Integrated HVAC Rooftop Unit Remote Monitoring Systems

Final Report

ET23SWE0037

Prepared by:

Angela Crowley RMS Energy Consulting LLC

David Wylie, P.E. RMS Energy Consulting LLC

Martin Vu, Esq. RMS Energy Consulting LLC

Fernando Miramontes III, P.E. Alternative Energy Systems Consulting, Inc.

August 8, 2025

Acknowledgements

Alternative Energy Systems Consulting, Inc. (AESC) and RMS Energy Consulting, LLC would like to acknowledge the host site's staff and management for their trust and welcoming our research team into their facilities. Energy efficiency and greenhouse gas emission impacts depend on forward-thinking facility owners and operators who believe in a more sustainable energy future. Thank you to the manufacturer, contractor, and subject matter experts who made this project and technology possible. We also thank all industry partner organizations involved in this effort. The entire project team specifically thanks the following for their insights, industry expertise, and time in supporting the development of this report:

- El Rancho Unified School District (ERUSD) in Pico Rivera, California
- Russell Sigler, Inc. – Siglers- Carrier
- BEMA

The project was conducted through the CalNEXT program under the auspices of Southern California Edison and the Emerging Technologies Program. The CalNEXT program is a statewide California electrical energy efficiency emerging technology initiative, focusing on a variety of technology priorities.

Disclaimer

The CalNEXT program is designed and implemented by Cohen Ventures, Inc., DBA Energy Solutions ("Energy Solutions"). Southern California Edison Company, on behalf of itself, Pacific Gas and Electric Company, and San Diego Gas & Electric® Company (collectively, the "CA Electric IOUs"), has contracted with Energy Solutions for CalNEXT. CalNEXT is available in each of the CA Electric IOU's service territories. Customers who participate in CalNEXT are under individual agreements between the customer and Energy Solutions or Energy Solutions' subcontractors (Terms of Use). The CA Electric IOUs are not parties to, nor guarantors of, any Terms of Use with Energy Solutions. The CA Electric IOUs have no contractual obligation, directly or indirectly, to the customer. The CA Electric IOUs are not liable for any actions or inactions of Energy Solutions, or any distributor, vendor, installer, or manufacturer of product(s) offered through CalNEXT. The CA Electric IOUs do not recommend, endorse, qualify, guarantee, or make any representations or warranties (express or implied) regarding the findings, services, work, quality, financial stability, or performance of Energy Solutions or any of Energy Solutions' distributors, contractors, subcontractors, installers of products, or any product brand listed on Energy Solutions' website or provided, directly or indirectly, by Energy Solutions. If applicable, prior to entering into any Terms of Use, customers should thoroughly review the terms and conditions of such Terms of Use so they are fully informed of their rights and obligations under the Terms of Use, and should perform their own research and due diligence, and obtain multiple bids or quotes when seeking a contractor to perform work of any type.

Executive Summary

The U.S. Commercial Buildings Energy Consumption Survey (CBECS) reports that there are 5.9 million commercial buildings nationwide, comprising 96 billion square feet of space, with over half used for education, warehouse, office, and service purposes. In California, commercial construction was valued at $360.4 billion in 2024, accounting for roughly 10 percent of total statewide building activity (Statista 2025; IBISWorld 2025). Heating, ventilation, and air conditioning (HVAC) systems, particularly rooftop units (RTUs), are responsible for approximately 26.8 percent of electricity use in commercial buildings. Nearly 95 percent of RTUs manufactured in California up to 10 tons in size represent 12.9 billion kilowatt-hours (kWh) of energy use annually (Morton and Vu 2025), indicating a substantial opportunity for energy efficiency improvements.

Despite this potential, small commercial buildings frequently operate inefficiently due to undetected faults and inadequate maintenance. Research suggests that proper controls and routine servicing can yield from 5 to 15 percent in annual energy savings (Markley, Pritoni, and Fortunato 2013). Inefficiencies also result in elevated energy use, poor indoor air quality, and costly system failures, with RTU replacements ranging from $5,000 to $15,000 (Modernize 2025). However, many units still lack integrated, real-time monitoring, making the case for cost-effective, factory-installed automated fault detection and diagnostics (AFDD) solutions supported by proactive maintenance practices.

This project evaluated Carrier's SystemVu, a factory-installed remote monitoring and AFDD platform for RTUs and heat pumps. SystemVu monitors over 260 operational variables and generates more than 100 alarm codes, enabling real-time diagnostics and maintenance tracking. It was paired with BEMA (BEMA 2025), a third-party cloud-based data acquisition system that analyzes equipment performance at one-minute intervals and issues alerts for faults and off-hours operation. Combined, these technologies support proactive maintenance strategies and drive energy savings.

The demonstration took place at El Rancho Unified School District (ERUSD) in Pico Rivera, California (climate zone 9), where 238 RTUs were installed across 16 schools. Of these, 164 featured the latest version of SystemVu. The study focused on 72 units ranging from 3 to 7.5 tons at four randomly selected campuses, with monitoring from the fall of 2024 through the spring of 2025. Results confirmed the effectiveness of integrating factory-installed AFDD with cloud analytics to optimize HVAC performance and reduce energy consumption. Due to limited staffing, ERUSD maintenance personnel were unable to consistently respond to alerts generated by the SystemVu and BEMA platforms. As a result, many RTUs operated during unoccupied hours, overnight, on weekends, and during holiday breaks, due to unadjusted thermostat setpoints and outdated scheduling. These inefficiencies led to prolonged runtimes and unnecessary energy use. The project team conservatively estimated that 15 to 20 percent of potential annual energy savings were lost due to delayed responses. During spring break, however, revised schedules successfully prevented unoccupied operation, validating the potential impact of timely intervention.

A preliminary cost-benefit analysis shows the system achieves annual energy savings of 463 kWh/ton and 3.8 therms/ton, with total resource cost (TRC) ratios of 2.11 for New Construction (NC) and 1.03 for Add-On Equipment (AOE) offerings. Based on these results, the project team recommends that the technology be included in California's statewide energy efficiency deemed

rebate portfolio. Additionally, a second phase CalNEXT study is recommended to explore broader deployment across different building types and climate zones. If not adopted into the deemed rebate portfolio within six years, the project team suggests proposing an update to the 2031 Title 24 Building Energy Code to expand fault detection requirements beyond the current economizer-only mandate in Section 120.2(i).

Abbreviations and Acronyms

Acronym	Meaning
AFDD	Automated Fault Detection Diagnostic
AI	Artificial Intelligence
AOE	Add-On Equipment
C&S	Codes and Standards
CAL/OSHA	California Occupational Safety and Health Administration Program
CalEPA	California Environmental Protection Agency
CA-TREC	California's Training for Residential Energy Contractors Program
CES	CalEnviroScreen
CEUS	Commercial Buildings Energy Consumption Survey
CHEEF	California Hub for Energy Efficiency Financing
CLEEN	California Lending for Energy and Environmental Needs
CMMS	Computerized Maintenance Management System
CPUC	California Public Utilities Commission
DAC	Disadvantaged Community
EE	Energy Efficiency
EEM	Energy Efficiency Measure
ERUSD	El Rancho Unified School District
ESA	Energy Savings Assistance
eTRM	Electronic Technical Reference Manual
EV	Electric Vehicle
FDD	Fault Detection and Diagnostics

Acronym	Meaning
FTE	Full-Time Equivalent
GHG	Greenhouse Gas
HEEHRA	Home Electrification and Appliance Rebates
HP	Heat Pump
HTR	Hard-to-Reach
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IOU	Investor Owned Utility
IT	Information Technology
M&V	Measurement and Verification
MERV	Minimum Efficiency Reporting Value
NC	New Construction
OEHHA	Office of Environmental Health Hazard Assessment
PEP	Public Energy Performance
PV	Photovoltaic
RTU	Rooftop Unit
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
Title 24	California's Title 24 Building Energy Efficiency Standards
TRC	Total Resource Cost
TSB	Total System Benefit
TSR	Technology Support Research
VAV	Variable Air Volume

Table of Contents

Acknowledgements i
Executive Summary ii
Abbreviations and Acronyms iv
Introduction 1
Background 2
Market Characterization 2
System Maintenance 3
Existing Codes and Standards 4
Current Funding Opportunities 6
Technical Description 6
Objectives 9
Methodology & Approach 10
Test Sites 10
Test Plan 15
Findings 19
Overview 19
Unoccupied Operation Due to Holiday and Break Schedules 20
Unoccupied Operation Due to Factory Default Setpoints 24
Lifecycle Savings Due to Equipment Failure 25
Technology Cost-Effectiveness 26
Stakeholder Feedback 27
Discussions 29
Resource Constrained Maintenance Staff 29
Factory Versus Add-on Retrofit Costs and Other Considerations 30
Recommendations 31
Maintenance Staff 31
Equipment and Building Type Restrictions 32
Energy Savings Opportunities 32
Broad Audience Awareness Creation and Technology Transfer Opportunities 32
References 36

List of Tables

Table 1: EEM Investigation Description 7
Table 2: Durfee Elementary School Description 11
Table 3: North Ranchito Elementary School Description 12
Table 4: Rio Vista Elementary School Description 13
Table 5: Rivera Academy Description 14
Table 6: Identified Opportunities for Energy Savings 19
Table 7: Potential Winter Avoided Costs 21
Table 8: Realized Spring Avoided Costs 22
Table 9: Potential Summer Avoided Costs 22
Table 10: Potential Commissioning Savings 25
Table 11: Total Resource Cost Analysis - New Construction 26
Table 12: Total Resource Cost Analysis - Add-on Equipment 27

List of Figures

Figure 1: ASHRAE Table 5-1 Standard 180 inspection and maintenance tasks for air distribution systems.

....5
Figure 2: SystemVu controller. 8
Figure 3: Durfee Elementary School site overview. 11
Figure 4: North Ranchito Elementary School site overview. 12
Figure 5: Rio Vista Elementary School site overview. 13
Figure 6: Rivera Academy site overview. 14
Figure 7: Overview of system layout. 17
Figure 8: Notification of simulated equipment failure. 18
Figure 9: Notification of simulated equipment failure. 19

Introduction

Existing non-residential packaged rooftop units (RTUs), including heat pumps (HP), lack real-time monitoring capabilities for key parameters such as temperature, pressure, and energy consumption. This limitation is commonly observed in commercial buildings, particularly in primary and secondary schools within public school districts. In such buildings, RTUs typically operate until failure with minimal preventative maintenance or upgrades (FMX 2024). Building owners are typically disincentivized to replace or retrofit functioning equipment, and tenants lack motivation to invest in improvements for assets they do not own. These challenges are amplified in CalEnviroScreen designated disadvantaged communities (DAC) and California Public Utilities Commission (CPUC) designated hard-to-reach (HTR) communities, where high equipment and labor costs further hinder system upgrades.

The overall target market for this research includes commercial facilities with RTUs ranging from 3 to 20 tons, which represents the most common size range in these applications. More specifically, this Technology Support Research (TSR) effort focused on primary and secondary schools in the El Rancho Unified School District (ERUSD). ERUSD is located in Pico Rivera, California, which is within climate zone 9 of Southern California Edison's (SCE) electricity grid service territory.

The integrated heating, ventilation, and air conditioning (HVAC) RTU remote monitoring system represents a novel solution, featuring factory-installed wiring and sensor assemblies integrated directly into new RTUs and HPs as part of a packaged offering. This system includes a pre-configured sensor harness and built-in monitoring capabilities, enabling real-time data collection and reporting on key operational parameters. Monitored variables include outdoor, return, and supply air temperatures, refrigerant suction and discharge pressures, fan speed, economizer status, and overall system performance. These data points align with standard diagnostic metrics typically collected during on-site technician assessments.

The system's wiring harness and sensor infrastructure use a BACnet communication protocol, enabling interoperability with Carrier's on-premises I-Vu building automation system or with third-party, cloud-based software as a service (SaaS) platform. This flexibility allows users to freely select cost-effective monitoring solutions while maintaining reliable data transmission and real-time performance alerts across various devices including computers, tablets, and smartphones. Although the SystemVu monitoring system is available for newly manufactured RTUs, a significant portion of the existing RTU market lacks such capabilities. As a result, legacy systems frequently operate inefficiently with suboptimal runtimes and undetected performance.

For this project, Carrier's SystemVu was selected as the factory-integrated controller. Introduced in 2023, the addition of the SystemVu integrated option must be specified at the time of equipment procurement. The SystemVu factory-installed option significantly reduces the cost and complexity compared to retrofitting equivalent aftermarket automatic fault detection diagnostics (AFDD) monitoring systems in the field.

Comprehensive HVAC system monitoring is critical for ensuring reliable performance, occupant health, and operational safety. Undetected system faults may lead to poor indoor air quality (IAQ), inadequate thermal comfort, and increased health and safety risks. Additionally, inefficient RTU and

HP system operation results in elevated energy consumption and utility costs for building owners and operators. Poor performance also accelerates equipment degradation, leading to more frequent repairs and higher maintenance expenses. HVAC unit replacements can range from $5,000 to $15,000 (Modernize 2025), depending on the system's SEER rating and configuration. Furthermore, HVAC systems often involve hazardous materials such as refrigerants and fuels, which pose risks of leaks, fires, or other safety incidents if the systems are not properly maintained. Real-time monitoring helps mitigate these risks by enabling early fault detection and facilitating proactive maintenance.

Background

Market Characterization

The Commercial Buildings Energy Consumption Survey (CEUS) estimates that there are 5.9 million buildings in the United States with 96 billion square feet of total commercial floor space. Within the total commercial floor space, education, warehouse and storage, office, and service buildings account for over half of all commercial buildings (US EIA 2018). Historical data from building code departments suggest that new commercial construction represents approximately $35.7 billion or roughly 10 percent of all California building construction (Statista 2025). Commercial building construction in California was estimated to be a $360.4 billion industry in 2024 across 8,123 businesses (IBISWorld 2025).

Accordingly, HVAC energy use in commercial buildings account for approximately 26.8 percent of all electricity use typically through chiller systems or constant volume RTUs. Nearly 95 percent of all RTUs manufactured, up to and including 10 tons of cooling capacity, account for 48 percent or 12.9 billion kilowatt-hours of energy use in California annually (Morton and Vu 2025). Thus, reducing commercial HVAC load during summer peak hours would make a significant contribution towards meeting California's energy goals, but few, if any, technologies adequately and economically address this market. Consequently, small commercial buildings considering RTU efficiency upgrades have proven to be a difficult segment to target.

The aggregate RTU energy management issue is compounded because only a small percentage of commercial buildings operate efficiently in alignment with the HVAC design intent due to undetected operational faults, and poor asset and management maintenance practices.

Prior research efforts suggest that with proper building control system and proper routine maintenance practices, detecting and fixing these operational faults typically achieve between 5 to 15 percent annual energy savings (Markley, Pritoni, and Fortunato 2013). However, at the time of this writing, many newly manufactured and existing RTUs, including heat pumps, do not have remotely integrated monitoring capabilities where temperature, pressure, and energy are known in real time as these building control optimization systems do not come as standard features at the time of manufacturing and are purchased aftermarket as an independent system. This often results in higher costs, compatibility issues, and operational complexity for the consumer. Accordingly, there is a significant need to have remotely integrated AFDD building controls coupled with proper asset and management maintenance practices to help solve this aggregate RTU energy management dilemma.

System Maintenance

Routine maintenance is essential for ensuring the reliable and efficient operation of commercial HVAC RTU systems. HVAC industry best practices recommend that RTU systems be serviced at least twice annually. Servicing typically occurs once in the spring and once in the fall to prepare for peak cooling and heating demands. However, the optimal maintenance frequency may vary depending on several factors including system type, age, operational load, and the environmental conditions of the facility. Currently, there is no standardized framework for maintenance across the HVAC industry. Equipment types, building characteristics, and vendor practices vary widely, complicating efforts to apply consistent strategies across facility portfolios. Establishing common goals, performance metrics, and documentation practices is critical for implementing scalable and effective maintenance programs (Propmodo Team 2024).

Reactive HVAC System Maintenance Practices

There are several distinct approaches to HVAC system maintenance, each with varying implications for cost, equipment longevity, and operational efficiency. One of the most basic methods is reactive maintenance, also referred to as breakdown maintenance, in which equipment is serviced only after a failure has occurred. While this approach offers low initial costs and requires no pre-planning, it is associated with higher long-term expenses due to emergency repairs, operational disruptions, shortened equipment life, and increased safety risks. Reactive maintenance may be appropriate for non-critical, low-cost assets or systems nearing the end of their operational life (Fiix Team 2023a).

Preventative and Predictive HVAC System Maintenance Practices

In contrast, preventive maintenance involves scheduled, routine inspections and servicing to reduce the likelihood of equipment failure and minimize downtime. Preventative maintenance enhances operational reliability, extends equipment lifespan, improves energy efficiency, and reduces long-term maintenance costs. Preventive maintenance is widely regarded as a best practice in HVAC system management despite requiring upfront planning and resource allocation (Fiix Team 2023b). Industry estimates indicate that unplanned and reactive maintenance may cost between three to nine times more than planned maintenance activities (Propmodo Team 2024).

However, preventive maintenance programs are not without challenges. Poorly designed programs may result in over-maintenance leading to inefficiencies and unnecessary costs. To mitigate this, facilities increasingly employ predictive maintenance strategies as part of their preventive maintenance plans. Predictive maintenance uses real-time monitoring and data analytics to forecast equipment failures before they occur, enabling timely and targeted interventions (Fiix Team 2023c).

Benefits and Drawbacks of a Computerized Maintenance Management System

Developing an effective preventive or predictive maintenance program requires comprehensive data collection and documentation. This includes defining equipment performance standards, maintaining service records, and establishing maintenance schedules. These tasks are best managed through a computerized maintenance management system (CMMS). A well-implemented CMMS streamlines maintenance workflows, improves recordkeeping, and enables data-driven decision-making.

However, setting up and managing a CMMS can be complex. Facilities without detailed inventories, service manuals, or warranty records often struggle to fully maximize CMMS capabilities (Propmodo

Team 2024). Additionally, transitioning from manual to digital tracking may represent a significant cultural shift for maintenance teams accustomed to paper-based systems. Even in facilities with formal preventive maintenance programs, execution gaps are common.

Scheduled tasks may be delayed or neglected due to staffing limitations or poor prioritization. In some cases, maintenance work is deferred because it requires system downtime that conflicts with operational demands. CMMS platforms may address these issues by automating task scheduling, assigning work orders based on criticality, and providing real-time progress tracking (Propmodo Team 2024). Integrated remote monitoring systems, such as those used with RTUs, can further verify task completion and system performance metrics.

Aging Skilled-Trade Operating Workforce

A key industry challenge is the aging workforce in skilled trades. In the United States, the median age of a maintenance worker is 43, approximately 10 percent older than the general labor force (Johnson 2024). This demographic trend has contributed to a shortage of experienced personnel and difficulties in recruiting and retaining qualified maintenance technicians. As a result, some organizations are outsourcing maintenance functions, though this can introduce variability in service quality and reduce internal oversight (Propmodo Team 2024).

Existing Codes and Standards

Title 24 Building Energy Efficiency Standards Requirements

A range of building codes and standards (C&S) govern the maintenance of commercial HVAC systems. More specifically, California's Title 24 Building Energy Efficiency Standards (Title 24) primarily apply to new construction. However, Title 24 includes provisions that mandate equipment acceptance testing during system installation, or replacement. Specifically, all ductwork must be sealed and tested for leakage. Acceptable leakage thresholds are defined as less than 15 percent for existing systems and less than six percent for newly installed ductwork. Additionally, all ducts and plenum boxes must be sealed and insulated to meet R-8 or R-11 thermal resistance values, depending on the applicable climate zone, in alignment with Home Energy Rating System (HERS) requirements (California Energy Commission 2022). With regards to fault detection, Title 24 currently requires newly installed systems with a cooling capacity greater than 54,000 Btu/hr, or 4.5 tons, be equipped with economizer fault detection and diagnostic (FDD) capabilities. This includes air temperature sensor failure or fault, not economizing when it should be, economizing when it should not be, damper not modulating, and excess outdoor air. The inclusion of FDD for HVAC economizers signals a trend towards these types of controls within California energy policy.

California Occupational Safety and Health Program (Cal/OSHA) Regulations

Workplace HVAC standards are further addressed by Cal/OSHA regulations, which require that HVAC systems be inspected at least annually. Identified issues must be resolved in a timely manner, and all inspections and maintenance activities must be documented. These records must include the name(s) of the individuals performing the work, the date of service, the findings, and corrective actions taken. Employers are required to keep these records for a minimum of five years (California Division of Occupational Safety and Health 1987).

California Assembly Bill 2232 Schools HVAC Maintenance Requirements

For educational facilities, California Assembly Bill 2232 mandates that schools maintain HVAC systems capable of meeting minimum ventilation rate requirements. The legislation also requires the use of air filtration systems rated at Minimum Efficiency Reporting Value (MERV) 13 or higher. While the bill does not specify an exact maintenance interval, it implicitly necessitates routine inspection and servicing to ensure continued compliance. Additionally, the bill mandates the installation of carbon dioxide (CO_2) monitoring in classrooms to verify IAQ (California Legislature Assembly Committee on Education 2022).

ASHRAE Standard 180-2018 Maintenance Requirements

ASHRAE Standard 180-2018 establishes the minimum requirements for inspection and maintenance of HVAC systems in commercial buildings to support acceptable IAQ, thermal comfort, and energy performance. The standard provides a structured framework for maintaining a wide range of HVAC components, including RTUs amongst other HVAC equipment.

Standard 180 specifies quarterly, semiannual, or annual maintenance intervals based on the equipment type and its operational role. The standard also provides detailed tables outlining required tasks and recommended corrective actions to ensure system performance and code compliance (ASHRAE and ACCA 2018). An overview of inspection and maintenance tasks for air distribution systems from ASHRAE is provided in Figure 1 below.

Table 5-1 Air Distribution Systems

	Normative	Normative	Normative	Informative
	Inspection Task	***Maintenance Task***	**Frequency***	**Recommended** ***Corrective Action***
a	Check control system and devices for evidence of improper operation.	Clean, lubricate, repair, adjust.	Semiannually	Replace components to ensure proper operation.
b	Inspect grilles, registers, and diffusers for dirt accumulation.	Clean as needed to remove dirt build up.	Semiannually	Replace if missing or damaged.
c	Check damper for *condition*, setting, and operation.	Clean, lubricate, repair, replace, or adjust as needed to ensure proper operation.	Semiannually	Replace if missing or damaged.
d	Inspect areas of moisture accumulation for biological growth.	If present, clean.	Annually	Disinfect as needed.
e	Inspect exposed ductwork for insulation and vapor barrier integrity.	Record damage locations.	Annually	Replace or repair if needed.
f	Inspect internally lined ductwork until the first turn or up to 20 ft (6.1 m) from a potential moisture source, such as a supply plenum, from air handler, outdoor air damper, humidifier, etc. for water damage and/or biological contamination.	Determine and record source of moisture.	Annually	Eliminate moisture source. Repair/replace wet insulation. Remove biological contamination and disinfect surfaces.

Figure 1: ASHRAE Table 5-1 Standard 180 inspection and maintenance tasks for air distribution systems.

Source: ASHRAE and ACCA, 2018

Current Funding Opportunities

Public Energy Performance (PEP) Program

California allocates funding to enhance EE and IAQ in public schools through HVAC system upgrades and other clean energy initiatives. This program aims to reduce greenhouse gas (GHG) emissions while fostering healthier educational environments by supporting the assessment, repair, and replacement of aging HVAC infrastructure (CLEAResult 2025).

California Lending for Energy and Environmental Needs (CLEEN)

The CLEEN Center offers low-interest financing to support large-scale HVAC and energy efficiency projects in schools, hospitals, and other public facilities (IBank 2025).

California Alternate Energy and Advanced Transportation Financing Authority (CAEATFA)

The CAEATFA administers the California Hub for Energy Efficiency Financing (CHEEF) program as part of a public-private partnership among state agencies and investor-owned utilities (IOUs) to help California meet its energy savings goals by increasing private investment in EE retrofits. By the authority of the CPUC, IOU ratepayer funds support administration of the CHEEF programs as well as a credit enhancement for participating finance companies (CAEATFA 2025).

Technical Description

Energy Savings and Reducing Energy Waste Opportunities

Energy savings are achieved by quantifying and addressing operational inefficiencies and maintenance deficiencies in HVAC systems. Remote monitoring facilitates:

- early identification of suboptimal conditions,
- enabling the implementation of enhanced operational practices, such as reducing unnecessary runtime during unoccupied periods, and
- delivering precise heating and cooling to meet comfort and environmental requirements.

Early fault detection allows maintenance scheduling before extended inefficient operation occurs, thereby reducing energy waste and equipment wear. The continuous monitoring, fault detection, and diagnostic feedback loop ensures faults are promptly corrected, minimizing inefficient RTU runtimes. Users receive immediate notifications of malfunctions via text or email, and corrective actions can be logged to close out alerts.

This study distinguishes itself by leveraging a cost-effective, factory-installed monitoring system capable of verifying whether RTUs deliver the expected heating and cooling capacity aligned with energy demand. The system also captures equipment performance degradation for incorporation into energy savings calculations. The specific energy efficiency measures (EEM) under investigation are listed in Table 1 below. Data evaluation algorithms generate notifications to responsible personnel detailing detected issues, facilitating timely intervention. Once resolved, feedback is recorded to close the notification loop.

Table 1: EEM Investigation Description

Investigation Item	EEM Investigation Description
1	HVAC operation during non-occupied periods
2	Temperature setpoints outside designated normal ranges
3	Low refrigerant charge
4	Excessive subcooling indicating high refrigerant charge
5	Elevated condenser temperatures caused by issues such as dirty condensers or fan failures
6	Low airflow resulting from dirty filters or obstructions
7	Economizer faults
8	Excessive runtime at given outdoor air temperatures

Source: RMS Energy Consulting LLC, 2025

SystemVu Monitoring System and BACnet Communication Protocol Interface

Carrier's SystemVu monitoring system is a commercial system controller capable of remote monitoring via the internet. This technology can monitor all essential variables in RTU operations, detects faults and produces alerts. The system is ordered and manufactured at the factory for new RTUs and can also be added as a retrofit application.

A fault is defined as a critical equipment failure where the HVAC unit is shutdown to prevent further damage to the unit or to prevent collateral damage to the building electrical system or structure. Faults require a manual reset of the system. SystemVu is capable of detecting and reporting 21 different faults such as low voltage, blown fuse, software/ROM errors, fire in conjunction with auxiliary smoke detector connections, condensate overflow, indoor fan failure, compressor failure, and compressor stuck on.

An alert generally signifies a warning of an improperly functioning component, circuit or sensor. In the mildest case, an alert does not affect the operation of the unit in any manner. However, alerts can also cause a "strike", where the circuit will shut down for 15 minutes. If three strikes occur before the circuit has an opportunity to show it can function properly, a shutdown fault will occur. This "three strike" feature reduces the likelihood of false alarms causing a properly working system to be shut down incorrectly. SystemVu detects and reports 63 different alerts such as sensor failures, temperatures exceeding sensor ranges, low discharge air, low pressure ratio, economizer errors, thermostat errors, and dirty filters.

The user can access faults and alerts directly through the SystemVu interface connected to each HVAC unit. The interface reports the reason for a fault shutdown and records a history of alerts. This interface also gives the user access to the unit configurations such as clocks and schedules, networking settings, space set points, and calibrations. See Figure 2 for a view of the SystemVu.

While the individual SystemVu interface may be useful for users with only a few HVAC units, monitoring alerts across a fleet of HVAC units, such as one would find in school districts, would be an incredibly daunting task. Faults would be more obvious since they involve a unit shutdown and the lack of cooling or heating would notify the occupants of an issue, but alerts would only be discovered if the user or maintenance team routinely monitors each unit. The solution for this is found in SystemVu's ability to connect via the internet to Carrier's i-Vu building automation system or a third party BACnet building management system. These systems can connect many HVAC units to one platform interface; however, many still require the user to actively monitor the units for faults and alerts.

Figure 2: SystemVu controller.

Source: Carrier, 2020

BEMA Fault Detection Data Acquisition System

BEMA is a 3rd party cloud-based platform designed to retrieve data from HVAC systems that run algorithms every minute and notify designated recipients via email or text when the equipment is operating outside specified parameters or is indicating impending failure. BEMA also sends notifications if the equipment is operating during unoccupied times.

BEMA uses a network of sensors, software and energy algorithms to monitor system performance and provide alerts to system issues before they become costly failures, enabling proactive maintenance and energy optimization. The ability to receive data from smaller rooftop HVAC equipment has been made considerably more feasible with the factory installed sensors made available with SystemVu. These factory-installed sensors work in conjunction with SystemVu's comprehensive alarm capability, which includes almost 100 alarm codes and contains more than 260 status points for troubleshooting, diagnostics, and maintenance, allowing BEMA to provide detailed system analysis and actionable alerts. In units without factory-installed sensors, BEMA can provide the same alert services with a network of add-on sensors. Upon detection of faults, facility managers and engineers at the customer sites receive diagnostic reports enabling prompt corrective actions.

BEMA allows the user to passively monitor HVAC units, only being notified via text or email when an issue arises, rather than needing to routinely check each unit or routinely log into a monitoring platform. In the case of the school district monitored in this study, only two maintenance workers are employed, and they are responsible for the maintenance of all school equipment across 16 schools, not just the HVAC units. Even with consolidating all alerts through the i-Vu building automation system, routine monitoring of these alerts is time consuming and most likely occurs mainly when a shutdown fault occurs. The project team collaborated closely with the school district stakeholders to define appropriate tolerance thresholds for monitored parameters, ensuring optimized system performance while maximizing energy savings.

Objectives

This TSR project aimed to:

- quantify the annual energy savings potential for a first of its kind Integrated HVAC RTU remote monitoring system.
- conduct a market assessment that identifies the levels of operational best practices and associated benefits and outlines barriers to adoption and HVAC maintenance and operation best practices.

The TSR project included field testing, on-site data collection, and the development of a new EEM incorporating factory-installed, low-cost monitoring capabilities which represents a significant advancement over incumbent technologies. This was the first known solution of its kind to integrate such monitoring functionality at the point of manufacture, enabling streamlined data acquisition and analysis.

The documented benefits include reductions in overall energy consumption, peak demand (kW), and carbon emissions, and improved load management. Energy savings were achieved through:

1. reduced equipment runtime enabled by optimized control strategies that delivered cooling only as needed to meet thermal loads
2. early detection of mechanical faults that allowed for timely intervention and corrective action
3. equipment performance degradation over time was also incorporated into the energy savings estimates.

A previous PG&E Emerging Technologies study reported 9 to 11 percent annual energy savings for a similar application and served as a benchmark for this study (Jump, Kubishta, and Sharma 2020).

The steps used to achieve the project’s goals included:

1. Determined site selection.

2. Obtained intel on mapping industry experiences with HVAC operations and maintenance.
3. Explored why known HVAC maintenance programs succeeded and failed to inform any future measure development.
4. Developed a thorough understanding of the new emerging technology system operations, its shortcomings, user acceptance, energy savings potential, and applicability of measure consideration and inclusion into Title 24 Part 6 Building Codes and Standards.
5. Developed an appropriate plan to collect relevant key performance data for systems at all sites including determining appropriate sensors and monitoring equipment location placement for various measurements at all test sites.
6. Collected data through an authorized representative of the building owners including building specifications and plans and outputs of energy management and metering systems. For the newly installed units, the baseline scenario was the system without reported faults, while the proposed scenario utilized the third-party BEMA software to provide notifications of out-of-bound operation.
7. Verified that the sensors meet industry standard accuracy for this level of diagnostics and verify that the test data is within acceptable accuracy and precision for the application by removing outliers and normalizing the collected data for known correlations.
8. Provided raw and synthesized data to relevant stakeholders as applicable.
9. Provided summary analysis of the data and determined energy savings estimates.
10. Provided calculations, technical analysis, and data to support total resource cost (TRC) energy and cost-benefit ratio energy saving claims by substantiating energy savings estimates with detailed engineering analysis using currently recognized professional methodologies.
11. Reported measurement and verification (M&V) methods utilized and findings.
12. Conducted a market assessment that identifies the levels of operational best practices and associated benefits and outlines barriers to adoption and HVAC maintenance and operation Abest practices.
13. Collaborated with relevant technology transfer stakeholders such as HVAC manufacturers, AHRI, ASHRAE and HVAC contractor training IHACI.

Methodology & Approach

Test Sites

The assessment was conducted at the ERUSD, in the City of Pico Rivera, California. All participating schools receive electric service from SCE and are located within California's climate zone 9. ERUSD is operating the integrated SystemVu remote monitoring platform on 238 RTUs in 16 schools. Of the 238 RTUs, 164 were equipped with the most recent version of SystemVu, while the other 74 units utilized an earlier version. Four schools were selected at random for the purposes of this analysis. A total of 72 constant volume RTUs, ranging in capacity from 3 to 7.5 tons and equipped with the latest version of SystemVu were included in the evaluation from those four randomly selected sites. The participating sites and corresponding units are described in Table 2Table 2 through Table 5Table 5 and Figure 3 through Figure 6 below.

Table 2: Durfee Elementary School Description

Site 1	Durfee Elementary School
Address	4220 Durfee Ave, Pico Rivera, CA 90660
RTUs Monitored	18
Site Type	Education, Primary School

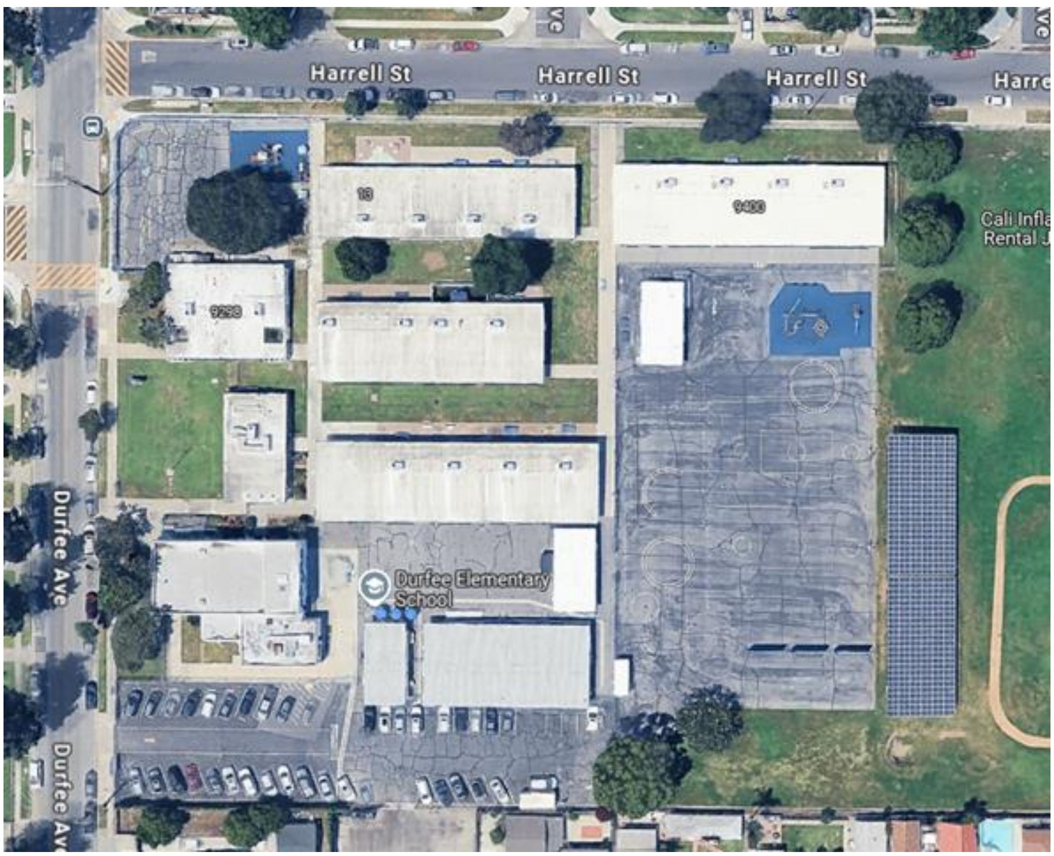


Figure 3: Durfee Elementary School site overview.

Source: Google Images, 2020

Table 3: North Ranchito Elementary School Description

Site 2	North Ranchito Elementary School
Address	8837 Olympic Blvd, Pico Rivera, CA 90660
RTUs Monitored	5
Site Type	Education, Primary School

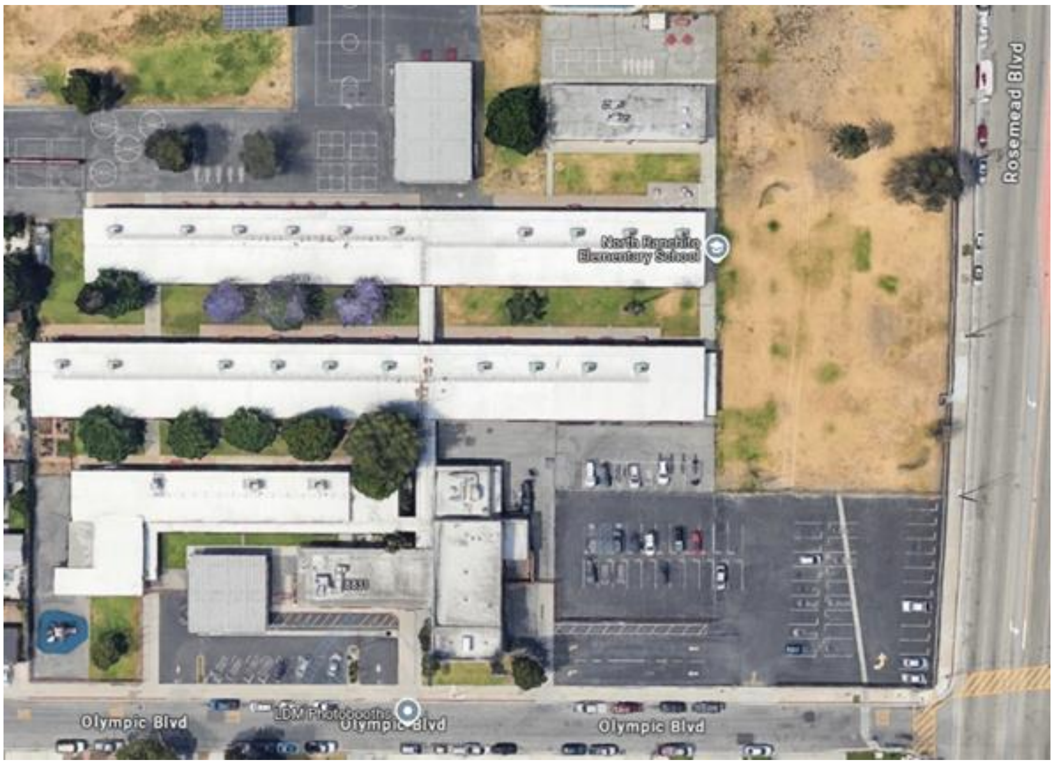


Figure 4: North Ranchito Elementary School site overview.

Source: Google Images, 2020

Table 4: Rio Vista Elementary School Description

Site 3	Rio Vista Elementary School
Address	8809 Coffman and Pico Rd, Pico Rivera, CA 90660
RTUs Monitored	17
Site Type	Education, Primary School

Figure 5: Rio Vista Elementary School site overview.

Source: Google Images, 2020

Table 5: Rivera Academy Description

Site 4	Rivera Academy
Address	7250 Citronell Ave, Pico Rivera, CA 90660
RTUs Monitored	12
Site Type	Education, Primary School

Figure 6: Rivera Academy site overview.

Source: Google Images, 2020

Disadvantaged Community (DAC)

California's Office of Environmental Health Hazard Assessment (OEHHA) identifies DACs using the CalEnviroScreen (CES) tool, developed on behalf of the California Environmental Protection Agency (CalEPA). A DAC is a community that is disproportionately burdened by environmental pollution and socio-economic stressors, such as:

- High levels of air and water pollution
- Hazardous waste exposure
- Proximity to freeways or industrial facilities
- Poverty

- High unemployment
- Low levels of education
- High rates of asthma or other health conditions

The California Climate Investments Priority Populations Mapping Tool 4.0 was used to determine the designation for each of the project sites within this effort. This tool combines pollution burden indicators with population vulnerability indicators to develop locational tracts. Each tract is assigned a percentile score, with higher scores indicating higher cumulative burdens. DACs are typically defined as the top 25 percent of census tracts with the highest scores.

Each of the test sites within this effort are in tracts designated as a disadvantaged and low-income communities, where the median income falls below 80 percent of the statewide or regional median household income.

Test Plan

The Customer Installation Agreement was finalized in April 2024, with the intent of beginning third-party software, BEMA, installation immediately thereafter. However, installation experienced a five-month delay due to concerns raised by the school district's Information Technology (IT) department regarding network security. Specifically, the IT department restricted BEMA's network access to outbound, read-only data transmission, prohibiting any inbound, write-access capabilities. Following these modifications, the technology was successfully commissioned in September 2024.

Data collection occurred over nine months from September 2024 through May 2025, under standard operating conditions and maintenance practices as recommended by district maintenance personnel. BEMA's data acquisition system was used to collect and archive data, while also responding to real-time alerts generated by the Carrier SystemVu monitoring system. Leveraging SystemVu's integrated sensor suite, the following variables were monitored continuously during normal HVAC operation:

- Circuit-1 compressor enable
- Circuit-1 discharge pressure
- Circuit-1 suction pressure
- Circuit-2 compressor enable/disable
- General system alarm status
- Outside air temperature
- Return air temperature
- Supply air temperature
- Effective cooling setpoint
- Effective zone setpoint

- Effective heating setpoint
- Occupied status
- Effective control temperature
- Supply fan VFD speed command
- Space/Zone CO_2 level
- Space/Zone temperature

Detected conditions span a range of operational parameters, including electrical supply as voltage, sensor functionality, economizer performance, thermostat communication, fire alarm interfacing, filter condition, refrigerant charge levels, and ventilation system operation. Using the data variables and alert infrastructure, BEMA was able to detect and classify a range of operational anomalies including:

- Operation during unoccupied periods
- Temperature setpoints outside expected ranges
- Low refrigerant charge
- Excessive subcooling which is indicative of overcharging
- Elevated condenser temperatures due to fouling or fan failure
- Restricted airflow likely from clogged filters or duct obstructions
- Economizer malfunction
- Excessive runtime under stable outdoor air temperature conditions

This monitoring framework enabled both proactive fault detection and targeted maintenance responses, contributing to overall system efficiency and reliability. Figure 7 below is a diagram of the connections between HVAC units, integrated SystemVu and add-on sensors, the school district's network, and the cloud-based BEMA notification system.

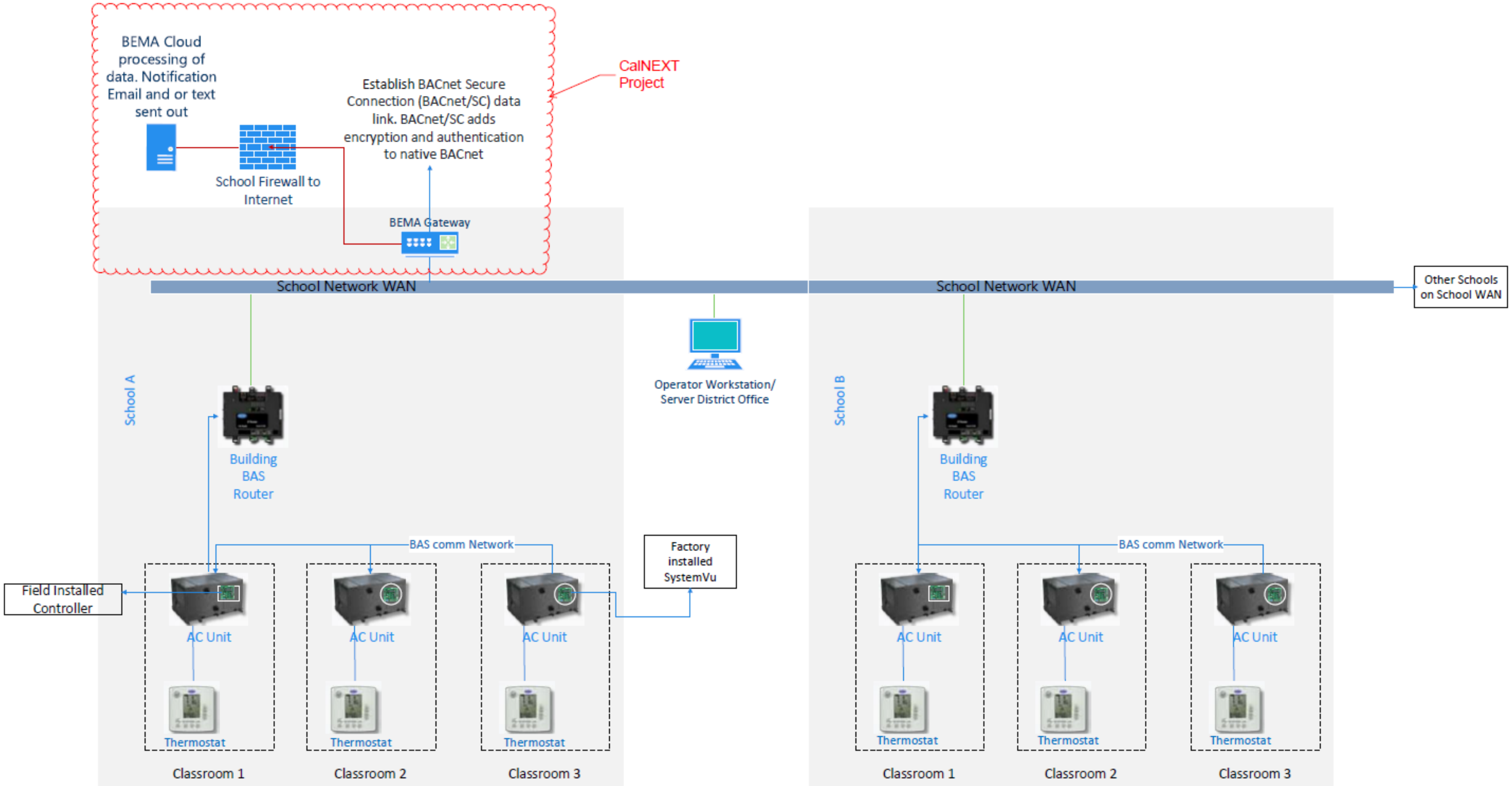


Figure 7: Overview of system layout.

Source: RMS Energy Consulting LLC, 2025

Figure 8 illustrates sample notifications sent by the BEMA data acquisition monitoring system based on the measurements by the system during the monitoring period. The notification denotes the site and affected HVAC system as well as the abnormal measurement detected.

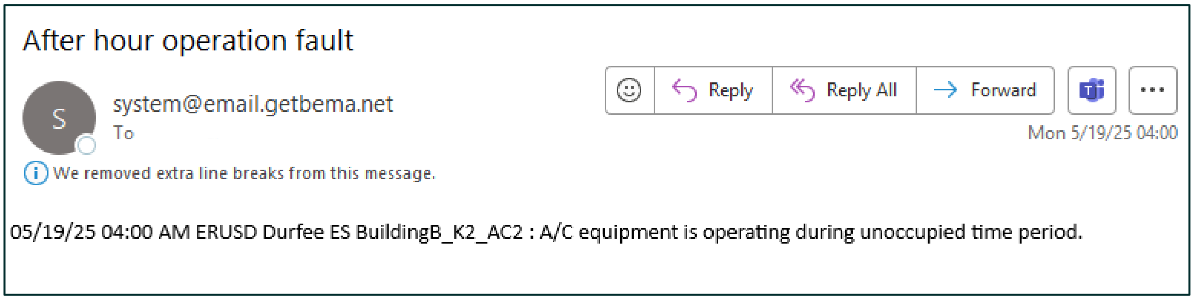


Figure 8: Notification of simulated equipment failure.

Source: RMS Energy Consulting LLC, 2025

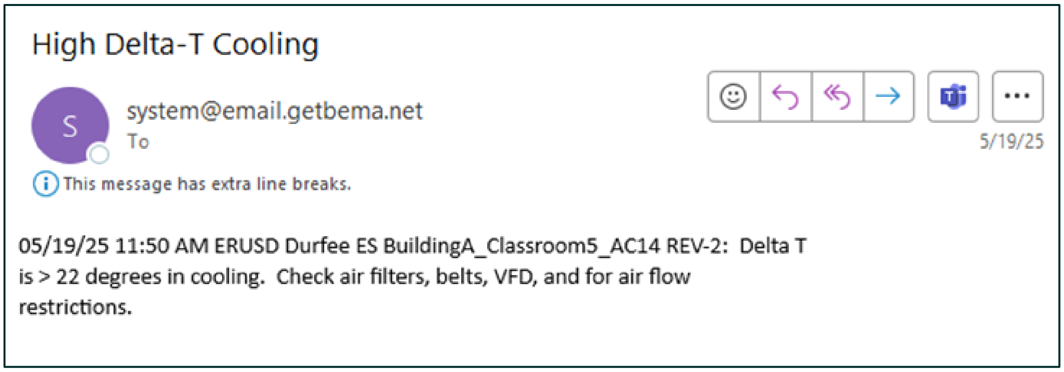
Notification Simulations

As previously mentioned, an alert generally signifies a warning of an improperly functioning component, circuit, or sensor. In the mildest case, an alert does not affect the operation of the unit in any manner. However, alerts can also cause a “strike”, where the circuit will shut down for 15 minutes. If three strikes occur before the circuit has an opportunity to show it can function properly, a shutdown fault will occur. This “three strike” feature reduces the likelihood of false alarms causing a properly working system to be shut down incorrectly.

The RTUs evaluated in this study were newly installed. Accordingly, the occurrence of fault alerts due to actual equipment degradation was expected to be minimal, barring any factory-related defects. To validate the system’s fault detection and alerting functionality, simulated fault conditions were created by adjusting operational thresholds.

Two simulations were conducted based on monitoring the differential between supply air temperature and return air temperature, commonly referred to as delta T (ΔT). Deviations in ΔT are indicative of several potential system anomalies. A low ΔT may suggest conditions such as low refrigerant charge, excessive airflow, compressor malfunction, or a fouled evaporator coil. Conversely, a high ΔT may be symptomatic of restricted airflow or blower motor deficiencies. Industry best practices typically define an acceptable ΔT range between 16°F and 22°F.

To simulate fault conditions, the alert thresholds within the BEMA monitoring platform were modified to fall outside of this standard ΔT range, thereby prompting alert generation under normal system operation. The BEMA system successfully issued alert notifications to the research team in response to the simulated events as shown in Figure 9. This outcome confirmed the functionality and responsiveness of the fault detection system, demonstrating that the platform would operate as intended in the presence of actual system faults.


High Delta-T Cooling

system@email.getbema.net
To
5/19/25
This message has extra line breaks.

05/19/25 11:50 AM ERUSD Durfee ES BuildingA_Classroom5_AC14 REV-2: Delta T is > 22 degrees in cooling. Check air filters, belts, VFD, and for air flow restrictions.

Figure 9: Notification of simulated equipment failure.

Source: RMS Energy Consulting LLC, 2025

Findings

Overview

This study evaluated the performance and potential energy impacts of the remote monitoring system across a sample of 72 constant volume RTUs, ranging in capacity from 3 to 7.5 tons. These units were selected from a total of 238 RTUs deployed districtwide. Of the 238 units, 164 were equipped with the latest version of the SystemVu monitoring system, while the remaining 74 utilized an earlier generation of the technology. The analysis focused exclusively on the performance of the most current version of SystemVu installed at four designated project sites.

As all monitored RTUs were recently installed and in new condition, no mechanical alerts or faults were reported during the observation period. Consequently, the assessment of energy savings potential was based on operational insights and system-level observations rather than direct fault-based interventions. Identified opportunities for energy savings are shown in Table 6.

Table 6: Identified Opportunities for Energy Savings

EEM	Identified Opportunities for Energy Savings
1	Avoided operational costs during unoccupied periods: Monitoring enabled the identification of runtime during holidays and school breaks, allowing for adjustments that prevented unnecessary energy consumption.
2	Optimization of factory-default setpoints: Commissioning efforts revealed default temperature setpoints and outside air configurations that were misaligned with actual site operational needs, leading to corrections that reduced excess energy use.

EEM	Identified Opportunities for Energy Savings
3	Future fault mitigation potential: While no faults were observed during the study period, the monitoring platform's capabilities support early detection of component failures such as economizer faults or compressor degradation, offering potential for significant cost avoidance and energy savings over the equipment lifecycle.

Unoccupied Operation Due to Holiday and Break Schedules

Several instances were observed in which air conditioning systems operated over extended unoccupied periods during the evaluation periods. Notably, over the Thanksgiving and Christmas school breaks RTUs operated during extended unoccupied periods resulting in wasted energy and missed opportunities for energy savings.

ERUSD's maintenance staff were notified of the wasted energy during the 2024 fall/winter holiday periods. Although adjustments were successfully implemented to curtail runtime during the spring 2025 break period, doing so required considerable coordination and manual effort. These observations highlight the challenges associated with accurately managing HVAC schedules, particularly during variable use periods such as summer school when classroom occupancy fluctuates and during scheduled holiday breaks.

Estimated RTU Cooling and Heating Operational Cost

The estimated operational cost for cooling is approximately $8.46 per day per RTU. Similarly, heating costs averaged $5.14 per day per RTU. These estimates are based on nameplate data gathered from the newly installed RTUs and runtimes gathered during the observation period between September 2024 and May 2025. Given the presence of several hundred RTUs within the school district, and significantly more across school districts statewide, these costs can accumulate rapidly when systems operate unnecessarily during unoccupied periods.

Despite the integration of advanced controls and AFDD, human intervention remains essential for tasks such as scheduling around holiday periods. This observation underscores the need for improved automation or policy-driven approaches to optimize HVAC operation schedules during school closures and minimize avoidable energy use. The SystemVu interface has substantial occupied and unoccupied scheduling capabilities, for time-of-day schedules, weekly schedules and holidays schedules to assist HVAC operators with improved and optimized automation approaches in solving HVAC unoccupied operational schedules assuming that preventative and predictive maintenance practices are adopted.

Winter Avoided Costs

During the evaluation period, the project team identified that ERUSD had not configured its building automation system to reflect the Thanksgiving holiday schedule accurately. As a result, heating systems remained operational for the entire week while school facilities were unoccupied. Although the district was promptly notified of the issue to allow for corrections ahead of the Christmas break, schedule adjustments were not implemented in time. Consequently, heating systems continued to operate unnecessarily for an additional two weeks during this time.

To estimate the potential energy costs that could have been avoided, supply air temperature data was collected from 18 representative RTUs during the Christmas break. This data was analyzed to determine the average daily operation times for both heating and fan components. Manufacturer specifications were used to obtain unit-specific fan power consumption and burner energy usage. These values were combined with applicable utility rates to calculate a representative daily cost per unit during the winter season.

The estimated per-unit costs were then extrapolated across the relevant units in the ERUSD inventory to determine the total potential cost avoidance for both the Thanksgiving and Christmas breaks. The table below summarizes the calculated avoided energy costs associated with unnecessary HVAC operation during these unoccupied periods.

Table 7: Potential Winter Avoided Costs

Number of Units	Fan Energy Usage per Day (kWh)	Heater Usage per Day (therms)	Cost per Day*	Cost for Thanksgiving Break	Cost for Christmas Break
72 Units Monitored as Project	730	73	$370	$1,850	$3,701
164 units in ERUSD with the new SystemVu	1,702	170	$863	$4,317	$8,635
238 Units in ERUSD with SystemVu or other monitoring/alert capabilities	2,715	272	$1,377	$6,887	$13,775

*Using SoCalGas 2024 rates of $2.324/therm and SCE 2024 GS-D rates $0.27/kWh

Spring Avoided Costs

Following the analysis of unnecessary HVAC operation during the winter break, the project team recommended that the school district revise its building automation system schedules in preparation for the spring break. In response, the district successfully implemented schedule modifications that prevented both cooling and heating system operation during unoccupied periods.

To quantify the avoided costs resulting from these modifications, an analysis was conducted using the same methodology applied during the winter break assessment. Supply air temperature data was collected from representative RTUs and analyzed to determine average air conditioning runtimes on a typical occupied day with a weather profile comparable to the first day of spring break. These runtimes were then combined with manufacturer-rated energy consumption values and applicable utility rates to estimate a daily per-unit energy cost. Table 8 below demonstrates estimated operational costs that were successfully avoided due to corrected scheduling practices.

Table 8: Realized Spring Avoided Costs

Number of Units	Energy Usage per Day (kWh)	Cost per Day*	Cost for Spring Break
72 Units Currently Monitored	2,257	$609	$3,046
164 units in ERUSD with the new SystemVu	5,265	$1,422	$7,108
238 Units in ERUSD with SystemVu or other monitoring/alert system	8,400	$2,268	$11,339

*Using SoCalGas 2024 rates of $2.324/therm and SCE 2024 GS-D rates $0.27/kWh

Summer Avoided Costs

The original HVAC operational schedule did not account for the summer break period, and it remains unclear whether the schedule was updated when modifications were made for the spring break. Due to the elevated ambient temperatures typical of Pico Rivera during the summer months, it is expected that HVAC systems would operate daily in the absence of an updated schedule.

To assess the potential energy impact of unmodified scheduling, an estimate of summer unoccupied usage was developed based on the spring break analysis. This assumes an eight-week period with temperatures comparable to those during spring break, representing a conservative baseline for potential summer energy consumption in unoccupied buildings. The table below demonstrates estimated operational costs that can be avoided due to corrected scheduling practices.

Table 9: Potential Summer Avoided Costs

Number of Units	Energy Usage per Day (kWh)	Cost per Day*	Cost for Summer Break
72 Units Currently Monitored	2,257	$609	$24,371
164 units in ERUSD with the new SystemVu	5,265	$1,422	$56,865
238 Units in ERUSD with SystemVu or other monitoring/alert system	8,400	$2,268	$90,713

*Using SoCalGas 2024 rates of $2.324/therm and SCE 2024 GS-D rates $0.27/kWh

Unoccupied Operation Due to Factory Default Setpoints

Energy Savings from Factory Default Setpoints

Additional instances of unoccupied HVAC operation were observed due to the system reaching unoccupied thermostat setpoints during nighttime and weekend hours, despite being scheduled to remain off. Investigation revealed that the factory default setpoints for unoccupied periods were configured to 60°F for heating and 85°F for cooling. While such setpoint ranges may be appropriate for specialized facilities with temperature-sensitive requirements, the monitored spaces in this study were standard classroom environments. This observation was communicated to the school district, along with a recommendation to consider broadening the unoccupied temperature ranges to capture additional energy savings. As of the conclusion of this study, no modifications to the default setpoints have been observed.

Energy Savings via Excessive Outside Air Ventilation

A further energy-saving opportunity was identified by using the BEMA software, which offers diagnostic insights not currently available through the factory-installed AFDD system. Specifically, the software suggested the possibility of excessive outside air ventilation. CO_2 levels during occupied hours were consistently maintained below 500 ppm, with a few exceptions reaching approximately 1,200 ppm. Given the consistently low CO_2 readings, there is reason to suspect that the demand-controlled ventilation (DCV) system may be over-ventilating, leading to unnecessary energy consumption.

An attempt was made to locate the factory-default setpoint for minimum ventilation in the equipment specifications. However, such information was not found. The ventilation control logic for these RTUs is complex and varies with indoor fan speed, involving multiple damper positions. These findings highlight the potential value of supervisory software for commissioning and retro-commissioning HVAC systems, providing enhanced oversight of operational parameters that may not be captured through standard factory diagnostics alone.

Proper commissioning of HVAC ventilation settings has the potential to achieve EE savings ranging between 5 and 15 percent with a median annual energy savings of 10 percent (Markley, Pritoni, and Fortunato 2013). In this study, the integrated HVAC RTU monitoring system was limited to read-only network access. As a result, configuration adjustments, including optimization of factory default settings, could not be performed remotely by the BEMA cloud-based supervisory platform. If write-access had been permitted, remote commissioning adjustments could have been executed, further enhancing operational efficiency and potential savings.

The estimated energy savings associated with proper commissioning are presented in Table 10. These projections are based on two months of heating operation, consistent with usage observed during the December winter break analysis, and four months of cooling operation during occupied periods, based on data collected in April during the spring break analysis.

Table 10: Potential Commissioning Savings

Number of Units	Total Annual Energy Usage due to Heating	Total Annual Energy Usage due to Cooling (kWh)	Estimated Annual EE Savings (10%)	Annual Cost of Improper Ventilation
72 Units Currently Monitored	29,200 kWh 2,920 therms	180,560	20,976 kWh 292 therms	$6,346
164 units in ERUSD with the new SystemVu	68,133 kWh 6,813 therms	421,307	48,944 kWh 681 therms	$14,807
238 Units in ERUSD with SystemVu or other monitoring/alert system	108,699 kWh 10,869 therms	672,084	78,077 kWh 1,086 therms	$23,621

*Using SoCalGas 2024 rates of $2.324/therm and SCE 2024 GS-D rates $0.27/kWh

Lifecycle Savings Due to Equipment Failure

The integrated HVAC RTU remote monitoring system is designed to detect performance anomalies indicative of impending equipment failure. Early detection through fault alerts enables timely maintenance or repair, often at a significantly lower cost compared to the replacement of critical components or complete unit failure.

The integrated HVAC RTU remote monitoring system includes capabilities to detect economizer faults in real time. In the absence of such a monitoring system, economizer failures may remain undetected for extended periods. This may be either until the next scheduled maintenance event or indefinitely if no routine maintenance is conducted.

California e-TRM Commercial Repair Energy Savings

California's statewide Electronic Technical Reference Manual (e-TRM) measure SWSV005, "Commercial Economizer Repair," has previously quantified the energy savings associated with correcting economizer faults, estimating up to 216 kWh/ton of annual savings, contingent on the applicable climate zone (California eTRM 2025). These established savings values, along with associated repair costs, can therefore be integrated into the overall cost-effectiveness and energy savings evaluation of the remote monitoring system.

Predictive Analytics and Maintenance Anticipating Failed Compressor

Additionally, the diagnostic system can assist with preemptively predicting a failed compressor, which is a much more capital-intensive item. The replacement cost of a compressor is approximately $3,500 and industry data indicates that, over a 10-year operational period, an estimated 20 percent of compressors are likely to fail (Siglers-Carrier). Therefore, the predictive diagnostic capabilities of the monitoring system provide substantial cost-avoidance opportunities by enabling proactive interventions.

Technology Cost-Effectiveness

Although not required as part of this TSR project, a preliminary TRC-benefit analysis was performed to determine SystemVu's viability to be considered as an adoptable measure into California's statewide EE rebate and incentive programs. Table 11 and Table 12 illustrate the assumptions used in calculating the TRC ratios for both New Construction (NC) and Add-on Equipment (AOE) scenarios. Preliminary cost-benefit estimates suggest that a 463 kWh/ton annual energy savings and 3.8 therms/ton result in a TRC ratio of 2.11 and 1.03 for NC and AOE program design approaches, respectively. Conversely, the total system benefit (TSB) for the NC and AOE scenarios was determined to $660.60/ton and $280.60/ton, respectively.

Table 11: Total Resource Cost Analysis - New Construction

Variable	TRC Determination for New Construction
Measure Application Type	New Construction
Unit kWh 1st Baseline Savings	463 kWh/ton 3.8 therms/ton
Unit Measure Cost 1st Baseline	$716/ton
Effective Useful Life	20 Years EUL ID: HVAC-airAC or HVAC-airHP
Normalized Unit	Cap-Tons
Load Shape	DEER:HVAC_Split-Package_AC
Net to Gross	0.85 | NTG ID: ET-Default
GSIA ID	Def-GSIA
TRC	2.11
TSB	$600.60/ton

Table 12: Total Resource Cost Analysis - Add-on Equipment

Variable	TRC Determination for Add-on Equipment
Measure Application Type	Add-on Equipment
Unit kWh 1st Baseline Savings	463 kWh/ton 3.8 therms/ton
Unit Measure Cost 1st Baseline	$421.20/ton
Remaining Useful Life	6.7 Years RUL ID: HVAC-airAC or HVAC-airHP
Normalized Unit	Cap-Tons
Load Shape	DEER:HVAC_Split-Package_AC
Net to Gross	0.85 | NTG ID: ET-Default
GSIA ID	Def-GSIA
TRC	1.03
TSB	$280.60/ton

Stakeholder Feedback

Stakeholder Outreach and Engagement Attempts with Other School Districts

The project team had identified a number of suitable sites prior to selecting ERUSD. However, on discovering that the school districts other did not pay California's Public Purpose Programs charge (PPP) for electricity, the project team had to pivot and identify another school district in southern California that was an electric rate-paying customer in SCE's service territory. This resulted in some delay in starting the project despite customer interest. Subsequently, the project team identified ERUSD as a suitable customer to participate in the CalNEXT TSR program.

Engagement with ERUSD and Manufacturing Teams on CalNEXT TSR Opportunity

The project team engaged with Carrier, BEMA, ERUSD and their maintenance operating staff. The purpose of engaging these stakeholders was to identify the right rate-paying customer within SCE's electric service territory where the SystemVu technology could be deployed on a statistically significant scale.

Several meetings were hosted by ERUSD because the school district received federal grant funding that allowed ERUSD to purchase new RTUs across all 16 campuses. ERUSD's planning process started well before this TSR was considered, due to the lead time of planning and coordinating with several key decision makers and timing of when ERUSD would receive funding. Therefore, when this TSR opportunity was made available in 2023, the timing of Siglers-Carrier release of the updated SystemVu was prime for demonstration. The key takeaway from these planning discussions were that if SystemVu could demonstrate energy savings on these ERUSD units manufactured by Siglers-Carrier, then ERUSD could receive funding from CalNEXT to help offset the incremental measure cost of SystemVu being factory-installed at the time of order before deployment.

Outreach Engagement with ERUSD and Manufacturing Teams on IT Security

Although the Customer Installation Agreement was finalized in April 2024, the installation experienced a five-month delay because the school district's IT department had concerns about adopting the combined SystemVu and BEMA data collection platform and how the BEMA cloud-based technology would impact network security. Specifically, the IT department restricted BEMA's network access to outbound, read-only data transmission, prohibiting any inbound, write-access capabilities.

Outreach Engagement with ERUSD Maintenance Operating Staff on SystemVu Alerts

HVAC maintenance operator stakeholder engagement was also challenging after SystemVu was installed as ERUSD HVAC operation maintenance staff was resource constrained and could not respond in a timely manner to emails and phone calls when alerts, notifications, and faults were triggered and communicated. Accordingly, many RTUs unnecessarily operated during unoccupied periods.

Federal Grant Funding, CalNEXT TSR Funding, and Future Utility Incentives

A key takeaway from these stakeholder meetings with ERUSD revealed that had it not been for the federal grant funding, ERUSD would likely not have taken steps to upgrade to adopt new RTUs and would not have considered SystemVu because of funding constraints. Therefore, even if utility incentives were available, ERUSD indicated that this project could only occur because of the federal grant funding available for the RTUs. Absent this federal grant funding, ERUSD likely would not have purchased the advanced functionalities of SystemVu, i-Vu, or BEMA data acquisition platforms.

Existing Relationships Helped the Adoption of SystemVu/BEMA Solutions

ERUSD's existing relationship with Siglers-Carrier spanned over the past decade. The rapport built between the school district and the HVAC manufacturer contributed to the adoption of SystemVu. Additionally, ERUSD maintenance operators indicated that BEMA provides an "easy button" solution for facilities like schools and others to be notified of equipment problems especially when other onsite controls are not being viewed on a consistent or non-existent basis.

ERUSD understood that with new RTUs, the chance to catch a mechanical fault or failure was unlikely and was not surprised that it did not occur during the TSR study. However, despite the "ease of use" platform from BEMA, ERUSD's HVAC maintenance operators were resource constrained to the point where they could not respond in a timely way to BEMA's alerts and notifications. Had ERUSD's HVAC maintenance operators had time to view those alerts and notifications, many of the unoccupied scheduling issues that occurred during Thanksgiving and Christmas periods likely would have been avoided.

Discussions

Resource Constrained Maintenance Staff

School districts and facilities in DACs are even less likely to have available staff to effectively monitor and maintain their HVAC units. Many school districts face significant staffing shortages in facilities maintenance, and ERUSD is no exception. Currently, only two technicians are responsible for maintaining over 250 HVAC units, in addition to other facility-related duties. This challenge is not unique to educational institutions; a widespread shortage of skilled tradespeople persists across commercial facilities more broadly.

The role of facility energy manager, once common, saw substantial declines following the 2008 economic downturn, with responsibilities either redistributed to general facility staff or left unaddressed. Facilities located in DACs are particularly affected, as they are less likely to have the resources or personnel necessary to support effective HVAC monitoring, maintenance, and optimization.

Communicating Thanksgiving Holiday Wasted Energy Use to ERUSD

The project kickoff meeting was attended by the district's financial manager, facilities manager, and two maintenance technicians, all of whom expressed interest in the potential energy and cost savings associated with the integrated HVAC RTU monitoring system. During the initial monitoring phase, the project team identified RTU operation during unoccupied hours over the Thanksgiving break. This observation was promptly communicated to the facilities manager via a formal memorandum. In response, the facilities team acknowledged the notification and expressed appreciation for the insight provided.

Communicating Christmas Holiday Wasted Energy Use to ERUSD

During the 2024 winter recess, the project team observed continued RTU operation during unoccupied hours across several ERUSD sites. Given the district's existing maintenance practices, the team conducted an analysis to quantify the energy waste and associated cost impacts resulting from this unscheduled HVAC runtime. The analysis estimated that implementing appropriate unoccupied scheduling alone could result in annual savings in the range of several thousand dollars, which if implemented could potentially be redirected to support additional maintenance personnel.

Following this observation, the project team submitted a memorandum to the district's facilities manager outlining the findings and inquiring why scheduling adjustments had not been implemented in SystemVu and BEMA platforms after the earlier advisory issued during the Thanksgiving break. In response, ERUSD HVAC maintenance personnel indicated that they lacked sufficient time and staffing resources to implement the recommended schedule modifications prior to the winter break.

To prevent further unnecessary energy consumption during future unoccupied periods, the project team engaged Siglers-Carrier representatives to explore the feasibility of assisting with RTU scheduling updates. As a result of continued coordination and follow-up, the RTU schedules were successfully revised to prevent operation during unoccupied hours for the 2025 spring break period.

Factory Versus Add-on Retrofit Costs and Other Considerations

Factory Installed and Add-on Retrofit Installed Sensors

The RTUs evaluated in this TSR project were equipped with a factory-installed AFDD system. The incremental cost of incorporating AFDD during RTU manufacturing is approximately $900 per unit. This integrated feature enables a comprehensive suite of alarms and fault detection capabilities, which can be accessed either directly at the unit or remotely via a centralized network interface.

In comparison, traditional RTUs that are not equipped with factory-integrated AFDD require retrofitting with five to six temperature sensors to achieve a similar, though more limited, diagnostic capability. The cost of such retrofits is approximately $1,200 per unit. As a result, the availability of factory-installed AFDD presents a cost-effective alternative to post-installation retrofits, particularly because it eliminates the need for additional labor associated with sensor installation on rooftop-mounted equipment.

As discussed in the Test Plan, the factory installed configuration is equipped with sixteen sensors as part of System Vu's integrated sensor suite. A field retrofit data collection, however, might only use five temperature sensors and one site outside air temperature to operate an ample set of AFDD algorithms unlike the RTUs with a rich set of factory-installed sensors, including:

- Return air temperature
- Supply air temperature
- Air temperature leaving the condenser coil
- Superheat temperature
- Subcooling temperature

Incorporating suction and discharge pressure sensors into RTU AFDD systems is advantageous, as these data points offer valuable telemetry for assessing equipment performance and identifying operational anomalies. However, such sensors are typically costly, challenging to install, and prone to reliability concerns. As a result, pressure measurements are generally excluded from retrofit applications. In contrast, temperature sensors are more commonly deployed, as they can be mechanically affixed to HVAC components and connected to a gateway that transmits the data to a cloud-based analytics platform. While installation requires some technical expertise, the training required is not considered overly complex for HVAC technicians who are already experienced with RTU systems and controls.

BEMA and SystemVu Compatibility and Associated Costs

In this TSR demonstration project, the BEMA cloud-based platform was deployed as a supervisory layer above the factory-installed SystemVu AFDD system. BEMA's role was to verify optimal functionality and utilization of the SystemVu platform, and to evaluate the feasibility of integrating a low-cost, cloud-based AFDD solution with SystemVu's proprietary architecture.

The implementation of BEMA involved one-time labor and material cost of approximately $1,000 for establishing the cloud connection. An additional configuration cost of $2,500 was required to tailor the platform to the specific operational parameters of the project. Ongoing monitoring and analytics services were supported through a monthly subscription fee of $250, covering all 72 rooftop air conditioning units included in the demonstration. Based on discussions with ERUSD staff, the monthly subscription is not a planned budget activity that the school district is willing to entertain at this time. This may change for the school district if the budget allows. The current plan is to allow ERUSD to have the BEMA automated alert system and the SystemVu monitoring system enabled until the end of 2025.

Life of Equipment

For factory-installed instrumentation, the integrated AFDD system is capable of generating alerts when a sensor malfunctions or transmits inaccurate data. These sensors are designed for durability and are expected to function reliably for the typical service life of the equipment, which is approximately 20 years or more. The temperature sensors, which are standard thermistors, are similarly robust and are also anticipated to maintain operational integrity over the equipment's lifespan.

Retrofit Technology and Manufacturer Compatibility

BEMA's cloud-based platform is manufacturer-agnostic and capable of integrating with HVAC equipment from any vendor. For this TSR demonstration project, BEMA deployed a system utilizing the BACnet communication protocol, which enabled efficient and streamlined data acquisition from the RTUs. Once the relevant data points were identified and mapped on the initial RTU, the configuration process for the remaining units was replicated with minimal effort.

A single gateway was installed at the district's maintenance office, serving as the central node for data aggregation. RTUs were then onboarded to the BEMA cloud-based platform, where data points and naming conventions were systematically organized to support consistent monitoring and analysis. This streamlined approach accelerated the integration of factory-installed sensors. Should additional field sensors be installed later, their corresponding data points can be incorporated into the system with appropriate labeling during setup.

Recommendations

Maintenance Staff

This TSR field study demonstrated that school facilities require trained HVAC maintenance personnel or energy managers to actively monitor equipment operation, both for scheduling accuracy during unoccupied periods and for responding to automated fault detection, alarms, and system notifications. School occupancy patterns often vary year by year, with greater variability during summer months, necessitating adaptive maintenance and scheduling strategies. Based on discussions with ERUSD staff, the continuation of BEMA is not a planned budget activity and will only be enabled until the end of 2025. The installed sensors will continue to monitor the RTU performance, however notifications of faults or out-of-bound operation will not be provided to the staff.

Preliminary estimates from the project team indicate that the potential energy savings achievable through optimized HVAC operation at this school district would be sufficient to justify the cost of additional personnel dedicated to implementing preventative and predictive maintenance best practices. The study also highlights the benefits of deploying a cloud-based monitoring platform, which functions as a virtual energy manager capable of remotely assessing equipment performance and identifying opportunities for energy optimization. Due to IT constraints, the district was not and is not interested in enabling two-way communication with the RTUs to facilitate automatic control for optimization activities. This enablement would have ensured persistency of savings and alleviate staff constraints from manual operational changes.

However, the effectiveness of such AFDD systems is contingent on follow-through by on-site staff. Without timely intervention by qualified personnel to address identified issues, the system's alerts may be ignored or silenced, ultimately negating the potential energy and cost savings benefits. This underscores the importance of pairing automated monitoring technologies with dedicated operational support to fully realize performance improvements.

Equipment and Building Type Restrictions

A wide range of building systems can be monitored using either factory-installed or field-installed sensors. Commonly monitored equipment includes unitary HVAC systems (gas, electric, or heat pump), chillers, boilers, pumps, AHUs, terminal variable air volume (VAV) boxes, PV systems, electric vehicle (EV) infrastructure, and building electrical service panels.

Adoption of AFDD technologies offers two primary benefits: (1) enhanced equipment reliability and extended service life, and (2) measurable energy and cost savings. These benefits are particularly valuable for small-to-medium-sized commercial facilities, which often lack dedicated, on-site HVAC maintenance personnel. In such cases, cloud-based AFDD platforms enable continuous remote monitoring of unmanned facilities and deliver real-time alerts to designated staff via text or email when faults or anomalies are detected. This facilitates timely intervention and supports proactive maintenance strategies.

Energy Savings Opportunities

Based on findings from this and other TSR demonstration projects, one of the most substantial opportunities for energy savings lies in eliminating unnecessary HVAC operation during unoccupied periods. This inefficiency often results from initial programming errors, operational changes that are not reflected in the control system, or manual overrides that are not reset. Primary schools exhibit variable occupancy schedules that require careful management of control settings to ensure HVAC systems operate only when needed.

Additional energy savings are achieved by maintaining HVAC equipment, such as RTUs, in proper operating condition. In many instances, an RTU with partial system degradation may continue to deliver cooling, but at a significantly reduced efficiency. These issues can often be addressed through proactive, scheduled maintenance. Alternatively, AFDD technologies can notify HVAC personnel of operational anomalies in real time, prompting targeted service interventions and minimizing energy waste associated with equipment inefficiencies.

Broad Audience Awareness Creation and Technology Transfer Opportunities

Equipment Distributor Awareness of AFDD

AFDD capabilities are now available as a factory-installed option in small-scale HVAC equipment. Equipment distributors are generally aware of these integrated AFDD features; however, broader market adoption will require clear guidance on installation procedures and integration requirements. Establishing standard installation practices and ensuring alignment with existing building systems are critical next steps to facilitate widespread deployment.

ASHRAE 90.1 Codes and Standards Community Socializing AFDD Technology

The ASHRAE Standard 90.1 committee is actively developing codes and standards language to support the integration of AFDD technology into new HVAC equipment installations. Emerging tools, including artificial intelligence (AI), can assist in interpreting and responding to fault notifications generated by AFDD systems. However, this TSR demonstration project highlighted that successful technology transfer into deemed incentive programs requires increased awareness, targeted incentives, and enhanced workforce education and training. Currently, the technical complexity of AFDD systems may exceed the skill set of many HVAC maintenance personnel. Without proper support and engagement, AFDD alerts risk being ignored, silenced, or overlooked, ultimately limiting the realization of potential energy and cost savings.

Empowering HVAC Maintenance Operators with AFDD Training and Decision Making

Many facilities, regardless of size, location, or community, face significant resource constraints, often resulting in overextended HVAC maintenance personnel who lack the capacity to respond to every alert, notification, or fault. In such environments, HVAC RTUs frequently operate until failure, at which point repairs are reactive and often costly. Predictive and preventive maintenance strategies, while effective, require adequate funding and a skilled workforce to implement. Similarly, addressing alarms and excessive energy consumption necessitates technical expertise and dedicated operational support.

A key finding from this TSR demonstration project is that the successful deployment of AFDD technology depends on its integration into day-to-day facility operations. Ensuring that HVAC maintenance personnel are both equipped and empowered to act on AFDD insights is essential. Doing so not only supports efficient HVAC operation but also provides a compelling economic rationale for expanding maintenance teams and investing in the continued training of technical staff.

A Divided HVAC Service Industry: Machinery and Controls

The HVAC service industry has traditionally been segmented into two distinct technical domains: mechanical systems and control systems. Both areas are critical to effective HVAC operation, yet each requires a unique set of specialized skills. Advances in HVAC technology, including the introduction of new refrigerants, variable-speed components, high-efficiency compressors, advanced materials, and evolving service protocols, have significantly increased the complexity of mechanical systems. As a result, HVAC service technicians face growing challenges in maintaining up-to-date knowledge and competencies to support the operation and maintenance of increasingly sophisticated equipment.

Updated Skills and Training Needed for an Aging Trade Workforce

The era of basic programmable thermostats and electro-mechanical controls has passed. Even small RTUs now incorporate advanced digital controls that require complex configuration often involving over 800 parameters at equipment startup. Modern RTU control logic and fault detection algorithms demand a level of technical proficiency comparable to operating sophisticated software platforms.

Furthermore, each HVAC manufacturer typically employs proprietary control strategies and naming conventions, adding another layer of complexity for technicians.

In the past, classroom teachers were often responsible for basic thermostat control to support energy conservation efforts. However, the increasing sophistication of HVAC systems has shifted this responsibility away from end users. With the integration of AFDD technologies and the growing complexity of system operation, there is concern that HVAC technicians may also become disconnected from day-to-day control responsibilities, unless comprehensive training is provided to ensure they are equipped to manage and optimize these evolving systems.

Aligning IT Staff with Technology Adoption

Effective adoption of AFDD technologies in school districts requires strategic alignment between facilities personnel and IT departments. As AFDD solutions increasingly rely on cloud-based connectivity and data integration with existing IT infrastructure, the support and cooperation of IT staff are critical to successful implementation. However, a significant challenge arises when IT departments, who are often risk-averse and focused on safeguarding network security, are hesitant to permit integration of third-party systems, even when those systems deliver clear operational and energy efficiency benefits.

Bridging this gap requires targeted outreach and education to inform IT stakeholders about the structure, data security protocols, and operational value of AFDD technologies. Ensuring alignment between emerging technology providers, energy managers, and IT departments is essential to overcome institutional resistance and facilitate widespread adoption of AFDD systems within school environments. Without this alignment, technology transfer efforts may stall, despite the demonstrated economic and operational advantages of AFDD-enabled HVAC optimization.

Overcoming Budgetary Constraints on Hiring Additional School District Technical Staff

School districts frequently encounter budgetary limitations that restrict their ability to hire additional qualified trade personnel to support preventative and predictive maintenance programs. In cases where districts cannot afford full-time equivalent (FTE) technical staff, alternative approaches such as utilizing a cloud-based energy manager or a shared energy management service present viable options. These solutions are particularly relevant for smaller or underfunded facilities lacking dedicated onsite expertise.

Within this TSR demonstration project, the project team functioned as a shared energy manager by identifying energy savings opportunities and mitigating energy waste. The cost savings realized through proactive preventative maintenance, facilitated by a shared energy manager in conjunction with an AFDD system, were equivalent to the operational value of employing between two and five FTE HVAC maintenance technicians. This approach thus offers a cost-effective strategy to enhance maintenance oversight while reducing overall expenditures for the school district.

Deemed Utility Incentive Recommendations for Education Sector

Based on the outcomes of this TSR field study, energy savings associated with this weather-dependent technology are expected to vary due to differences in pre-existing site conditions. To address this variability, the project team recommends that the energy savings data collected from the sample of 72 RTUs be averaged and normalized by unit cooling capacity, in tons, to establish a single deemed savings value. This normalized value can then be applied to future deployments in comparable primary and secondary school settings. Conducting detailed, site-specific M&V for each installation would likely exceed the cost of the AFDD system itself, thereby diminishing the cost-effectiveness and overall benefit of the technology deployment.

References

BEMA. 2025. BEMA - Building Energy Management Platform. https://getbema.net/.

California Division of Occupational Safety and Health. 1987. California Code of Regulations, Title 8, Section 5142. Mechanical Ventilation Systems. Sacramento, CA: California Department of Industrial Relations. https://www.dir.ca.gov/title8/5142.html.

California Energy Commission. 2022. 2022 Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Sacramento, CA: California Energy Commission.

California Energy Commission. 2025. "Inflation Reduction Act Residential Energy Rebate Programs." California Energy Commission. https://www.energy.ca.gov/programs-and-topics/programs/inflation-reduction-act-residential-energy-rebate-programs.

California Energy Efficiency Measure Data (eTRM). 2025. "Economizer Repair, Commercial." SWSV005-04. eTRM. https://www.caetrm.com/measure/SWSV005/04/.

California Infrastructure and Economic Development Bank (IBank). 2025. "IBank CLEEN Criteria." California Infrastructure and Economic Development Bank (IBank). https://www.ibank.ca.gov/ibank-cleen-criteria/.

California Legislature Assembly Committee on Education. 2022. AB 2232 (McCarty) – As Introduced February 15, 2022: School facilities: heating, ventilation, and air conditioning systems. Sacramento, CA.

California Public Utilities Commission. 2025. "Energy Savings Assistance." California Public Utilities Commission. https://www.cpuc.ca.gov/consumer-support/financial-assistance-savings-and-discounts/energy-savings-assistance.

California State Treasurer's Office California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA). 2025. "California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA)." California State Treasurer's Office. https://www.treasurer.ca.gov/caeatfa/.

Carrier. 2025. Single Package Rooftop Units with SystemVu™ Controls Version 4.X and Puron® (R-410A) Refrigerant: Controls, Start-Up, Operation, and Troubleshooting. Carrier.

CLEAResult. 2025. "The PEP Program." CLEAResult. https://www.clearesult.com/us/programs/the-pep-program.

Fiix Team. 2023a. "What Is Reactive Maintenance? Pros, Cons & Examples." Fiix. https://fiixsoftware.com/maintenance-strategies/reactive-maintenance/.

Fiix Team. 2023b. "What Is Preventative Maintenance? Pros, Cons & Examples." Fiix. https://fiixsoftware.com/maintenance-strategies/preventative-maintenance/.

Fiix Team. 2023c. "What Is Predictive Maintenance? Types, Pros & Cons." Fiix. https://fiixsoftware.com/maintenance-strategies/predictive-maintenance/.

FMX. 2024. "5 Preventive Maintenance Resources for Your School." FMX. https://www.gofmx.com/blog/5-preventive-maintenance-resources-for-your-school/.

IBISWorld. 2025. “Commercial Building Construction in California - Market Research Report.” Accessed June 2025. https://www.ibisworld.com/united-states/industry/california/commercial-building-construction/11011/.

Johnson, Angelique P. 2024. "An Ode to Building Maintenance Workers." Propmodo. https://propmodo.com/an-ode-to-building-maintenance-workers/.

Markley, John, Marco Pritoni, and Paul Fortunato. 2013. HVAC Equipment Demographics and Capacity Analysis Tools Applicable to Multi-Tenant Light Commercial Buildings. Davis, CA: Western Cooling Efficiency Center-UC Davis, University of California, Davis.

Modernize. 2025. "2025 HVAC Replacement Cost Calculator by Brand & Size." Modernize. https://modernize.com/hvac/cost-calculator.

Morton, Rob, and Martin Vu. 2025. *Thermal Energy Storage System for Packaged HVAC Systems*. CEC-500-2025-015. Sacramento, CA: California Energy Commission.

Propmodo Team. 2024. "5 Reasons Why Preventive Maintenance Programs Fail." Propmodo. https://propmodo.com/5-reasons-why-preventive-maintenance-programs-fail/.

Statista. 2025. “Forecast: Industry Revenue of ‘Construction’ in California 2012–2024.” Accessed June 2025. https://www.statista.com/forecasts/1204652/construction-revenue-in-california.

Tech Clean California. 2025. "Higher Efficiency Electric Home Rebate Act (HEEHRA) Rebates." Tech Clean California. https://techcleanca.com/incentives/heehrarebates/.

U.S. Energy Information Administration (EIA). 2018. “2018 CBECS: Principal Building Activities.” Accessed June 2025 https://www.eia.gov/consumption/commercial/pba/overview.php#:~:text=2018%20CBECS:%20Principal%20Building%20Activities&text=The%20Commercial%20Buildings%20Energy%20Consumption,for%2043%25%20of%20energy%20consumption.