REPORT FOR

Scaled Deployment of Advanced Rooftop Unit (RTU) Controls in New York State (Final Report)

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FINAL REPORT

This report provides a summary of the scaled deployment of Transformative Wave's CATALYST Advanced Rooftop Controller that occurred between December 2015 and June 2019.

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ABOUT ENERGY SOLUTIONS

Energy Solutions is an employee-owned engineering services, demand management, and program design firm founded in 1995. Our mission is to create large-scale environmental impacts by providing market-based, cost-effective energy, carbon, and water management solutions. We seek to develop reliable, high-value partnerships with our clients through a strong commitment to innovation, collaboration and industry-leading quality.

ABOUT NYSERDA

The New York State Energy Research and Development Authority (NYSERDA), a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975. To learn more about NYSERDA's programs, visit nyserda.ny.gov or follow on Twitter, Facebook, YouTube, or Instagram.

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1. EXECUTIVE SUMMARY

New York Governor Andrew M. Cuomo's Reforming the Energy Vision (REV) initiative includes the climate goal of a 40% reduction in greenhouse gas emissions (GHGs) by 2030 from 1990 levels. In April 2018, Governor Cuomo announced an additional 40% increase in current energy efficiency targets, which would enable New York to achieve annual electric efficiency savings of 3% of investor-owned utility sales by 2025.[1]

Commercial heating, ventilation, and air conditioning (HVAC) makes up a substantial portion of New York's energy consumption. Rooftop Units (RTUs) provide HVAC services to a large portion of commercial and industrial buildings in New York. In the United States, RTUs condition 46% of all commercial buildings and serve more than 60% (39 billion square feet) of commercial building floor space (EIA 2003). More than 90% of RTUs utilize constant speed supply fans that run continuously at full speed and draw significantly more power than is necessary to maintain occupancy comfort. Advanced Rooftop Controls (ARC), like Transformative Wave's CATALYST, are retrofit solutions for constant air-volume (CAV) single-zone packages that can be installed on existing RTUs without waiting until the unit needs to be replaced. ARCs convert the RTU supply fan from single-speed to multi-speed, resulting in significant energy savings. The CATALYST and other ARC retrofit solutions are particularly important in reaching New York's aggressive efficiency goals because they target an existing building stock that is unlikely to have a major HVAC replacement in the near term.

As part of NYSERDA's Emerging Technology and Accelerated Commercialization (ETAC) initiative, Energy Solutions managed a scaled deployment of the CATALYST in New York State from December 2015 through March 2018 to achieve the following objectives:

1) Validate energy savings claims at scale and across a wide variety of building types throughout New York State.
2) Build consumer and contractor awareness of the CATALYST and other Advanced RTU controls in general by providing trainings and informational sessions.
3) Increase the number of Affiliate contractors certified to sell and install the CATALYST through market outreach and new contractor partnerships with Transformative Wave.

During this time period, the CATALYST was installed on 191 HVAC units across 24 sites within New York State.[2] In addition to deployment and energy monitoring, Energy Solutions conducted workforce education and training to increase customer and contractor awareness of both the CATALYST and other intelligent controls, including:

- **Five "Contractor and Customer Engagement" webinars** that informed the targeted contractor network of the deployment opportunity and the benefits of the CATALYST. Across five webinars, there were 102 attendees from different market sectors, including HVAC contractors, commercial real estate partners, design engineers, and end-use customers such as retail and restaurant chains.
- **Six "Intelligent Controls 101" webinar training sessions** that focused on communicating the energy, facility, human resources, and business value associated with advanced controls and how they're disrupting the market. Across these sessions

[1] "Governor Cuomo Announces New Energy Efficiency Target to Cut Greenhouse Gas Emissions and Combat Climate Change". April 20, 2018. https://www.nyserda.ny.gov/About/Newsroom/2018-Announcements/2018-04-20-Governor-Cuomo-Announces-New-Energy-Efficiency-Target-to-Cut-Greenhouse-Gas-Emmisons

[2] The unit count includes all units at sites that received deployment incentives regardless of whether all of the units were submitted for incentives. In total, 142 units across 24 sites received incentives.

there were between 72-83 attendees from the contractor market, end-use customers, and utility stakeholders that benefitted from the webinar series.

- **Two case studies** that communicated a different customer experience which highlighted energy and non-energy benefits. They focused on initial customer interest such as integration opportunities or customer comfort.

The deployment also conducted a comprehensive measurement and verification (M&V) plan to confirm Transformative Wave's claim that the CATALYST saves between 25% and 50% of energy consumption and to validate the data reported by the Catalyst eIQ platform. The M&V plan was based on the International Performance Measurement and Verification Protocol (IMPVP) 2012 framework and included three key activities:

1. Validation of Transformative Wave's energy savings claim through calculating the savings achieved by the sites in the pilot. CATALYST reported savings data was used to calculate the individual site savings. All units in the deployment were included in this validation step. This component of the M&V plan was based on IMPVP Option A
2. Validation of savings data reported by eIQ using plan based on IMPVP Option B. About 40% of the incentivized units in the deployment were included in this validation step.
3. Validation of data points collected by the sensors installed with the Catalyst using independent data loggers. Of the incentivized units in the deployment, 10% had loggers installed.

FINDINGS AND RECOMMENDATIONS

Finding #1- Sites participating in the deployment achieved an average of 35% electricity savings and 5% therms savings.

Across the 186 units from 24 project sites participating in the deployment, data monitoring showed electricity savings from 5%[3] to 50% with an average of 35% electricity savings and 75% of projects achieved at least 30% electricity savings. These interim results support Transformative Wave's claim that the CATALYST saves between 25%-50% RTU energy consumption.

Table 1. Therms and cost savings for sites participating in the deployment.

Building Type	Number of Sites	Total Units	Electricity Savings	Therms Savings	Cost Savings	Average Monitoring Duration (months)
Assembly	1	7	24%	1%	24%	30
Education	3	7	44%	7%	35%	23.7
Office	6	112	41%	10%	26%	25.8
Restaurant	5	19	23%	0%	17%	18.6
Retail	9	41	34%	5%	32%	22.1
Total	**26**	**186**	**35%**	**5%**	**28%**	**24**

Finding #2 The CATALYST is particularly well-suited to buildings with long operating hours, large capacity units, and/or sites with proportionally large HVAC loads and variable occupant loads, such as restaurants and retail.

[3] The two sites that achieved the lowest savings (5% and 17%) had data issues preventing the actual savings data from being reported accurately as discussed in eIQ Monitoring Results. Of the sites accurately reporting savings, the lowest kWh percent savings was 21%.

Energy savings are affected by two primary drivers: total occupancy hours and fan size. Based on these drivers, the CATALYST is particularly well suited for restaurants, retail, and other building types with increased annual occupancy hours. Restaurants also have proportionately high HVAC loads, and therefore, achieve strong total savings. Restaurants and retail spaces also have variable occupancy loads, making them strong candidates for the CATALYST since it can react to space changes and only provide the cooling or ventilation needed instead of operating based on the assumption that the space is always fully occupied.

Finding #3 – Successful deployment of CATALYST and other ARC technologies at scale requires a dedicated focus on workforce education and training.

Selling and installing ARC solutions (and intelligent controls more broadly) has an initial learning curve and requires dedicated training and experience to successfully integrate it into contractor core competencies. Of the four affiliates who participated in the deployment, 80% of affiliate sales came from the two affiliates who participated in sales training and had previous experience selling intelligent controls. Affiliates who attended sales strategy training in addition to the required installation training, were more equipped to identify new customer opportunities. 88% of total sales were either from experienced affiliates or national chain accounts. These affiliates were able to communicate the business value of ARC technologies to new customers and can use this new area of expertise to seek opportunities for business growth.

Recommendation #1 – Utility program measures should integrate the CATALYST into their program portfolios as standalone measures or large-scale pilots.

Savings results from this deployment and previous CATALYST studies, provide utility program managers with sufficient data to support the development of a measure for the CATALYST in their energy efficiency programs.

We recommend that programs use the CATALYST energy monitoring capabilities to collect data on an ongoing basis to refine program assumptions over time. However, the technology is sufficiently well demonstrated that in most cases should not require further “field demonstrations” prior to integrating into a program. If a pilot is necessary, we recommend that it be at sufficient scale (at least 150 units) to ensure that all relevant information is collected and that the pilot activities warrant the time and investment required by the manufacturer. A large pilot scale is required to get new contractors on board and increase the number of installations in a given area. We recommend a subset of these installations go through an independent site-based measurement and verification protocol.

Recommendation #2 – Utility ARC programs should develop deemed estimates by leveraging real-time reporting capabilities of ARC technologies and consider adopting a standardized reporting format to facilitate program participation and streamline the process.

Savings programs play a critical role in scaling new technologies since they simplify participation in utility incentive programs. A major barrier to energy efficiency programs is the lack of a streamlined data collection method to develop and update deemed savings over time. While the CATALYST has more than 12 thousand units in the field with real-time reporting capabilities, the largest published monitoring study is 130 units. Rather than complete additional small-scale demonstrations that are unlikely to substantially improve industry knowledge of ARC performance and improve deemed savings estimates, we recommend future demonstration efforts focus on standardizing energy monitoring data specifications for previously tested and verified ARC technologies so that savings estimates can be based on a much larger scale and on an ongoing basis. In addition to ongoing performance validation, future pilot programs should focus on scaling market adoption through new delivery mechanisms.

Recommendation #3 – Utility programs and other national entities should incorporate significant workforce education and training components into programs to ensure increased awareness and training for ARCs (and intelligent controls more broadly).

While controls can provide significant new business value to customers by reducing energy costs, improving insight into facility operations, and ensuring occupant comfort, there is an important learning curve for both customers and contractors. In addition to providing financial incentives to reduce first cost, utility programs that target ARCs and other intelligent controls should provide a series of education and training programs that include introductions to the technologies and in-depth trainings to help contractors understand how to sell and install the technology. Utility programs should also highlight the business value of intelligent controls to customers.

Recommendation #4 - As the number of trained affiliate contractors familiar with the CATALYST and other ARC solutions grows, utilities should consider additional program mechanisms to focus on achieving scale.

As familiarity with ARC technologies and the number of trained contractors grows over time, utility programs should pilot new deployment mechanisms for the CATALYST and other ARC technologies such as midstream promotion through contractors to scale its adoption. Midstream approaches typically achieve far higher uptake than downstream programs but do require resolving important issues such as ensuring successful installation and operation.

2. MARKET AND TECHNOLOGY CHARACTERIZATION

MARKET CHARACTERIZATION

New York Governor Andrew M. Cuomo's Reforming the Energy Vision (REV) initiative includes the climate goal of a 40% reduction in greenhouse gas emissions (GHGs) by 2030 from 1990 levels. Energy efficiency is expected to play a major role in meeting New York's aggressive GHG reduction goals. In April 2018, Governor Cuomo announced an additional 40% increase in current energy efficiency targets, which would enable New York to achieve annual electric efficiency savings of 3% of investor-owned utility sales by 2025.[4]

Commercial heating, ventilation, and air conditioning (HVAC) makes up a substantial portion of New York's energy consumption. Rooftop Units (RTUs) provide HVAC services to a large portion of commercial and industrial buildings in New York and nationally, conditioning 46% of all commercial buildings and serving more than 60% (39 billion square feet) of commercial building floor space in the United States (EIA 2003). Building codes require that when a building is occupied, RTU supply fans must operate continuously to meet ventilation needs, regardless of whether the RTU is providing heating or cooling to the conditioned space (PNNL 2013). More than 90% of RTUs utilize constant speed supply fans that run continually at full speed, meaning that the unit draws significantly more power than necessary to maintain occupancy comfort. Multi-speed supply fans can save significant energy by modulating fan speed to meet building demands as they change throughout the day and year.

A major challenge to meeting these aggressive energy efficiency targets are long equipment stock turnover lifetimes. Stock turnover refers to the frequency and length of time it takes building owners to replace aging or faulty equipment. New York's Technical Reference Manual assumes that RTUs have an average lifetime of 15 years,[5] and well-maintained units may operate for significantly longer.[6] Advanced Rooftop Controls (ARC), like Transformative Wave's CATALYST, are retrofit solutions for constant air-volume (CAV), single-zone packages that can be installed onto existing RTUs and achieve significant energy savings. CATALYST converts the RTU supply fan from single-speed to multi-speed, creating savings without waiting until the unit needs to be replaced. In addition, most utility programs offer incentives for the purchase and installation of new HVAC units. Even if 100% of buildings participated in utility programs, they are limited by stock turnover of HVAC equipment (roughly 5% of stock per year). There are very few technological solutions that currently exist to improve HVAC efficiency after installation, making the CATALYST and other ARC retrofit solutions particularly important in meeting New York's aggressive efficiency goals. By enabling efficiency measures that target existing building stock, savings are possible regardless of plans for major HVAC replacements.

The CATALYST can be installed on any age unit but is most cost-effective when installed on RTUs with at least five years of expected remaining useful life.

[4] NYSERDA, 2018
[5] New York State Department of Public Service. 2016
[6] Studies, including one conducted by the DOE in 2013 (https://www.regulations.gov/document?D=EERE-2013-BT-STD-0007-0105), shows HVAC lifetimes significantly greater than 15 years. However, energy efficiency programs around the country typically use 15 years as the useful life for HVAC units.

Advanced rooftop controllers can be installed on most of the existing constant air volume RTUs and are particularly well suited for climates with extended shoulder seasons and buildings with long operating hours such as hotels, restaurants, retail, warehouses with small offices, industrial/manufacturing, and educational facilities.

While this study reflects installations in New York State, ARC solutions are broadly applicable throughout North America. As of May 2018, the CATALYST has just under 12,000 installations throughout the U.S and Canada.[7] Of these installations, more than 90% participated in an ARC incentive program. These utility programs offer both custom and deemed rebates for ARC technologies such as the CATALYST.

ADVANCED ROOFTOP CONTROLS (ARC) OVERVIEW

Technology Overview

Advanced Rooftop Controls are retrofit solutions for constant air-volume (CAV), single-zone packaged rooftop units (RTU)[8] that save energy by converting the RTU supply fan from single-speed to a multi-speed. While this conversion provides most of the ARC's energy savings, ARC technologies can also include additional energy savings measures unique to the specific product. While there are several different ARC technologies (Enerfit, Digi-RTU, and Schneider Electric Single Zone retrofit solution) available on the market, each with a unique set of energy saving components, this deployment and report is based on Transformative Wave's CATALYST product, which includes the following capabilities:[9]

- Variable frequency drive (VFD) on the supply fan converts the supply fan from single-speed to multi-speed. The CATALYST logic chooses between three programmed speeds (40%, 75%, and 90%) to run the fan at depending on the building occupancy level and mode the RTU is currently in (ventilation, heating or cooling[10]). This feature saves electricity because reducing fan speed reduces fan power consumption.
- Advanced Economizer Logic integrates outside air free cooling with mechanical cooling over a wider range of outdoor air temperatures. This logic provides electricity savings by decreasing the need for compressor energy.
- Demand Control Ventilation (DCV) senses return air carbon dioxide levels to determine the occupancy levels and adjusts the outside air volume accordingly to provide only the ventilation needed at the given moment. This feature saves electricity because it allows the RTU to modulate the amount of air needed instead of providing the maximum design amount at all times.[11]
- Integration with Transformative Wave's online eIQ dashboard. The eIQ dashboard capabilities include visualization of RTU operation, a fault detection and diagnostics system, and internal graphing capabilities.

[7] Transformative Wave website. http://transformativewave.com/

[8] CAV Single-Zone RTUs are small systems that serve a single thermal zone. A CAV unit operates the fan and compressor at full capacity until the zone space temperature reaches the specified setpoint. Once the setpoint is reached, the compressor turns off, but the fan continues to run at full capacity to provide the needed ventilation. CAV systems run the compressor and fan at full capacity regardless of the amount of cooling or ventilation needed.

[9] Transformative Wave also offers a "CATALYST Lite" version which includes only the multi-speed fan conversion component.

[10] For larger units, the fan speed varies with the stage of cooling – 75% for stage 1 cooling and 90% for stage 2 cooling.

[11] Additional information about the CATALYST functionalities can be found in reports previously published by the Pacific Northwest National Laboratory (PNNL 2013) and the National Renewable Energy Laboratory (NREL 2016).

Product Installation and Contractor Training

To facilitate installation, the CATALYST is sold as a retrofit kit with all parts coming in a single package including the VFD, the economizer controller, an eIQ central hub, temperature sensors (if the project includes the optional BMS), and cell tower to facilitate communication between the eIQ central access point and the eIQ cloud server.[12] Figure 1 shows how the individual units communicate with the Transformative Wave cloud server.

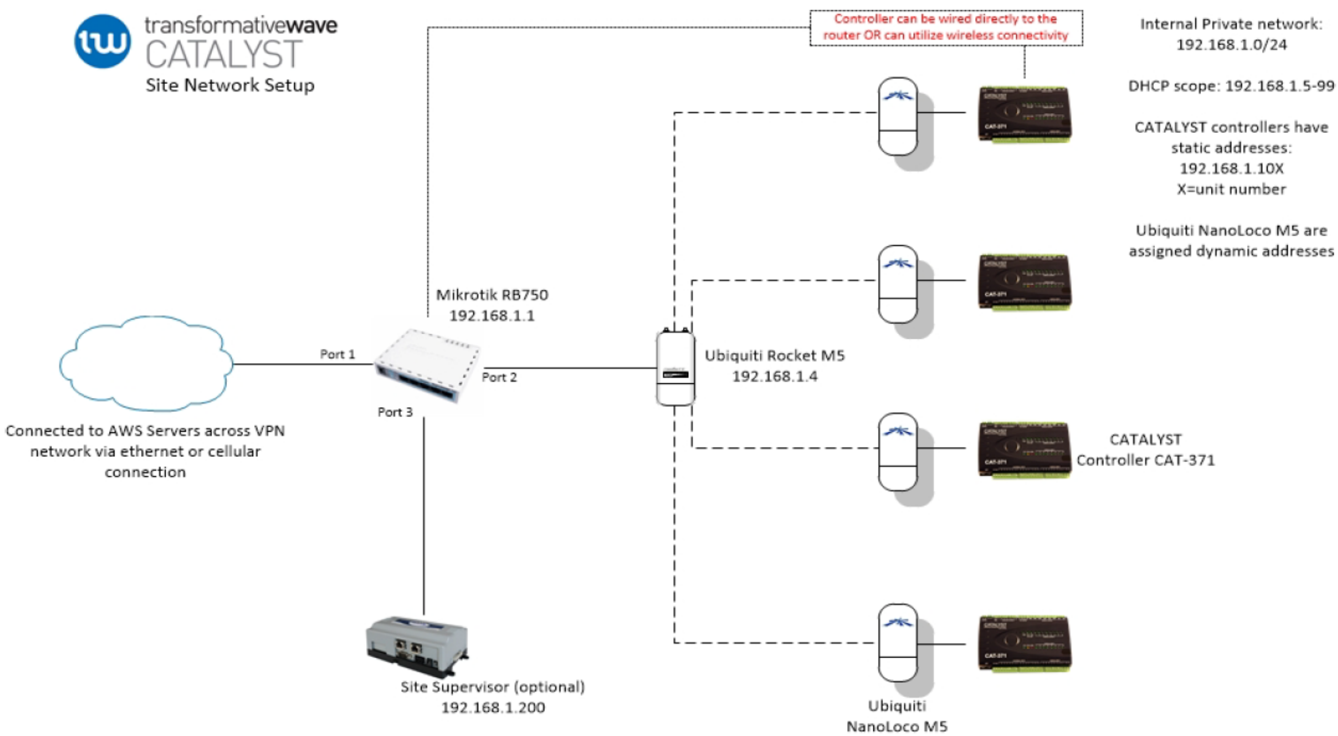

Figure 1: Catalyst/eIQ Communication Architecture. The signals from the individual CATALYST units are either grouped together and communicate with the cloud server via a central point (Ubiquiti Rocket) or each individual unit can be hardwired directly into a modem to communicate directly with the cloud server. The optional site supervisor is used for very large sites which require a more robust communication option for all the data coming in from the units.

For each site, the economizer controller is pre-wired and pre-programmed at Transformative Wave's headquarters, which simplifies on-site installation for contractors. The wiring is color coded to ensure that they are connected to the correct terminal[13]. Once at the site, the economizer controller is bolted to the RTU and wired to the economizer, the VFD is installed on the fan, and the eIQ hub is installed on the roof to receive signals from each economizer controller box. Once the hardware is fully installed, eIQ begins receiving unit operation information and determines the general health of the unit at the time of installation. Any faults identified are then followed up upon by the contractor as they would for any fault identified during the CATALYST operation.

Contractors installing the CATALYST are required to complete specific Transformative Wave training sessions at their headquarters in Kent, Washington to ensure that installation is completed correctly. The three-day technical training includes both classroom and hands-on training segments. Classroom training includes sessions on the purposes and applications of the various CATALYST options, and installation best practices. Participants apply the

[12] Cell tower is not required if eIQ access point can tie directly into facilities existing network.
[13] The CATALYST specification document clearly notes the final terminal for each color-coded wire.

knowledge they learned in the classroom in hands-on trainings by learning how to install, commission and trouble shoot CATALYST units in Transformative Wave's training lab.[14]

eIQ Platform

The eIQ platform provides a web-based visualization of RTU efficiency, system performance, fault detection, and energy accountability tools that can either be integrated with an existing building management system (BMS) or can be installed along with the eIQ Tridium BMS. The CATALYST controllers communicate either over Wi-Fi or physical wiring to the central eIQ communication hub (one per site), which then communicates with the eIQ cloud server via a cellular connection. The eIQ online interface streams information from all units within a site together into a single online interface that can be used to remotely adjust setpoints, visualize the current operation of a given unit, provide fault detection and diagnostics, and real-time energy monitoring and reporting. eIQ can integrate multiple sites into a single portfolio view so that building portfolio managers can control them from a single access point.

eIQ's fault detection and diagnostics feature functions by tracking the operation of a unit and alerting the building owner if the unit appears to be experiencing a fault of some kind. When the CATALYST's series of sensors locate where the fault is occurring, the location and suggested causes are displayed within eIQ. eIQ's home view has a series of indicators that are lit either green, orange, or red depending on whether the unit is operating well or has a potential fault, meaning that a building operator can quickly identify any units with potential issues.

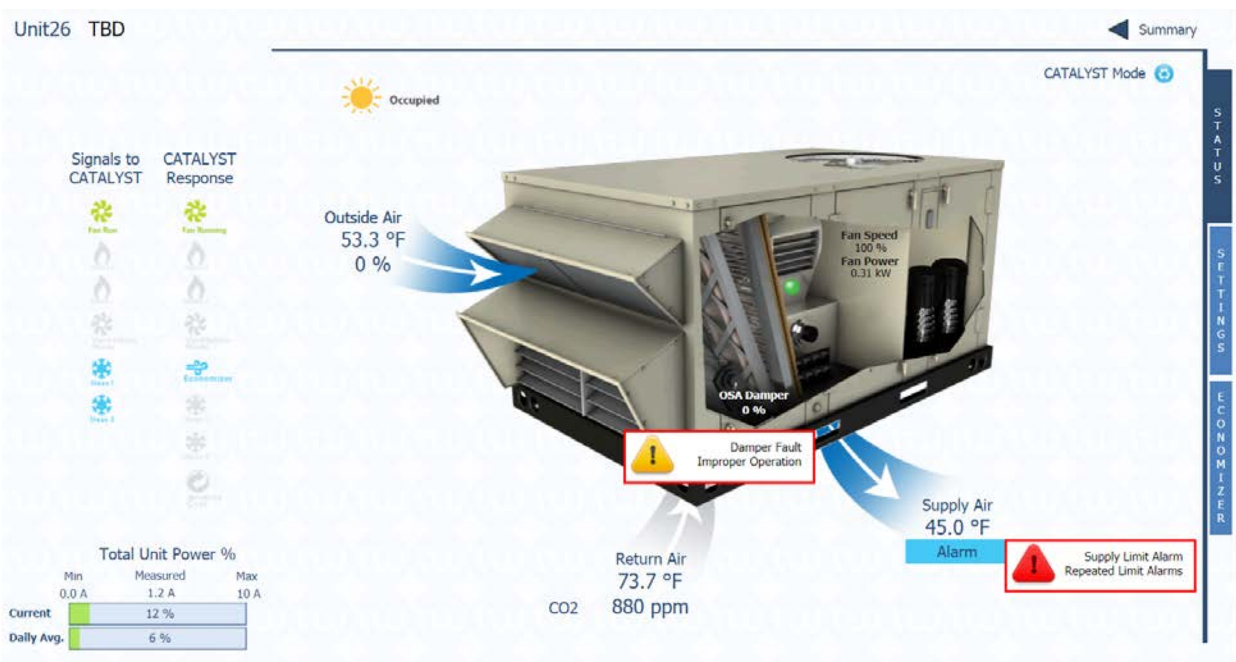

Figure 2. View of a unit operating with a fault identified through the eIQ portal (Credit: Transformative Wave)

The eIQ automated fault detection and diagnostics feature has additional energy benefits as it decreases the amount of time an inefficient unit is running due to an undiagnosed fault. Although this brings additional energy savings, it is generally difficult to quantify as the amount of time and energy saved is often site specific.

[14] Installation training takes about 24 hours over three days to complete. Transformative Wave also offers sales training one-on-one and through formal training events at their Kent Headquarters.

eIQ can also create trend analyses for any of the data points collected by the series of CATALYST sensors for a specified timescale. Images of the eIQ interfaces and reporting capabilities are included in Appendix B - eIQ Screenshots.

Product Cost

Transformative Wave provides contractors with a pricing and specification tool that enables them to estimate project economics for a given building based on building type, estimated run hours, RTU capacity, and fan horsepower. While individual sites may vary, the CATALYST's pricing can be generally broken down into three primary components:

- **Site materials**: This includes the VFD, the economizer controller, the eIQ central hub, and optional temperature sensors. There is a single eIQ central hub per location and one VFD and economizer controller for each unit. The eIQ central hub and economizer controllers are both fixed costs, whereas the VFD cost varies with the size of the unit.
- **Contractor/in-house labor:** Labor costs include in-house work done by Transformative Wave at their factory and on-site work completed by the installing contractor. The wiring and programming are all done in house by Transformative Wave to leverage economies of scale and simplify on-site installation. The cost of the in-house labor is a one-time cost that varies with both the number of controllers being installed and the complexity of the logic being programmed. On-site labor includes installing the VFDs and bolting the economizer controller to the RTU. Additional labor may be needed to include the temperature sensors and to repair any faults identified by the CATALYST once fully installed.
- **eIQ cloud server subscription**: An ongoing subscription to the cloud server is required for the user to be able to view the information being collected by individual controllers that are sent to the cloud via the eIQ central hub.

The cost of the CATALYST is primarily driven by the size of the VFD required for each RTU, and therefore, CATALYST units installed on units with larger cooling capacity and fan horsepower will cost more because of the increased VFD cost. However, because energy savings also scale with fan size, project economics are typically more favorable for larger units. Other CATALYST unit materials, including sensors and wiring, are fixed and therefore, do not change with RTU size.

Transformative Wave includes a two-year warranty for the VFD and a one-year warranty for the remainder of the CATALYST components. The warranty covers any unexpected mechanical failures. Transformative Wave quotes the replacement VFD at about $500–$800. Transformative Wave finds that the VFD is very reliable with failures occurring typically due to installer error or water damage.

ADOPTION BARRIERS

While the CATALYST has been successful in its demonstrations and received awards from organizations for its energy savings capabilities, it still faces several common adoption barriers for technologies in the commercialization process:

CUSTOMER AND SUPPLY CHAIN BARRIERS

- **Low consumer awareness** – While it has been successfully demonstrated in multiple previous third-party validations,[15] the CATALYST and other ARCs are relatively new technologies and fundamentally different than simply installing new, more efficient equipment that facility managers may be used to. This information barrier requires additional customer education and awareness.
- **Underdeveloped supply chain and lower contractor awareness** – Because the CATALYST and other ARC technologies are retrofit solutions and different than selling new equipment, contractors have an initial learning curve to successfully sell and install them. Since HVAC contractors and design/build engineering firms have traditionally focused on selling and installing new equipment in replacement of existing units, they may not be aware of retrofit opportunities and how controls can support new business models moving toward a more ongoing, service-based customer relationship.
- **First cost investment** – Customers are often concerned with up-front capital investments, and the common use of performance metrics such as simple payback does not accurately characterize performance of longer-term investments and critical infrastructure such as HVAC. Metrics such as savings to investment ratio (SIR) or life cycle cost (LCC) analysis better reflect the total value of energy savings. Identifying non-energy benefits (through reduced maintenance and downtime, improved occupant comfort, etc.) also identifies additional business value that ARCs provide. Since the landlord owns the building's HVAC units but the tenants receive the main benefits from the energy savings, it is difficult to decide who should invest in and commit to the cost. The benefits are often split between the two parties in an unknown amount making the decision difficult.

REGULATORY BARRIERS

- **Limited utility support and ongoing need for pilot demonstrations** – Although the CATALYST has roughly 12,000 units installed nationally and numerous previous published third-party validations, utilities often require their own pilots to validate energy savings claims for technologies prior to incorporating them as a measure in their portfolio. This requires technology companies to conduct many time-intensive pilots across multiple utility territories, limiting their ability to achieve scale following successful demonstration.

TECHNICAL BARRIERS

- **Existing Equipment Issues** – Technology like ARCs, which dependent on the condition of existing building equipment, is less likely to be successful if it is installed on aging and poorly maintained units. Older equipment may be in bad enough shape to preclude installations from moving forward or require significant work to bring the unit up to baseline working order.
- **IT Coordination** – Facility and IT managers may be concerned with networked controls, which tap into the building's network, limiting or delaying access which extends deployment timelines. The CATALYST circumvents this issue by establishing its own separate network and not tapping into the building's IT infrastructure.

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[15] Third-party validations include NREL 2016, E Source 2016, PNNL 2013, SMUD 2014, and UC Davis 2014.

3. ETAC DEPLOYMENT OBJECTIVES

SUMMARY OF PROJECT GOALS

NYSERDA's Emerging Technology Accelerated Commercialization (ETAC) initiative supports market adoption of commercially available yet under-used energy saving and load-reduction strategies or technologies in commercial, institutional, and non-process industrial settings through large-scale and high-impact demonstrations of these strategies and technologies. This large-scale deployment of Transformative Wave's CATALYST focused on showcasing solutions that address barriers to broad market acceptance of the CATALYST and ARCs more broadly through three key goals:

1. **Demonstrate performance at scale and support integration into utility programs:** Increase confidence of building owners and utility program managers by installing many units across a wide variety of building types, providing sufficient performance data to increase consumer and utility confidence in ARC technologies and integrate the technology into New York utility programs. To ensure accurate measurement and validation of energy savings claims, NYSERDA's Technical Consultant, LaBella, provided M&V planning and oversight.

2. **Develop the supply chain and market awareness:** Increase the number of affiliate contractors who are trained to sell and install the CATALYST (and ARCs more generally) through marketing and outreach efforts, ensuring there is a robust supply chain that can support and meet the needs of New York building owners and operators. In addition, provide more general training to contractors, building engineers, and design/build engineering firms on the role that intelligent and networked controls in savings energy and optimizing building operations.

3. **Build consumer awareness and confidence through transparent project reporting:** Publish case studies, project reports, and an online public dashboard to communicate project energy savings and non-energy benefits over time, highlighting customer experience with the technology across different building types. Because of the CATALYST's energy monitoring capabilities, ongoing performance reporting can be conducted and reviewed through the dashboard on an ongoing basis to review the product's performance and financial performance over time.

DEPLOYMENT OVERVIEW

Project eligibility and incentive structure

The ETAC initiative offered a $2,400 per unit incentive to certified Transformative Wave Affiliate[16] contractors for selling and installing each CATALYST unit, which contractors provided as a pass-through incentive to customers to reduce project first cost. This flat-per unit incentive approach was used to improve the project economics for smaller units and encourage installations across all building types and unit sizes, since large units typically have better financial returns. The ETAC initiative for the CATALYST accepted project applications from

[16] In order to become a certified Affiliate, contractors must attend Transformative Wave's multi-day training on selling and installing the CATALYST, which is described in more detail in the Product Installation and Contractor Training section.

November 2015 to December 2017. All commercial buildings within New York State who paid the System Benefits Charge were eligible for incentives. Upon completion of installations, Energy Solutions verified installation through the eIQ interface to ensure that the controls were installed and the HVAC unit was performing properly. For a detailed overview of the project process, see Appendix A.

Performance Monitoring Requirements: As part of the customer program agreement, all customers agreed to anonymized energy reporting through the eIQ system for up to three years to collect performance monitoring data across all sites and ensure persistence of energy savings over time. A full description of the performance monitoring process is detailed in the Measurement and Verification Plan Details section.

Contractor engagement and education

The project team and NYSERDA conducted two types of contractor and industry outreach:

- Five introductory webinar sessions on the CATALYST for HVAC contractors, facility managers, building owners, and specific customer verticals in the New York market that demonstrate its benefits to customers.
- Offering a three-part series of webinars to contractors and end-use customers highlighting the value proposition of intelligent controls and how to use the newfound insights from the advanced data analysis to inform their decisions and take action. This series focused on distinct technologies and emerging market trends and was provided to 60 attendees from utilities, design engineering firms, and contractor companies.

Project performance dashboard

The dashboard was built to be fully interactive and enables potential customers, utility program managers, and/or potential contractors view anonymized project reporting that best addresses their interests and needs. The dashboard provides both a portfolio-level summary of the deployment to understand general project trends, as well as drill-down capability to see detailed information on a project by project basis, including:

Portfolio level:

- Average savings across entire deployment (in both therms and kWh)
- Average portfolio savings per month
- Financial performance (Savings to Investment Ratio) with an adjustable discount rate

Project level:

- General geographic location[17]
- Number of units
- Number of months of data collection
- Building type
- Building square footage
- Project cost

The Tableau-based dashboard integrates updated energy monitoring data from the Transformative Wave Server every 15 minutes, enabling ongoing monitoring of energy and financial performance over time at both a portfolio and individual project level.

[17] To preserve project site anonymity, each site is represented as a point on the map without any other identifying characteristics such as zip code.

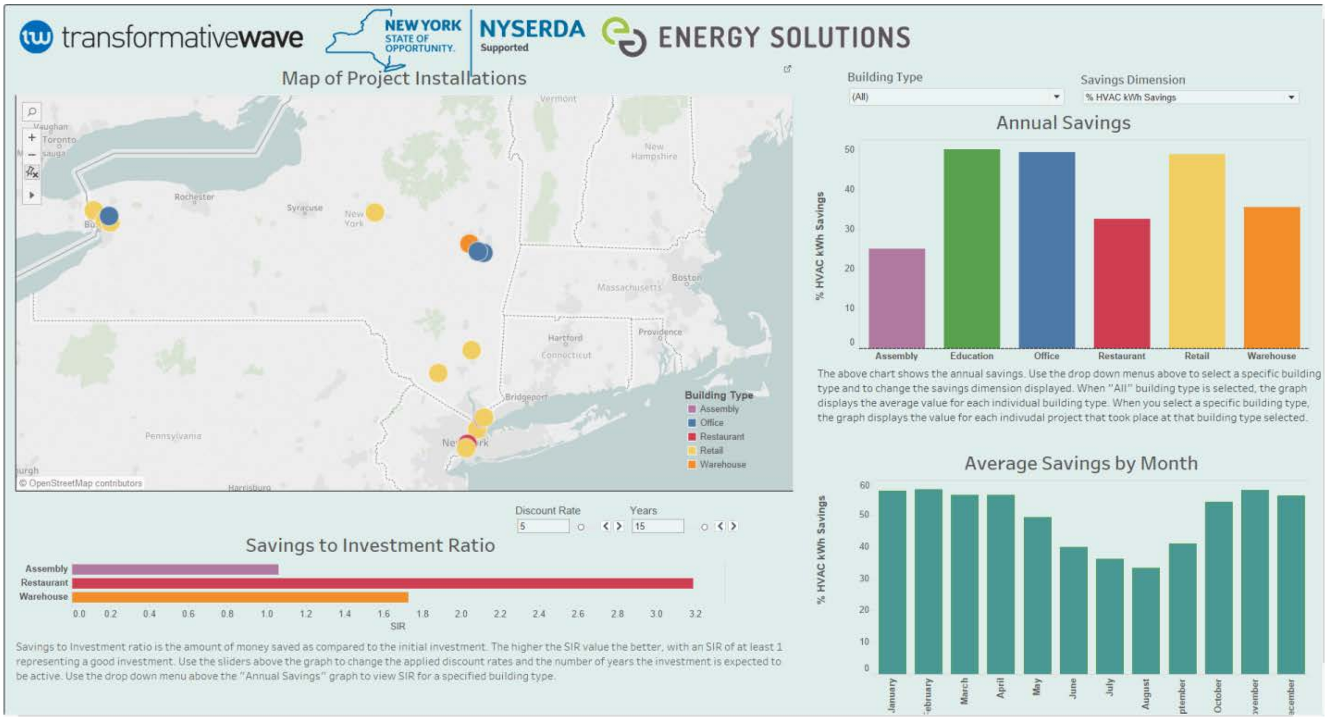


Figure 3. Interactive Performance Monitoring Dashboard. All information is streamed from the eIQ database and updated on a 15-minute basis.

The viewer can hover over the points in the map to see project specific information. The building type and savings dimension can be toggled to show a single building type and to change the savings type shown. The discount rate and years of investment assumptions in the "Savings to Investment Ratio" chart can be adjusted to meet user preferences. Additional dashboard images can be found in Appendix D: Additional Dashboard Screenshots.

MEASUREMENT AND VERIFICATION (M&V)

The project conducted measurement and verification activities to determine the energy and cost savings realized at each site in the deployment, and to assess the accuracy of the eIQ predicted savings and the data points reported by eIQ. The M&V was based on the International Performance Measurement and Verification Protocol (IMPVP) 2012 framework.[18] The energy savings calculation methods are listed below, along with how they were applied in this deployment's specific M&V plan, and how many units went through each step of the plan.

Energy Savings Calculation Methods

There are two primary methods to quantify energy and cost savings, which are listed below in order of relative accuracy. Both methods use data reported in the eIQ, which is based on usage measurements taken by installed current transductors, heating and cooling calls made by the site's BMS, and site occupancy levels determined by the carbon dioxide sensors in the HVAC return air ducts.

[18] Efficiency Valuation Organization. January 2012," *International Performance Measurement and Verification Protocol*"

RETROFIT ISOLATION / CALIBRATED SIMULATION APPROACH (IPMVP OPTION B)

The retrofit isolation/calibrated simulation approach uses CATALYST'S ability to run in Energy Savings Mode (ESM), which is the full CATALYST energy savings operation, and Standard Operating mode (SOM), which is an emulation of the pre-retrofit conditions. Switching between these modes runs on a prescribed schedule during the first year after installation to build a temperature regression model that is used on given timescales to estimate savings. This method is based on IPMVP Option B, Retrofit Isolation and was used in this study to determine the accuracy of the eIQ predicted savings.

Energy use in both ESM and SOM are reported by the CATALYST. The savings is then calculated as:

$$Savings = (Annualized\ SOM\ Energy\ Use - Annualized\ ESM\ Energy\ Use) \pm Adjustments$$

This method provides the savings to the highest degree of accuracy of the options above because the CATALYST is recording true energy use in both modes and calculating the difference. The annualized baseline and post-retrofit energy use calculations can be found in Appendix C: Savings Calculation Details.

CALCULATED SAVINGS APPROACH (IPMVP OPTION A):

Power measurements and other data collected from sub-meters and controllers can be used to calculate the estimated savings achieved by CATALYST operation. The pre-retrofit consumption is estimated by adding the avoided energy consumption back to the actual energy use. The pre-retrofit conditions are based on a series of measurements taken prior to installation. This option is based on IPMVP Option A, where key parameters are measured, and additional baseline information is approximated. This option was used to calculate the savings realized at each site participating in the deployment.

The power measurements and other data collected by the eIQ Platform from each of the RTU's full unit sub-meters and CATALYST controllers during CATALYST operation can be used to calculate the estimated savings achieved by CATALYST operation. The pre-retrofit consumption is estimated by taking the measured CATALYST energy use and adding back the calculated avoided energy consumption associated with each conservation measure implemented by CATALYST control.

Savings from each measure component (VFD, demand control ventilation, and advanced economizer) are calculated separately and are added together to calculate the full system savings. The full calculations for each measure component can be found in Appendix C: Savings Calculation Details.

The savings due to the VFD are calculated to a high degree of accuracy because they are based on two known quantities: the peak fan kW (measured at the time of installation) and the instantaneous fan power draw (measured by the CATALYST sensors). The savings from demand control ventilation and the advanced economizer sequence have a lower degree of accuracy because there is a series of assumptions made about how the unit would have been operating in the pre-retrofit condition.

Measurement and Verification Plan Details

The plan included the following features and parameters for all sites in the deployment:

- **Recording of Pre-Installation Conditions**: Existing conditions were collected during installation to establish the baseline condition and verify the accuracy of the data reported by the CATALYST system. Data collected included economizer changeover setpoint, economizer control type, space setpoints and occupancy schedules, baseline fan power, and outside air damper position.
- **Savings Calculated via the Calculated Savings Approach:** eIQ calculates the savings at each site internally and reports the data daily. The savings calculated were processed to determine average deployment savings and savings for subsets of the deployment. The reported savings values were also combined with site details collected during the project process to determine what site and equipment characteristics drives energy and cost savings.

In addition to the features above, about 40% of the 142 incentivized units went through additional M&V activities, including:

- **Data Validation through Mode Switching:** The CATALYST was programmed to switch between pre- and post-retrofit conditions, or Standard Operating Mode (SOM) and Energy Savings Mode (ESM), respectively. Switching occurred daily for the first two weeks of every other month. Mode switching started on the first day of the month immediately following CATALYST installation. It was estimated that this schedule would result in the loss of only 5% of the first-year energy saving. The site savings calculated via mode switching was compared to the site savings reported by eIQ to determine the accuracy of eIQ reported savings. Figure 4 details how each component of the M&V plan was applied to the sites participating in the deployment.

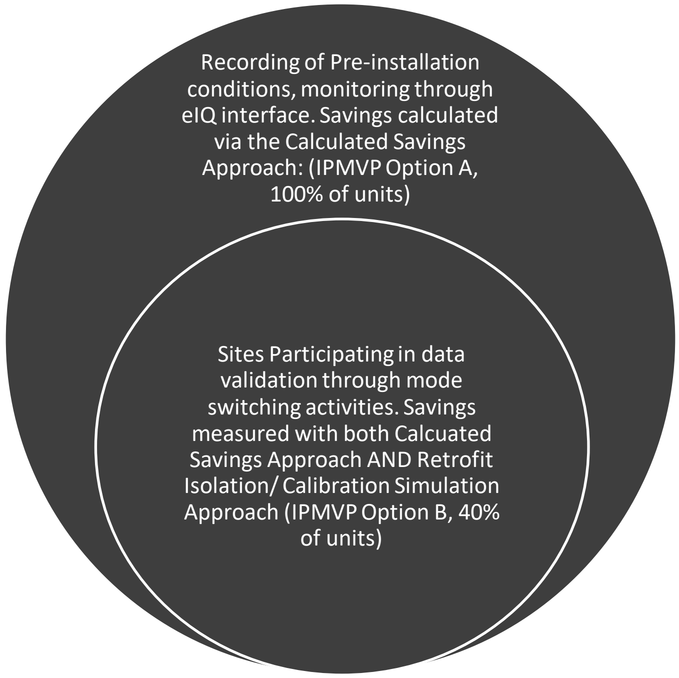


Figure 4: Overview of M&V methods across projects within the ETAC deployment

Data recording began the first day of the month immediately following installation completion. The data recording proceeded for one full year, meaning at the completion there would be 12 weeks of recorded data for each site: six weeks of SOM and six weeks of ESM runtime.

Table 2. Overview of M&V strategies by building type.

	Monitored Through eIQ and savings calculated via calculated savings approach[19]		**Sites participating in data validation through mode switching. Savings calculated via Retrofit Isolation/Calibration Simulation Approach**	
Building Type	Total Sites	Total Units	Total Sites	Total Units
Retail	9	41	6	29
Education	3	7	0	0
Office	6	112	2	9
Restaurant	5	19	5	15
Assembly	1	7	0	0
Total	24	186	13	53

Out of the 142 incentivized units, 53 participated in the data validation through the mode switching protocol outlined in detail above. The original implementation of the data validation protocol was delayed due to continuous Measurement and Verification plan revisions, which impacted the execution schedule and collateral development. Not all incentivized units were required to participate in switching, as this condition was not included in the original customer

[19] The units monitored through eIQ was greater than the number of units incentivized because two sites had units that had the CATALYST installed but were not eligible for the incentive. In one case, the units did not qualify because they served multiple zones while the program limited eligibility to units with single zone control. In the other case, the units were not eligible because there was a cap on the number of units an individual customer could submit for incentives. These units were still able to be monitored for savings validations because eIQ groups all the units on an individual site together.

agreement form since the plan was not finalized at the time of collateral distribution. All customers who submitted applications using the updated customer agreement beginning in September 2017 were required to participate in the data validation protocol along with a sampling of the customers who submitted applications prior to September 2017 and agreed to participate.

In addition to the plan components detailed above, LaBella installed on 5% of all RTUs in the deployment to confirm that measurements reported through the eIQ interface accurately reflected independent measurements in the field. Data collected included full unit power draw, fan power draw, and compressor status. The data collected was compared to data output by the CATALYST to confirm the accuracy. Discrepancies of 5% or less were ignored, and the CATALYST data was used. Larger discrepancies resulted in the adjusting of reported data.

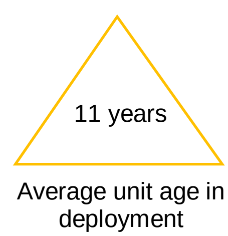
4. RESULTS

DEPLOYMENT SUMMARY

Deployment marketing and outreach efforts began in October 2015, application submission opened in December 2015 and project installation and commissioning took place between June 2016 to March 2018, with participation from the following Affiliate contractors: Atlantic Westchester; EMCOR Betlem; American Energy Care and SureTemp. In addition to Affiliate contractors, projects were also completed through Transformative Wave's National Accounts arm.

Table 3. Summary of Key Deployment Results Statistics

Building Type	Total Sites	Total Units[20]
Assembly	1	7
Retail	9	35
Restaurant	5	15
Office	6	76
Education	3	9
Total	24	142



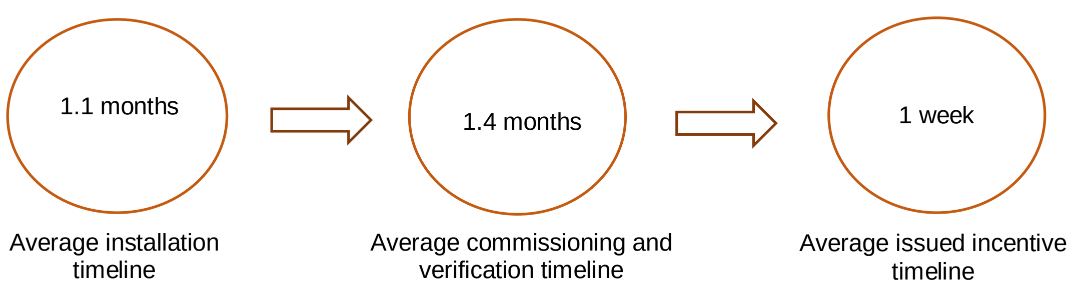


Figure 5: Average Project Timeline

[20] The unit count includes all units at sites that received NYSERDA incentives. In a few cases, not all units within a project site were applied for and/or received NYSERDA incentives. In total, 142 units across 24 sites received NYSERDA incentives.

The average installation timeline from start to finish was 1.1 months and ranged from one to three months depending on the number of units and the specific customer needs. The site installation began after the project team approves the project and the customer ordered the CATALYST equipment. Site installation was considered completed after all units were online and visible in the eIQ platform. After installation was completed, the commissioning and quality assurance period averaged about 1.4 months across all units. The commissioning and verification concluded when the project team received all unit startup documentation and when the eIQ platform indicated that all units and controls were fully functioning. On average, the final incentive payment was issued one week after a site was commissioned and verified by the project team.

Some sites had a longer installation timeline if they had extensive site specifications such as stringent occupant requirements, integration with other advanced systems, and installing a BMS that controlled several sites. In cases where the project did not move forward with installation, this was rarely due to technical barriers and more so attributed to customer acquisition hurdles.

The average age of RTUs across the deployment was 11 years, ranging from one year to 19 years. Since the CATALYST has an expected lifetime of at least eight years, this suggests many building owners are operating their RTUs well beyond New York's assumed measure life of 15 years. This has important implications for a utility program trying to comprehensively address HVAC in existing buildings by targeting existing units that are still in good working condition and will not be replaced with more efficient units in the near future.

The sites in the deployment were spread across the State as can be seen in Figure 6. Projects in areas with higher population density, such as New York City, tended to be smaller buildings with less RTUs while the remainder of the state had a range of small, medium, and large buildings. The installations also were spread through the three climate zones present in New York State–zones 4, 5, and 6.

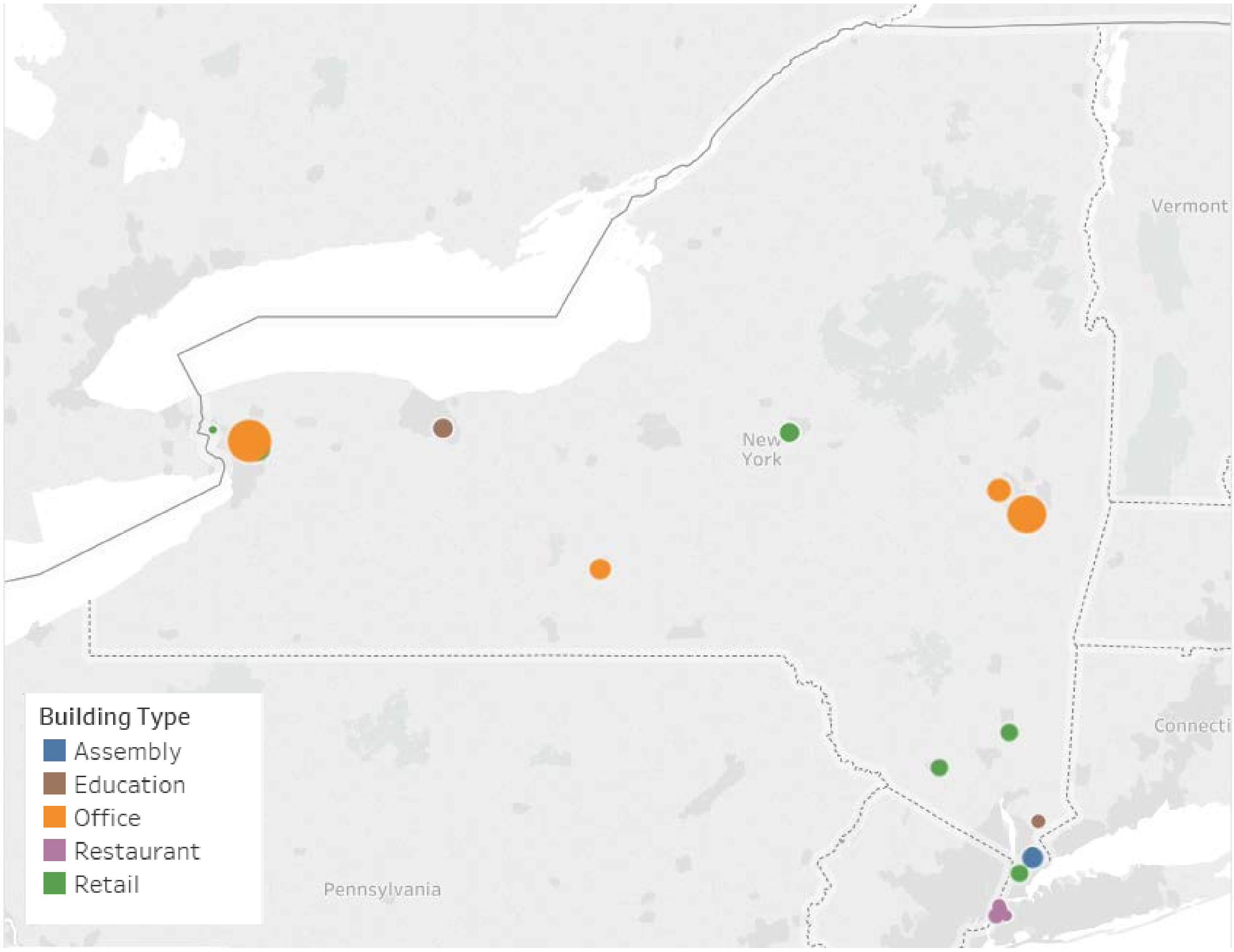


Figure 6: Map of Project Installations. The size of the point indicates the relative number of units installed at the location (Of the 186 units installed at 24 sites, the smallest installation size was 1 unit, the largest 30 units). Not all projects are visible due to close geographic proximity causing overlapping points.

ENERGY SAVINGS

eIQ Monitoring Results

Overall, the CATALYST achieved 35% electricity savings, 5% therms savings, and 28% operating cost savings over an average monitoring duration of two years. Table 4 shows the average energy and cost savings as a percentage of the baseline usage.

Table 4. Energy and Cost Savings (%) for all sites. The total savings are a weighted average based on the number of sites within each building type. Data for this report was collected through May 2019

Building Type	Number of Sites	Total Units	Electricity Savings	Therms Savings	Cost Savings	Average Monitoring Duration (months)
Assembly	1	7	24%	1%	24%	30
Education	3	7	44%	7%	35%	23.7
Office	6	112	41%	10%	26%	25.8
Restaurant	5	19	23%	0%	17%	18.6
Retail	9	41	34%	5%	32%	22.1
Total	**26**	**186**	**35%**	**5%**	**28%**	**24**

Cost savings were calculated by multiplying the kWh and therms saved by a flat kWh and therms rate respectively and adding together. The kWh and therm rates are blended rates calculated by Transformative Wave based on the specific customer's rate schedule.

Table 5 shows the differences in kWh savings percentage savings outcomes for each building type.

Table 5. Electricity Savings statistics

Building Type	Average	Range	Std. Deviation
Assembly	24%	N/A	N/A
Education	44%	38% - 50%	4%
Office	41%	28% - 50%	7%
Restaurant	23%	16% - 31%	5%
Retail	34%	5% - 48%	11%
Total	35%	5% - 50%	8%

The range in energy savings within a given building type was primarily due to differences in annual operating hours. For example, the maximum office savings (50%) was from a facility that operated for about 7,600 hours[21] during the year while the minimum savings (28%) was from a facility that operated closer to 3,200 hours during the year. The impact of hours of operation on percent savings is discussed in more detail below.

Changes in percent savings between the interim report and this final report are also most likely due to normal fluctuations in annual savings impacted by average temperature.

Explanations for Underperforming Retail and Restaurant Facility

There were two facilities, one retail site and one restaurant site, that performed lower than expected when taking the main drivers such as average daily temperature and occupancy into account.

Retail

eIQ reported the retail facility saved about 5% kWh annually on average, far below the expected value and average for the building type. Transformative Wave informed the project team that the site went through a second retrofit after the initial project, where monitoring, but **not control,** was added for a 20-ton unit. Therefore, the daily usage from the 20-ton unit was added to the total site usage but there were no savings associated with the unit. Originally, there was only 30

[21] These operating hours are atypical for this building type.

tons of cooling both monitored and controlled, so the additional unit almost doubled the amount of cooling monitored without having energy savings associated with that second half of cooling.

Restaurant

There were two main issues impacting the savings of the restaurant site, which averaged 17% annual kWh savings—one related to incorrect data reporting and one due to a fan belt fault. The data issue was a result of the Standard Economizer Position listed at 0% between June 2018 and August 2018. Demand Control Ventilation savings were reported as negative during this period because the post-retrofit usage calculations assumed more outside air than in the pre-retrofit case. The issue has since been fixed and DCV savings are reported as positive currently. The second issue, which occurred between October 2018 and December 2018, resulted in inaccurate fan power values causing negative fan savings. These incorrect values were a result of an issue of the fan drive assembly. eIQ was accurately reporting a fan belt fault during this time and the savings have since returned to normal after the fan drive repaired.

SEASONAL IMPACT ON ENERGY SAVINGS

Figure 7 shows the electrical savings percentage per month for each building type.

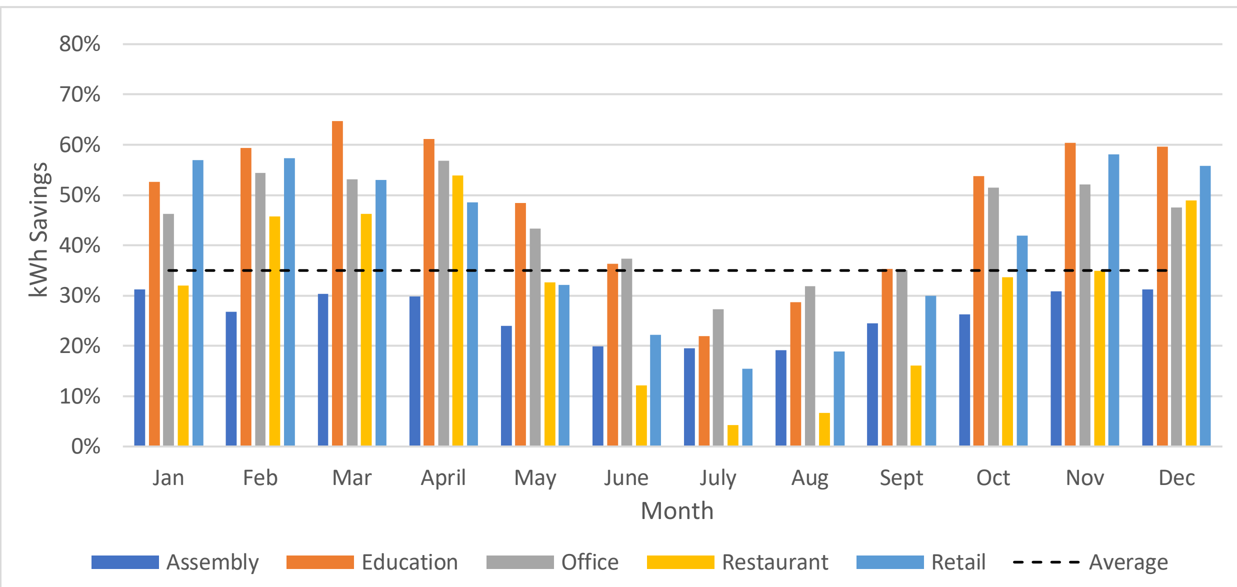


Figure 7. Electrical (kWh) Savings as Percentage of the Baseline kWh per building Type. The value for each building type is the average across all sites for the specific building type and the chart also includes a line showing the average across all sites.

Energy savings were highest in shoulder seasons, when the CATALYST takes advantage of outside air for cooling, and lowest in summer when compressors are needed for a higher percentage of facility runtime and RTUs operate at full load much of the day. Savings are high during winter because the units have a lower overall electricity use because there is no compressor input needed (the units all used gas heating). Therefore, because the units only use electricity to run the fans in the winter, they realized a higher overall percent savings since the fan savings provide most of the overall unit electricity savings.

The restaurant building type had the biggest range of savings month to month. This is consistent with expectations because restaurants have a higher internal heat load due to the cooking equipment. The higher internal heat load increases the need for compressor energy during the summer and decreases the need for heating (and thus fan energy) input during the winter months. The assembly had the smallest range. However, this is likely due either to the overall lower savings as compared to the other building types, or the small sample size for this building type.

ELECTRICAL SAVINGS BY MEASURE

Electrical savings are a sum of the savings due to the VFD, the advanced economizer sequencing and the use of demand control ventilation.

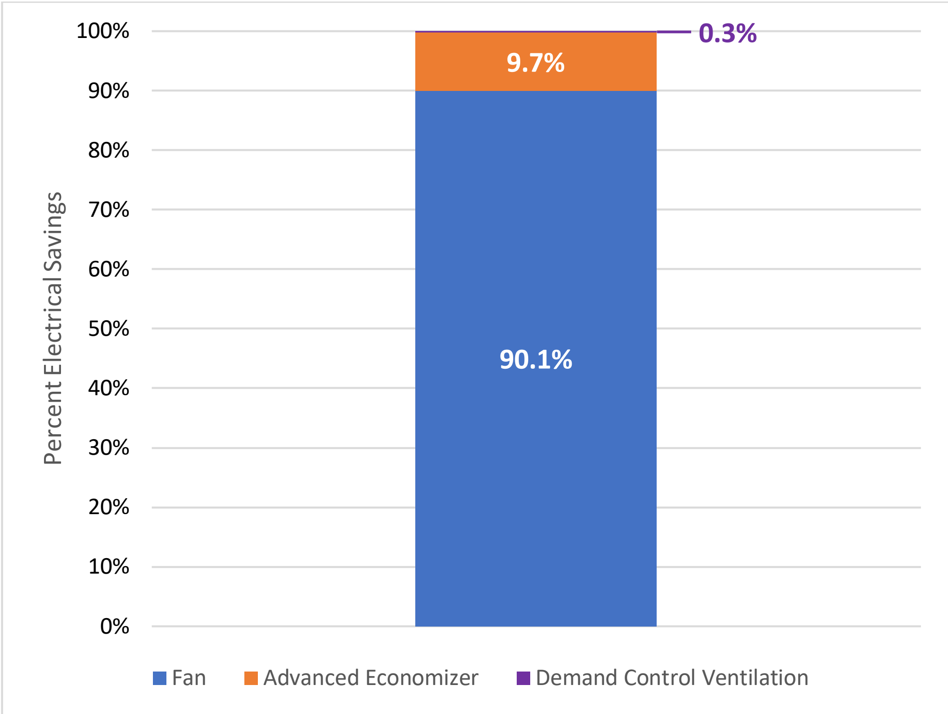


Figure 8. Breakdown of electrical savings by measure averaged across all units, based on reported data from eIQ interface which reports savings from the three measures separately

The chart shows that the VFD provides most of the savings. The fan speed reduction provides the majority of the savings because fan power decreases at the same rate as the cube of the speed reduction. The CATALYST VFD controls the fan to run at 40%, 75%, or 90% speed depending on what is needed. These represent an 88%, 58%, and 27% reduction in power consumption respectively.

In addition, as noted in Figure 8, the fan savings are calculated to a high degree of accuracy because the calculations are only based on two inputs—fan power at 100% speed and instantaneously measured fan speed. Therefore, because the fan savings constitutes almost 90% of the total system savings, it can be inferred that the total system savings are also calculated to a high degree of accuracy as well.

IMPACT OF OCCUPANCY HOURS ON PERCENT ENERGY SAVINGS

The CATALYST uses a carbon dioxide sensor installed in the return air duct to sense the carbon dioxide levels in the return air to infer building occupancy status. The CATALYST reports that a space is occupied based on CO_2 thresholds. The standard setpoint for the CATALYST is 1,000 PPM above this point and the CATALYST adjusts operations to open the dampers to bring in more outside air. Occupancy hours is one of the data points in eIQ and reported as a percentage of the hour the CATALYST sensed that the space was occupied. For example, if the CATALYST sensed that the space is occupied for 15 minutes out of the hour, the data point would be reported as 25% occupied for the hour. The annual occupancy hours for each site was compared to the percent electrical (kWh) savings to determine whether occupancy is a driver for energy savings. The following charts show the relationship for the retail and office building types.

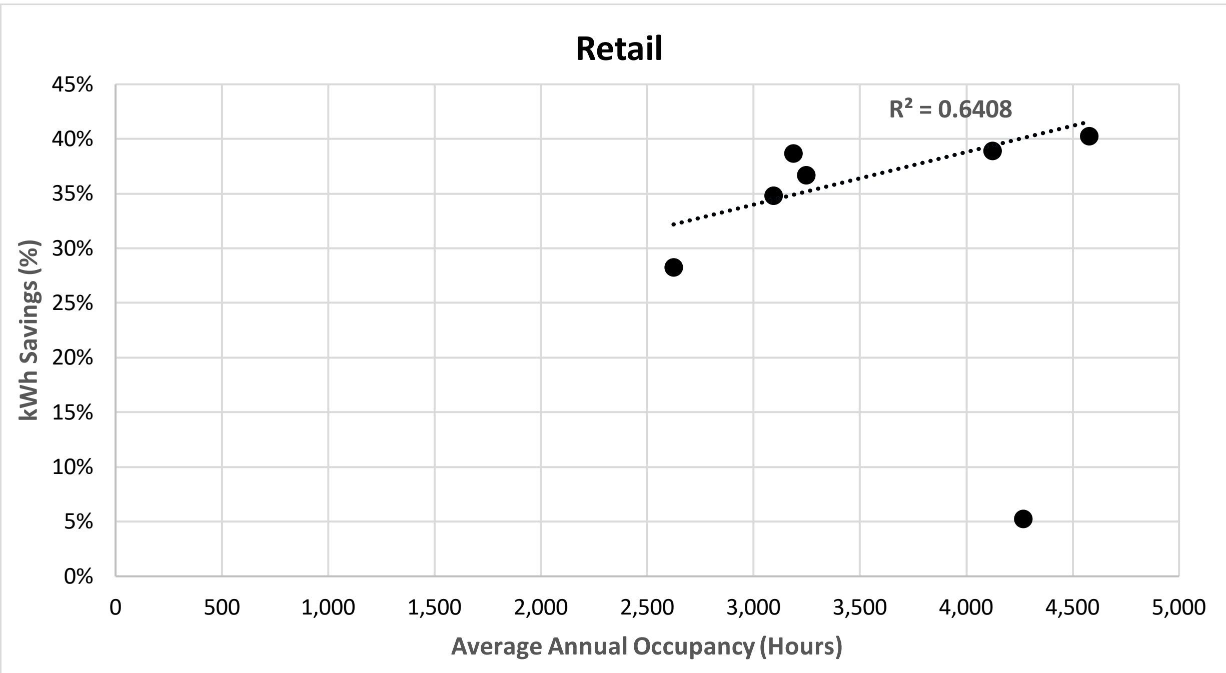


Figure 9. Impact of annual occupancy hours in percent kWh savings for the retail building type. The site with lower than expected savings was excluded from the trendline to better accurately show trend

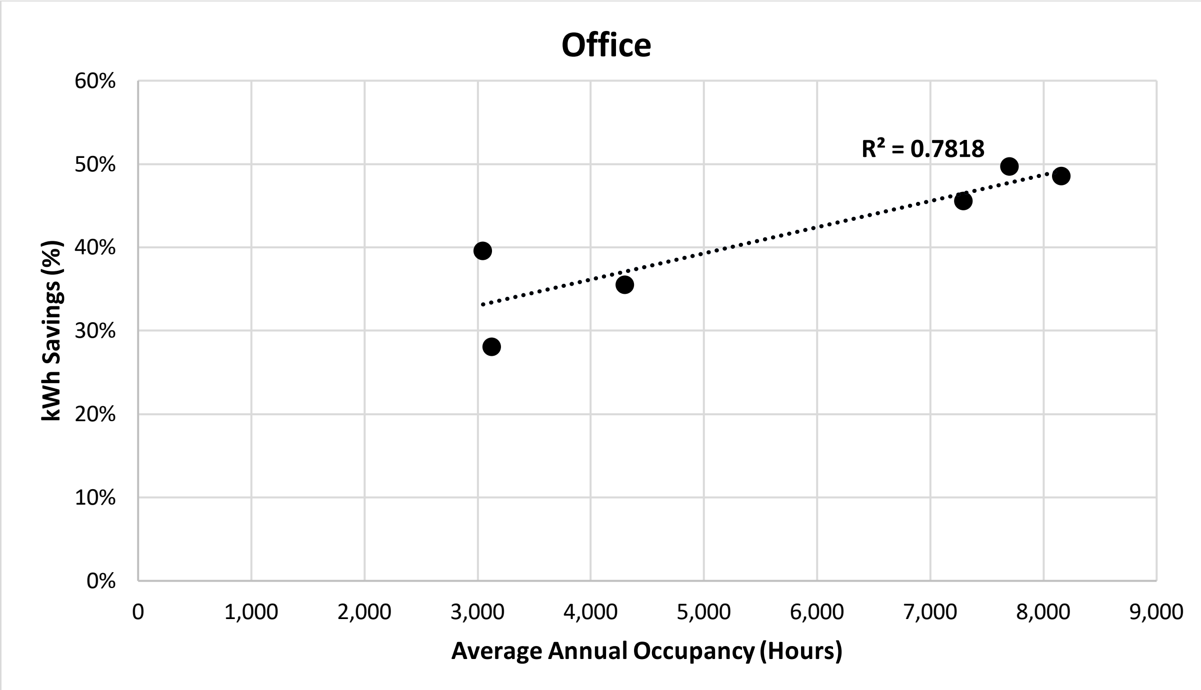


Figure 10. Impact of annual occupancy hours in percent kWh savings for the office building type.

Based on the occupancy data across projects sites, a site saves a higher percentage of electricity over their baseline usage if it is occupied for a greater number of hours. The sites that fell into the retail building type were all clothing/retail locations, whereas the office building type had sites that ranged from a traditional 8 a.m. to 6 p.m. runtime office and a call center that operated 24 hours a day. The CATALYST can provide increased savings for sites with longer occupancy hours because they have a higher percentage of total operating hours where they are in partial load conditions.

Contractors who participated in the deployment agreed with the finding that sites with longer run times represent an ideal use case for the CATALYST. One contractor noted that a site that has 10-ton units running for at least two shifts per day is a perfect site to install the CATALYST.

Validation of eIQ Reported Data

LaBella conducted two sets of analysis that were used to validate savings data reported be eIQ-savings calculations through mode switching, as discussed in detail in Retrofit Isolation / Calibrated Simulation Approach (IPMVP Option B), and comparison of unit and fan power readings from a smaller subset of units.

LaBella calculated savings on a per unit basis and did not include savings from all units on site in the rolled-up site totals. The methodology followed by LaBella can be found in Appendix C: Savings Calculation Details. LaBella used hourly unit usage data reported by eIQ in their calculations. In addition, data points reported as “invalid” by eIQ’s system were removed from the calculations. The invalid data field in eIQ is a binary field that reports when there is a sensor issue at the given timestamp. eIQ data used to generate the comparison was reported on the daily level and included the number of hours in a given day that eIQ reported as having invalid/bad data. To account for the differences in data sources and methodologies used, any day that had more than two hours’ worth of invalid/bad data was removed. Data points removed accounted for a maximum of 3% for a given site and 1% of total data on average, meaning the removal of these data points lacks a significant impact on the results. Next, savings lost due to the unit running in Standard Operating Mode were added back to the estimation to generate an estimated annual savings with the assumption that the unit was running in Energy Savings Mode the entire time. To account for lost savings, 12.5% kWh savings were added back to the calculated total because it was estimated that the unit was running in SOM for about 12.5% of the monitored period. A site average was calculated by comparing the summation of the unit level standard usage and kWh savings.

Table 6 summarizes the site level results comparing kWh and % kWh savings reported by both eIQ and by LaBella.

Table 6 Comparison of annual kWh savings (total and percentage) reported by eIQ and calculated by LaBella.[22]

	eIQ		LaBella	
Site	**Total kWh Savings**	**% kWh Savings**	**Total kWh Savings**	**% kWh Savings**
848	27,854.71	28%	21,843	39%
855	27,363.41	35%	23,210	69%
1002	10,392.79	34%	6,852	43%
1066	51,947.42	42%	49,466	58%
1255	119,915.54	52%	147,126	83%
1547	29,637.99	38%	21,974	45%
1554	40,367.30	43%	46,464	62%
1557	25,715.17	40%	22,259	43%
1695	7,208.49	43%	20,889	77%
1726	15,939.79	24%	25,084	46%
1727	15,757.22	22%	33,322	47%
1728	19,796.01	31%	20,823	54%
1729	12,239.06	16%	19,475	33%

Total kWh savings and percent kWh savings calculated by LaBella were both higher on average than what eIQ reported. LaBella reported about 27% more kWh savings and 35% percent kWh savings.

LaBella's second set of analysis compared unit power calculated by eIQ to that calculated by themselves. Unit power was calculated by measuring the current using a current transducer installed on the high leg of the unit. LaBella and eIQ convert the amperage readings to power readings using the following equation:

$$\text{kW} = \sqrt{\frac{3 * Volts\ @\ startup * CT\ amps * Power\ Factor}{1{,}000}}$$

[22] This data was originally reported in LaBealla Associates "Transformative Wave CATLAYST Evaluation" report prepared for NYSERDA. This report was conducted as an internal evaluation of the deployment and will not be made publicly available aside from the results referenced in this report.

The equation used by both LaBella and Transformative Wave was the same except that Transformative Wave assumed a power factor of one when there is no compressor activity and 0.8 when there is compressor activity, and LaBella assumed a power factor of one in both cases. Transformative Wave said that their use of 0.8 as a power factor was an assumed value, which was based on estimated inductance from the compressor. The following table shows the unit power reported by eIQ and calculated by LaBella.

Table 7 Comparison of unit power readings reported by eIQ and LaBella.

Site Detail		Fan Power		Difference	
Site ID	**Unit ID**	**LaBella**	**eIQ**	**kW**	**%**
847	6037	2.699 kW	2.333 kW	0.365 kW	13.5%
847	6042	4.532 kW	3.493 kW	1.039 kW	22.9%
847	6054	4.204 kW	3.468 kW	0.735 kW	17.5%
847	6039	5.362 kW	4.234 kW	1.128 kW	21.0%
847	6045	1.934 kW	1.739 kW	0.195 kW	10.1%
847	6051	5.173 kW	2.437 kW	2.736 kW	52.9%
1695	13136	0.166 kW	0.165 kW	0.001 kW	0.8%
Average				0.88 kW	20%

POTENTIAL SOURCES OF ERROR

There were three potential sources of error identified: time interval sampling period, difference in equation inputs, and weather data used to generate the regression curve. The following sections include investigations into each of these sources and final determinations about potential scale of impact.

Sampling Period

Transformative Wave's current transducers record spot amperage readings every minute. This data is reported on the hourly level, which is also the minute level data average. In comparison, LaBella took spot data readings on 10-second intervals, which were subsequently rolled up to the hourly level for comparison to eIQ reported values. It was determined that this difference in sampling periods could have had a significant impact on the final values reported as shown in Figure 11.

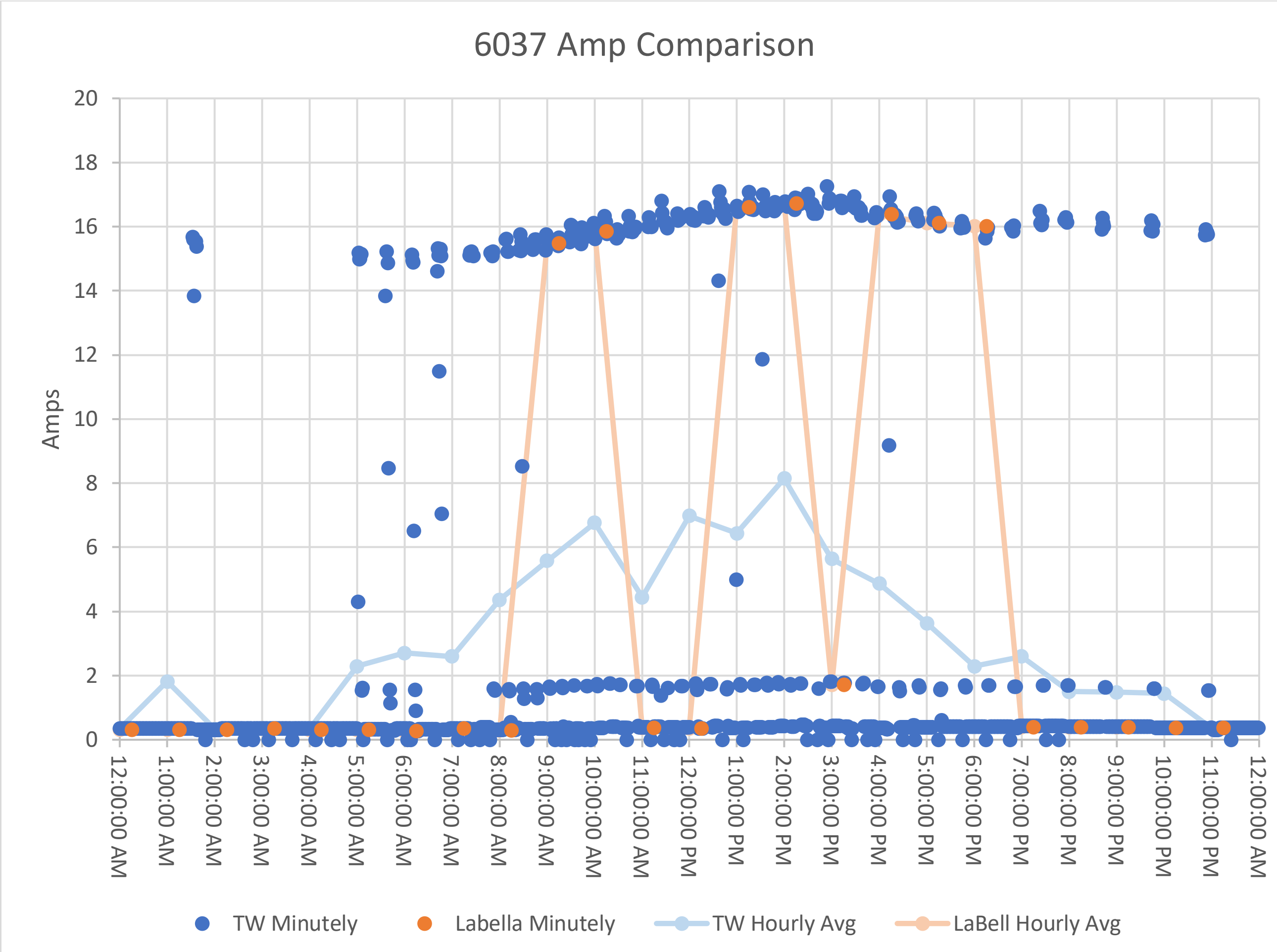


Figure 11. Amp Hourly Average Readings Resulting from Different Data Recording Intervals

LaBella provided their hourly data for the analysis, which was compared to eIQ minute level readings. The Figure 11 shows that the average reading over an hour could differ significantly depending on the number of data points taken during the hour. The LaBella hourly data points matched up in magnitude to the readings reported by eIQ. However, in the example above, the eIQ reported data has much more granular readings, meaning a better calculation of average use over the given time frame. The impact of the reported average can be clearly seen by comparing the two hourly average lines.

The Catalyst controls each RTU to run at a constantly optimized operation. Therefore, usage data will not be reported accurately unless the data readings are taken as rolling averages or as spot measurements in increments small enough to accurately account for changes in the operation.

The exact time the data measurements were taken likely had an impact on reported data. Transformative Wave reported their current transducers recorded readings at the beginning of every minute. However, equipment operation drifts over time and there is a possibility for delays on the scale of seconds between the time stamp and recording of the data.

Equation Inputs

LaBella and Transformative Wave both measured amp readings from the same point on the RTUs and converted them to unit power using the same equation. However, as previously, Transformative Wave used a 0.8 power factor when the compressor was active and a power factor of one when it was not. LaBella used a power factor of one in all cases. Transformative Wave's differing power factors would cause the eIQ reported unit power to be about 10% lower during times of compressor activity compared to power readings calculated by LaBella.

The voltage used by Transformative Wave and LaBella was compared as well. Transformative Wave uses the equipment nameplate data in most cases, but occasionally uses the actual voltage reading taken at unit startup. LaBella used the equipment nameplate voltage in all cases. For the units monitored by LaBella, both Transformative Wave and LaBella used the same voltage in all but one case. As a result, this potential source of error was ignored.

Differences in equation inputs will only have an impact on the magnitude of the savings and not the percentage. This is because the same equation and inputs were used in both the pre-retrofit and post-retrofit conditions, and the percentage is calculated by using the following equation:

$$kWh\ savings\ \% = \frac{Preretrofit\ kWh - postretrofit\ kWh}{Preretrofit\ kWh}$$

This, however, does likely explain why there is a larger range of differences in the magnitude of kWh savings when compared to the differences in kWh savings percentages.

Weather Data

LaBella created a regression curve based on the 30-year average of heating degree days (HDD) and cooling degree days (CDD) to estimate the annual savings achieved by each RTU. The savings estimated using the regression analysis can vary significantly from the actual savings achieved if there is a large variation in the actual HDD and CDD during the monitored time-period when compared to the 30-year average. This is because savings achieved by the Catalyst are weather dependent. To determine relative impact, LaBella recreated their regression curves using actual HDD and CDD that occurred during the time period when each unit was monitored. The following table compares eIQ reported savings to those originally reported by LaBella and those recalculated using actual HDD and CDDs.

eIQ	LaBella (Original)	LaBella (Updated)
28%	39%	38%
35%	69%	65%
34%	43%	12%
42%	58%	56%
52%	83%	83%
38%	45%	45%
43%	62%	61%
40%	43%	53%
43%	77%	80%

24%	46%	43%
22%	47%	46%
31%	54%	53%
16%	33%	34%

There were minimal changes between LaBella's original reported values and the updated values. As a result, weather was not considered a major factor in the differences in savings reported by eIQ and LaBella.

Conclusion

Both LaBella and eIQ independently reported significant savings from the Catalyst. In fact, LaBella's analysis shows higher savings than eIQ's report. The difference in sampling periods and exact time the data was recorded is determined to be the most likely cause of reported differences in savings. The equation inputs used to convert unit amps to power readings is also determined to have an impact, but only for savings and not percentage.

These differences in results also enforce the idea that measurement and verification plans need to be thought out and consistent if used alongside a utility program focused on Catalyst installations. In particular, the sampling periods and data analysis methods need to be consistent to ensure that the program is reporting consistent results.

While the actual values differ, LaBella's analysis does show significant savings potential compared to the Catalyst. Transformative Wave expects the savings calculated by eIQ to be about 80%–85% accurate. The eIQ values lack accuracy because the savings are calculated based on assumptions about the unit operating in pre-retrofit conditions instead of based on actual usage data. The pre-site conditions are combined with actual operating conditions in equations, which can be found in Appendix C: Savings Calculation Details, to calculate the avoided energy use. These equations do not capture all unique unit operation cases, but rather capture overall unit operation. Therefore, small changes in actual unit operation would lead to data inaccuracy.

Comparison to Previous Studies

The savings reported by the sites in this deployment were compared to the savings reported in the Pacific Northwest National Labs study. Overall, the savings in this deployment are about 15% lower than the savings reported in the PNNL study. This difference could be explained in part due to the location of the sites, along with general deployment assumptions. A portion of the sites in the PNNL study were in Washington State, near Seattle. The cooler climate in that region would likely increase the savings provided by the CATALYST because of the CATALYST's use of outside air to provide cooling whenever possible. New York State, with its hotter summer climate, has fewer opportunities for the CATALYST to leverage outside air and a greater need for compressor energy, reducing the available savings in the NYSERDA deployment.

The PNNL study concluded that run-hours was a strong driver for percent energy savings. The finding in that study agrees with the findings from this deployment.

FINANCIAL METRICS

The CATALYST reports cost savings as one of the savings metrics. To calculate cost savings, eIQ assumes a flat kWh and therm rate, which are both blended rates based on the customer's actual rate schedule. Sites with at least 1 full year of data reported about a 33% reduction in energy costs. All project data will be updated, and these financial return values will be updated once all projects have reported data for at least one full year.

Project Financial Metrics and Impact of Incentives

Project costs were compared to annual estimated cost savings to determine overall financial impacts. Table 9 shows both the simple payback and savings to investment ratio (SIR) for each building type. The chart shows what the simple payback and SIR would be without the addition of the incentive. The deployment's incentive of $2,400/unit was used in most of the projects to buy down the cost of installation. The use of the incentives was either noted on the invoice by the inclusion a line item or by contractors during interviews post deployment.

Table 8. Simple payback and SIR by dollars. The SIR calculations assume a 6% discount rate and that the CATALYST will be in operation for 7 years[23]

	With Incentives		Without Incentives	
Building Type	**Simple Payback (Years)**	**SIR ($/$)**	**Simple Payback (Years)**	**SIR ($/$)**
Assembly	12.4	0.9	18.0	0.6
Education	9.8	1.6	13.3	1.1
Office[24]	6.0	4.9	9.3	3.4
Restaurant	9.4	1.4	13.0	1.0
Retail	4.6	2.4	6.7	1.7
Average[25]	**6.9**	**2.6**	**10.0**	**1.9**

According to the data collected in the deployment, the office represents the best financial return with $3.40 for each $1 invested.

Overall, the NYSERDA incentive decreased the average payback by about 3.1 years and increased the SIR by about 0.7. The incentive had the highest impact for office building types, which typically had many smaller units, meaning there was a higher overall incentive paid out to those customers. The high participation rate of office building suggests that the flat incentive structure successfully supported the deployment of the CATALYST on smaller projects with longer simple paybacks.

Project Cost and Energy Saving Drivers

The primary CATALYST cost driver is the size of the unit being controlled because the VFD size and cost (including installation cost) will increase with unit capacity. Data generated through Transformative Wave's pricing tool shows the relationship between installation cost and unit capacity. The installation cost provided included both the material and estimated labor cost. The

[23] As discussed in the Market Characterization section, the CATALYST is most financially viable on RTUs with at least seven years of life remaining.
[24] One office site was excluded from the financial analysis because the project costs were reported for only the two units that qualified for incentives while the site cost savings was aggregated together for all 37 units at the site.
[25] Average is weighted based on number of sites.

cost data showed while both the material and labor costs increase with unit capacity, the project cost per ton and per fan horsepower both decrease with unit size.

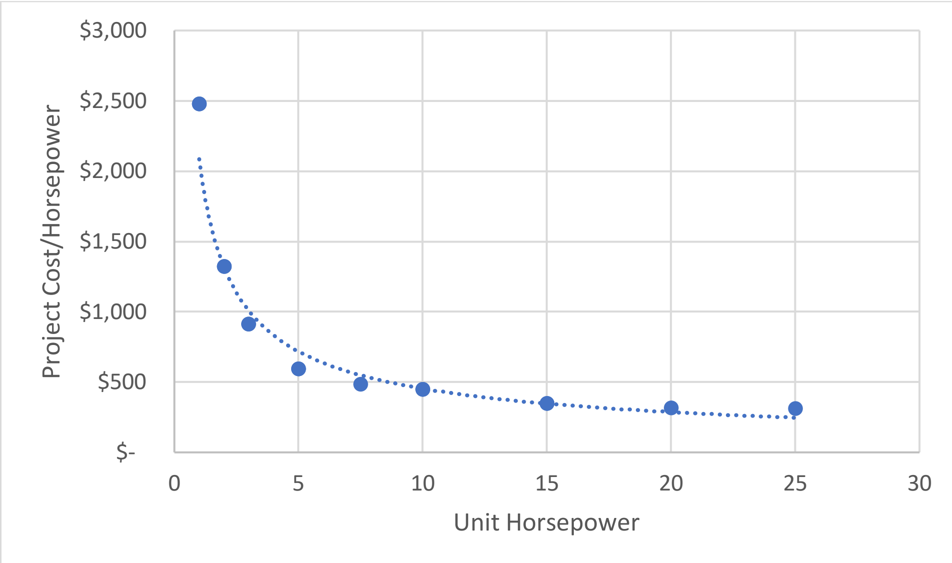


Figure 12. Project Cost/Horse Power vs. Unit Horsepower.

The Project cost includes the material and labor costs.

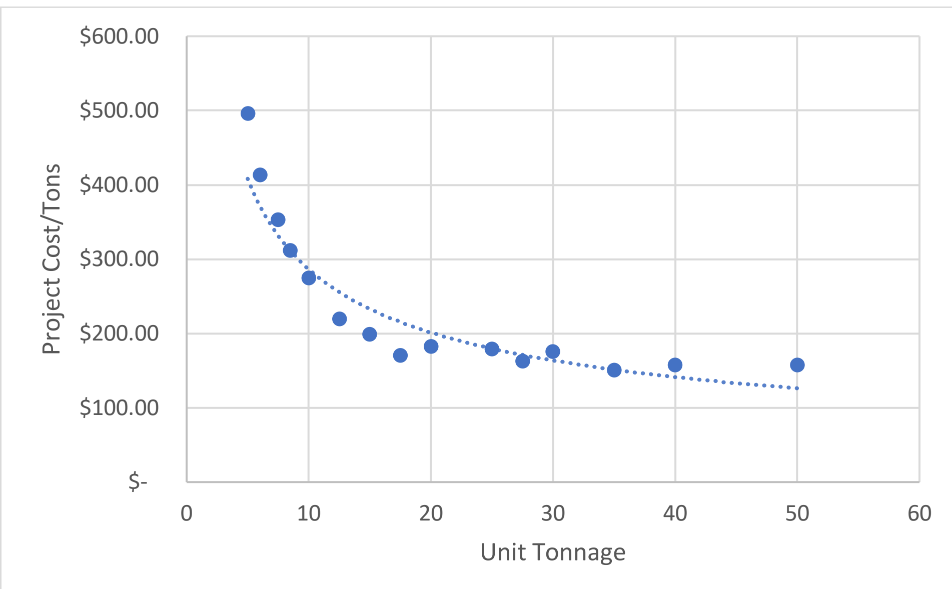


Figure 13. Project Cost/ton vs. Unit Tons.

The project cost includes the material and labor costs.

The VFD cost increases with motor horsepower, while the labor hours remain consistent up until the unit increases size increases past about 50 tons with a 25-horsepower fan. This consistency in labor cost is what drives the overall cost per ton to decrease with unit size.

Savings are predominantly driven by unit size and occupancy. Occupancy appears to be a primary driver (as shown in Figure 9) and unit size to a lesser degree.

NON-ENERGY VALUE

CATALYST NON-ENERGY BENEFITS

Based on discussions with building owners and affiliate contracts, one of the major benefits is increased comfort within a conditioned space. The CATALYST's ability to provide the appropriate amount of cooling or heating needed at a given moment ensures that the space will hover around the defined temperature setpoint instead of experiencing large swings in temperatures that could occur when a unit provides cooling or heating at full unit capacity. The CATALYST's carbon dioxide sensors also ensure air quality is at a comfortable level at all times, and the use of outside air ensures that the internal space temperature will match that of the outdoor ambient air. Internal space comfort is a key benefit across all building types.

In an interview to learn about the benefits experienced from the CATALYST installation, a franchisee owner of a major fast-food chain noted that customer comfort is "probably one of the most critical drivers in terms of someone being in a restaurant. They are coming in from the hot or cold and want a comfortable place to enjoy a meal while warming up or cooling down or whatever it may be." A children's day care center also highlighted that a major benefit from the CATALYST installation was the improvement of air quality as their main building occupants particularly sensitive to the indoor air quality.

eIQ PLATFORM NON-ENERGY BENEFITS

eIQ's portfolio view, fault detection and diagnostics, and energy monitoring and graphing features all provide benefits beyond energy savings.

FAULT-DETECTION AND DIAGNOSTICS

The fault detection feature allows building operators to identify and fix problems with the RTUs shortly after they develop. The fault detection and diagnostics system works first by monitoring the operation and energy draw of many of the RTU components for regular usage. The system then alerts the user to any abnormalities that are potentially the result of a unit malfunction. The eIQ dashboard interface provides building operators alerts and transparency into real-time RTU performance, allowing for quicker detection of underperforming RTUs. In many cases building operators can use the information from eIQ to diagnose the problem with an RTU so they set foot on the roof with the necessary knowledge and equipment to resolve the issue. Overall the fault detection, diagnostics and alert system benefits everyone involved with the management of the building for various reasons.

Building Owners and Operators
Early fault detection and diagnostics lead to cost savings for the building owner because they can repair malfunctions before they lead to larger catastrophic issues, which mean major repairs or unit replacement. The automatic alert and unit visualization systems also allow for building operators to focus on tasks other than regular manual unit checks because they will be notified of any potential issues as they occur.

A building owner from a participating site noted the benefits of the site monitoring by saying that CATALYST's ability to constantly monitor the units ensures that all systems are working 100%, which is not something that would have been previously manually monitored.

Space Occupants and Business Owners
Units that are repaired quicker are going to experience less downtime, meaning that occupants are less likely to experience space comfort issues. Increased occupant comfort benefits the building owners' bottom line because when workers are more productive when they are comfortable and customers will likely spend longer amounts of time in the space.

One business owner from a participating site noted that the built-in fault detection and diagnostics system was saving upwards of five hours between the time an issue occurs and when it is detected.

Contractors
Fault detection and diagnostics could lead to increased revenue for the contractor because they can spend less time diagnosing the issue and more time resolving it. A contractor realizes increased revenue when they can complete more jobs and spend less time diagnosing issues. It will also allow the contractor to spend less time completing repairs for a client and more time completing higher value add tasks such as identifying areas where the building could run more efficiently. Identifying this additional business value will likely strengthen the relationship between the building owner and the contractor.

EIQ INTERNAL GRAPHING FEATURE

eIQ also has a graphing function that allows the user to view energy and cost savings on a specified time scale. These graphs can be viewed in the eIQ dashboard itself or exported to an excel file. The user can also make fully customized graphs with any of the about 40 data points captured by the CATALYST. Typically, creating these graphs requires a large data set that could be exported from a sophisticated BES, which can then be further analyzed for trends on a large complex spreadsheet. In addition, these spreadsheets frequently need to be updated manually or programmed to be run automatically, which can be extremely complex to initially program. The graphing feature of eIQ decreases the amount of time needed to create the graphs and increases the likelihood that the information is correct because the data processing takes place by the eIQ system itself. This means the building operators can spend more time analyzing and acting upon trends, instead of setting up systems to determine them.

5. FINDINGS AND RECOMMENDATIONS

Finding #1- Sites participating in the deployment achieved an average of 42% electricity savings and 7% therms savings

Across the 130 units from 13 project sites with data monitoring for 12 months or more, electricity savings ranged from 24% to 57% with an average of 42% electricity savings with 75% of projects achieving at least 32% electricity savings. These interim results support Transformative Wave's claim that the CATALYST saves between 25% and 50% RTU energy consumption. Complete results from the full 24-site, 191-unit deployment will be provided in an updated report in June 2019.

Finding #2 The CATALYST is particularly well-suited to buildings with long operating hours, large capacity units, and/or proportionally large HVAC loads, such as restaurants and retail.

Energy savings are affected by two primary drivers: total occupancy hours and fan size. Based on these drivers, the CATALYST is particularly well suited for restaurants, retail and other building types with increased annual occupancy hours. Restaurants also have proportionately high HVAC loads, and therefore, achieve strong total savings.

Finding #3 – Successful deployment of CATALYST and other ARC technologies at scale requires a dedicated focus on workforce education and training.

Selling and installing ARC solutions (and intelligent controls more broadly) has an initial learning curve and requires dedicated training and experience to successfully integrate this into contractor core competencies. Of the four affiliates who participated in the deployment, 80% of affiliate sales came from the two affiliates who participated in sales training and had previous experience selling intelligent controls. Affiliates who attended sales strategy training in addition to the required installation training, were more equipped to identify new customer opportunities. In total, 88% of sales were either from experienced affiliates or national chain accounts. These affiliates were able to communicate the business value of ARC technologies to new customers and can use this new area of expertise to seek opportunities for business growth.

Finding #4 – Data measurement method will have a significant impact on reported savings when the equipment's operation has potential to significantly vary

The Catalyst operates by optimizing the operation of each RTU to provide the exact amount of cooling, heating, and ventilation inputs needed at a given moment. Therefore, the unit controlled by the Catalyst will likely change operation often when conditioning a space that has significant variations in occupancy and conditioning needs. Therefore, usage information will likely lack accuracy unless the data is reported at small enough increments to capture the change in operation.

Recommendation #1 – Utility program measures should integrate the CATALYST into their program portfolios as standalone measures or large-scale pilots.

Savings results from this deployment and previous CATALYST studies provide utility program managers with sufficient data to support a measure for the CATALYST in their energy efficiency programs.

The recommendation is that programs use the CATALYST energy monitoring capabilities to collect data on an ongoing basis to refine program assumptions over time. However, the technology is sufficiently well demonstrated that, in most cases, it should not require further “field demonstrations” prior to integration into a program. If a pilot is necessary, it is recommended that it include a scale of at least 150 units to ensure that all relevant information is collected and that the pilot activities warrant the time and investment required by the manufacturer.

Recommendation #2 – Utility ARC programs should develop deemed estimates by leveraging real-time reporting capabilities of ARC technologies and consider adopting a standardized reporting format to facilitate program participation and streamline the process

Deemed savings programs play a critical role in scaling new technologies since they simplify participation in utility incentive programs. A major barrier to deemed energy efficiency programs is the lack of a streamlined data collection method to develop and update deemed savings over time. While the CATALYST has more than 12,000 units in the field with real-time reporting capabilities, the largest published monitoring study is 130 units. Rather than complete additional small-scale demonstrations that are unlikely to substantially improve industry knowledge of ARC performance and improve deemed savings estimates, future demonstration efforts should focus on standardizing energy monitoring data specifications. This is so that savings estimates can be based on a much larger scale and on an ongoing basis. In addition to ongoing performance validation, future pilot programs should focus on scaling market adoption through new delivery mechanisms.

Recommendation #3 – Utility programs and other national entities should incorporate significant workforce education and training components into programs to ensure increased awareness and training for ARCs (and intelligent controls more broadly).

While controls can provide significant new business value to customers by reducing energy costs, improving insight into facility operations, and ensuring occupant comfort, there is an important learning curve for both customers and contractors. In addition to providing financial incentives to reduce first cost, utility programs that target ARCs and other intelligent controls should provide a series of education and training programs that include introductions to the technologies. Utility programs should also provide more in-depth trainings to help contractors understand how to sell and install the technology and highlight the business value of intelligent controls to customers.

Recommendation #4 – As the number of trained affiliate contractors familiar with the CATALYST and other ARC solutions grows, utilities should consider additional program mechanisms to focus on achieving scale.

As familiarity with ARC technologies and the number of trained contractors grows over time, utility programs should pilot new deployment mechanisms for the CATALYST and other ARC technologies such as midstream promotion through distributors to scale its adoption. Midstream approaches typically achieve far higher uptake than downstream programs but require resolving important issues such as ensuring successful installation and operation.

Recommendation #4 – Data should be recorded by ARC technologies should be a rolling average or taken at small enough increments to capture the impact of changing operations.

ARC technologies should capture usage information on small enough time scales, such as every 10-seconds, or recorded as rolling averages (read every second but stored at a rolled-up average). However, capturing more data points will result in a need for increased storage space. Therefore, the exact time scale needed should be determined by estimating how often the unit's operation and usage may change.

6. REFERENCES

Wang, W., S. Katipamula, H. Ngo, R. Underhill, D. Taaseviga, R. Lutes. 2013. *Advanced Rooftop Control (ARC) Retrofit: Field-Test Results.* Pacific Northwest National Laboratory https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22656.pdf

NYSERDA. 2018. *Governor Cuomo Announces New Energy Efficiency Target to Cut Greenhouse Gas Emissions and Combat Climate Change.* https://www.nyserda.ny.gov/About/Newsroom/2018-Announcements/2018-04-20-Governor-Cuomo-Announces-New-Energy-Efficiency-Target-to-Cut-Greenhouse-Gas-Emmisons

Transformative Wave. *Home of the CATALYST & eIQ Platform*. https://transformativewave.com

Doebber, I., M. Deru, K. Trenbath. 2016. *Turkey Heating, Ventilating, and Air Conditioning and Lighting Retrofit Solution Combining Energy Efficiency and Demand Response Benefits.* National Renewable Energy Laboratory https://www.nrel.gov/docs/fy16osti/65064.pdf

Chapmand, D., B. Baccei. 2014. *Catalyst RTU Controller Study Report.* Sacramento Municipal Utility District. ET Project Number: ET13SMUD1037. http://staging.transformativewave.com/docs/default-source/default-document-library/catalyst-report-smud.pdf

Grupp, D., Johnson, K. 2013 *RTU Efficiency Optimizers: California State University Long Beach and San Diego State University.* Western Cooling Efficiency Center's State Partnership for Energy Efficient Demonstrations HVAC Case Study.https://wcec.ucdavis.edu/wp-content/uploads/2014/06/Case-Study-Catalyst_0619014.pdf

New York State Department of Public Service. 2016. *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Version 3*. Markets and Innovation, Office of Clean Energy. http://www3.dps.ny.gov/W/PSCWeb.nsf/ca7cd46b41e6d01f0525685800545955/06f2fee55575bd8a852576e4006f9af7/$FILE/TRM%20Version%203%20-%20June%201,%202015.pdf

Efficiency Valuation Organization. 2012. *International Performance Measurement and Verification Protocol.* www.eeperformance.org/uploads/8/6/5/0/8650231/ipmvp_volume_i__2012.pdf

Jungers, Bryan. August 2016. *Rooftop Unit Retrofit Controls Mature.* E Source Companies LLC. https://www.esource.com/TAS-RB-111/RTU-Controls

7. APPENDIX A: PROJECT PROCESS

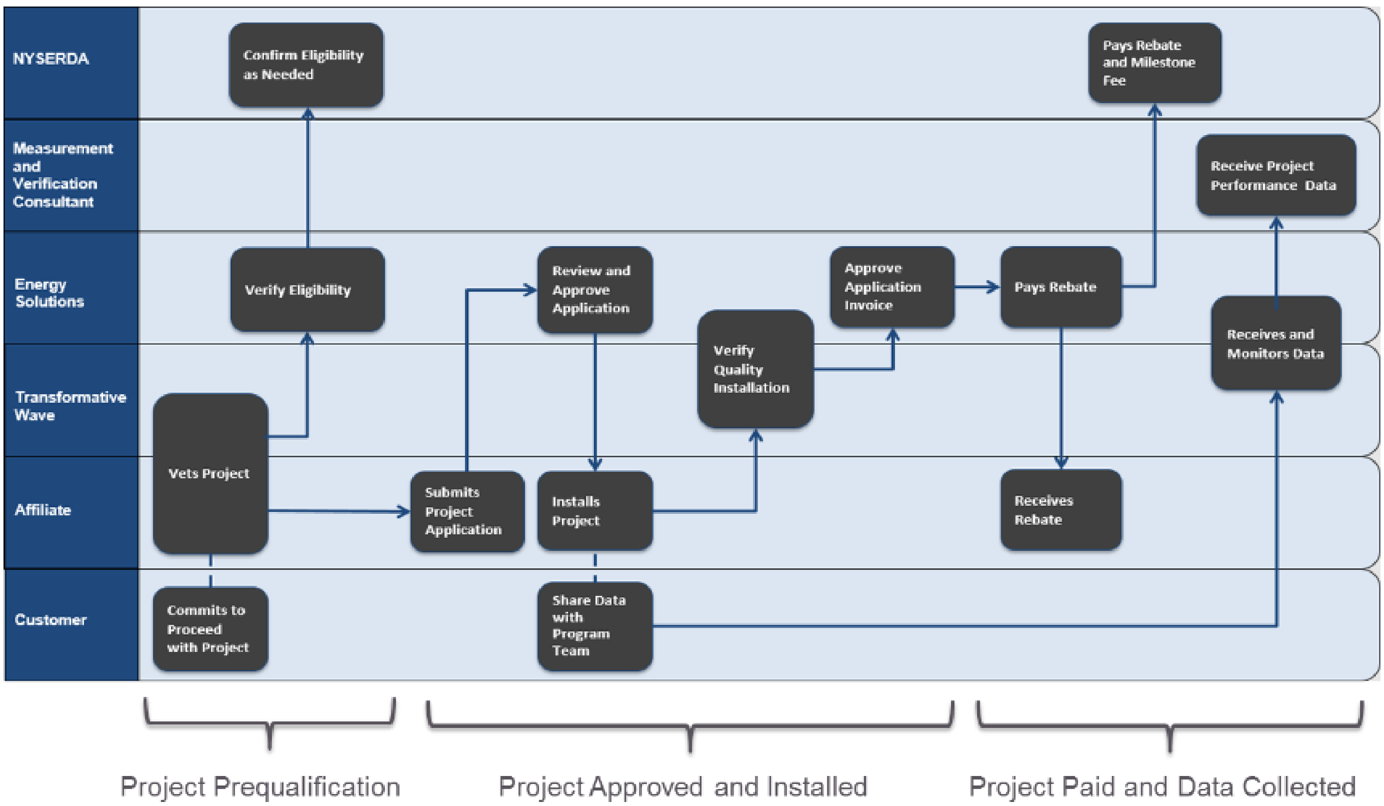


Figure 14. Project process flow and deployment stages

Once an affiliate is certified by Transformative Wave and enrolled in the incentive deployment, they can submit a project. The project process is outlined in Figure 12 starting from project submission to incentive distribution and data collection.

8. APPENDIX B - EIQ SCREENSHOTS

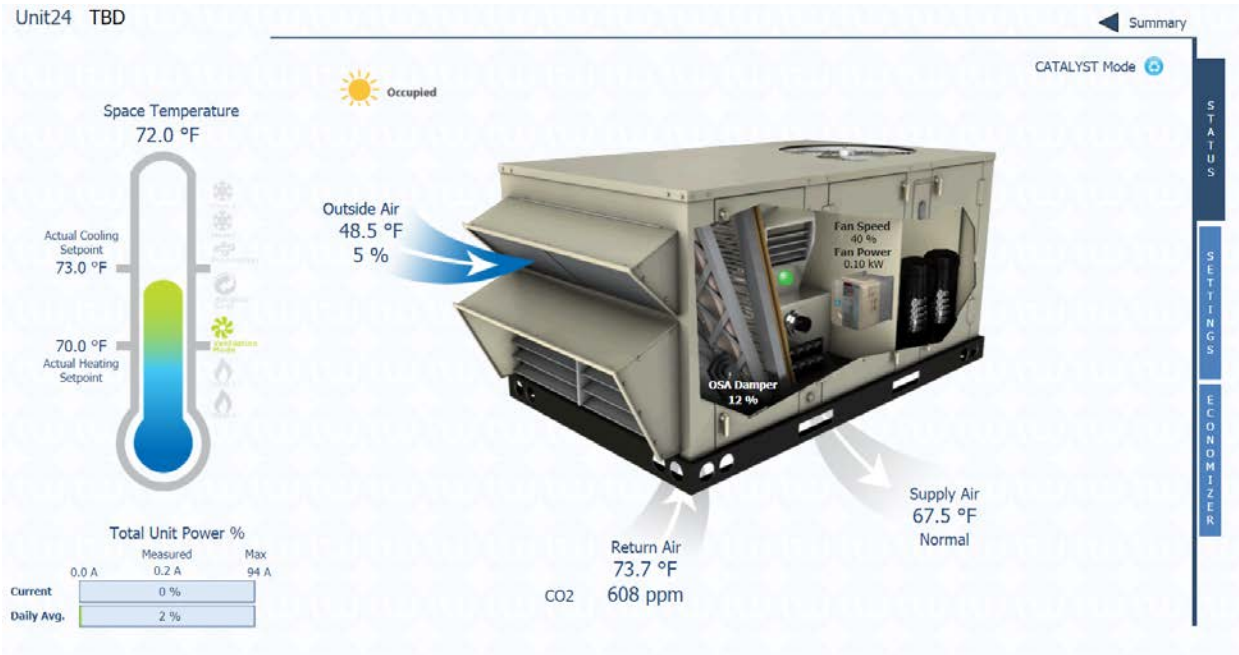


Figure 15. View of a Single RTU without any faults identified

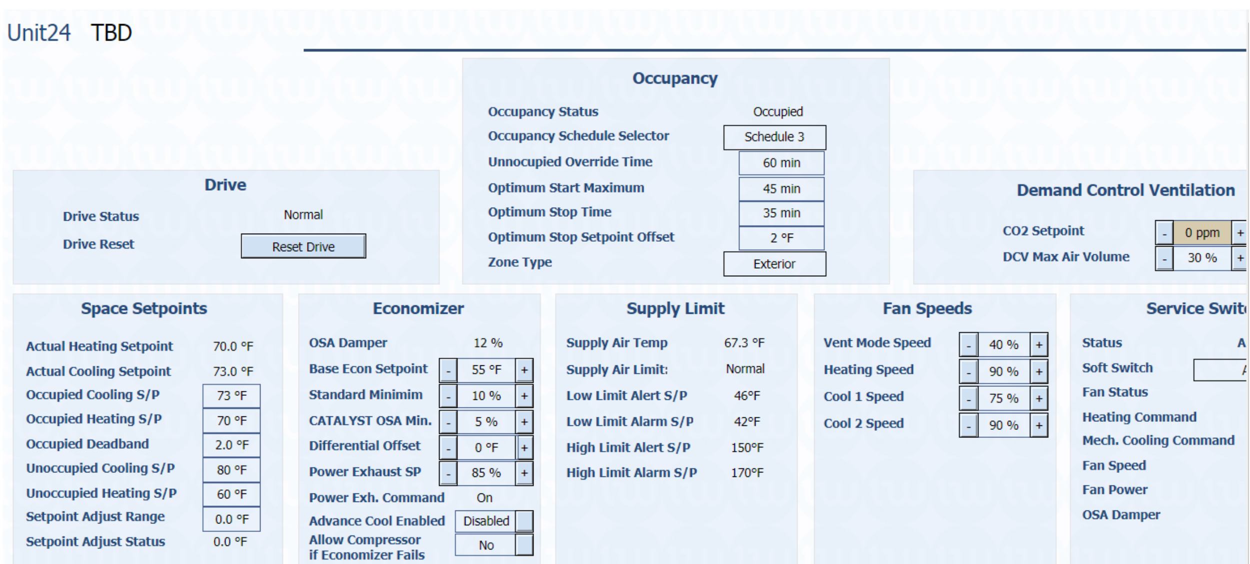


Figure 16. Setpoint Adjustment User Interface

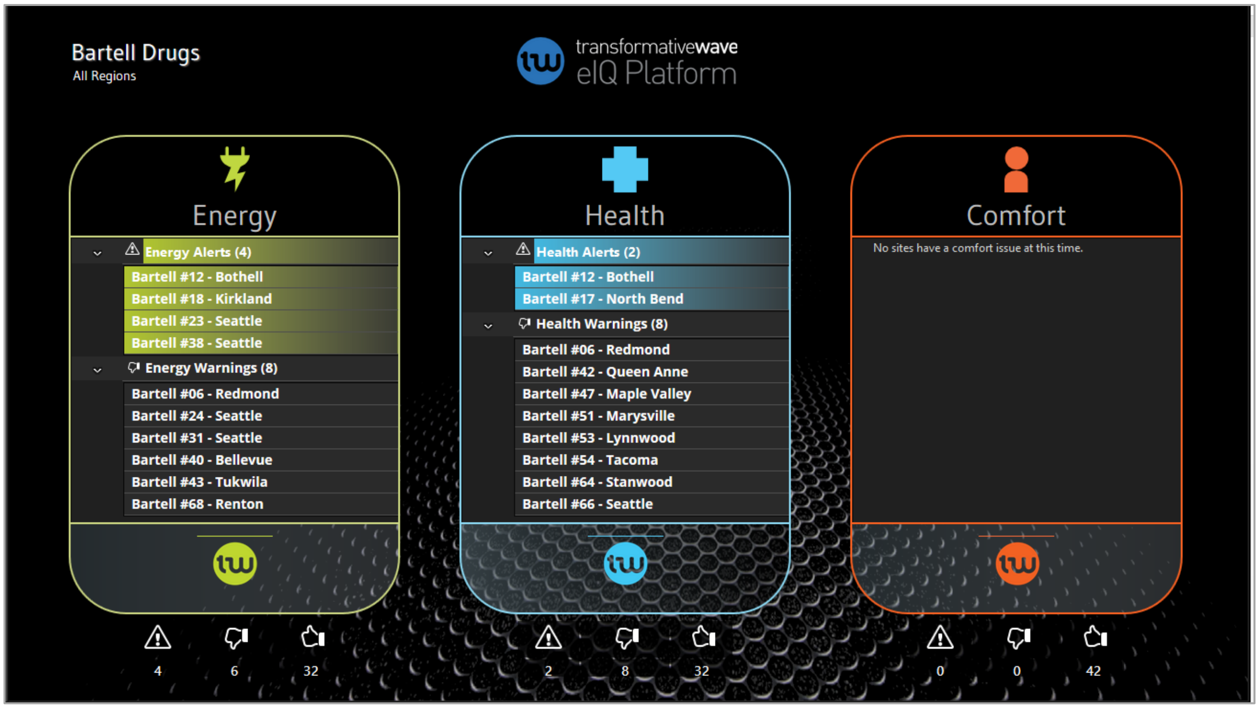


Figure 17. Portfolio View showing faults identified at multiple locations

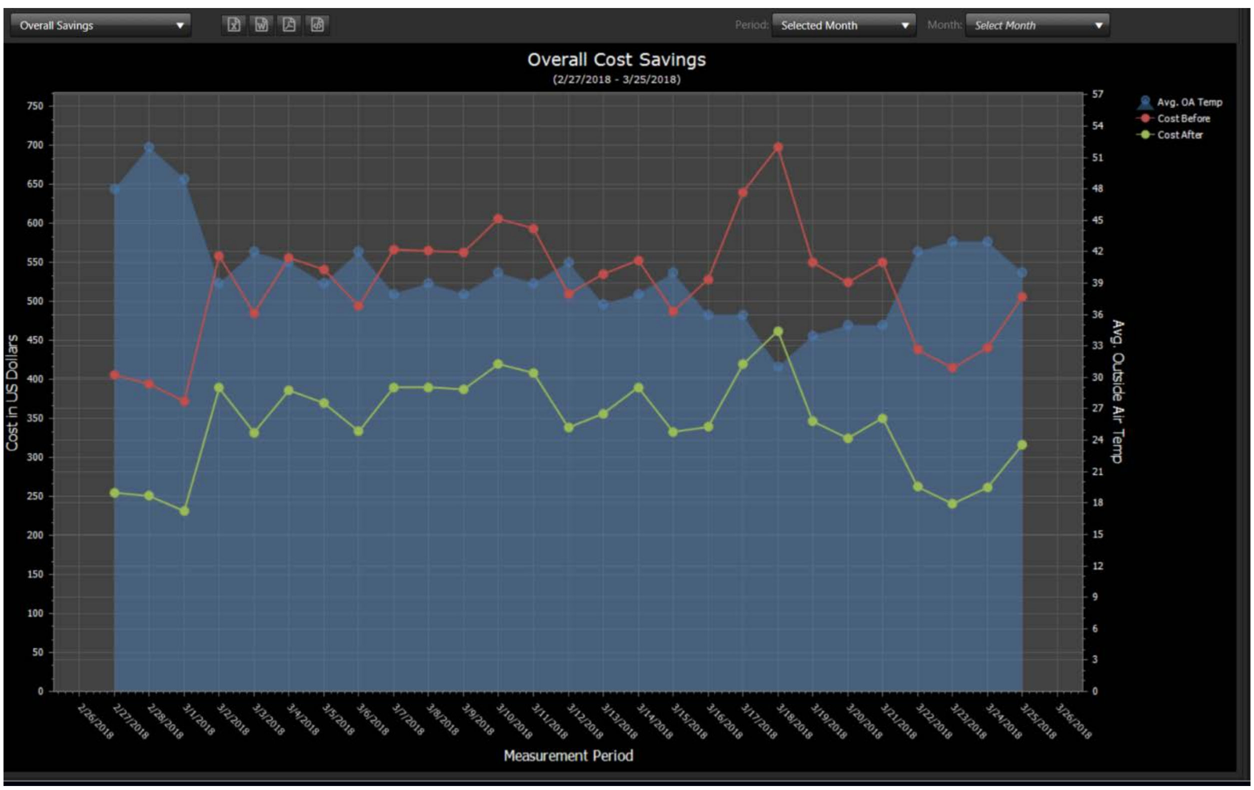


Figure 18 eIQ Graphing User Interface. This current view shows the actual estimated daily cost vs the estimated baseline cost. The outdoor air temperature is also plotted

9. APPENDIX C: SAVINGS CALCULATION DETAILS

The report used two separate savings calculation methods: eIQ calculated savings and Retrofit Isolation / Calibrated Simulation Approach. This appendix details how the savings are calculated for each method.

eIQ Calculated Savings

This section details how eIQ reported savings values are reported. The inputs to the savings equations are either quantities measured by the CATALYST sensors, inputs from the building's EMS, quantities measured prior to CATALYST installation, or estimated/assumed quantities.

Savings for each conservation measure are calculated based on the following operational parameters at one-minute intervals:

- maxcfm = total unit airflow estimated at 400 CFM/Ton (CFM)
- stdfankw = static baseline fan power (100% Fan Speed) measured at drive during startup (kW)
- fanpower = real time fan power measured at drive (kW)
- esmmode = command to run in energy saving mode (CATALYST Mode)
- stdeconmin = As found (Standard Mode) minimum damper position recorded during DSI (%)
- stdeconstpt = As found (Standard Mode) single point economizer changeover setting recorded during DSI (F)
- fanspeed = commanded fan speed (%)
- damper = commanded damper position (%)
- oatemp = measured dry bulb outside air temp (F)
- ratemp = measured dry bulb return temp (F)
- coolcall = cooling request from stat or BMS
- heatcall = heat request from stat or BMS
- EERadj = recorded unit energy efficiency ratio adjusted to remove fan power (Btu/Wh)
- COP = recorded coefficient of performance for heat pumps (Btu/Btu)

The energy reduction associated with each conservation measured is calculated at the one-minute interval level as follows:

Fan Speed Control
fankwsavings = (stdfankw –fanpower)/60
WHEN: fancall = 1 AND esmmode = 1

Advanced Economizer
diffeconkwh = (1.08 * (ratemp - oatemp) * ((fanspeed * .01 * damper * .01 - stdeconmin * .01) * maxcfm))/
(EERadj * 1000) / 60
WHEN: coolcall = 1 AND oatemp < ratemp AND esmmode = 1 AND oatemp > stdeconstpt

Demand Control Ventilation (DCV)
Cooling
Cooldcvkwh = 1.08 * (maxcfm * stdeconmin * .01 - maxcfm * fanspeed * .01 * damper * .01) * (oatemp - ratemp) / (EERadj * 1000) / 60
WHEN: coolcall = 1 AND oatemp > ratemp AND esmmode = 1

Heating-Electric (Electric Resistance or Heat Pump)
heatdcvkwh = 1.08 * (maxcfm * stdeconmin * .01 - fanspeed * .01 * damper * .01 * maxcfm) * (ratemp - oatemp) / 3412 / 60
WHEN: heattype = (Electric OR (heattype = HeatPump AND oatemp < 35)) AND heatcall = 1 AND esmmode = 1

OR
heatdcvkwh = 1.08 * (maxcfm* stdeconmin * .01 - fanspeed * .01 * damper * .01 * maxcfm) * (ratemp - oatemp) / 3412 / 60 / COP
WHEN: heattype = HeatPump AND oatemp >= 35 AND heatcall = 1 AND esmmode = 1

The savings from each individual energy asvings measured are summed together to calculate the full system savings.

<u>Retrofit Isolation / Calibrated Simulation Approach</u>

The annual savings is calculated using the following equation:

$$Savings = (Annualized\ SOM\ Energy\ Use - Annualized\ ESM\ Energy\ Use) \frac{+}{-} Adjustments$$

There are three components that need to be calculated separately:
1. Fan kWh (not weather dependent)
2. Cooling kWh (weather dependent)
3. Heating Therms (weather dependent)

The cooling kWh and heating therms are both weather dependent meaning they must be weather normalized to allow for true comparisons between ESM and SOM energy usages.

The following procedure was followed to calculate the annualized energy use for each component above:

kWh (Fan Demand Only):
1. Fan demand at 100% speed was determined by isolating periods where the RTU was in vent mode only for the full hour, meaning there was no compressor use.
2. Fan demand at 40%, 75%, and 90% speeds was calculated using the following fan speed and power relationship:

$$Fan\ Demand\ for\ Y\%\ Speed = (Fan\ Demand)_{100\%}\ x\ Y^{2.5}$$

3. Fan total energy use during each hour was calculated by adding up the fan usage in each run mode.

4. The fan total kWh for ESM and SOMs were divided by the number of fan run time hours in each mode during to calculate an average fan kWh per hour of fan runtime in both SOM and ESM.
5. The average fan kWh for ESM and SOM were multiplied separately by the total fan call hours during the period of data recording. The results are the estimated total fan usage during each mode over the course of the reporting period.

kWh (Cooling Demand Only):

1. The cooling demand needs to be separated from the fan usage because it is weather de
2. pendent, so it needs to be normalized by historical weather values. The fan usage is not weather dependent, which is why the same normalization is not needed.
3. The cooling load is calculated during each hour by subtracting the fan energy calculated above from the total unit energy usage.
4. The total cooling load for each mode is normalized by the cooling degree days (CDD) that occurred while the unit was in each mode to calculate a normalized kWhcooling / CDD.
5. The kWhcooling / CDD for each mode are multiplied by the total CDD during the period of data collection to calculate the estimated total kWh cooling for each mode.

The total kWh usage was then calculated by adding together the fan kWh and then cooling kWh. Estimated kWh savings were then calculated using the equation above.

Therms Savings

1. Therm usage was calculated at each during ESM and SOM runtimes by multiplying the number of hours the CATALYST called for stage 1 and stage 2 heating by the RTU’s stage 1 and stage 2 therm inputs, which were collected during unit installation.
2. Total therm usage was added together for each mode and divided by the total number of heating degree days (HDD) during each time period to calculate a weather normalized therm/HDD.
3. The therm/HDD for ESM and SOM were multiplied by the total number of HDD during the data collection period to calculate the baseline and energy savings mode estimated annual therm usage.
4. The energy savings mode therm usage is subtracted from the baseline therm usage to calculate the estimated savings.

10. APPENIDIX D: ADDITIONAL DASHBOARD SCREENSHOTS

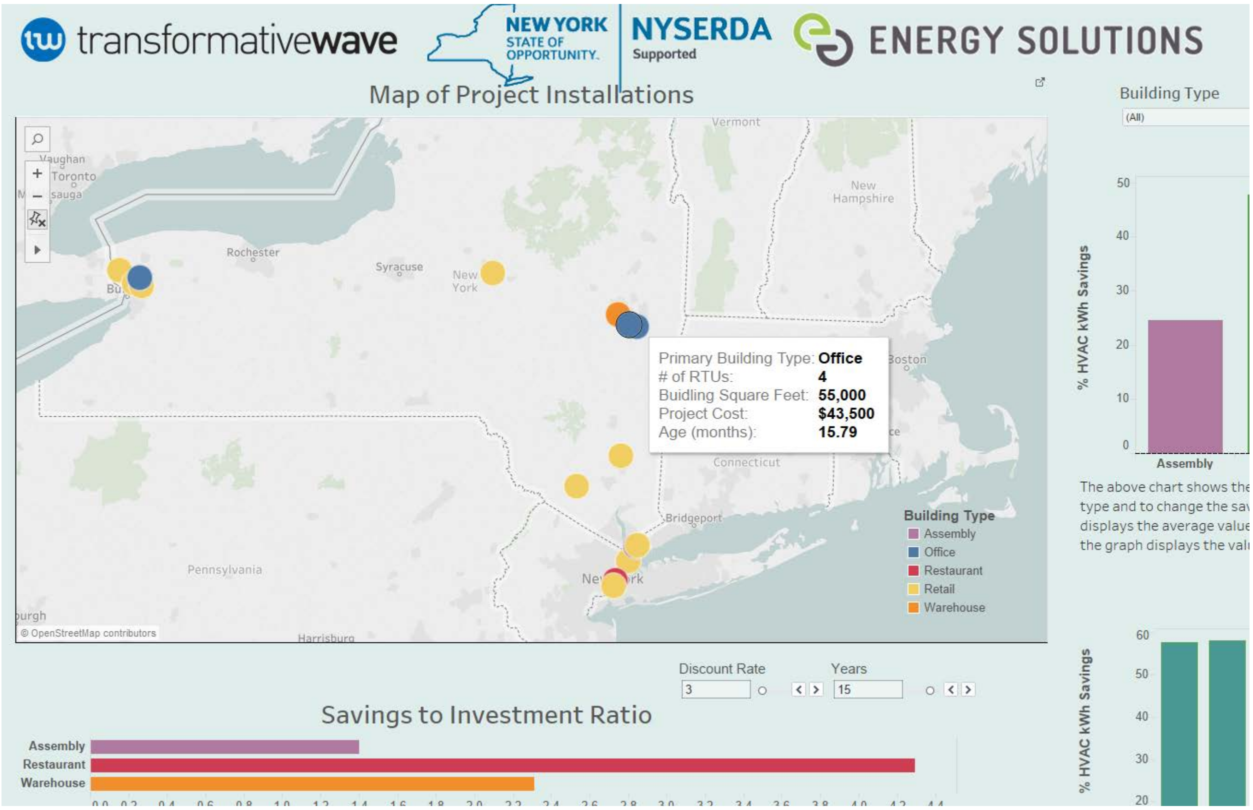


Figure 19. Dashboard Map View Showing "Hovering" Capability