling. Energy savings are achieved by the overall improved efficiency and reduced runtime of the cooling system and by the reduction in cooling load caused by the efficient lighting equipment upgrades.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8040 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
HVAC, Pumps, Fans	HVAC	2,340,719	1,039.24
	Total	**2,340,719**	**1,039.24**

Data Collection

The ex ante energy savings were estimated by comparing a baseline building model of the existing building mechanicals with core and shell alterations to a model of the existing building with new mechanicals and the same core and shell alterations. The evaluation team collected the project documents, installation scheduling chart, invoices, and post-installation equipment photos, and the pre- and post- building model inputs for load, energy, and simulation outputs.

The evaluation team compared building model input data to the collected project-specific data and other sources. The evaluation team also collected data from the St. Louis city tax assessor database for building envelope size and reviewed satellite imaging to verify the building size and glazing percentage of the exterior wall space.

Analysis

The IES software model developed for the ex ante savings was detailed with the building envelope, loads, and HVAC equipment and modeled the energy savings in three components, as described in the table below.

Site 8040 Ex Ante Modeled Savings

End Use	Modeled Baseline	Modeled Efficient	Modeled Savings
Cooling	1,713,423	1,064,019	649,404
HVAC	2,595,905	1,273,719	1,322,186
Heating	2,230,675	1,861,546	369,129
Total	**6,540,003**	**4,199,284**	**2,340,719**

The evaluation team reviewed the inputs for the external shell, floor levels, core spaces, existing and proposed HVAC equipment, and the thermal templates. Since the building is still leasing and not fully occupied, the evaluation did calibrate the model facility consumption data, as the model estimates performance for a fully occupied building.

The evaluation team reviewed the modeling output files to aggregate the energy usage for the baseline and the proposed simulations. The following table modeled monthly energy performance for key HVAC equipment in the baseline and efficient models and shows the savings as a percentage of baseline energy consumption.

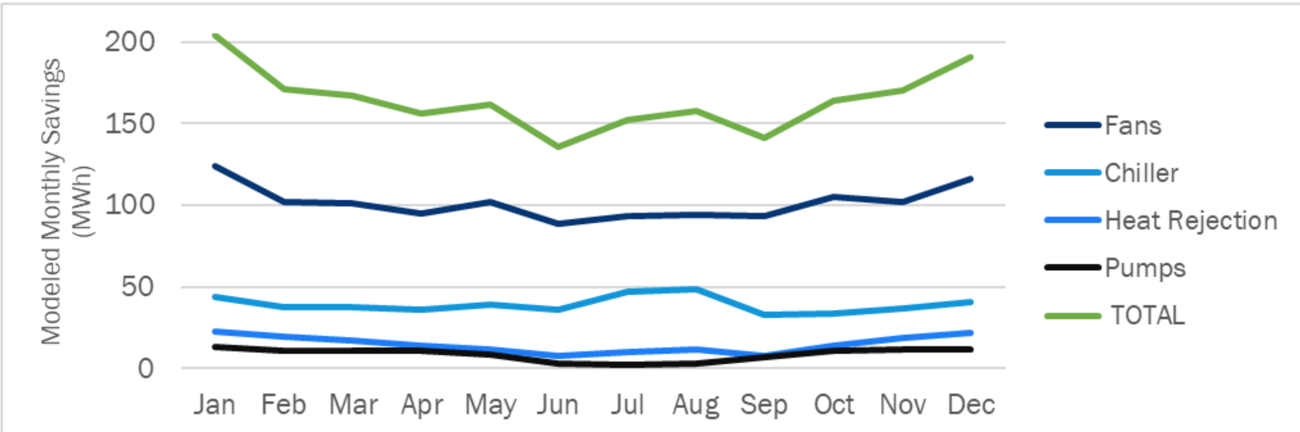
Site 8040 Simulation Models – Monthly Energy Usage and Savings Percent

	Energy Usage (MWh)												
Baseline	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Chiller	72	69	93	97	119	149	175	171	127	95	82	74	1,323
Fans	210	185	200	192	198	196	205	202	194	198	195	208	2,385
Pumps	17	15	17	17	18	18	20	20	18	17	17	17	211
Heat Reject	31	28	31	30	32	36	40	40	32	31	30	31	390
Total	**330**	**297**	**341**	**336**	**367**	**399**	**440**	**433**	**371**	**341**	**324**	**330**	**4,309**
Efficient	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Chiller	28	31	55	61	80	113	128	122	94	61	45	33	851
Fans	86	83	99	97	96	107	112	108	101	93	93	92	1,167
Pump	4	4	6	6	9	15	18	17	11	6	5	5	107
Heat Reject	8	8	14	16	20	28	30	28	24	17	11	9	213
Total	**126**	**126**	**174**	**180**	**205**	**263**	**288**	**275**	**230**	**177**	**154**	**139**	2,338
	Modeled Savings as a Percentage of Baseline (%)												
Savings	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Chiller	61%	55%	41%	37%	33%	24%	27%	29%	26%	36%	45%	55%	36%
Fans	59%	55%	51%	49%	52%	45%	45%	47%	48%	53%	52%	56%	51%
Pumps	76%	73%	65%	65%	50%	17%	10%	15%	39%	65%	71%	71%	49%
Heat Reject	74%	71%	55%	47%	38%	22%	25%	30%	25%	45%	63%	71%	45%

To review the seasonal load shape, the evaluation team examined the monthly energy savings for each component of the energy simulation model as well as the savings for all components combined (figure below).

The ex ante peak demand savings were all binned to the HVAC Enduse. The Fans, Heat Rejection, and Pump groups have decreasing usage during Summer and are binned appropriately to the HVAC Enduse. The chiller energy use averages 41 MWh during the summer, and 38 MWh the remainder of the model year. The minimal summer increase trend aligns best with the HVAC Enduse.

Site 8040 Energy Savings Per Month Over Baseline (MWh)



Results

The ex post savings were 100% of the ex ante savings for energy and peak demand use.

Site 8002 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
HVAC, Pumps, Fans	2,340,719	2,340,719	100%	1,039.24	1,039.24	100%
Total	**2,340,719**	**2,340,719**	**100%**	**1,039.24**	**1,039.24**	**100%**

Reasons for Discrepancies

- None – the ex post analysis verified the inputs of the building model.

Other Findings and Recommendations

- The project retained major equipment such as the water cooled chillers, while replacing the waterside pumps in the building. The air handling unit has a long effective useful life, but the components such as fans and motors have a lesser useful life. Future modeling efforts should consider disaggregating components of custom measures with significant savings to increase the certainty of baseline assignment.

Site ID: 8021 (Enduse: Motors)

Project Description

This project, completed at a manufacturing plant, replaced the motor starters on five cooling tower fan motors with variable frequency drives (VFD) and installed a new controller, to reduce both the run time and fan speed based on the cooling tower water discharge temperature.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8021 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
VFD for Fan	HVAC	621,935	276.13
	Total	**621,935**	**276.13**

Data Collection

During the site visit with the project manager on December 10, 2020, the field engineer photographed the new VFD system including motor nameplates. Additionally, the field engineer collected information on the plant operating schedule, new control system, operating speed of all five drives, and the wet and dry bulb outdoor temperatures at the time of the visit. Although, trending was not enabled in the control system, the discharge water temperature setpoint was identified, along with manually logged water temperatures. Following the site visit, the evaluation team utilized field collected cooling tower model numbers to locate manufacturer specification datasheets containing capacity, horsepower, and airflow data. The evaluation team conducted a review of all field collected information following the site visit.

Cooling tower operating conditions at 61°F wet bulb outdoor air temperature—the weather conditions at the time of the site visit—are provided in the following table. At 61°F wet bulb temperature, only two cooling towers are needed to meet building demand, by system design. As a result, three of the cooling towers were in OFF mode during the site visit. As temperatures increase, heat rejection of the cooling towers decreases, requiring additional cooling towers to turn on to meet building demand.

Site 8021 Cooling Tower Operation at 61°F Wet Bulb (Site Visit 12/10/2020 11:45 AM)

Cooling Tower ID	Hertz (Hz)	Cooling Tower Model Number	Drive Installed	VFD Display Brake hp (bhp)
CT2	0	VTI1-N325-P	Y	
CT4	0	VT1-N325-P	Y	
CT5	29.1	VT1-N325-P	Y	4.883
CT7	29.1	VTI-340-OM	Y	4.883
CT8	0	VTI-340-OM	Y	

Analysis

The ex ante savings estimate did not provide the method or source for the estimate of the annual energy savings other than an existing and proposal annual usage value. The ex post savings estimate was informed by the ASHRAE Fundamentals Handbook, primarily by the Cooling Tower Model section indicating that “for energy calculations, cooling tower performance is typically described in terms of the outdoor wet-bulb temperature, (range), and (approach)”, and later stating “more sophisticated models use rating performance data.” The cooling tower model nameplate data collected by the field evaluation staff informed the development of the wet bulb temperature load profile on the cooling tower manufacturer’s interactive website.

The weather bins were selected for the incrementing load of additional cooling towers based on the wet bulb temperature and the increasing fan speed. The table below shows the model of the installed VFD drives on the fan motors along with the same weather conditions and water flow for the Motor Starter baseline condition.

Site 8021 Cooling Tower Weather Bin Analysis

Minimum Wet Bulb Temperature (T_{wb}) for Bin Range	Bin Hours	Variable Frequency Drives on Fan Motors					Baseline Motor Starter		Savings (kWh)
		Towers	BHP	Total BHP	Speed (%)	Hz	Towers	Total BHP	
0	170	2	4.42	8.84	48	29	2	90	11,041
10	339	2	4.42	8.84	48	29	2	90	22,018
20	898	2	4.42	8.84	48	29	2	90	58,324
30	1,306	2	4.42	8.84	48	29	2	90	84,823
40	1,525	2	4.42	8.84	48	29	2	90	99,047
50	1,414	2	4.42	8.84	48	29	2	90	91,838
60	135	2	4.42	8.84	48	29	2	90	8,768
61	389	2	4.84	9.68	49	30	2	90	25,004
63	689	2	5.90	11.80	53	32	2	90	43,118
66	475	3	2.63	7.89	40	24	2	90	31,212
68	827	3	3.52	10.56	45	27	2	90	52,574
72	274	4	2.43	9.72	39	23	3	130	26,374
74	113	4	4.40	17.60	62	37	3	130	10,164
75	99	4	5.10	20.40	50	30	3	130	8,683
76	84	4	7.00	28.00	56	34	4	180	10,218
78	22	5	3.15	15.75	39	24	4	180	2,892
80	1	5	6.46	32.31	51	30	5	220	150

The ex ante demand savings applied the HVAC Enduse factor; the ex post analysis considered both the HVAC and Process Enduse for estimating peak demand savings. The load on the tower is not weather dependent from the manufacturing plant, but the heat rejection by the cooling tower is highly temperature dependent, requiring five cooling tower cells to operate when outdoor wet bulb temperatures exceed 80°F. The Process Enduse factor underestimates the total peak demand savings, while the HVAC Enduse factor overestimates the savings for this application. The ex post analysis determined that, based on the year-round load profile with an increase in demand with outdoor temperature, the HVAC Enduse better represented the measure's annual performance.

Results

The ex post analysis resulted in electric energy savings of 586,248 kWh for a 94% realization rate and demand savings of 260 kW for a 94% realization rate.

Site 8021 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
VFD for Fan	621,935	586,248	94%	276.13	260.28	94%
Total	**621,935**	**586,248**	**94%**	**276.13**	**260.28**	**94%**

Reasons for Discrepancies

- The ex post savings used two known points to model the cooling tower operation, the first based on a low wet bulb temperature day with two cooling towers operating and known fan speed. The second known point is the maximum operating capability based on St. Louis TMY weather data and the cooling tower design capability engineering data sheets.

Other Findings and Recommendations

- The peak demand savings, calculated as the product of the annual energy savings and the coincidence factor for the HVAC Enduse, likely overstates the peak demand savings for this project. To avoid overstating peak demand savings, the program should consider (1) developing custom, site-specific coincidence factors, and/or (2) setting an upper limit to the peak demand savings based on the physical capacity of the equipment or, for equipment that operates continuously throughout the year, based on the following equation:

$$kW_{Upper\ Limit} = kWh_{saved} / 8760\ hours$$

Site ID: 8022 (Enduse: Motors)

Project Description

This project installed six variable frequency drives (VFD) to control the motors controlling shot blasting equipment at a metal processing and fabrication facility. VFDs installed for the shot blast wheels, which increase air pressure, generate air flow, and propel abrasive materials are a primary contributor to savings.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8022 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Install VFDs to shot blast equipment motors	Motors	288,266	39.76
Total		**288,266**	**39.76**

Data Collection

Evaluation team staff collected project documents from the program tracking database and requested additional photographic verification of the equipment operation from the program implementer. The evaluation team also reviewed baseline operating hours, equipment schedule, and duty cycle of the equipment. The initial VFD photo documentation was obtained before the programming of the equipment was complete. A final series of photos showed the VFDs operating at a frequency of 48 hertz (Hz), 80% of the full motor speed.

The ex ante analysis used the Yasakawa Energy Savings Predictor to estimate savings for each motor (see table). The evaluation team found that six motors included in the ex ante analysis show negative savings.

Site 8022 Ex Ante Measure Savings

VFD	Energy Savings (kWh)
Blast Wheel Motor 1	53,463
Blast Wheel Motor 2	53,463
Blast Wheel Motor 3	53,463
Blast Wheel Motor 4	53,463
Dust collector fan	44,553
Blow off fan	35,642
Elevator[a]	-1,590
Auger 1[a]	-1,103
Auger 2[a]	-1,103
Screw Drive[a]	-662
Chain drive 1[a]	-662
Chain drive 2[a]	-662
Total Savings	**288,264**

[a] Did not receive an incentive through the Custom program.

Additional project documentation showed that the equipment labeled Elevator, Auger 1, Auger 2, Screw Drive, Chain Drive 1, and Chain Drive 2 did not receive an incentive through the program. Since these motors were not incented, the ex post considered these motors outside the evaluation boundary and did not include these motors in the ex post savings calculations. The total annual ex ante savings without the non-incented equipment is 294,047 kWh.

Analysis

The evaluation team estimated the energy savings for the six VFDs for which the customer received incentives and which control Blast Wheel Motors 1 through 4, the dust collector fan, and the blow off fan.

The ex post used the Default Curve method from the *Uniform Methods Project (UMP) Chapter 18 VFD Evaluation Protocol* to evaluate the reduction in motor power from adding VFDs to the equipment.[7] The evaluation team selected this method, in part, because the ex ante project documentation included the Energy Savings Predictor results in PDF format, so the evaluation team could not access the ex ante power curves.

Using the UMP protocols, the team selected the Default Curve method due to lack of equipment-specific performance curves, for the shot blast wheels. The UMP protocols provide default equations and curve correlation coefficients for different fan types and control strategies. The evaluation team selected the coefficient values for a Forward Curved fan type controlled using discharge dampers, determined through project documentation.

$$kWh_{savings} = kWh_{Motor/base} - kWh_{Motor/VFD}$$

$$kWh_{motor} = hp \times Power\ \% \times 0.746\ kW/hp \times HOU \times (1/\eta_{motor})$$

$$Power\ \% = a + b \times Flow + c \times Flow^2$$

Where:

Value	Fan	Variable Frequency Drive
a	0.190667	0.219762
b	0.31	-0.874784
c	0.5	1.652597
Flow	100%	80%

The table below shows the ex post calculated parameters and energy savings for each motor included in the final ex post analysis (i.e., excluding the motors that did not receive a project incentive).

Site 8022 Savings by Measure

VFD	Motor hp [A]	Motor Efficiency, η_{motor} [a]	Pre Power % [b]	Post Power % [c]	Annual operating hours [d]	Energy Savings (kWh) [e]
Blast wheel motor 1	30	0.936	100	58	5200	52,581
Blast wheel motor 2	30	0.936	100	58	5200	52,581
Blast wheel motor 3	30	0.936	100	58	5200	52,581
Blast wheel motor 4	30	0.936	100	58	5200	52,581
Dust collector fan	23	0.936	100	58	5200	43,817
Blow off fan	20	0.936	100	58	5200	35,054
					Total	**289,193**

[a] Motor nameplate data

[b] Percentage of full power without VFD

[c] Percentage of full power with VFD, estimated based on verified 48 Hz operation and UMP default curve model

[7] National Renewable Energy Laboratory (2017), The Uniform Methods Project, Chapter 18: Variable Frequency Drive Evaluation Protocol (pp. 10-18) retrievable at https://www.nrel.gov/docs/fy17osti/68574.pdf

[d] Based on 20 hours per day, 5 days per week, 52 weeks per year.

[e] Calculated based on reduction in average motor power and annual hours of operation: Motor hp x 0.746 kW/hp x % Power / Motor Efficiency x Annual Operating Hours

Results

The ex post energy savings are 100.3% of the ex ante energy and peak demand savings. The ex post savings did not include the negative effect of the drive motors that were installed and not incented, as they were capable of operating independent of the incented motors. The savings could have been achieved without installing the non-incented drive motors.

Site 8022 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
VFD for Process Motor	288,266	289,193	100%	39.76	39.89	100.3%
Total	**288,266**	**289,193**	**100%**	**39.76**	**39.89**	**100.3%**

Reasons for Discrepancies

- Ex ante savings estimate included six VFDs with negative savings which were installed but not incented. The ex post considered these non-incented drives as outside the evaluation boundary, as the savings could be achieved without their installation. The removal of these negative ex ante savings was offset by slightly lower savings for each of the six incented VFDs included in the ex post savings.

Other Findings and Recommendations

- N/A

Site ID: 8023 (Enduse: Motors)

Project Description

This project, completed at a high-rise office building, replaced the centrifugal supply air fan, return air fan, motors, and variable frequency drives (VFDs) with an array of direct drive electronically commutated motors (ECM). The project replaced the 75-hp supply fan motor with a 20-fan array and replaced the 40-hp return fan motor with a 10-fan array. The system efficiency increased by removing the efficiency losses associated with the fan V-belts and VFD input-to-output power ratio and by reducing the excess static pressure in the air supply duct plenums. The project achieved additional savings by rescheduling the fans to operate during occupied periods only, instead of the previous continuous schedule.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8023 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
ECM Motor for HVAC	Motors	197,181	87.55
	Total	**197,181**	**87.55**

Data Collection

During the site visit on December 1, 2020 with the maintenance manager, the field engineer collected photographic documentation of the supply and return fan nameplates, screenprints of the system operation in the building management system (BMS), and operating history of the supply and return fan.

The evaluation team collected the manufacturer's specification datasheets from the implementer's tracking system, along with the ex ante Fan Array Selection Savings Tool. Collected specification datasheets for the baseline VFD provided the efficiency value. The US Department of Energy's website provides typical motor V-belt efficiencies, which the evaluation team used to assess the losses from belt slippage.[8]

Analysis

The ex post analysis updated the Fan Array Selection Savings Tool with field collected data and information sourced from manufacturer specification datasheets. A comparison of ex ante and ex post assumptions are presented in the table below. The evaluation team confirmed the System Effect Efficiency through the BMS by comparing the air handler static pressure sensor with the new static pressure sensors further downstream in the plenum, which subsequently determines the variable air volume (VAV) mixing box demand.

Site 8023 Algorithm Inputs

Factor	Ex Post Source	Ex Ante Value	Ex Post Value
Hours – Baseline	Site contact	8,760	8,760
Hours – As Installed	BMS Schedule	4,380	4,380
Motor efficiency – Baseline	Implementer pre-install pictures	0.87	0.95
VFD efficiency – Baseline	VFD manufacturer	0.93	0.97
Centrifugal fan efficiency – Baseline	eQuest tables	0.82	0.82
Drive belt efficiency – Baseline	US DOE & Gates published docs[a]	RA = 0.87 SA = 0.87	RA = 0.91 SA = 0.95
Motor x Fan efficiency – Installed	Manufacturer Specification	0.61	0.61
System Effect – Installed	Ex Ante Value/BMS Confirmed	0	0

[a] Gates Rubber Company (1997), "Synchronous Belt Drives Restore Energy Savings," is retrievable at: https://ww2.gates.com/IF/facts/documents/Gf000188.pdf

The following table compares the ex ante and ex post estimates for the baseline and installed energy consumption and savings for supply fan and return fan equipment. The ex ante and ex post analyses calculate

[8] The US DOE (2012) "Replace V-Belts with Notched or Synchronous Belt Drives" states that V-belts have a peak efficiency of 95% or more with potential degradation of efficiency by as much as 5% over time if belt slippage occurs. The article is retrievable at: https://www.nrel.gov/docs/fy13osti/56012.pdf

the same energy consumption values for installed supply and return fans. However, the ex post analyses estimates lower energy consumption compared to ex ante for the baseline equipment. This reduction in ex post baseline energy consumption is due to the inclusion of the manufacturer's efficiency rating for the VFD model and the adjustments made to the V-belt efficiency, and results in a lower total savings for ex post compared to ex ante.

Site 8023 Fan Array Savings

Fan	Ex Ante kWh	Ex Post kWh
Supply Fan - Baseline	210,408	169,186
Supply Fan - Installed	64,188	64,188
Supply Fan – Savings	146,220	104,998
Return Fan - Baseline	73,331	64,976
Return Fan - Installed	22,370	22,370
Return Fan – Savings	50,961	42,606
Total Savings (kWh)	197,181	147,606

Results

The ex post energy and demand savings are 75% of the ex ante energy and demand savings.

Site 8023 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
ECM Motor for HVAC	197,181	147,605	75%	87.55	65.53	75%
Total	**197,181**	**147,605**	**75%**	**87.55**	**65.53**	**75%**

Reasons for Discrepancies

- The ex post analysis utilized model specific VFD efficiencies to calculate savings. In contrast, the ex ante analysis used a VFD efficiency slightly lower than the manufacturer-specified value.
- The ex ante analysis assumed a V-belt efficiency of 0.87, without providing a source of the assumption. The ex post analysis used US DOE published V-belt efficiencies ranging between 0.91 and 0.95.

Site ID: 8025 (Enduse: Motors)

Project Description

This project, completed at a high-rise office building, replaced the constant volume domestic water pumps for both the low-rise loop and the high-rise loop with six efficient pumps and motors controlled by variable frequency drives (VFDs).

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8025 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
VFD for Pump	Motors	70,285	9.70
VFD for Pump	Motors	57,159	7.88
	Total	**127,444**	**17.58**

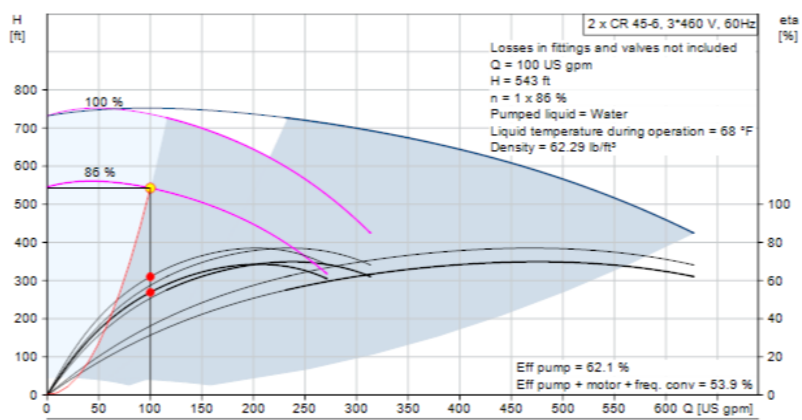
Data Collection

During the site visit with the facility manager on December 7, 2020, the field engineer collected photographic documentation for the six new motors and VFDs, new control systems, and the current operating setpoints for differential pressure, water flow, and motor speeds. The evaluation team obtained baseline equipment specifications from the post-installation site visit documentation.

COVID-19 has affected the facility occupancy and operating schedules. The evaluation team confirmed the current daily operating and water usage schedules as the basis of design with the site contact. The reduced building occupancy, confirmed at 30% of the pre-COVID-19 pandemic occupancy, levies a small effect on domestic water usage, but the domestic water system has the same requirements for discharge pressure to the upper stories, minimizing the effects of reduced occupancy on savings.

The pump performance curves for the two models of the new pumps were constructed at the manufacturer's product website (shown below). The baseline pump curves were also constructed, using the same system head (ft), water flow (gpm), but at constant speed.

Site 8025 Performance Pump Curve – Efficient Case – Low Zone Pumps



Source: Grundfos Website: https://www.grundfos.com/

Analysis

The tables below show the Water Flow load profile for each baseline pump system and efficient pump system, including (1) the basis of design inputs for daily water flow and usage, (2) the varying speed for the new VFDs (installed case) or the constant speed of the baseline pumps (baseline case), (3) the input horsepower and motor power at the flows and the total dynamic head of 543 feet (high zone system) and 289 feet (low zone system), and the annual energy consumption for each case. The cases are for the Baseline Case and As-Installed case for both the High Zone and Low Zone.

The pump differential pressure during the site visit, recorded at 231 psi (521 feet of head) is similar to the design head of 543 feet. The pump differential pressure for the low zone system, recorded at 128 psi (289 feet of head) is the same as the basis of design value of 289 feet of head.

Site 8025 High Zone Load Profile and Energy Usage: Baseline Case

Flow (GPM)				Hours		Speed (%)			Input Horsepower (HP)			Input (kW)	Annual (kWh)
Pump 1	Pump 2	Pump 3	Total	Annual	Day	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	All	All
100	-	-	100	2,555	7	100	-	-	33.0	-	-	27.3	69,695
170	-	-	170	2,190	6	100	-	-	39.8	-	-	32.9	72,049
-	185	185	370	1,095	3	-	100	100	-		86.5	72.9	79,798
-	200	-	200	1,460	4	-	100	-	-	44.2	-	37.2	54,367
150	-	-	150	1,460	4	100	-	-	33	-	-	27.3	39,826
			Total	**8,760**	**24**								**315,736**

Site 8025 Low Zone Load Profile and Energy Usage: Baseline Case

Flow (GPM)				Hours		Speed (%)			Input Horsepower (HP)			Input (kW)	Annual (kWh)
Pump 1	Pump 2	Pump 3	Total	Annual	Day	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	All	All
75	-	-	75	2,555	7	100	-	-	14.7	-	-	12.4	31,607
-	150	-	150	2,190	6	-	100	-	--	18.9	-	16.8	36,739
-	140	140	280	1,095	3	-	100	100	-		37.5	33.3	36,448
--	100	100	200	1,460	4	-	100	100	-		33.0	29.3	42,765
-	135	-	135	1,460	4	-	100	-		18.4	-	16.3	23,845
			Total	**8,760**	**24**								**171,405**

Site 8025 High Zone Load Profile and Energy Usage: As Installed Case

Flow (GPM)				Hours		Speed (%)			Input Horsepower (HP)			Input (kW)	Annual kWh
Pump 1	Pump 2	Pump 3	Total	Annual	Day	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	All	All
100	-	-	100	2,555	7	86	-	-	22.1	-	-	19.0	48,468
170	-	-	170	2,190	6	91	-	-	31.2	-	-	26.1	57,203
185	185	-	370	1,095	3	92	92	-		66.8	-	55.7	61,024
200	-	-	200	1,460	4	93	-	-	35.8	-	-	29.7	43,377
150	-	-	150	1,460	4	89	-	-	28.4	-	-	23.9	34,938
			Total	**8,760**	**24**								**245,010**

Site 8025 Low Zone Load Profile and Energy Usage: As Installed Case

Flow (GPM)				Hours		Speed (%)			Input Horsepower (HP)			Input (kW)	Annual kWh
Pump 1	Pump 2	Pump 3	Total	Annual	Day	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	All	All
75	-	-	75	2,555	7	81%	-	-	8.0	-	-	7.0	17,967
75	75	-	150	2,190	6	90%	Stand by	-	14.5	Stand by	-	12.4	27,047
140	140	-	280	1,095	3	88%	88%	-		27.2	-	23.0	25,152
100	100	-	200	1,460	4	82%	-	-		19.7	-	17.1	24,908
135	-	-	135	1,460	4	88%	-	-	13.1	-	-	11.1	16,177
			Total	**8,760**	**24**								**111,250**

Site 8025 High Zone and Low Zone Energy Savings by Hour Bin

Hours	High Zone				Low Zone			
Annual	Pre	Post	kWh	kW	Pre	Post	kWh	kW
2,555	69,695	48,468	21,227	2.93	31,607	17,967	13,640	1.88
2,190	72,049	57,203	14,846	2.05	36,739	27,047	9,693	1.34
1,095	79,798	61,024	18,774	2.59	36,448	25,152	11,296	1.56
1,460	54,367	43,377	10,991	1.52	42,765	24,908	17,858	2.46
1,460	39,826	34,938	4,888	0.67	23,845	16,177	7,668	1.06
Total	**315,736**	**245,010**	**70,726**	**9.76**	**171,405**	**111,250**	**60,155**	**8.30**

Results

The ex post savings for the high zone pumps are 101% of the ex ante energy and peak demand savings, and the ex post savings for the low zone pumps are 105% of the ex ante energy and peak demand savings, for a project total of 103%.

Site 8025 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
VFD for Pump	70,285	70,726	101%	9.70	9.76	101%
VFD for Pump	57,159	60,155	105%	7.88	8.30	105%
Total	**127,444**	**130,880**	**103%**	**17.58**	**18.05**	**103%**

Reasons for Discrepancies

- The ex ante analysis used four data points to create the performance curves used in estimating savings. The ex post analysis utilized the manufacturer's interactive pump design tool to identify a minimum of ten data points, subsequently used in creating the performance curves. The additional data points in the ex post analysis increases the precision of the calculated savings.

Other Findings and Recommendations

- The evaluation team recommends revision of the Custom Program application requirements to specify submission of Excel-based calculations. Calculations for this project are submitted in a PDF file format, preventing the evaluation team from fully assessing the significance of the discontinuity in the efficient pump model name and performance curves.

Site ID: 8026 (Enduse: Motors)

Project Description

This project installed a variable frequency drive (VFD) on the pump motor for the washing equipment that washes trucks exiting the outdoor facility loading area. The VFD saves energy by reducing the pump's operating time and motor speed.

The following table describes the energy-efficiency measure and ex ante gross savings claimed for this project.

Site 8026 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
VFD installation to pump motor	Motors	186,828	25.77
	Total	**186,828**	**25.77**

Data Collection

Field staff met with the site electrician on December 3, 2020. During the sit visit, the field engineer collected photographic data of the 100-hp motor nameplate, VFD displayed parameters, operating schedule, holiday schedule, and overtime schedule and video-recorded the VFD display for motor speed and motor amperage during truck wash cycles. Field staff also noted the outdoor temperature operating range, as the site cannot perform washes when freezing may occur.

Analysis

The ex post savings work produced two estimates: (1) utilizing the same algorithm as the ex ante method, and (2) using IPMVP Option C, Whole Facility Analysis.

IPMVP Option A, Retrofit Isolation with Key Parameter Measurement

The ex ante provided baseline kWh usage based on a one-time power measurement of the VFD pump motor, along with a one-time meter reading of the VFD shortly after installation. The ex post kWh per truck was based on the recording the VFD display during the wash cycle, a few months after installation.

$$kWh = (kW_{motor}\ x\ workhours/year)_{Baseline} - \left(\frac{trucks}{year}\ x\ \frac{kWh}{truck}\right)_{Efficient}$$

$$kW = kWh\ x\ End\ Use\ Factor$$

Site 8026 Savings Algorithm Inputs

Factor	Ex Post Source	Ex Ante Value	Ex Post Value
$kW_{Baseline\ Motor}$	Project documents	61.1	70.5
$Workhours/year_{Baseline}$	Site Contact	3,150	3,088
Trucks/year	Site contact & weather data	150,000	120,890
$kWh/truck_{Efficient}$	Ex Post video of operating cycle	0.0376	0.096007
End Use Factor	Ameren MO End Use table - Motors	0.000137944	0.000137944

The ex ante value for baseline motor power appears to have been adjusted to provide a more conservative saving estimate, as the ex ante claimed savings of 186,828 is approximately 65% of the annual billed energy usage. The ex post value for the baseline motor power is based on a measurement from the site electrician, after the VFD was installed, but running in VFD Bypass mode. The ex post used the actual amperage reading, adjusted for the power factor, VFD efficiency, and the input voltage.

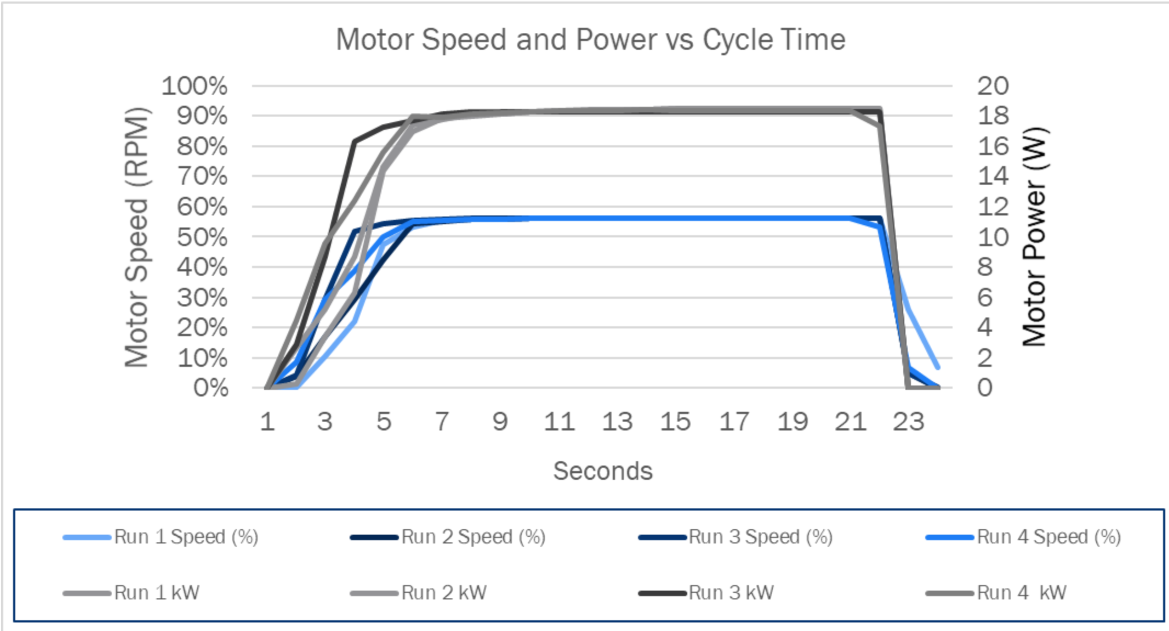
The ex post value for annual work hours is less than the ex ante value, as the ex post value included data obtained from the site visit contact to account for holidays per year, approximate number of Saturdays worked, and hours per day.

The ex post value for trucks per year is less than the ex ante value, as the site contact demonstrated the control thermometer, which disables the truck wash operation when the outdoor temperature falls below 37 degrees Fahrenheit due to possibility of placing ice on the exiting trucks.

The ex post value for kWh per truck during the post period is about two and a half times larger than the Ex Ante value of 0.0376 kWh. Field staff recorded the VFD panel display for motor speed and motor amperage, along with the washing cycle time for four wash cycles (see figure below). The ex ante pump motor data indicated an operating range of 700 to 900 RPM after the ramp up period. The ex post measured operating range after ramp up was 985 to 1002 RPM. The difference is due to programming revisions since the initial installation as supported by the site electrician, to obtain better removal of debris during the truck wash (see table on next page).

The figure below shows the average motor speed and power profiles for four wash runs.

Site 8026 Measured VFD Speed and Power for Four Wash Cycles



Site 8026 Measured Motor Current, Speed, Time for Four Wash Cycles

Seconds	Run 1 (Amps)	Run 1 Speed (RPM)	Run 2 (Amps)	Run 2 Speed (RPM)	Run 3 (Amps)	Run 3 Speed (RPM)	Run 4 (Amps)	Run 4 Speed (RPM)
0	0	0	0	0	0	0	0	0
1	64	9	87	70	87	76	66	155
2	42	187	39	305	38	524	42	523
3	37	395	38	523	41	920	41	691
4	39	843	44	756	41	966	40	892
5	41	950	41	966	41	988	42	980
6	42	985	42	981	42	994	42	986
7	42	990	42	992	42	998	42	990
8	42	995	42	995	42	998	42	995
9	42	997	42	997	42	998	42	998
10	42	998	42	999	42	998	42	999
11	42	1000	42	1000	42	998	42	999
12	42	1000	42	1000	42	998	42	999
13	42	1001	42	1000	42	998	42	1001
14	42	1002	42	1002	42	998	42	999
15	42	1002	42	1002	42	998	42	999
16	42	1002	42	1002	42	998	42	999
17	42	1002	42	1002	42	998	42	999
18	42	1002	42	1002	42	998	42	999
19	42	1002	42	1002	42	998	42	999
20	42	1002	42	1002	42	998	42	999
21	42	1002	42	1002	42	998	42	946
22	0	466	0	90	0	92	0	120
23	0	122	0	2	0	7	0	2
Average kW	17		16		17		17	
Cycle kWs	334		342		355		351	
Cycle kWh	0.092871		0.094946		0.098667		0.097546	

IPMVP Option C, Whole-Facility Measurement

The ex post work also analyzed savings using IPMVP Option C, as the truck wash motor is the largest user of electric power at the site. The other loads include a small office with LED lighting, gas heat, and a few LED pole lamp fixtures. The regression equation is:

$$kWh = Days \times Coefficient_{Days} + Weather \times Coefficient_{Weather} + PrePostFlag \times Coefficient_{PrePost} + Intercept$$

The ex post savings considered the weather factor, as trucks are not washed when the outdoor temperature is less than 37 degrees Fahrenheit.

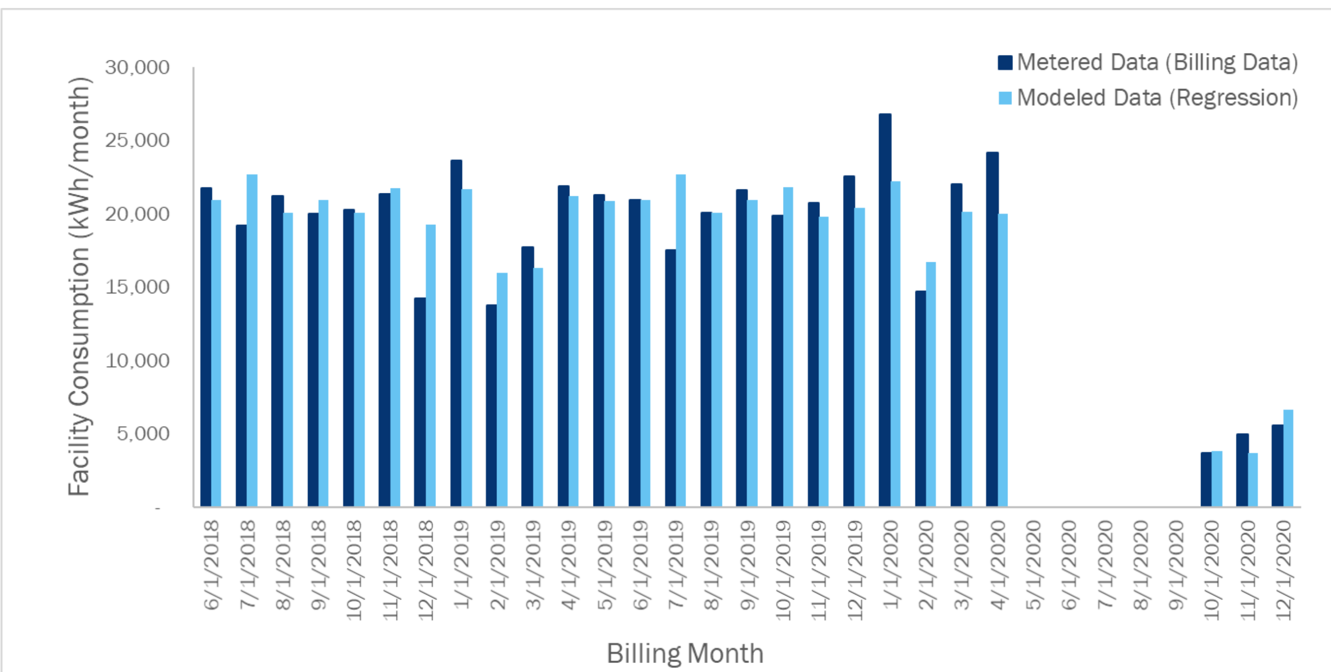
The variable coefficients for the billing data and the regression statistics are in the following table. The R Square value of 0.84 indicates a good model and the variable coefficients all have significance with a P-value less than 0.05 and a significant t-Stat. The intercept is not as significant, but considers all variables not expressed.

Site 8026 Regression Statistics

R Square	0.84		
Observations	26		
Variable	**Coefficient**	**P-value**	**t-Stat**
Cold weather Less than 37F	-9	0.01	-2.69
# of Hours- Temp less than 37F	873	0.01	2.74
Pre/Post flag	-16223	0.00	-10.47
Intercept	-5245	0.59	-0.54

The figure below shows the comparison between the metered monthly consumption data (billing data) and the modeled monthly consumption data based on the regression analysis. The data show a large reduction in whole facility energy consumption after the measure installation.

Site 8026 Comparison of Metered and Modeled Monthly Site Energy Usage



Results

The IPMVP Option A analysis estimated annual savings of 206,080 kWh (10% higher than the ex ante estimate), and the Option C analysis estimated savings of 194,676 kWh (4% higher than the ex ante estimate). There is some uncertainty in the number of trucks washed per year from the ex ante value of 150,000 trucks. The site contact provided photographs of the truck counter for the periods of August 24 through August 28 and August 31 through September 5. When extrapolated annually, these records indicate 143,387 truck washes per year, but is exclusive of the operating constraint to not wash trucks when freezing temperature are expected, set at 37F by the equipment controls. Since the true truck count value is difficult to verify, the final ex post savings are based on the Option C method, which utilizes two years of billing data with a good fit of the regressed model to billing data and which captures the significant reduction in energy usage change for the previous three months.

Site 8026 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
VFD installation to pump motor	186,828	194,676	104%	25.77	26.85	104%
Total	**186,828**	**194,676**	**104%**	**25.77**	**26.85**	**104%**

Reasons for Discrepancies

- N/A - The evaluated ex post savings are consistent with the estimated ex ante savings.

Other Findings and Recommendations

- The project savings results are extraordinary; with one measure implemented, the site's annual energy usage was reduced by 80%.

Site ID: 8027 (Enduse: Motors)

Project Description

This project added variable frequency drives (VFD) to each of the three fluid coolers with 60-hp cooling fan motors at a senior living facility. Originally, the fluid towers adapted to the heat rejection load by operating either with a 7.5-hp motor or the 60-hp motor.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8027 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
VFD for Fan	Motors	69,270	63.08
	Total	**69,270**	**63.08**

Data Collection

During the site visit on December 3, 2020 with the Trade Ally, the field engineer collected photographic documentation of the variable frequency drives and motor nameplates and took screenshots of the building management system (BMS) user interface. The fluid cooler fans only operate at temperatures above 5° Fahrenheit (and therefore, were not operating during the site visit), so the field engineer downloaded historical trend data from the BMS for the output command to the motor drives.

Analysis

The ex post analysis estimated the energy savings following the IPMVP Option A, Retrofit Isolation method, similar to that used in the ex ante analysis, with revisions based on field collected data and observations. The ex post analysis set the weather bin profile based on the wet bulb temperature, in contrast to the ex ante analysis' use of dry bulb temperature. The fluid cooler is a closed loop system, but also has a water pump for evaporative cooling over the tower fins. The fluid cooler rating is based on the range, approach, and wet bulb temperature.

The ex ante and ex post analyses both determined the motor power by factoring the rated horsepower by 0.7456 kW/hp, but the ex post analysis did not include the motor rated load factor of 1.15, in contrast to the ex ante analysis. This motor load factor is based on the locked rotor amps and not applicable to normal operating conditions.

The ex ante analysis expressed the affinity relationship between fan speed and power by a cubic factor. The ex post analysis applied the Uniform Methods Project default curve quadratic equation to determine motor input power at the range of fan speeds. The table below presents the results of the ex post analysis, binned by wet bulb temperature (T_{wb}).

Site 8027 Wet Bulb Temperature Bi Analysis

wb	Hours	CFM_{VFD}	kWh		
			Constant Speed	VSD	Savings
82	0	60,900	-	-	-
81	1	59,055	71	68	3
80	9	57,209	613	568	44
79	13	55,364	849	758	91
78	30	53,518	1,879	1,609	270
77	54	51,673	3,240	2,657	583
76	99	49,827	5,688	4,456	1,232
75	113	47,982	6,211	4,637	1,574
74	138	46,136	7,251	5,145	2,106
73	136	44,291	6,826	4,590	2,236
72	170	42,445	8,145	5,176	2,969
71	208	40,600	9,504	5,692	3,812
70	217	38,755	9,449	5,318	4,131
69	231	36,909	9,578	5,053	4,525
68	256	35,064	10,099	4,983	5,116
67	220	33,218	8,251	3,801	4,449
66	236	31,373	8,408	3,615	4,793
65	240	29,527	8,116	3,259	4,857
64	213	27,682	6,832	2,570	4,262
63	217	25,836	6,596	2,338	4,259
62	172	23,991	4,952	1,670	3,283
61	135	22,145	3,679	1,197	2,482
60	133	20,300	3,429	1,097	2,332
59	163	14,700	3,973	1,261	2,712
58	154	14,700	3,548	1,191	2,357
57	110	14,700	2,395	851	1,544
56	138	14,700	2,839	1,068	1,771
55	133	14,700	2,585	1,029	1,556
54	157	14,700	2,884	1,215	1,670
53	147	14,700	2,554	1,137	1,417
52	134	14,700	2,204	1,037	1,167
51	128	14,700	1,995	990	1,004
50	184	14,700	2,721	1,423	1,298
49	190	14,700	3,476	1,470	2,007
48	158	14,700	2,891	1,222	1,669
47	148	14,700	2,708	1,145	1,563

Site 8027 Wet Bulb Temperature Bi Analysis

wb	Hours	CFM_{VFD}	kWh		
			Constant Speed	VSD	Savings
46	173	14,700	3,165	1,338	1,827
45	137	14,700	2,507	1,060	1,447
44	138	14,700	2,525	1,068	1,457
43	154	14,700	2,818	1,191	1,626
42	130	14,700	2,379	1,006	1,373
41	130	14,700	2,379	1,006	1,373
40	146	14,700	2,671	1,129	1,542
		Total	**184,881**	**93,093**	**91,788**

Results

The ex post savings are 133% of the ex ante savings for both energy and peak demand. The wet bulb temperature aligns with the evaporative cooling tower operation more than the dry bulb temperature used in the ex ante analysis.

Site 8027 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
VFD for Fan	69,270	91,788	133%	63.08	83.59	133%
Total	**69,270**	**91,788**	**133%**	**63.08**	**83.59**	**133%**

Reasons for Discrepancies

- The ex ante analysis applied a motor rated load factor of 1.15. The evaluation team determined that the load factor is not applicable under normal operating conditions, because it is based on the locked rotor amps. The ex post analysis did not apply the load factor, resulting in an increase in savings.
- The ex ante analysis used dry bulb temperatures. The evaluation team applied wet bulb temperatures for binning the fluid tower loads. This resulted in an increase in savings.

Other Findings and Recommendations

- Consider updating the Custom Incentive Program guidelines to include measure-specific requirements for demonstrating the energy savings. For cooling towers, we recommend (1) including of wet bulb temperature instead of dry bulb temperature for weather bins, and (2) specifying the bin size as 5°F bins or smaller, to accurately model the equipment with approach temperatures.

Site ID: 8028 (Enduse: Motors)

Project Description

This project added two variable frequency drives (VFDs) to a hotel's three-motor domestic water booster system and removed the pressure reducing valves. The project achieved energy savings by reducing the average speeds and energy required by the domestic water pump motors.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8028 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
VFD for pump motors	Motors	38,783	5.35
Total		**38,783**	**5.35**

Data Collection

Field staff visited the site on December 7, 2020 and discussed the project with the maintenance manager. During the site visit, the field staff took photos of the motor nameplates, pump nameplates, existing power panel, current VFD frequency values, pump enable switches, and operating pressure. The new VFDs installed on one 5-hp pump and one 10-hp pump were not connected to the building management system (BMS) for either input or output points to collect trend data. During the interview with the site contact, field staff documented estimates for the conditions of pump sequencing, information on hotel occupancy by season, and the frequency for filling the cooling tower pits from the domestic water pump system.

Site 8028 Site Visit Data for Domestic Water Loop

	Discharge Pressure (psi)	Flow (GPM)	Suction Pressure (psi)	Head (ft)
System Max	175		40	312*
System Design	100	320	23*	178*
System Site Visit	60			

*Calculated, 1 psi = 144 in^2/62.4 lbs/ft^3

Analysis

The evaluation team sourced the pump curves for the 5-hp motor with the model 1207 Taco pump and the 10-hp motor with the model 1507 Taco pump. The system design head of 178 feet determined the impeller curve, with the full load flow capacity at the intersection of the brake horsepower for each pump.

The ex ante flow bin profile was applied to the constant volume pumps and the new VFDs on the same pumps in the following table.

Site 8028 Flow Profile with Baseline Pumps and VFD Pumps

Flow (GPM)	Hours (per year)	Pump Status			Constant Volume Pumps (kWh)			VFD Pumps (kWh)		
		5HP ON	10HP ON	10HP ON	5HP ON	10HP ON	10HP ON	5HP ON	10HP ON	10HP ON
320	88		1	1	0	738	738	0	84	84
288	88		1	1	0	738	738	0	61	61
256	175		1	1	0	1,477	1,477	0	85	85
224	263	1	1		1,146	2,215	0	1,146	270	0
192	350	1	1		1,529	2,954	0	1,529	187	0
160	437		1		0	3,692	0	0	418	0
128	526		1		0	4,430	0	0	256	0
96	701		1		0	5,907	0	0	133	0
64	1,752		1		0	14,768	0	0	22	0
32	4,380	1			19,108	0	0	19,108	0	0
					21,783	36,921	2,954	21,783	1,515	230
Totals					61,658			23,528		
Savings (kWh)					38,130					

Results

The ex post savings were 98% of the ex ante energy and peak demand savings.

Site 8028 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
VFD for pump motors	38,783	38,130	98%	5.35	5.26	98%
Total	**38,783**	**38,130**	**98%**	**5.35**	**5.26**	**98%**

Reasons for Discrepancies

- N/A – The evaluated ex post savings are consistent with the estimated ex ante savings.

Reasons for Discrepancies

- N/A

Site ID: 8031 (Enduse: Other)

Project Description

This project at a plastic injection molding facility replaced three existing injection molding machines (IMMs) with three new efficient servo motor molding machines. Energy savings are achieved by the higher efficiency of the new machines compared to the old machines for the same production process and volume.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8031 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Misc. Equipment - 2 injection molding machines	Process	473,616	65.33
Misc. Equipment - 1 injection molding machine	Process	661,848	91.30
Total		**1,135,464**	**156.63**

Data Collection

The ex post method is based on the desk review of the available project documentation. During the desk review evaluation, the evaluation team aggregated ex ante project documents, along with additional manufacturer specification sheets collected from manufacturer website. The evaluation team reviewed invoice documentation to confirm the purchase of the three new IMMs.

The project replaced two existing CLF 950 TX Series IMMs with two new Nissei FVX 860 Series IMMs and one existing CLF 1200 TX Series IMM with one new Nissei FVX 1100 Series IMM. The additional specification sheets provided data for an hourly production rate of the machines, as the old machines did not have same output as the new servo-driven IMMs. All the machines perform injection and heating operations nearly simultaneously, but the specification sheets did not provide the total cycle time, as the types of product molded have many unique parameters. The ex post analysis used the plasticizing rated maximum output as a surrogate for all the component cycle times to enable a comparison of the baseline machine to the new, efficient machine.

Analysis

The table below lists the baseline and efficient injection molding machine models, along with the available screw diameters for each set. The kg/h column is the plasticizing capacity of the machine from the specification sheets. The sum of the provided power values for the hydraulic pump motor and the heating elements over the plasticizer capacity is summarized in the kWh/kg/h column. This factor expresses the power in common terms for each machine. The normalizing factor is calculated based on the plasticizer capacity of a new machine at 580 kg/h with the 112-mm diameter screw. The actual production rate was not provided, so the maximum capacity boundary with the maximum power was considered, like the ex ante usage of only a maximum power value. The last column shows the energy consumption for each machine when producing the same product by weight and at the same production rate.

Site 8031 IMM Normalization of Power

Model	Screw diameter (mm)	Plasticizing Capacity (kg/h)	kWh/kg/h	Normalizing Factor	Power (kWh)
CLF 950 TX Series	95	365	0.38	1.6	225
	100	424	0.33	1.4	194
	105	498	0.28	1.2	165
					Average: 194.4
CLF 1200 TX Series	95	365	0.38	1.6	225
	100	424	0.33	1.4	194
	105	498	0.28	1.2	165
					Average: 194.4
Nissei FVX 860-600	112	580	0.29	1.0	173
	125	785	0.22	0.7	128
					Average: 150.2
Nissei FVX 1100-600	112	580	0.29	1.0	173
	125	785	0.22	0.7	128
					Average: 150.2

The analysis of equipment performance data indicates an average energy rate of 194.4 kWh for the existing IMMs and 150.2 for the new IMMs, with an average energy rate reduction of 44.3 kWh per unit. The ex ante analysis assumed an average savings rate of 39 kWh for the two CLF 1200 TX Series replacements and 109 kWh for the Nissei FVX 1100-600 replacement.

The ex ante analysis compared metered input power of a CLF 950 TX and a CLF 1400 TX with a 51-second and 43-second cycle time, respectively, to the results of from an injection molding calculation worksheet. The replaced machine was a CLF 1200 TX and not the CLF 1400 TX series. The metered input power study did not normalize output production to input electric power, nor did it normalize to cycle time. The following table lists the savings per model, as a product of the normalized power rate and the annual hours of operation.

Site 8031 Savings per IMM Model

Measure	Screw diameter (mm)	Annual Hours	Savings/hour (kWh/h)	Quantity	Annual kWh	Annual kW
Nissei FVX 860-600	ALL	6,072	44.25	2	537,412	74.13
Nissei FVX 1100-600	ALL	6,072	44.25	1	268,706	37.07

Results

The total project savings of 806,118 kWh is 71% of the ex ante energy and demand savings. The ex post savings were the same for each pair of replaced machines, as the specification sheets were also nearly equal for all the input parameters. The ex ante comparison of a metering input power study to a calculated savings did not normalize to production rate nor cycle time.

Site 8031 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Misc. Equipment - 2 injection molding machines	473,616	537,412	113%	65.33	74.13	113%
Misc. Equipment - 1 injection molding machine	661,848	268,706	41%	91.30	37.07	41%
Total	**1,135,464**	**806,118**	**71%**	**156.63**	**111.20**	**71%**

Reasons for Discrepancies

- The reduced ex post savings is based on a difference in the estimated energy savings for one of the IMM replacements. Although, the manufacturer specification sheets show comparable energy performance for the two IMM models, the ex ante savings assumed one model replacement will save significantly more energy than the other. The ex ante savings are based on a comparing a power input metering study to manufacturer specification data with unknown testing conditions. The ex ante savings were based solely on annual production hours and an energy (kWh) rate for each machine, which the evaluation team was not able to replicate in the specification sheets. The ex post savings also considered the energy rate (kWh) and applied the production capacity rate of each machine as identified in the specification sheets, use the plasticizing capacity (kg/hour) as a surrogate for the total cycle time, to provide an equivalent comparison.

Recommendations

- Require a clear source for each significant factor used to estimate the energy and demand savings.
- When developing savings for equipment upgrades in manufacturing processes, normalize the baseline and efficient case scenarios to the same production output (in the same way an HVAC project would normalize baseline and efficient system energy performance to the same heating and cooling load).

Site ID: 8032 (Enduse: Other/Refrigeration)

Project Description

This project, at an ice rink facility, installed a new ammonia refrigeration system for rink operations and utilized heat reclaim on compressors to provided subfloor heating requirements. This system is more efficient than the baseline system consisting of a package chiller system using R134a for refrigeration and a 120-kW electric boiler for the sub-flooring heating requirements.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8032 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Replace ice rink refrigeration with ammonia refrigeration system	Refrigeration	552,029	74.93
Total		**552,029**	**74.93**

Data Collection

The evaluation team reviewed the project documentation, engineering calculation spreadsheets, post-inspection photos, and project record notes available in the tracking database. During this review, the evaluation team verified the key inputs to the savings algorithms using project documents and other published documents, including manufacturer specifications and the trending log data from a similar facility. The sources of the key inputs included:

- Equipment quantities and model numbers for the installed system were verified through project invoices.
- Compressor #1 and #2: Baseline peak demand kW are sourced from the chiller submittals; efficient system peak kW is sourced from post-inspection nameplate photos.
- Refrigeration load profile was sourced from the ex ante chiller trend data for two months from a similar ice rink facility and efficiency project.
- Baseline pump and fan motors horsepower (HP): The HP of the baseline rink pump, cooling tower pump, cooling tower fan motor and components were sourced from the preliminary equipment schedule available in the project documentation.
- Efficient pump motor HP: The HP of the installed rink pump and subfloor pump were sourced from the post-inspection nameplate photos.

The table below shows ex post adjustments to installed equipment information based on this review.

Site 8032 Equipment Power Verification

Parameter	Source for Ex Post Values	Ex Ante Value	Ex Post Value
Installed Compressor kW	Nameplate photos	54.7 kW	56 kW
Installed Rink pump HP	Nameplate photos	15 HP	25 HP
Installed Subfloor Pump HP	Nameplate photo	3 HP	1.5 HP

Analysis

The ex post savings estimate leveraged the methods used to develop the ex ante savings estimate. Both estimates used the following algorithm and inputs (see table below) to estimate system energy savings:

$$kWh = (Equipment\ kW_{baseline} \times AOH \times Equipment\ \%Load) - (Equipment\ kW_{efficient} \times AOH \times Equipment\ \%Load)$$

Site 8032 Savings Algorithm Inputs

System	Factor	Source for Ex Post Values	Ex Ante Value	Ex Post Value
Baseline	Total Compressor kW	Submittal	213.41	213.41
	Auxiliary kW Rink Pump Electric Boiler Subfloor pump	Preliminary equipment schedule	155.81	158.05
Efficient	Total Compressor kW	Nameplate photo	109.40	112.00
	Auxiliary kW Rink Pump (less kW) Heat Reclaim Subfloor Pump (more kW) Cooling tower fan	Nameplate photo & Preliminary equipment schedule	29.47	35.81
AOH	Actual operating hours	Site website; 24/7 cooling load	8,760	8,760
Load Profile	Compressor 1 %Load	Trend data on equipment loading from a similar ice rink	50%	52%
	Compressor 2 %Load		13%	13%
	Rink Pump %Load		50%	50%
	Subfloor Pump %Load		25%	25%
	Boiler %Load		25%	25%
	Cooling Fan		50%	50%
	Cooling Tower additional fan		13%	13%

As shown in the table above, the ex post evaluation verified the ex ante value for the baseline compressor and found slightly higher kW values for the efficient system compressor and for both the baseline and efficient system auxiliary equipment. The majority of savings are achieved in the significant reductions of electric power required by the efficient equipment compared to the baseline equipment.

The ex post analysis used the same loading values for comparable equipment in the baseline and efficient cases, using load data from the trend data provided for a similar ice rink facility.

Results

The ex post savings are 95% of the ex ante savings for both energy and peak demand.

Site 8032 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Head Pressure Controls	552,029	526,891	95%	74.93	71.52	95%
Total	**552,029**	**526,891**	**95%**	**74.93**	**71.52**	**95%**

Reasons for Discrepancies

- The ex post analysis updated parameters for several installed equipment—including the compressor kW, the rink pump horsepower, and subfloor pump horsepower—based on nameplate photos collected through the project post-inspection activities. These adjustments slightly increased the installed/efficient case total power; therefore, reducing the overall project savings.

Other Findings and Recommendations

- Equipment load profiles are an important parameter in the estimation of equipment energy performance and savings, and the load profiles used in this analysis are based on similar equipment at a different but similar facility. To improve the accuracy of savings estimates, especially for large projects, implementation contractors should make a best effort to determine load profiles specific to the project facility and/or update the savings based on load profiles developed from post-inspection activities.

Site ID: 8033 (Enduse: Other)

Project Description

This project added a geothermal ground source field loop to the chiller/heaters at a high school to utilize rejected heat from the cooling cycle for hot water heating and efficient heat from the chiller/heater operating in the heating mode. The project integrated new variable speed domestic hot water loop pumps and a pool heating loop into the recently-installed chiller/heaters.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8033 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
Water Heating Heat Pump	Water Heating	264,087	47.84
Total		**264,087**	**47.84**

Data Collection

During a site visit on December 2, 2020 with the Trade Ally, the field engineer collected photo documentation of the model nameplates for the chiller/heater, fluid cooling tower, and hot water loop pumps; collected photos of the existing electric water heater; and estimated the surface area of the indoor swimming pool.

The field engineer also collected data for the typical annual student enrollment, staff size, and online calendar of school days.

The facility operations and occupancy schedules have been impacted by COVID-19, and—due to the virtual class schedule (and reduction in in-person occupancy)—the installed system has not incurred the full water heating loads. Therefore, the evaluation team did not include trend data in the savings analysis.

Analysis

The ex post savings analysis leveraged the ex ante savings estimation method using weather and load bin worksheets along with engineering equations. The ex post analysis verified chiller/heater model nameplate data to manufacturer published specifications and verified these input parameters in the savings worksheet. The ex post analysis also reviewed annual bin hours to verify that the typical domestic water heating usage aligned with the occupied hours and that the pool heating aligned with the sum of the occupied and unoccupied hours.

The ex ante savings determined the heating load for the swimming pool by the equation:

$$\textit{Heat loss} = \textit{Heat Loss Factor} \times (Temp_{air} - Temp_{water}) \times \textit{Pool Surface Area}$$

The ex ante estimates used an unsourced value of seven for the surface heat loss factor. The evaluation team identified an online source with the value of seven, but this input appeared to be applicable to outdoor pools as the source provided a range of 4 to 7 BTU/hr-ft^2 with varying wind speeds.[9]

The ex post included both the convection surface heat loss as well as the evaporative heat loss, as suggested by the ENERGY STAR® Portfolio Manager for indoor pool heating.[10] The ex post analysis used the algorithms below to estimate the hourly pool heating load:

$$\text{Evaporation heat loss} = 368.56 \times AF \times A_{pool} / 8760$$

$$\text{Convection heat loss} = 40.88 \times A_{pool} / 8760$$

Where:

AF = Activity Factor for Schools = 1.036

A = Pool Surface Area = 3,150 square feet

The sum of the evaporation and convection heat loss totaled 152 MBH, 15% higher than the ex ante value of 132 MBH.

The ex post savings estimate included the motor efficiency for the chilled water pump (94.1%), geothermal pump (94.1%), and hot water pump (91.7%) in the plant equipment calculations for the chiller operating in chiller mode as well as heating mode.

Results

The ex post energy and demand savings were 109% of the ex ante savings. The increase in savings is primarily due to the addition of the evaporation heating load to the total water heating school load along with the conversion of horsepower to kW including the installed motor efficiency.

Site 8033 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Water Heating Heat Pump	264,087	287,891	109%	47.84	52.15	109%

[9] Engineering ToolBox, (2005). Sizing Swimming Pool Heaters. [online] Available at: https://www.engineeringtoolbox.com/swimming-pool-heating-d_878.html [Accessed 3/1/2021].
[10] ENERGY STAR Portfolio Manager Technical Guide: Swimming Pools and the ENERGY STAR Score in the United States and Canada: https://www.energystar.gov/sites/default/files/tools/Swimming_Pool_August_2018_508.pdf

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Total	264,087	287,891	109%	47.84	52.15	109%

Reasons for Discrepancies

- Ex post savings included convective surface loss and evaporative loss for the swimming pool load, increasing the estimated water heating load for the pool by 15% compared to ex ante.
- Ex ante savings did not include the motor efficiencies in the savings calculation; ex post savings included the pump motor efficiencies, resulting in slight reduction to energy savings.

Other Findings and Recommendations

- N/A

Site ID: 8034 (Enduse: Other)

Project Description

This project installed solar window film on 2,500 square feet of glazing on the south-facing side of a community recreation center building. The window film has a lower shading coefficient and lower visible light transmittance than the existing double pane windows, reducing the demand for space cooling. Savings are achieved by the reduced cooling load on the building's HVAC equipment.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8034 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
Window film on the interior of south windows	Building Shell	46,587	20.68
Total		**46,587**	**20.68**

Data Collection

During the site visit with the Facility Director on December 2, 2020, the field engineer collected photographic documentation of the new window film installed on the interior of the south-facing side of the building. The field engineer counted the windowpanes with film to verify the 2,500 square feet of film over the glazing. The field engineer also downloaded data from the building management system for rooftop unit operation, took screenshots of the graphic representation of each of the RTUs, and obtained the unoccupied/occupied schedules, including the current operating times, which were reduced intermittently during the COVID-19 pandemic period.

COVID-19 has substantially impacted the normal operation of this recreation center; however, the Facility Director confirmed that the facility will return to normal, pre-COVID operations when safe to do so.

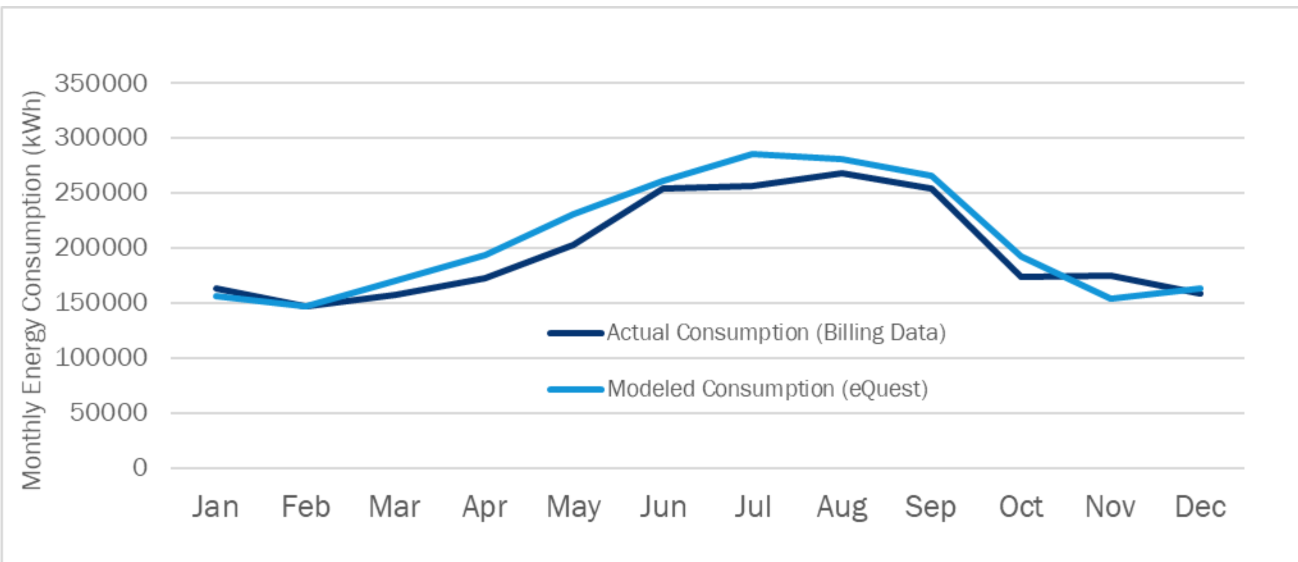
Analysis

The ex ante savings analysis was performed with eQuest modeling. Neither the native format model nor the model inputs/outputs were available with the project documentation.

The evaluation team built a model from a prototypical building located in St. Louis and calibrated the simulation using facility billing data and weather data from the year 2019. The year 2020 had low correlation due to the intermittent closing of the recreation center and altering of the operating times during the COVID-19 pandemic months. As there were other HVAC measures installed within the project scope, the HVAC equipment for both the pre- and post-models were set to the original RTU model with a 9.3 EER and natural gas heating. The south-facing windows were modeled with a u-factor of 0.50 from the project study and with a shading coefficient of 0.81 and transmittance of 78% based on the 3M window film specification table.

The figure below compares the modeled monthly energy consumption to monthly billed energy consumption for the year 2019.

Site 8034 Building Simulation Calibration Model (2019)



After calibrating the building model, the evaluation team ran the model using TMY3 typical year weather data to estimate the ex post baseline energy usage.

The evaluation team then revised the south-facing window characteristics to incorporate the window film on the glass surface. The baseline and efficient values are both from the 3M brand table for the window film corresponding to a dual pane, clear glass window with EU15 film.

Site 8034 Baseline and Efficient Window Characteristics

Factor	Baseline	Efficient
Thermal transmittance	0.500	0.47
Shade coefficient	0.810	0.37
Transmittance	0.790	0.08

The following table compares the modeled monthly energy use of the baseline building (clear glass on the south building side) and the as-built building (window film installed) and shows the monthly energy savings as the difference between the two modeled outputs. The total savings are about 2% of the total energy consumption of the modeled building.

Site 8034 Clear glass and Window Film Models

Clear (kWh)	Window film (kWh)	Savings (kWh)
158,000	156,300	1,700
147,500	146,000	1,500
171,000	169,100	1,900
195,600	192,200	3,400
233,900	229,000	4,900
264,900	258,700	6,200
289,900	282,300	7,600
285,200	278,300	6,900
269,300	262,400	6,900
195,000	191,600	3,400
154,800	153,100	1,700
164,800	163,000	1,800
Total		**47,900**

Results

The ex post savings are 103% of the ex ante savings for both energy usage and the peak demand.

Site 8034 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Window Film	46,587	47,900	103%	20.68	21.27	103%
Total	**46,587**	**47,900**	**103%**	**20.68**	**21.27**	**103%**

Reasons for Discrepancies

- N/A – the evaluation confirmed that the measure was installed as planned.

Other Findings and Recommendations

- The ex ante analysis was developed using building simulation models, but the models and key model reports were not available with the project documentation or accessible to the evaluation team. The program implementer should collect and store all native format files related to the method of calculating the ex ante energy savings.

Site ID: 8035 (Enduse: Other)

Project Description

A retail store replaced a medium temperature two-door refrigerated case lineup with a higher-efficiency two-door case and removed a seven-door low temperature case lineup without replacement. The project claimed savings for both the improved efficiency of the new medium temperature equipment and for the removal without replacement of the low temperature equipment.

The following table describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8035 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Refrigerated case replacement (7-door low temp lineup, 2-door medium temp lineup)	Refrigeration	16,330	2.22
Total		**16,330**	**2.22**

Data Collection

Field staff met with the store manager on December 2, 2020, collected photographic data of the installed refrigerated case nameplates, documented the store hours, and noted the operation schedule and product usage of the medium temperature cases.

The field team verified the installation of the new medium temperature case and confirmed that the facility did not install a low-temperature unit to replace the removed seven-door low temperature case lineup. The store manager stated that the retail chain store discontinued selling frozen foods (low temperature), removed the low temperature cases, and replaced only the dairy (medium temperature) two-door case.

The ex ante savings calculation had included savings from the replacement of the medium temperature cases and the removal (without replacement) of the low temperature cases.

Analysis

The ex post savings analysis utilized the same algorithm as the Ex Ante method for each type of case:

$$kWh = \left(Quantity\ x\ \frac{kWh}{day}\ x\ 365\ \frac{days}{year}\right)_{Baseline} - \left(Quantity\ x\ \frac{kWh}{day}\ x\ 365\ \frac{days}{year}\right)_{Efficient}$$

$$kW = kWh\ x\ End\ Use\ Factor$$

Where:

Factor	Source	Ex Ante Value	Ex Post Value
Medium Temperature Case			
Quantity $_{Baseline}$	Site contact	1	1
Quantity $_{Efficient}$	Site Visit	1	1
(kWh/day $_{Baseline}$	Manufacturer Specification	6.42 kWh	6.42 kWh
(kWh/day $_{Efficient}$	Manufacturer Specification	4.12 kWh	4.12 kWh
Low Temperature Case			
Quantity $_{Baseline}$	Site contact	2	N/A
Quantity $_{Efficient}$	Site Visit	0	0
kWh/day $_{Baseline}$	Manufacturer Specification	21.22 kWh	N/A
kWh/day $_{Efficient}$	N/A – no equipment installed	0 kWh	N/A
General			
End Use Factor	Ameren MO Table-Refrigeration	0.000135738	0.000135738

The medium temperature case savings were equal for the ex ante and ex post methods. The ex post savings excluded the low temperature frozen food case lineup as the cases were removed and not replaced with new energy efficient cases.

Results

This project achieved 5% of the ex ante gross annual kWh savings and 5% of the ex ante gross demand savings. The low realization rate was due to the inclusion of savings from the frozen food cases that were removed, as the store discontinued selling frozen food items. The savings for replacing the medium temperature two-door dairy case with a new energy-efficient case achieved 100% realization of energy savings but was a small portion of the total project savings.

Site 8035 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Refrigerated case replacement	16,330	840	5%	2.22	0.11	5%
Total	**16,330**	**840**	**5%**	**2.22**	**0.11**	**5%**

Reasons for Discrepancies

- Ex ante savings included savings from the removal of the frozen food case lineup, which was not replaced with a new energy-efficient refrigerated case; ex post savings only considered the replacement of the existing two-door medium temperature dairy case with a new energy-efficient case.

Other Findings and Recommendations

- Review of similar projects with the same participant and trade ally indicated other occurrences of overestimating the project savings from inclusion of the savings from the removal of the low temperature frozen food cases when replacing the medium temperature dairy cases. The stores all discontinued the sales of frozen foods.

- Consider revising the random Post-Inspection procedure to (1) include projects that may fall under the inspection threshold individually but exceed that threshold when aggregated with other projects for the same Parent Company, and (2) set a threshold for inclusion in mandatory post inspections.

Site ID: 8036 (Enduse: Other)

Project Description

This project replaced door sweeps and door seals on 23 openings to reduce infiltration losses at a children's school facility. The project saves energy by reducing the heating and cooling loads required to make up for the infiltration losses.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8036 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Door seals and sweeps – 23 openings	Building Shell	12,128	5.38
Total		**12,128**	**5.38**

Data Collection

Evaluation staff aggregated the project documentation and savings calculations from the program implementer's tracking database and obtained the information about the facility's HVAC equipment from the documentation associated with installed measure at the site. The evaluation team used county real estate records and internet satellite mapping websites to verify the building size, glazing, and doors.

The evaluation team collected the building envelope savings calculator from the trade ally and added NOAA TMY3 weather data for St. Louis and facility billing data to determine the HDD and CDD balance points.

Analysis

The ex ante energy savings were estimated by using an infiltration algorithm to determine the heat loss. Information about the building's heating and cooling system efficiencies was used to determine heating and cooling consumption and TMY3 weather bins to estimate annual energy savings.

The infiltration algorithm within the ex ante calculator is a simplified version of the infiltration empirical models in the ASHRAE Fundamentals. The following algorithms were used in the ex ante and ex post savings estimate. The simplified method captured the intent of the algorithm with the known variables.

$$\text{Cooling Loss} = \text{Leakage} \times K \times \text{Wind P Factor} \times CDD / COP_{cool}$$

$$\text{Heating Loss} = \text{Leakage} \times K \times \text{Wind P Factor} \times HDD / COP_{heat}$$

Where:

Leakage	Total area displaced by seals, square feet
K factor	Variable based on sheltering of building
Wind Pressure	½ x Mass x Wind Speed^2
CDD	Cooling Degree Days
HDD:	Heating Degree Days
COP_{cool}	Air conditioning efficiency
COP_{heat}	Heating efficiency

The ex post analysis adopted the ex ante inputs with several exceptions:

- Although the NOAA TMY3 weather data for wind speed was the same, ex post updated the heating and cooling degree days (HDD and CDD) based on heating and cooling balance points determined from a billing data and weather degree data linear regression. The optimum balance point temperatures were selected when the maximum R^2 value for the linear relationship between metered monthly energy and outdoor air temperature was reached.
- Ex post updated the efficiency values of the heating and cooling equipment. The ex ante savings worksheet referenced the same COP value for both the heating and cooling equipment; the ex post savings used two independent values based on equipment data available in the trade ally model of the other measures installed within the project.

The table below compares the ex ante and ex post input values.

Site 8036 Savings Algorithm Inputs for Ex Ante and Ex Post

Input	Ex Ante	Ex Post	Ex Post Source
Wind Speed	7.93–11.49	7.93–11.49	NOAA TMY3 St Louis
HDD	4,975	4,943	Weather billing data regression balance temp
CDD	2,974	1,707	
Heating Efficiency (COP)	2.5	1.50	Ex Ante Building Model Data
Cooling Efficiency (COP)	2.5	2.43	Ex Ante Building Model Data
Leakage Area (SF)	3.59	3.59	Trade Ally Replaced Seal Area
Cooled Area (%)	100	100	Ex Ante Building Model Data

Results

The ex post energy and peak demand savings are 102% of the ex ante estimates.

Site 8036 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Door seals and sweeps	12,128	12,346	102%	5.38	5.48	102%
Total	**12,128**	**12,346**	**102%**	**5.38**	**5.48**	**102%**

Reasons for Discrepancies

- Ex post adjusted input values for CDD and HDD (based on updated heating and cooling balance points) and for the heating and cooling equipment efficiencies (based on documented facility equipment).

Other Findings and Recommendations

- Require native format documents upon application submission.

Site ID: 8037 (Enduse: Other)

Project Description

This project added a head pressure and evaporator fan controller to the existing walk-in refrigeration unit at a restaurant. The self-contained evaporator/condenser unit is in the interior of the building, adjacent to the freezer unit. The installation included the control unit, evaporator temperature sensor, and modification of the expansion valve. Energy savings from head pressure controllers are achieved from reducing compressor run time and pressure along with cycling evaporator fan motors.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8037 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex ante Gross	
		kWh	kW
Head pressure and fan controller for walk in cooler	Refrigeration	2,635	0.36
Total		**2,635**	**0.36**

Data Collection

Field staff met with the restaurant manager on December 11, 2020 and collected photographic documentation of the new controller installation, nameplate data for the existing packaged refrigeration unit, operating temperatures, and dimensional data of the walk-in cooler. Field staff also interviewed the store manager for operating schedules and usage patterns of the cooler. The field team measured the zone temperature by the unit thermometer after the setpoint was satisfied and the compressor stopped cycling and found an average zone temperature of 38° Fahrenheit.

Analysis

The ex post savings utilized the same tool used for the ex ante savings, from the Adaptive Refrigeration Control Energy Savings Estimator v2.0 workbook. The tool requires inputs for the zone characteristics, refrigeration system (including fan and compressor power), and seasonal loads to develop a bin analysis for the baseline period. The Savings Estimator workbook applies logic from the programming of the controller to estimate the system savings. The evaluation team used data collected from the site visit to update the calculator for the as-built condition.

The table below lists those inputs that differed from the ex ante savings estimation.

Site 8037 Savings Calculator Input Differences

Input	Source	Ex Ante Value	Ex Post Value
Zone Temperature (degrees Fahrenheit)	Site visit pictures/contact interview	34	38
Reach in Access	Site visit pictures/contact interview	Yes	No
Compressor horsepower	Manufacturer specification sheets	1.5	0.5
Condenser fan horsepower	Manufacturer specification sheets	0.25	1/15 (0.06)
Number of evaporator fans	Manufacturer specification sheets	3	1
Evaporator fan horsepower	Manufacturer specification sheets	0.1	1/15 (0.06)

The evaluation team obtained the specifications for the self-contained refrigeration unit to determine the number of evaporator and condenser fans and collected additional manufacturer specifications for the subcomponents from the model numbers, such as evaporator fan motor horsepower, condenser fan horsepower and compressor nominal power.

The ex post savings calculator revision verified the new control strategies that generated the savings estimate were operational for head pressure control and fan cycling, but the load of the existing equipment was less than that used in the ex ante Energy Savings Workbook Estimator. The following table lists the differences of the loads used by the ex post and the ex ante savings workbook inputs.

Site 8037 Baseline Component Load Differences

Component	Power (kW)
Compressor	(0.75)
Condenser Fan	(0.18)
Evaporator Fans	(0.10)

Results

The table below shows the ex post energy savings calculated using the site-verified Savings Calculator inputs. The project achieved 30% of the ex ante gross annual kWh savings and 30% of the ex ante gross demand savings.

Site 8037 Evaluation Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex ante Gross	Ex Post Gross	RR	Ex ante Gross	Ex Post Gross	RR
Head pressure/fan controller	2,635	790	30%	0.36	0.11	30%
Total	**2,635**	**790**	**30%**	**0.36**	**0.11**	**30%**

Reasons for Discrepancies

- Although the adaptive refrigeration control was operating with the new control measures, the controlled baseline load was less than the values used for the ex ante savings estimate. The largest differencesw were in the compressor (0.75 kW), followed by the condenser fan (0.18 kW) and finally by the evaporator fans (0.10 kW).

Recommendations

- Require photographic documentation of the primary baseline equipment with the largest loads when savings are determined by calculator workbooks.

Appendix C. Desk Review Reports: New Construction Program

Site ID: 8200 (New Construction)

Project Description

This project implemented high-efficiency lighting, HVAC, and building shell measures as part of the build-out of an uninsulated warehouse space into a horticultural growing facility (with some associated office and manufacturing spaces). Lighting measures included full-spectrum LED grow lights installed in the new propagation, vegetative, and flowering rooms and LED lighting in the new office and manufacturing support areas. The whole building measure included improvements to the building envelope (roof and wall insulation) and an efficient air-cooled water chiller, reducing the cooling load and improving cooling efficiency compared to the ASHRAE 90.1 building simulation alternative (baseline) model.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8200 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
New Construction LED lighting-Flowering room	Lighting	1,446,171	275
New Construction LED lighting-VR Room	Lighting	706,741	134
New Construction LED lighting-Propagation Room	Lighting	31,536	6
New Construction LED lighting-Mfg., Office	Lighting	127,580	24
Whole Building - New Chiller, Roof Insulation, Lighting HCIF	HVAC	2,708,812	1,203
Total		**5,020,840**	**439.20**

Data Collection

The evaluation team conducted an in-depth desk review of available project documentation, performed a detailed review of the building simulation files used to develop the ex ante savings estimates, requested additional project information and documentation, and discussed the project's development and savings estimation methods with the Trade Ally and implementation contractor (IC).

Grow Area Lighting Fixtures

The evaluation team reviewed project documents, lighting layout, and manufacturer specification sheets for the installed LED fixtures to verify the input wattage, photosynthetic photon flux (PPF), and photosynthetic photon flux density (PPFD). The PPF and PPFD specifications are similar to the units of lumens and lux and are more applicable to horticultural lighting as color spectrum output is considered.

The evaluation team reviewed an LED-to-HPS lighting study from the manufacturer OSRAM, and marketing data to verify the baseline lamp ballast wattage and the LED fixture characteristics from the study.[11]

The heating cooling interactive factor (HCIF) includes both the waste heat factor (WHF) component and the interactive factor (IF) for electric-heated buildings to account for the additional heat load from reduced waste heat. The effects of the reduced wattage for lighting were determined within the building model simulations for the whole building analysis.

The peak coincident kW savings were calculated using the algorithm below, with the Coincident Factor applied to the energy savings from each measure.

$$kW_{peak\ coincident} = kWh_{savings(WHF)} x\ \ CF$$

Office and Manufacturing Area Lighting Fixtures

The energy savings for lighting measures in the office and manufacturing areas were determined by comparing the installed wattage to the building code allowed lighting power density (LPD). The LPD for a manufacturing building, factored by the building square feet, determined the total baseline wattage for the office and manufacturing area. The difference between the total installed and baseline wattages multiplied by the annual hours of use determined the LPD lighting savings.

The heating, cooling interactive effects were determined by the building simulation modeling.

Whole Building Measures

The ex ante analysis used two baselines for the building simulation modeling. For the building shell improvement measure, the ex ante analysis used the existing, uninsulated building envelope as the baseline. For the lighting and cooling systems (that did not exist previously in the warehouse space), the ex ante analysis used the baseline adopted by St. Louis County and the local municipality, the IECC 2015 Energy Conservation Code, and the ASHRAE 90.1 2013 edition.

The evaluation team discussed the baseline methodology with the Trade Ally, who had responded after the team sent an emailed request for a follow up interview with the program participant. The decision process to install insulation, and insulation exceeding the minimum code requirement for New Construction, was influenced by the total incentive provided for the project. The Trade Ally identified a similar horticulture project that did not install additional insulation to the buildout of the retail box store building. This informed the evaluation team that the added roof insulation for this project was not a prerequisite for the grow space, but a source of additional energy savings.

Analysis

Grow Area Lighting Fixtures

The new LED light fixtures achieved energy savings over similar light output from High Pressure Sodium (HPS) fixtures and over high output linear fluorescent tube fixtures (T5HO).

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[11] Brady Nemeth, “Comparison Analysis, Base case vs Fluence LED,” (March 18, 2020): 4.

For the growing areas of the facility, in the horticultural growing rooms, the evaluation team counted fixtures from the project drawings, compared the fixture types and counts to the project invoices, and reviewed the input wattages collected from the manufacturer specification sheets.

The ex post updated the baseline fixture selection based on a study from the lighting manufacturer OSRAM, which compared an LED lamp (similar to those installed in this project)[12] to a 1,000W high HPS lamp in a simulated growing facility of two levels with 80 lamps. The study accounted for the varying installation elevation of the two types of lights, as the LED lamps were placed closer to the growth canopy, and the HPS—which has a higher output in the center of the lit area—farther from the growth canopy. The ex post analysis added the ballast wattage to the study, for a project baseline wattage of 1045 Watts. The study indicated a similar average PPFD light output for the two type of lighting.

The “LED Spyder 2x” light fixture was listed with a single wattage but found on the drawing to have a “G1” specification of 342 watts and a “G3” specification of 171 watts. The Lighting Schedule drawing indicated the G1 with a size of 4’ x 4’ and the G3 with a size of 2’ x 4’. Upon a request for clarification, the IC confirmed the lighting drawings were not updated for the as-built condition. The ex post lighting analysis referenced the invoiced quantities to update these inputs for the as-built project savings.

The ex ante analysis based the Razr4 light fixture savings on the baseline fixture 4’ 8L T5HO. As the PPF was approximately one equivalent lamp more than the Razr3 light fixture with its baseline of 4’ 4L T5HO, the evaluation team consulted the manufacturer’s utility rebate coordinator. The coordinator indicated the Razr4 light output aligns with the 4’ 5L T5HO. Since the 5L fixture is not common, their practice is to underestimate with a four-lamp fixture, rather than overestimate with a six-lamp fixture. The ex post baseline used the closest PPF light equivalent fixture, the 5L T5HO.

The following table summarizes the Non-Lighting Power Density measure. The ex ante and ex post values were the same for the installed quantity and installed watts but differed on the equivalent baseline fixture watts.

Site 8200 Non-LPD Fixture Quantities and Wattages

Model	Quantity	Installed Watts	Base Fixture Ex Post	Base Watts Ex Ante	Base Watts Ex Post	Source
Spyder 2P	704	631	HPS1000	1,100	1,045	OSRAM Study
Spyder 2X	417	342	T5 10L	577	588	MO TRM 4' 10L T5HO
Razr4	28	126	T5 5L	468	294	OSRAM Utility Rebate Coordinator
Razr3	40	90	T5 3L	180	176	MO TRM 4' 3L T5HO

The evaluation team determined the baseline for the Spyder 2P in the previous table based on the manufacturer’s lighting study and inputs listed in the following table.

[12] The installed LED fixtures have the same input wattage and fixture PPF as the study lamps.

Site 8200 Determination of Baseline Equivalent for Spyder 2P LED

Feature	Units	Baseline	Efficient	Source
Lamp type		HPS	LED	OSRAM Study
Quantity	Per level	40	40	OSRAM Study/Market Review
PPFD (study average)	μ mol/m²/s	944	958	OSRAM Study
Lamp watts	watts	1000	630	OSRAM Study/Market Review
Ballast watts	watts	45		Market Review
PPF (lamp)	μ mol/s	2100	1700	Market Review

The LED high intensity lighting in the grow spaces reduce energy consumption both from the reduction in watts compared to the baseline lighting equipment, and from the reduction in the cooling load (resulting from reduced waste heat from the lighting equipment). This reduced energy consumption is partially offset by the increased heating load resulting from a loss of waste heat into the space due to the high-efficiency lighting equipment. The heating source is natural gas and outside the evaluation boundary.

The table below shows the total watt reduction and energy savings associated with the lighting energy consumption only. The heating and cooling interactive effects are included in the building model simulations assessed for the whole building measure.

Site 8200 Non LPD Lighting Energy Savings

Measure	Qty	Watts		Annual Hours	kWh		RR
		Base	New		Ex Ante	Ex Post	
HPS 1000W to SYDR 2p	704	1,045	631	4,380	1,446,171	1,276,577	88%
T5HO 10 Lamp to SYDR 2x	417	588	342	6,570	706,741	673,964	100%
T5HO 5 lamp to RAZR4	28	294	126	6,570		30,905	
T5HO 3 lamp to RAZR3	40	176	90	8,760	31,536	30,134	96%
				Total	**2,184,448**	**2,011,581**	**92%**

Office and Manufacturing Area Lighting Fixtures

For the lighting in the office and support areas, the evaluation team reviewed data from the lighting product invoices, the lighting schedule, and the lighting drawings to determine the types and quantity of lights installed within the usage area and the square feet of the area. The evaluation team found several different values than those reported in the ex ante savings calculations, indicated by the italicized values in the table below. These minor differences may be due to rounding in the ex ante project documents: the values stated on the Lighting Schedule are whole numbers, and the ex post collected the inputs watts from the manufacturer specification sheets. The most significant difference was in the quantity and location of the installed "K1" lighting fixture, with 6 of the 44 installed on the exterior loading dock. This area was not included in the ex ante building floor square footage for the interior lighting power density savings.

Site 8200 LPD Fixture Quantities and Wattages

Fixture Code	Ex Ante		Ex Post		Fixture Code	Ex Ante		Ex Post	
	Quantity	Total Watts	Quantity	Total Watts		Quantity	Total Watts	Quantity	Total Watts
P2A	3	33	3	*27*	D3	23	897	23	897
P3A	3	33	3	*27*	E1	26	1,144	26	1,144
L32	1	208	1	*230*	F1	57	855	57	*906*
L32	1	208	1	*230*	H1	53	5,459	53	*5,512*
L8	2	104	2	104	H2	4	376	4	*377*
P12	1	99	1	99	H3	2	151	2	151
P16	7	924	7	*806*	K1	44	2,772	*38*	*2,409*
P4	12	396	12	396	K3	8	632	8	*630*
P8	1	66	1	66	K3	9	711	9	*708*
P8	1	66	1	66	K4	7	273	7	*280*
W14	3	150	3	*148*	K5	1	24	1	24
A1	2	76	2	76	L1	18	990	18	*987*
B1	6	102	6	*96*	L2	18	1,706	18	1,706
C1	4	128	4	128	P1A	23	460	23	460
C2	12	624	12	624	S1	17	1,003	17	1,003
C3	8	336	8	336	M1	1	80	1	80
D1	8	224	8	224	V1	8	1,200	8	1,200

The lighting power density savings over the code allowed LPD, is presented in the following table. The ex post savings were higher than the ex ante, after omitting the exterior lights installed on the loading dock exterior. The table below shows the total watt reduction and energy savings associated with the lighting energy consumption only.

Site 8200 LPD Lighting Energy Savings

Input	Units	Ex Ante	Ex Post
Area	Square feet	44,135	44,135
Code	St. Louis Co	IECC 2015	IECC 2015
Building	IECC table	Manufacturing	Manufacturing
LPD	Allowed	1.17	1.17
Baseline kW	kW	51.638	51.638
Installed kW	kW	22.510	22.157
Hours	Annual	4,380	4,380
HCIF[a]	1	1.0	1.0
	kWh Savings	**127,585**	**129,127**
		Realization Rate	**101%**

[a] The heating and cooling interactive effects are included in the building model simulations assessed for the whole building measure.

Whole Building Measures

The ex post work for the estimation of savings for the whole building and chiller installation savings started with the replication of the annual energy usage from the baseline model and the as-installed model on the Trane Trace 3D platform. Upon identification that the as-installed model had not been updated for the installed chiller specification, the IC provided an updated set of building simulations that included two vacant rooms in the facility and the corrected specifications of the installed air-cooled chiller. The evaluation team compiled and compared the inputs and outputs from the modeling output reports to examine the differences between baseline and as-built models. The changes were appropriate for the dual baseline modeling method to estimate the energy savings.

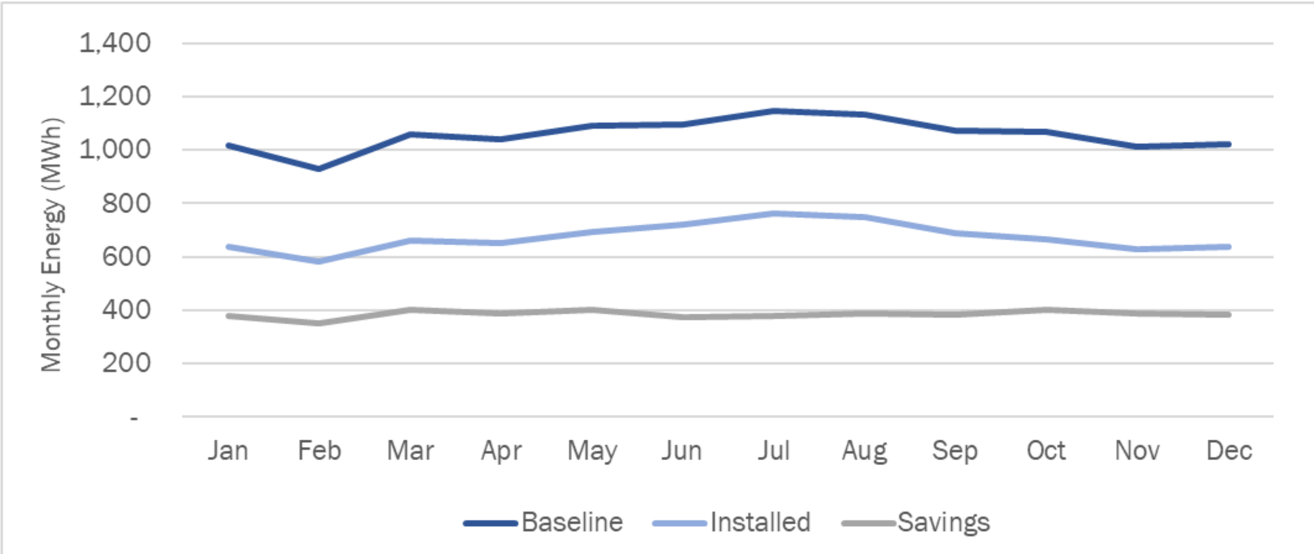
The following table lists the modeled annual energy consumption for baseline model and the as-built model and shows the savings for Cooling, HVAC (Fans), and Pumps.

Site 8200 Whole Building Energy Savings

Equipment	Baseline Total kWh	Installed Total kWh	Savings
Cooling	6,697,445	4,627,318	2,070,127
HVAC (Fans)	10,301,08	185,482	844,626
Pumps	0	138,390	-138,390
Non-Lighting Total	**7,727,553**	**4,951,190**	**2,776,363**

The figure below presents the modeled monthly energy usage for the baseline and as-built models and presents the estimated monthly energy savings as the difference between the two models. For the baseline model, the cooling season usage is 6% higher than the average monthly consumption; for the as-built model, the cooling season consumption is 10% higher. The average monthly savings is almost constant throughout the year, regardless of savings.

Site 8202 Whole Building Energy Models by Month, HVAC, Cooling, Lighting



The Enduse factor for HVAC, factored by the energy savings results in a value of 1,232 kW. Given the scenario of the savings occurring every hour for 8,760 hours in a year, the maximum achievable kW is 316 kW.

Since there is not a dominant outdoor temperature relationship with the building energy usage and since the as-built model is now insulated from the exterior with an R-42 roof and R-21 walls with foam insulation, the evaluation team determined the that the load shape is more comparable to a process load than a cooling load. The Process Enduse best represents this load profile, and results in peak demand savings of 382 kW, aligned closer to the 316 kW than 1,232 kW.

Results

The following table describes to the evaluated ex post energy and demand savings and the gross realization rate for each measure. The ex post energy savings are 98% of the ex ante energy savings, and the ex post demand savings are 48% of the ex ante demand savings.

Site 8200 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
New Construction LED lighting-Flr	1,446,171	1,276,577	88%	274.72	242.50	88%
New Construction LED lighting-VR	706,741	704,869	100%	134.26	133.90	100%
New Construction LED lighting-Prop	31,536	30,134	96%	5.99	5.72	96%
New Construction LED lighting-Mfg., Office	127,580	129,127	101%	24.24	24.53	101%
New Chiller, Roof Insulation, HCIF	2,708,812	2,776,363	102%	1,202.67	382.98	32%
Total	**5,020,840**	**4,917,070**	**98%**	**1,642**	**789.64**	**48%**

Reasons for Discrepancies

- The largest contributor to the difference in the lighting savings is the equivalent baseline fixture for the incented 630W, 1,700 micro-mol/s LED fixture. The ex post determined a light equivalent fixture using a comparable lighting study inclusive of the PPFD light output.
- The HCIF value was set to 1.0 for the lighting ex post savings, as the ex ante had included the interactive effects with the whole building simulation. The ex post savings did the same, as the Ameren MO TRM does not list HCIF factors for indoor horticultural buildings.
- The HVAC Enduse significantly overestimates the peak demand savings. The horticultural facility operates closer to the Process Enduse, with less than 10% increase in energy due to outdoor temperature.

Recommendations

- The evaluation found differences between the ex ante installed model and the as-built equipment and specifications. When the site is completed and operational, the IC should verify the Installed Energy Model represents the operating conditions determined through the post-installation inspections (and or final project invoices).
- Cooling equipment does not always serve space-comfort loads or follow seasonal weather patterns. In cases where cooling equipment is installed to serve weather-independent or other process-oriented loads, review the annual load shape to determine the appropriate enduse designation and CF selection.
- There is some evaluation risk in the ex post energy savings estimate, due to lack of clarity in the implemented energy conservation measures and the usage of two baselines for the building simulation modeling. The project application listed a single measure, labeled “Air-Cooled Chiller” with ex ante savings of 2,708,812 kWh, which was found to represent the evaluated measures: lighting heating/cooling interactive energy, roof insulation from existing R1.5 to R42, efficient chiller savings over building code based cooling system, wall insulation from code based R15 to installed R21, dehumidification savings, and efficient fan savings, along with the negative pump energy savings for the water distribution loop. The usage of two baselines within an energy model is not typical of other projects evaluated this program cycle for the New Construction program. At a minimum, the savings from each baseline should be disaggregated across multiple measures for separation of total cost and incremental cost tracking. The evaluation team consulted with the program implementer and Trade Ally to resolve questions to establish the baseline methodology and the source of the energy savings, but the initial desk review lacked details to inform the ex post evaluation.

Site ID: 8201 (New Construction)

Project Description

This project installed a new water-cooled ammonia refrigeration system instead of the alternative air-cooled freon refrigeration system at a new ice rink facility. Energy savings are achieved by the improved efficiency of the upgraded refrigeration system compared to an alternative standard system.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8202 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Refrigeration system upgrade	Refrigeration	1,343,869	182.41
Total		**1,343,869**	**182.41**

Data Collection

The evaluation team reviewed the available project documentation to examine the methods, data, and assumptions used to estimate energy and demand savings, and collected additional information from the implementation contractor upon requests for clarification about the project boundaries and savings estimation methods.

The project's final application included a lighting measure; the evaluation team confirmed with the IC that the lighting measure is not part of the project.

The ex ante analysis used manufacturer specifications for selected and baseline equipment, estimates of equipment loading and sequencing based on trend data collected at another ice rink facility, and engineering algorithms to calculate energy consumption for the baseline and proposed refrigeration systems. The table below shows key assumptions used to estimate the baseline and proposed energy consumption.

Site 8201 Algorithm Input Summary – Ex Ante Methods

Input	Baseline	Proposed	Source
Refrigeration System ($TR_{Chiller}$)	Three 350-ton air-cooled chillers with 161.4 TR capacity	Four water-cooled chillers: one with 138.8 TR and three with 112.1 TR capacity	Project application
Auxiliary Equipment	None	Cooling tower pumps and fans	Project application
Refrigeration efficiency ($kW/ton_{Chiller}$)	2.01 kW/ton	1.07 kW/ton	Manufacturer's data for selection equipment
Annual Operating Hours ($Hours_{Chiller}$)	8,760 for main chiller; 6,570 for secondary chiller; 4,380 for third chiller	8,760 for main chiller; 6,570 for secondary chiller; 4,380 for third and fourth chillers	Project description
%Loading on chillers ($\%Load_{Chiller}$)	51.6% for two chillers; 20.5% for third chiller	51.6% for two chillers; 20.5% for third and fourth chiller	Three months of trend data on similar chillers at a different ice rink facility

The evaluation team made the following observations for the ex ante savings estimation methods:

- Verified equipment capacity and efficiency specifications for the installed and selected baseline equipment, using manufacturer specifications and documentation of the project description;
- Verified pump and fan hp ratings for the installed cooling tower pumps and fans using invoice documentation;

- Reviewed the use of chiller trend data from another ice rink to develop the estimated load profiles for the new chillers at this new facility;
- Identified that the total refrigeration load estimated for the installed case is only 85% of the total refrigeration load estimated for the baseline case;
- Identified that the main chiller in the installed case has a lower performance efficiency than used for the ex ante calculations;
- Identified that the energy consumption for the cooling tower pumps did not include equipment efficiency in the calculation; and
- Identified that the selected baseline chillers may not be the most appropriate baseline due to poor performance at low operating temperatures.

Analysis

Key parameters for the energy consumption and savings calculations include the chiller equipment specifications (e.g., capacity and efficiency) and the chiller runtime and load profile. Energy savings for the baseline and proposed chillers are calculated using the following algorithm, in both the ex ante and ex post analyses (where inputs are defined in the previous table):

$$kWh_{Chiller} = TR_{Chiller} \times kW/ton_{Chiller} \times Hours_{Chiller} \times \%Load_{Chiller}$$

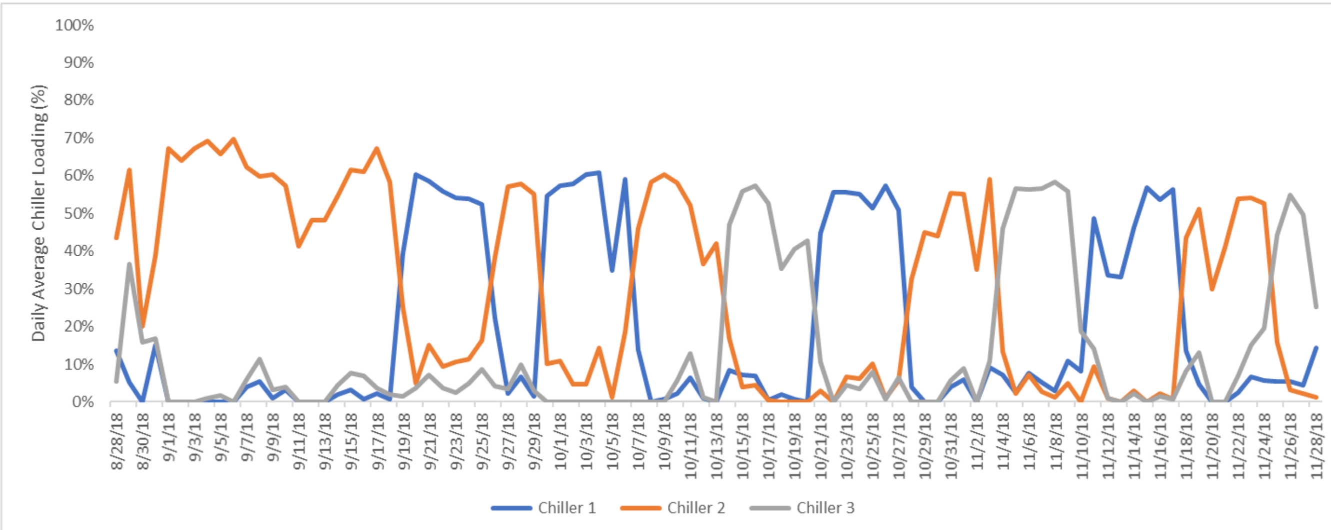
$$kW/ton_{Chiller} = BHP/TR_{Chiller} \times 0.746 \div Eff_{Chiller}$$

The evaluation team verified the input parameters used in the ex ante analysis and made the following adjustments:

- Ex post analysis adjusted the baseline refrigeration load to match the installed refrigeration load;
- Ex post analysis updated the installed main chiller efficiency from 1.43 BHP/TR (value for the other three chillers) to 1.40 BHP/TR based on equipment specifications;
- Ex post analysis added motor efficiency values in the calculations (91.7% for the 7.5-hp unit; 92.4% of the 15-hp unit; 96.2% for the 200-hp chiller; and 95.4% for the 250-hp chiller);
- Ex post analysis adjusted the installed chiller load profiles to match the baseline total refrigeration production.

The evaluation team reviewed the chiller trend data (from the comparable facility) used to estimate the loading on the new chillers. The figure below shows the average daily power and loading on each chiller and how the facility rotates the primary chiller each week. The evaluation calculated the average daily power and loading on each chiller and found that the average loading over all chillers is about 20%, the average loading for the primary chiller is 51%, and the average loading for the secondary chillers is 5%.

Site 8201 Average Daily Chiller Loading (8/28/2018-11/28/2018) for Example Facility



These chiller trend data are from a facility that operates one sheet of ice. The new facility operates three indoor ice rinks and one seasonal outdoor ice rink. Two of the indoor rinks are operated continuously, and one is available only 50% of the time; the outdoor rink is available about 25% of the year.

The project developer estimated a total refrigeration capacity requirement of 475 tons and, based on the assumptions about baseline chiller loading and runtime, a total annual refrigeration production of 1,421,640 ton-hrs. However, the ex ante assumptions for the installed scenario estimate total refrigeration production of 1,208,740 (85% of the baseline value).

The evaluation requested trend data for the new equipment to verify actual operating schedules and loading, but the implementation contractor confirmed that trend data were not available. To normalize the baseline and installed scenarios in terms of refrigeration production, the ex post analysis adjusted the average estimated loading on each installed chiller to match the total baseline refrigeration production. The chiller loading and runtime assumptions for ex ante and ex post are described in the table below.

Site 8201 Algorithm Input Summary – Ex Ante Methods

Scenario	Input	Ex Ante		Ex Post	
		$Hours_{Chiller}$	$\%Load_{Chiller}$	$Hours_{Chiller}$	$\%Load_{Chiller}$
Baseline System	Main Ice Sheet	8,760	51.6%	8,760	51.6%
	Secondary Ice Sheets	6,570	51.6%	6,570	51.6%
	Secondary Ice Sheets	4,380	20.5%	4,380	20.5%
	Total Ton-Hrs of Refrigeration	**1,421,640**		**1,421,640**	
Proposed/Installed System	Main Ice Sheet (Indoor)	8,760	51.6%	8,760	*60.7%*
	Secondary Ice Sheet (Indoor)	6,570	51.6%	6,570	*60.7%*
	Third Ice Sheet (Indoor)	4,380	20.5%	4,380	*24.1%*
	Outdoor Ice Sheet	4,380	20.5%	4,380	*24.1%*
	Total Ton-Hrs of Refrigeration	**1,208,740**		**1,421,640**	

Results

The evaluated energy and demand savings are 78% of the ex ante estimates.

Site 8201 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Refrigeration system upgrade	1,343,869	1,048,760	78%	182.41	142.36	78%
Total	**1,343,869**	**1,048,760**	**78%**	**182.41**	**142.36**	**78%**

Reasons for Discrepancies

- In the ex ante analysis, the total refrigeration load for the installed case is 85% of the total baseline refrigeration load. To normalize the savings to the same refrigeration production levels, the ex post analysis adjusted the installed chiller load profile to match the installed case refrigeration production to the total baseline refrigeration production, reducing savings.
- The ex ante savings for the installed cooling tower pumps and fans did not include the equipment efficiency in the consumption calculations. The ex post analysis assumed rating of 91.7% for the 7.5-hp unit; 92.4% of the 15-hp unit; 96.2% for the 200-hp chiller; and 95.4% for the 250-hp chiller and incorporated these efficiency ratings into the calculations, reducing savings.

Recommendations

- Key project documentation and analysis files were missing from the documents available in the tracking database. Develop and follow clear guidelines to ensure key documentation is available.
- Due to the seasonal operation of this facility (with more activity in the winter months), the calculated peak demand savings—calculated as the product of the annual energy savings and the coincidence factor for "Refrigeration" Enduse—likely does not reflect the actual summer peak demand reduction. To avoid overstating peak demand savings, the program should consider (1) developing a custom, site-specific coincidence factor, and/or (2) setting an upper limit to the peak demand savings based on the physical capacity of the equipment or, for equipment that operates continuously throughout the year, based on the following equation: $kW_{Upper\ Threshold} = kWh_{saved} / 8760$ hours.
- This project used data from a similar facility to estimate the chiller loading. Use of data from a comparable facility is acceptable as an estimate but should be described clearly and justified in the project documentation—and, especially for large projects—the savings should be updated based on actual performance data collected through post-installation inspection and verification activities.
- The project summary document describes that "the water-cooled ammonia refrigeration system is much more efficient at creating ice and typically used in ice arenas around the country." The current program cycle has included multiple projects at ice rink facilities. Although there is no specific code requirement for ice rinks, the program implementer should provide guidance for determining applicable counterfactual baselines. The decision hierarchy should consider local building code first, followed by the corresponding ASHRAE 90.7 publication year, followed by documentation requirements for common practice baselines.

Site ID: 8202 (New Construction)

Project Description

This project installed LED full spectrum grow lights in the greenhouse, research labs, stocking rooms, and plant nursery at a new horticultural grow facility. The alternative lighting for horticultural applications is high intensity discharge (HID) type fixtures or high-output T5 (HOT5) linear fluorescent lamps. Energy savings are achieved by the higher-efficiency LED lighting compared to the baseline lighting systems.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8202 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
New Construction LED Lighting-Greenhouse	Lighting	443,684	84.28
New Construction LED Lighting-Research	Lighting	26,432	5.02
New Construction LED Lighting-Stocking	Lighting	308,378	58.58
New Construction LED Lighting-Nursery	Lighting	378,865	71.97
Total		**1,157,359**	**219.86**

Data Collection

The evaluation team reviewed project documents to collect the inputs for the energy savings lighting algorithms below. The evaluation team verified installed quantities using the lighting drawings and project invoices and determined hours of use to be applicable to the usage area for the greenhouse, stock plants room, nursery, and R&D rooms.

The heating cooling interactive factor (HCIF) includes both the waste heat factor (WHF) from the TRM to include additional interactive HVAC cooling savings and the interactive factor (IF) for electric-heated buildings to account for the additional heat load from reduced waste heat. The ex post HCIF value is set to 1.07, based on the Illinois TRM V8 building value, with a water-cooled chiller, lighting hours of 7,616 and VAV air units, similar to the grow facility.

$$kWh_{Ex\ Post\ Gross} = kWh_{savings(WHF)} - kWh_{electric\ heat\ penalty(IF)}$$

$$kWh_{savings(WHF)} = \left(Qty_{pre} x\ Watts_{pre} - Qty_{post} x Watts_{post}\right) x HOU_{annual} x\ WHF\ x\ \frac{1\ kWh}{1{,}000\ Wh}$$

$$kWh_{electric\ heat\ penalty(IF)} = \left(Qty_{pre} x\ Watts_{pre} - Qty_{post} x Watts_{post}\right) x HOU_{annual} x\ \ IF\ x\ \frac{1\ kWh}{1{,}000\ Wh}$$

The peak coincident kW savings are calculated using the algorithm below, with the Coincident Factor applied to the energy savings from each measure. When the usage area has electric heat, only the cooling component of the HCIF is used, to consider the peak period occurring in the summer.

$$kW_{peak\ coincident} = kWh_{savings(WHF)} x\ \ CF$$

The table below shows the ex ante and ex post values for each key input. The evaluation found different values for the baseline wattage ($Watts_{pre}$).

Site 8202 Algorithm Input Summary

Input	Ex Ante	Ex Post
Qty_{pre}	920	920
$Watts_{pre}$	1,100	1,045
Qty_{post}	920	920
$Watts_{post}$	630	630
HOU_{annual}	1,167 – 8,760	1,167 – 8,760
WHF + IF	1.07	1.07[A]
CF (Lighting)	0.000189964	0.000189964

The ex post analysis used the standard 1.07 HCIF value, and the program implemented will “true-up” the combined HVAC interaction in the second phase of the project at this facility.

Although the ex post analysis initially calculated a combined WHF and IF value of 1.066 based on the verified facility operating hours and cooling and heating equipment type, the ex post analysis used the standard 1.07 assumption based on the program implementer’s confirmation that the combined HVAC interaction will be modeled and “trued-up” in the second phase of a project at this facility.

To establish the applicable baseline for lighting with a similar photosynthetic photon flux (PPF) and photosynthetic photon flux density (PPFD), the evaluation team sourced a study from the lighting manufacturer OSRAM that compared high pressure sodium (HPS) to LED lighting for a multi-tier growing rack.[13] The study determined that a similar photosynthetic photon flux density is created by a 1,000W HPS lamp compared to a 630 W LED fixture. When including the ballast wattage, the total HPS fixture wattage is 1,045 W. Based on this study, the ex post analysis uses a baseline of 1,045 Watts.

Site 8202 HPS baseline equivalent to 630W LED fixture

Parameter	Baseline	Efficient	Source
Lamp type	HPS	LED	OSRAM Study
Quantity/level	40	40	OSRAM Study/Market Review
PPF (lamp)	2100	1700	Market Review
PPFD (study average)	944	958	OSRAM Study
Lamp watts	1000	630	OSRAM Study/Market Review
Ballast watts	45	N/A	Market Review
Fixture watts	1045	630	

[13] Brady Nemeth, “Comparison Analysis: Base case vs Fluence LED,” (March 18, 2020): 4.

Analysis

The evaluation team calculated ex post savings using the algorithms and inputs described above.

For this New Construction lighting measure, which was not lighting power density based, a minimum efficient high pressure sodium vapor light fixture had been used by the ex ante savings method, with a value of 1,100 watts.

The site is an all-electric site, without any fossil fuels for heating. An HCIF factor would have a positive value for the reduction in air conditioning energy but would also have a negative component for increased heating energy. To accurately determine the heating cooling interaction effects, the program implementer has modeled the building, and will report the interactive heating cooling savings in a companion project. Because the HVAC interactive savings, including cooling savings due to the reduced cooling load and heating penalty due to the increased heating load, will be counted in the second phase of the project at this facility, they are not included in this ex post evaluation.

Results

The table below lists the lighting energy savings per measure. As all measures had the same combination of base and efficient fixtures, all the measures achieved the same 88% savings of the ex ante energy and peak demand savings.

Site 8202 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
New Construction LED lighting-Greenhouse	443,684	390,299	88%	84.28	74.12	88%
New Construction LED lighting-Research	26,432	23,252	88%	5.02	4.42	88%
New Construction LED lighting-Stocking	308,378	271,274	88%	58.58	51.53	88%
New Construction LED lighting-Nursery	378,865	333,279	88%	71.97	63.31	88%
Total	**1,157,359**	**1,018,104**	**88%**	**219.86**	**193.41**	**88%**

Reasons for Discrepancies

- The largest contributor to the difference in savings is the change in the equivalent baseline fixture for the incented 630W, 1,700 micro-mol/s LED fixture. The ex post determined a light equivalent fixture using the manufacturer's HPS-to-LED lighting study and added the typical ballast wattage of 45 Watts.

Recommendations

- The project savings are based on projected facility production levels. The program implementer should follow up when the site is operational with horticulture growth advanced to each space to verify the annual hours of use, as the billing data indicates the site is not in full production.

Site ID: 8203 (New Construction)

Project Description

As part of the new construction of a 400,000-square feet warehouse, this project installed LED high bay fixtures with annual usage less than the local building code allowed baseline lighting power density (LPD). The site also installed 10 exterior pole lamp fixtures and 35 emergency lights/exit signs. Energy savings are achieved by the lower energy consumption of the installed lighting equipment compared to a lighting system that just meets the baseline LPD requirements.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8203 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
New Construction Lighting Power Density	Lighting	350,749	66.63
Total		**350,749**	**66.63**

Data Collection

The evaluation team reviewed project documents to collect the inputs for the energy saving lighting algorithms below. This project documentation review included (1) review of the lighting drawing and schedule to tally the installed fixtures by type; (2) review of the manufacturer specification sheets to verify the fixture wattages; and (3) review of the TRM to determine the appropriate heating and cooling interaction factor (HCIF). Since this building is warehouse space with tempered air from makeup units and gas unit heaters, the ex ante analysis considered the space to be unconditioned and used an HCIF value of 1.0.

The ex ante and ex post analysis calculated the energy savings using the following standard algorithms:

$$kWh_{savings} = (Qty_{pre}x\ Watts - Qty_{post}xWatts_{post})xHOU_{annual}x\ HCIF\ x\ \frac{1\ kWh}{1{,}000\ Wh}$$

The ex ante and ex post analysis calculated the peak coincident kW savings using the algorithm below, with the Coincident Factor applied to the energy savings from each measure.

$$kW_{peak\ coincident} = kWh_{savings(WHF)}x\ \ CF$$

The following table lists the fixtures, quantities, and wattages from the ex ante savings estimate for the LPD measure. Also, listed are the ex post values for the eligible fixtures.

Site 8203 LPD Eligible - Verification of Quantity and Wattage

Measure	Quantity		Watts	
	Ex Ante	Ex Post	Ex Ante	Ex Post
LED High Bay	359	359	215	215
LED High Bay E	64	64	215	215
8' LED Strip	1	1	30	86
Exterior LED Pole	10	0	225	N/A
Exit Signs	35	0	11	N/A

Analysis

The ex post analysis reviewed the ex ante calculations and made the following adjustments:

- Removed the 10 exterior LED pole lamps as they were installed outside the evaluation boundary for the LPD; and removed the 35 emergency exit lights, as IECC 2015 considers these required lighting and excludes from the allowable LPD. The removal of these light fixtures from the installed LPD calculation increased the energy savings.
- Increased the wattage for the 8' LED strip light to 86 Watts based on the specification sheets (compared to the ex ante 30 Watts). This change increased the installed lighting power density wattage, slightly reducing savings.

The building was unoccupied after construction was completed, so the evaluation team could not determine actual operating hours for an occupied facility. The evaluation team compared the ex ante annual hours of use at 2,000 hours to the Ameren TRM hours for a warehouse space (2,827 hours). As the high bay fixtures had integrated 180-degree motion sensors, applying the TRM energy savings factor of 24% results in 2,148 annual operating hours. As there is uncertainty of the future tenant's operating schedule, the ex post analysis maintained the ex ante annual hours of 2,000 to estimate the energy savings.

Site 8203 LPD Power and Energy Savings

Fixture	Power (watts)	Quantity	Totals
F1 LED High Bay	359	215	77.19 kW
F1E LED High Bay	64	215	13.76 kW
AE 8' LED Strip	1	86	0.086 kW
Power Reduced			**91.03kW**
Annual Hours of Use			2,000 hr
HCIF			1.0
Annual savings (kWh)			**355,906 kWh**

Results

After removing the exterior lights, emergency lighting, and the additional wattage for the LED strip light, the final ex post savings are 101% of the ex ante savings for both energy usage and peak demand.

Site 8203 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Lighting Power Density	350,749	355,907	101%	66.63	67.61	101%
Total	**350,749**	**355,907**	**101%**	**66.63**	**67.61**	**101%**

Reasons for Discrepancies

- The ex ante analysis included exterior lighting and emergency lighting in the installed case LPD calculation; since these lighting types are outside of the LPD warehouse space, the ex post removed these from the installed lighting calculation, increasing the overall savings.
- 8' LED strip light rated at 86 watts has higher wattage than the ex ante 4' LED strip light of 40 watts.

Other Findings and Recommendations

- For this project, since the leasing occupancy and the future tenant's hours of operation are unknown, both the ex ante and ex post analysis had to make assumptions for runtime estimates. Ameren Missouri should consider recommending that the program implementer to add a task to the tracking system to "true-up" the estimated savings for projects that reach completion but were not operating at the level during post-installation inspections.

Site ID: 8204 (New Construction)

Project Description

This project installed above-code high bay lighting in the manufacturing area of a new construction manufacturing facility.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8204 Ex Ante Savings Summary

Measure Name	End Use Category	Ex Ante Gross	
		kWh	kW
New construction lighting LPD (lighting power density)	Lighting	438,889	83.37
Total		**438,889**	**83.37**

Data Collection

The evaluation team reviewed project documents to collect the inputs for the energy saving lighting algorithms below. The evaluation team also verified the annual hours of operation during a phone call with the site, as two shifts working four days per week. The heating cooling interactive factor (HCIF) includes both the waste heat factor (WHF) from the TRM to include additional interactive HVAC cooling savings and the interactive factor (IF) for electric heated buildings for the reduced heating savings.

$$kWh_{Ex\ Post\ Gross} = kWh_{savings(WHF)} - kWh_{electric\ heat\ penalty(IF)}$$

$$kWh_{savings(WHF)} = (Qty_{pre} x\ Watts_{pre} - Qty_{post} x Watts_{post}) x HOU_{annual} x\ WHF\ x\ \frac{1\ kWh}{1{,}000\ Wh}$$

$$kWh_{electric\ heat\ penalty(IF)} = (Qty_{pre} x\ Watts_{pre} - Qty_{post} x Watts_{post}) x HOU_{annual} x\ \ IF\ x\ \frac{1\ kWh}{1{,}000\ Wh}$$

The evaluation team calculated the peak coincident kW savings using the algorithm below, with the Coincident Factor applied to the energy savings from each measure. Since the peak period occurs in the summer (i.e., cooling season), only the WHF for cooling interaction is used to calculate peak kW savings.

$$kW_{peak\ coincident} = kWh_{savings(WHF)} x\ \ CF$$

The collected data for each input is listed in the following table, for both the ex ante and ex post values. The ex post review found that all parameters matched the ex ante analysis, with the exception of the annual hours of use (HOU) for some lighting equipment and the WHF.

Site 8204 Algorithm Input Summary

Parameter	Ex Ante	Ex Post
Qty $_{pre}$	88	88
Watts $_{pre}$	1,477	1,477
Qty $_{post}$	88	88
Watts $_{post}$	230.4	230.4
HOU $_{annual}$	4,000	4,000 to 8,760
WHF	1.00	1.04
IF	0	0
CF	0.000189964	0.000189964

Analysis

The energy savings algorithm inputs for the factors of HOU and WHF varied from the ex ante to the ex post. The ex post included four fixtures that operate continuously (i.e., HOU = 8760 hours per year) on an emergency lighting circuit. This was not expressed on the high bay lighting drawing, but an additional drawing for the machine shop area. Also, the ex ante applied a WHF of 1.0 to all New Construction lighting power density projects, but the ex post applied the applicable WHF from the Ameren Missouri TRM (1.04) based on the building type and HVAC system. The site is heated with natural gas, resulting in the application of a zero value for the electric heating interaction factor (IF) in both the ex ante and ex post calculations.

The table below shows the verified parameters and total savings for the LPD measure.

Site 8204 Key Savings Parameters

Measure	Qty	Watts $_{pre}$	Watts $_{post}$	WHF	Annual Hours (Wtd. Avg)	Annual kWh Savings
Lighting power density	88	1,477	230	1.04	4,216	481,134

Results

The project savings are summarized in the following table, with the project Ex Post energy savings at 110% of the Ex Ante energy savings, and the demand savings also at 110%.

Site 8204 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
New construction lighting LPD	438,889	481,134	110%	83.37	91.40	110%
Total	**438,889**	**481,134**	**110%**	**83.37**	**91.40**	**110%**

Reasons for Discrepancies

- Ex post savings are higher than ex ante due to the usage of the additional hours for the four light fixtures that operate continuously on emergency lighting circuits and inclusion of the HCIF factor for the air conditioned, gas-heated building.

Recommendations

- For custom projects, develop project-specific HVAC interaction estimates or use the Ameren Missouri TRM factors, WHF and IF, that are based on the building type and heating/cooling system type.

Site ID: 8205 (New Construction)

Project Description

This project upgraded the efficiency for 12 roof-top units (RTUs) ranging in capacity from four tons to 25 tons and implemented enthalpy controls as part of a major renovation of an existing single-story building into a restaurant and entertainment venue. Energy savings are achieved by increasing the efficiency of the RTUs and, for the controls measure, by reducing cooling load in lower temperatures.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8202 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Packaged / Rooftop Unit (Incremental)	Cooling	47,585	43.33
HVAC Controls / EMS (Incremental)	HVAC	40,380	17.93
Total		**87,965**	**61.26**

Data Collection

The evaluation team reviewed available project documentation, including the project application forms, energy savings analysis workbooks, equipment specification sheets, and other project submittals.

The evaluation team verified that the equipment specifications sheets matched the "proposed" equipment information used in the savings calculations; and we verified that the baseline IEER assumptions are consistent with the ASHRAE 90.1 minimum efficiency requirements.

Site 8202 Algorithm Input Summary

Equipment	Capacity (tons)	Baseline IEER	Proposed IEER
RTU-1	20.0	10.10	13.00
RTU-2	10.0	11.40	14.20
RTU-3	8.5	11.40	13.00
RTU-4	7.5	11.40	13.10
RTU-5	4.0	13.00	14.50
RTU-6	4.0	13.00	14.50
RTU-7	20.0	10.10	13.00
RTU-8	20.0	10.10	12.30
RTU-9	15.0	11.20	13.00
RTU-10	20.0	10.10	12.30
RTU-11	25.0	10.10	12.10
RTU-12	10.0	11.40	12.70
Weighted average baseline IEER			**10.63**
Weighted average proposed IEER			**12.82**

The ex ante savings for both measures used a spreadsheet-based weather bin analysis that estimates the baseline and proposed HVAC equipment performance and energy consumption for both occupied and unoccupied periods. The analysis developed savings for the HVAC equipment upgrade by compared the energy performance of 12 standard efficiency RTUs against the 12 proposed high-efficiency RTUs; then the analysis incorporated the high-efficiency RTUs into the baseline scenario to estimate savings for the incorporation of enthalpy controls.

The bin analysis used hourly weather data for St. Louis and facility operating schedule assumptions to estimate the cooling equipment operating hours in each temperature bin. The analysis uses equipment design data and weather conditions to estimate the total cooling load for each bin, and then calculates the cooling energy consumption for each weather bin using the following equation:

kWh _bin = Hours_bin x Cooling Load (tons) x 12,000 / (3413 x COP_cooling)

The table below shows key assumptions used in the weather bin analysis.

Site 8202 Algorithm Input Summary

Parameter	Baseline	Proposed – HVAC Only	Proposed – HVAC and Controls	Evaluation Notes
Occupied Hours (April-Nov)	1,391	1,391	1,391	Occupied hours are default settings based on an eight-hour day, five days/week; these hours understate typical occupied and operating hours for a restaurant facility
Unoccupied Hours (April-Nov)	4,469	4,469	4,469	
Design Cooling Load (Tons)	164	164	164	Based on HVAC equipment design conditions and weather data; verified equipment capacity values for installed units
Total Annual Cooling Load – Occupied (tons)	120,484	120,484	104,204	No change to cooling load during occupied hours
Total Annual Cooling Load – Unoccupied (tons)	125,488	125,488	98,613	No change to cooling load during unoccupied hours
Average HVAC Equipment IEER	10.63	12.82	12.82	Verified rated efficiency values for installed units
Cooling COP	3.11	3.76	3.76	Calculated from IEER
Controls	Dry bulb economizers	Dry bulb economizers	Enthalpy economizers	Verify economizer controls from equipment specification sheets

Analysis

The evaluation verified the installed equipment capacity, efficiency, and economizer controls settings through project invoice and installation documentation, and reviewed the ex ante calculations and input values and assumptions for accuracy and reasonableness.

The ex post analysis updated the ex ante weather-bin analysis calculated with more appropriate occupancy schedules for the restaurant and entertainment facility. The ex ante weather bin workbook used default occupancy schedules—eight hours per day (7 a.m. to 3 p.m.) and five days per week—which are likely based on a typical office schedule. The ex post analysis update the schedules to reflect eight hours per day (2 p.m. to 10 p.m.) and seven days per week operation based on the restaurant's posted operating hours. This change increased the bin analysis occupied hours from 1,391 annual hours to 1,956 annual hours and decreased the unoccupied hours from 4,469 to 3,904 annual hours. The occupied and unoccupied hours are only included in the weather bin analysis for the months of April through November when the cooling equipment is likely to be used.

Results

The following table lists the lighting energy savings per measure.

Site 8202 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Packaged / Rooftop Unit (Incremental)	47,585	51,497	108%	43.33	46.90	108%
HVAC Controls / EMS (Incremental)	40,380	45,469	113%	17.93	41.41	231%
Total	87,965	96,966	110%	61.26	88.31	144%

Reasons for Discrepancies

- The ex ante analysis used default operating hours that understated occupancy and operation; increasing the operating hours to reflect restaurant operation increased savings.
- The ex ante analysis calculated demand savings using the “HVAC” enduse loadshape; however, these savings occur only during cooling season. Ex Post used the “Cooling” coincidence factors, which increased the peak demand savings.

Recommendations

- When using bin analyses for other existing savings calculators, check all default settings—and especially those input that have a large effect on savings—to determine whether the settings should be updated to reflect the specific project parameters.

Appendix D. Desk Review and Onsite Reports: Retro-Commissioning Program

Site ID: 8100 (RCx)

Project Description

A manufacturing facility completed a retro-commissioning (RCx) study and implemented two measures identified in the study. The study identified (1) 174 cubic feet per minute (CFM) of air leakage in various compressor equipment components, and (2) 1,114 CFM of air generated at high pressure that is used for blow-off processes and that could be displaced with lower pressure air blowers and efficient nozzles.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8100 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Repair equipment air leaks	Air Compressor	299,845	41.36
Displace compressor load with lower pressure air blowers	Air Compressor	1,385,349	191.10
	Total	**1,685,194**	**232.46**

Data Collection

The field engineer reviewed the manufacturing process during the site visit on January 20, 2021 with the plant manager, maintenance manager, trade ally energy sales manager, and repair technician. The field engineer obtained production data comparing August 2020 to January 2021 aggregated at the monthly level. The field engineer collected photo documentation on the sampled air leak repair tags and verified that all leaks are repaired and have not returned. Additionally, photos were collected on the new lower pressure air blowers installed on five production lines, the new larger air nozzles used to dry ink or remove paper debris from the bailer equipment, and nameplate information for the air compressor. Following the site visit, logged operational data from the RCx study was obtained through the program implementer tracking database for both the pre- and post-installation periods. Compressed Air and Gas Institute (CAGI) data sheets were downloaded from the manufacturer website.[14]

Analysis

The ex ante method follows the Uniform Methods Project (UMP) Chapter 22 Compressed Air Evaluation Protocol, and utilizes a number of different data sources in meeting the UMP protocols.[15] Data sources include metered data in 12-second intervals of the four air compressors over a one-week period in August 2020,

[14] Compressed Air and Gas Institute (CAGI) provides testing methods and links to manufacturer specification data sheets, retrievable at: https://www.cagi.org/performance-verification/data-sheets.aspx

[15] Chapter 22: Compressed Air Evaluation Protocol. The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, September 2011–August 2020, retrievable at: https://doi.org/10.2172/1762439

estimated air flow based on the percent of full load power metered, and the known CFM air reduction from the air leak repair and new blower equipment. Ex ante calculations then determined the power usage per CFM reduced for the post installation period.

The ex post analysis followed the same UMP protocols as the ex ante analysis, with updated assumptions based on field observations and review of project documentation. The ex post analysis determined the percentage of air flow to percentage of air compressor power using the CAGI compressor curve data sheets. The revision of the ex ante compressor curves with the CAGI compressor curves for the four air compressors resulted in a negligible change in the energy savings and verified the accuracy of ex ante savings assumptions.

During the field verification of the repaired air leaks, the field engineer noted the operating pressure on each repair. The ex ante savings estimated the savings for each air leak, based on the orifice size of the opening and applying typical CFM values per air leak at an operating air pressure of 100 psi. The ex post determined the equivalent CFM of the air leak at the pressure where the leak occurred in the process. The leaks in the following table are repaired after the filter regulator lubricator (FRL), with the pressure gauge reading at the point of use.

Site 8100 Result of Air Leak Verification

Pressure at point of use (psi)	CFM leaks at 100 psi (ft^3/min)	Size	Qty	CFM at point of use (ft^3/min)	Verified Air Leakage Change
40	3.6	Medium	2	1.37	-2.23
60	0.44	Small	1	0.25	-0.19
30	2.20	Small	5	0.63	-1.57
				Total	**-3.99**

The table below presents the distribution of plant operating hours at varying air flows (in CFM) under three scenarios: (1) the Measured Pre-Period, (2) Modeled Post-Period with air leaks repaired, and (3) Modeled Post-Period with efficient air blower and efficient nozzles installed. The table illustrates the reduction in plant air flow as efficiency measures are implemented, resulting in the ex post verified savings.

Site 8100 Compressed Air Bin-Hour Table, Pre- and Post-Periods

Plant Air Flow (CFM)	Measured Pre-Period		Modeled Post-Period Air Leak Repair		Modeled Post-Period Air Blower Installation	
	Hours per year	Power (kW)	Hours per year	Power (kW)	Hours per year	Power (kW)
2980	214	556				
2920	208	550				
2860	228	546				
2800	276	541				
2740	260	537				
2680	668	528	190	475		
2620	2487	466	383	469		
2560	3649	462	914	462		

Plant Air Flow (CFM)	Measured Pre-Period		Modeled Post-Period Air Leak Repair		Modeled Post-Period Air Blower Installation	
	Hours per year	Power (kW)	Hours per year	Power (kW)	Hours per year	Power (kW)
2500	525	453	1537	453		
2440	164	445	1739	445		
2380	83	437	1792	437		
2320			1091	430		
2260			542	425		
2200			347	423		
2140			156	416		
2080			69	407		
1940						
1800					58	144
1590					58	144
1530					330	279
1460					955	271
1390					1783	265
1320					2025	262
1250					1922	253
1180					870	242
1110					460	232
1040					221	220
970					51	163
900					25	154

Results

After updating the flow bin model with the verified air leak repair and updated air compressor CAGI power-to-air flow tables, the ex post savings are 99.9% of the ex ante savings for both energy and peak demand.

Site 8100 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Repair equipment air leaks	299,845	295,736	99.9%	41.36	40.80	99.9%
Displace compressor load with lower pressure air blowers	1,385,349	1,385,415	100.0%	191.10	191.11	100.0%

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Total	1,685,194	1,681,151	99.9%	232.5	231.9	99.9%

Reasons for Discrepancies

- N/A – the project was implemented and is operating as expected.

Other Findings and Recommendations

- Retro-commissioning air leak repair measures verified during the site visit are similar to other evaluated projects in that the majority of repaired air leaks are outside the equipment operating envelope and located within peripheral equipment, such as air lines to pneumatic tools or blow off guns, because of safety concerns with opening operating compressor equipment to detect air leaks. The evaluation team recommends developing methods to safely identify air leaks within operating equipment, which consumes more air than other equipment and where larger air leaks potentially exist.

Site ID: 8101 (RCx)

Project Description

A recently constructed science and technology building completed a retro-commissioning (RCx) study and implemented energy savings measures within the building management system (BMS) with programming changes to reduce conditioned outdoor air flow and excess reheating of air.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8101 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
RCx – BMS programming changes	HVAC	909,875	403.97
Total		**909,875**	**403.97**

Data Collection

During the site visit on January 11, 2020, the building mechanic provided access to the equipment rooms and the rooftop, where the field engineer collected photo documentation of the rooftop units (RTUs). Access to the BMS was not available at the time of the site visit. In response, the Trade Ally provided extensive data to the evaluation team. The evaluation team reviewed the data provided by the Trade Ally to determine minimum airflow values for a sample of air terminal units for the pre- and post-period. The BMS control logic showed the logic for the terminal units to reduce the occurrences of simultaneous heating and cooling.

The evaluation team noted the RTU airflow setpoints and recorded the occupancy schedules, which were set up for each tenant's needs. The evaluation team collected the air flow study for comparison to the BMS terminal unit entered values for minimum and maximum air flows for both heating and cooling.

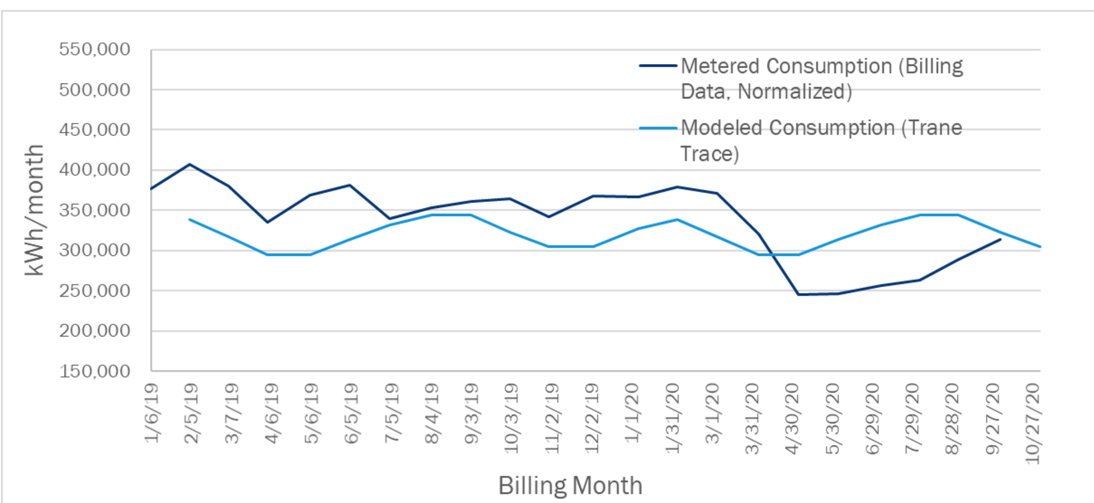
COVID-19 has affected the typical occupancy rates and schedules for this building. The site contact, working for the building management company, did not have insight to the work-at-home status of the tenant's employees to forecast the daily occupancy, but could readily measure the lower daily building usage by the reduced quantity of vehicles in the parking areas.

Analysis

The ex post savings estimate leveraged the ex ante baseline and proposed modeling from the Trane Trace software program. The ex ante baseline model had been calibrated to the billing data. The ex post analysis applied the baseline model monthly energy usage to each of the years 2018, 2019, and 2020 and found the correlation to be low for all years. The evaluation team was unable to obtain an acceptable statistical correlation when comparing the billing data to the base model simulation monthly usage. The factors hindering correlation include: the timeline of the building construction, tenant improvements, and the COVID-19 pandemic work-at-home period. Construction of this building was completed in the year 2018 as a core and shell build, with tenants leasing space and continuing finish improvements. As the tenants were from different companies, the number of work-at-home employees during the COVID-19 pandemic period varied. Lastly, as the building has electric cooling and electric heating, the billing data did not significantly correlate with heating or cooling degree days. The best correlation occurred with a high heating balance temperature of 79° Fahrenheit. This is indicative of the simultaneous reheat occurring during the cooling periods.

The figure below compares the Trane Trace modeled monthly energy consumption to the normalized metered energy consumption for this facility. The evaluation team determined that the overall building model is acceptable as a conservative savings estimate, as the average modeled consumption is less than the actual consumption without significant weather variation.

Site 8101 Base Simulation Model and Billing Data



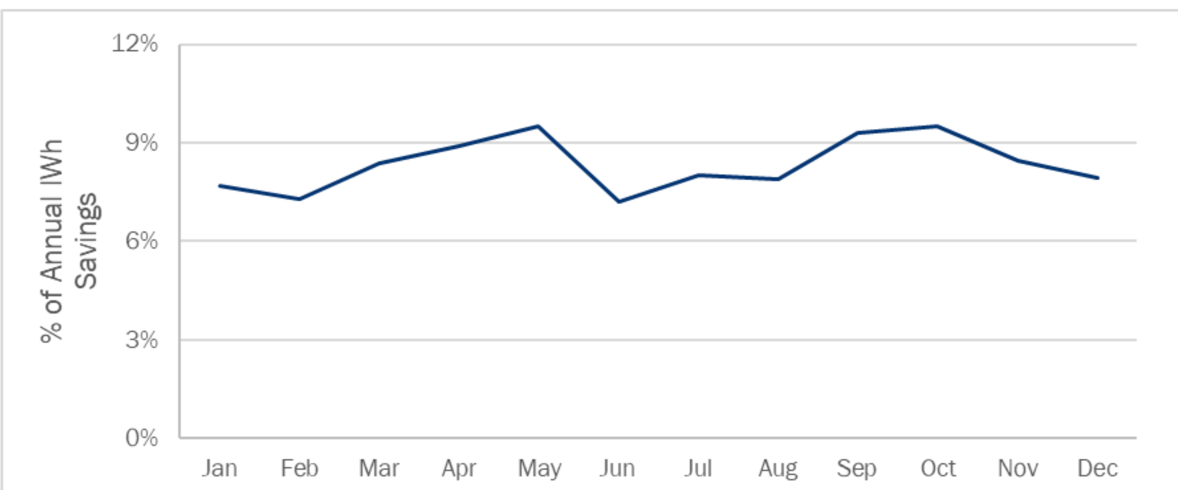
The evaluation team verified the Trane Trace baseline model and proposed model inputs based on the BMS trend data, BMS control logic, sequence of operations, and air flow study, summarized in the following table.

Site 8101 Baseline and Proposed Building Model Input Check

Factor	Sampled Terminal Units	Ex Post Differences
Max Air Flow Cooling	20 FTU, 20 VAV, 10 FPB	None
Max Air Flow Heating	20 FTU, 20 VAV, 10 FPB	None
Min Air Flow Occupied	20 FTU, 20 VAV, 10 FPB	None
Min Air Flow Unoccupied	20 FTU, 20 VAV, 10 FPB	None
Aux Heat Air Flow	20 FTU, 20 VAV, 10 FPB	None
RTU minimum OA setpoint	RTU1, RTU 2, RTU 3, RTU 4	None
Occupancy Schedule – Baseline	RTU1: 6 a.m.–11 p.m. RTU2,3,4: 6 a.m.–9 p.m.	None
Occupancy Schedule – Installed	26 schedules by tenant	None

Without any discrepancies with the inputs used for the Trane Trace baseline modeled, and with proposed model matching the installed conditions, the evaluation team reviewed the model outputs. The heating savings of 588,530 kWh are significantly larger than the cooling savings of 125,647 kWh, with the remainder of the savings in the category of supply fans at 195,677. The ex ante assigned the Enduse of HVAC to all the energy savings, resulting in 404 kW of peak demand savings. Although, the heating savings were reheating savings occurring all year, from the reduction in simultaneous heating and cooling, the percent of savings by month are compared in the following chart. As the savings occur at a similar magnitude each month (8.3% on average compared to 8.1% for the peak cooling period of June–September), the ex post also considered the Enduse of HVAC to be applicable to estimate the peak demand savings.

Site 8101 Monthly Percent of Energy Savings



Finally, the ex post analysis compared the two verified models. The baseline model estimated total annual consumption at 3,841,135 kWh, and the proposed/installed model estimated total annual consumption at 2,931,282 kWh, resulting in total annual energy savings of 909,853 kWh for a typical weather and occupancy year. The ex post savings value differs from the ex ante savings value of 909,875 kWh due to rounding. The ex post analysis included all original values from the model outputs including decimals; it appears the ex ante totaling whole numbers.

Results

The ex post savings are 100% of the ex ante savings for both energy and peak demand.

Site 8101 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
RCx-Schedules, air flow reset	909,875	909,853	100%	403.97	403.96	100%
Total	**909,875**	**909,853**	**100%**	**403.97**	**403.96**	**100%**

Reasons for Discrepancies

- N/A – the project was installed as planned and is performing as expected.

Other Findings and Recommendations

- Among the trade allies that perform retro-commissioning, there are a few that exhibit best practices for updating expected savings with trended data from their building management system. Sharing these best practices among the trade allies may raise awareness to consistently request and collect the data or provide a method for the implementer to remotely obtain access to the system for the same type of post installation data.

Site ID: 8102 (RCx)

Project Description

The office building of a manufacturing facility conducted a retro-commissioning (RCx) study and implemented measures based on the RCx study recommendations. Changes to seven HVAC rooftop units (RTU) and three air handling units (AHU) include programming of occupancy schedules and static pressure reset of the air plenum. The savings are compared to the baseline condition with all HVAC units operating continually (24/7) with a fixed static pressure of 1.5” water column.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8102 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
RCx: Scheduling, static pressure reset	HVAC	309,530	137.43
RCx: Scheduling, static pressure reset	Cooling	163,423	148.83
Total		**472,953**	**286.25**

Data Collection

A field engineer collected trend data from the building management system (BMS) during the site visit on January 6, 2021, in addition to the data collected from the RCx study and other project documentation. The evaluation team leveraged mechanical drawings collected from a previous site visit in the ex post analysis and downloaded manufacturer specification data sheets for the RTUs from the equipment website, which provided details on fan motor horsepower and air flow at standard operating conditions. The evaluation team also incorporated evaluated savings from other implemented projects at the site to inform the weather and billing data regression model.

Analysis

The ex post savings utilized the IPMVP Option C, Whole Building Analysis to estimate the savings and IPMVP Option A to validate the differences in the ex ante and ex post estimates.

The historical billing data for the site, which includes the evaluated office building and the associated manufacturing plant, was linearly regressed to the heating degree days (HDD), cooling degree days (CDD), a Pre/Post flag, and an additional Pre/Post flag for projects implemented at the start of the year.

$$kWh = Pre/Post\ Flag \times Coef_{Pre/Post} + CDD \times Coef_{CDD} + HDD \times Coef_{HDD} + Pre/Post\ Days \times Coef_{PrePost} + Intercept$$

The following table contains the statistics for the algorithm and its coefficients. The algorithm exhibits good representation of the historical usage with an R-squared of 0.97. The coefficients for the variables of the number of Pre/Post Flag, HDD, and CDD all exhibit significant p-values much less than 0.05, along with t-stats contributing to the statistical significance.

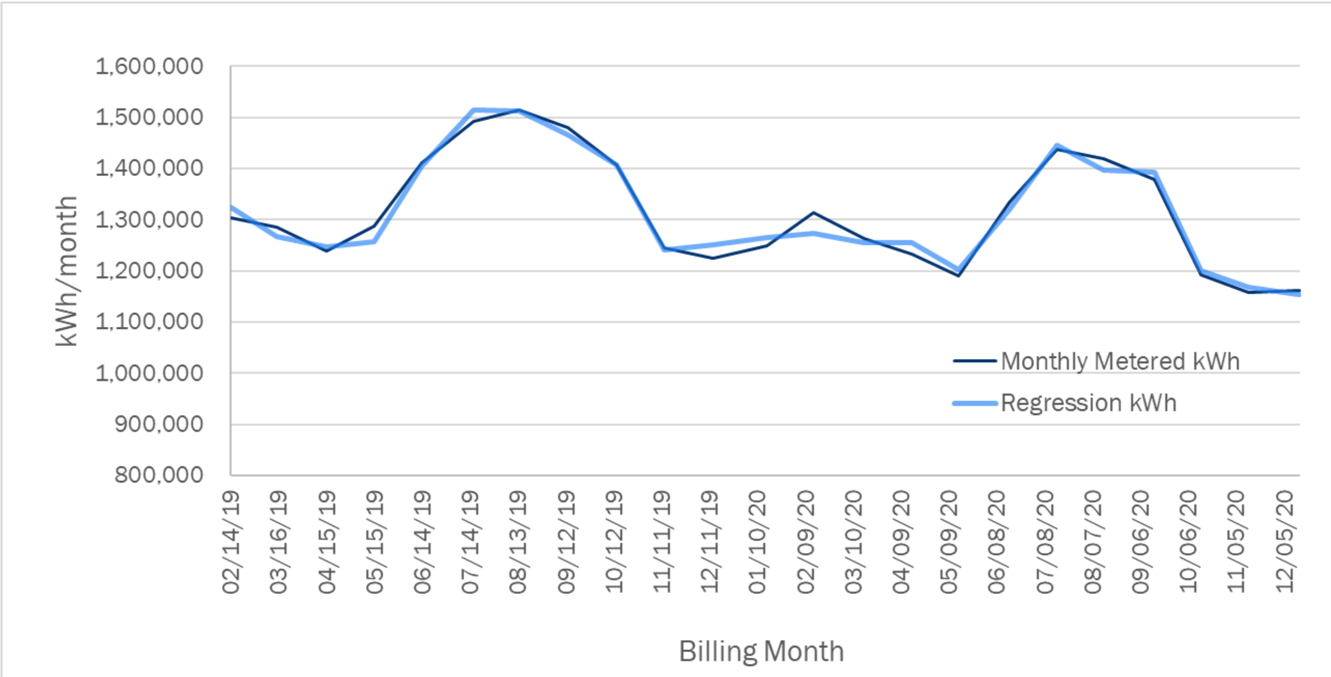
Site 8102 Algorithm Inputs (Observations, n=23)[a]

Term	Coefficients	P-value	t-stat
Intercept	1,178,513	0.0000	73.70
Pre/Post Flag	(3,046)	0.0000	-9.88
CDD	673	0.0000	17.87
HDD	94	0.0002	4.51

[a] The regression equation achieved an R-squared value of 0.97.

The following figure compares the actual metered billing data with the regression model. The regression model excludes the months of December 2020 and January 2021, as the adjacent manufacturing plant on the same electric meter increased production and added building occupancy with the hiring of new employees. This RCx project was completed in early April 2020, resulting in eight sample billing months in the post period, covering both heating and cooling periods.

Site 8102 Billing Data, Weather Data and Regression Model



The ex post analysis then applied the weather regression model to TMY3 weather data and subtracted the savings from an associated project at the same facility to estimate 700,213 kWh of annual energy savings for the RCx project.

To understand the difference in the ex ante and ex post savings, the evaluation reviewed an ex ante weather bin analysis, finding the ex ante analysis used different supply air volume (in cubic feet per minute, CFM) assumptions for two RTUs of the same model and a 1,500 CFM assumption for RTU 26. The ex post used the actual nominal equipment model data, resulting in an increase of 57,539 kWh savings over ex ante. The differences in supply air volume from the two methods are illustrated in the table below.

Site 8102 Weather Bin Analysis Input Differences

Unit	Ex Ante (CFM)	Ex Post (CFM)
RTU 26	1,500	7,000
RTU 27	2,000	5,000
RTU 28	3,000	5,000

The ex ante analysis assumptions for the other seven units closer to those found in the manufacturer specification data sheets for motor horsepower and air flow. The difference is the ex ante assumption of a 1,000 CFM/HP factor to determine the equipment air flow capacity based only on the fan motor size. The ASHRAE 90.1 guideline has listed a fan power upper limit value for Variable Volume fans at 0.0015 x CFM which equates to 1,500 CFM/HP. Neither method should be utilized to determine the equipment airflow, as the manufacturer specification sheets are based on product testing.

Results

The ex post savings for the RCx project are 148% of the ex ante savings for energy and peak demand. The contribution to the increase in savings is the difference in the RTU 26, 27, and 28 nominal fan supply volume used by each analysis.

Site 8102 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
Scheduling: Night Set Back, Economizer, and Static Pressure	309,530	458,263	148%	137.43	203.46	148%
Scheduling: Night Set Back, Economizer, and Static Pressure	163,423	241,950	148%	148.83	220.34	148%
Total	**472,953**	**700,213**	**148%**	**286.25**	**423.80**	**148%**

Reasons for Discrepancies

- The ex ante analysis used a generalized assumption of 1,000 CFM/HP to estimate airflow based on AHU and RTU fan motor sizes. The ex post analysis used manufacturer specification data sheets to derive more precise assumptions on fan motor size and air flow rates.

Other Findings and Recommendations

- The weather bin analysis provided for the ex ante savings analysis has desirable features such as latent and sensible cooling loads, but also has uncertainty with the equipment capacity defined solely by the supply fan motor size and a rule of thumb reference for determining airflow capacity from motor horsepower. Recommend the program implementer to parse the program tracking database and extract the best features from weather bin analysis, to publish with the program guidelines.

Site ID: 8103 (RCx)

Project Description

A multi-use office building received a retro-commissioning (RCx) study and implemented programming changes within their building management system (BMS). The changes included revising building occupancy schedules for the heating, ventilation, and air conditioning (HVAC) system, increasing the “dead band” of the thermostats, and starting the economizer cycle earlier at 65°F from the existing 60°F. Savings were achieved by the rooftop units and electric heat units, over the building’s historical usage.

The table below describes the energy efficiency measures and ex ante gross savings claimed for this project.

Site 8103 Ex Ante Savings Summary

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
RCx-Schedules, setbacks, resets	HVAC	598,933	265.92

Measure Name	Enduse Category	Ex Ante Gross	
		kWh	kW
Total		598,933	265.92

Data Collection

During the virtual site visit, the field engineer reviewed the programming changes within the BMS and captured screenshots of the occupied/unoccupied building schedule, discharge air temperature reset points, and changes to the dead band of the space temperature setpoint. The field engineer reviewed the BMS trend data and verified the programming changes in the following table.

Site 8103 BMS Programming Changes

Measure / Control	Verification Source	Observations
Building schedule	BMS trend data	RTU1, RTU2 unoccupied at 8 PM
Economizer setpoints	BMS trend data	OA damper open, OA<65°F
Discharge air temperature	BMS trend data	Heating zone calls, DA SP up to 70°F Cooling zone calls, DA SP down to 52°F
Duct static pressure	BMS trend data	Static pressure SP resets from 0.3” to 1.3”
COVID-19 pandemic fresh air response	BMS trend data	Unoccupied at 8 PM; RTU’s still enabled for additional ventilation air

The evaluation team estimated that the few hours of additional ventilation air from the RTU schedule during the COVID-19 pandemic period were equivalent to the reduction in heating/cooling loads from some employees of the tenants working-at-home.

Analysis

An IPMVP Option C, Whole Building Analysis, estimated the annual energy savings with site billing data and weather data, using the following algorithm.

$$kWh = Pre/Post\ flag \times Coef_{Pre/Post} + CDD \times Coef_{CDD} + HDD \times Coef_{HDD} + Intercept$$

The variables used in the algorithm are in the following table.

Site 8103 Billing-Weather Data Regression Variables

Coefficient	Predictor Variables	Source
Pre/Post	Binary flag for pre and post periods	Project dates
CDD	Cooling Degree Days	NOAA Lambert STL
HDD	Heating Degree Days	NOAA Lambert STL
Intercept	Constant value	Regression output

The linear regression model with the variables in the previous table, were linearly regressed with the output in the next table. All coefficients exhibit a p-value less than 0.05 and a significant t-stat. The regression equation for the post-period model exhibits an acceptable fit with an R-squared value of 0.82.

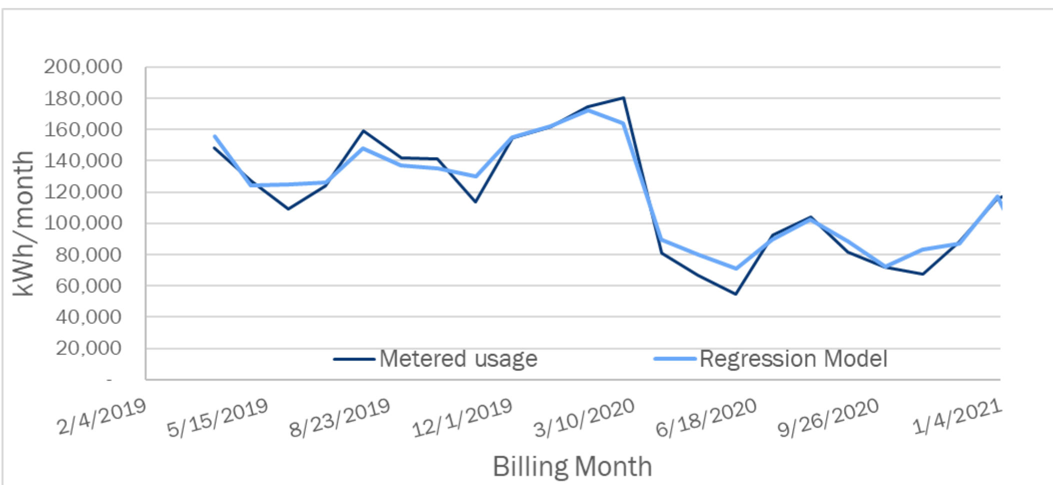
Site 8103 Algorithm Inputs (Observations, n=23)[a]

Term	Coefficients	P-value	t-stat
Intercept	86,695	0.0000	5.74
Pre/Post	(48,745)	0.0000	-6.69
CDD	124	0.0037	3.31
HDD	80	0.0004	4.30

[a] The regression equation for the post-period model achieved an R-squared value of 0.82

The regression model fit is acceptable with the 0.82 R-squared value but is hindered by the discontinuity in the project implementation; substantial completion of the project occurred in April 2020, followed by implementation of an air purge routine, and final completion a few months later. Although the project started achieving savings after substantial completion in April 2020, the site implemented an evening air purge during the COVID-19 pandemic period, affecting savings negatively. The first hour of the additional ventilation air existed in the baseline case, as the building previously went to unoccupied at 9:00 p.m., and the schedule updated to 8:00 p.m. by the project. The second and third hours of ventilation do have a negative impact on the post-period model but is considered by the evaluation team to be offset by some employees of tenants who work worked at home.

Site 8103 Billing Data, Weather Data and Regression Model



Results

The ex post energy and demand savings are 98% of the ex ante claimed savings.

Site 8103 Evaluation Savings Results

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
RCx-Schedules, setbacks,	598,933	584,935	98%	265.92	259.70	98%

Measure Name	Annual Energy (kWh)			Demand (kW)		
	Ex Ante Gross	Ex Post Gross	RR	Ex Ante Gross	Ex Post Gross	RR
resets						
Total	598,933	584,935	98%	265.92	259.70	98%

Reasons for Discrepancies

- COVID-19 air purge was not disaggregated from the measure savings within the whole building analysis, resulting in a small decrease in verified savings. The evaluation team assumes the air purge is a temporary change of increased energy usage offset by the employees of tenants who worked at home.

Other Findings and Recommendations

- N/A

Appendix E. Data Collection Instruments

Data collection instruments used in the PY2020 evaluation of the BizSavers Program are embedded below.

Standard & Custom Participant Survey

PY2020 Ameren MO_Standard-Custo

PY2020 Ameren MO_Standard-Custo

New Construction Participant Interview Guide

PY2020 Ameren MO_NC Program Pai

Retro-Commissioning Participant Interview Guide

PY2020 Ameren MO_RCx Program Pa

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