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ABSTRACT

Multi-zone variable air volume (MZ VAV) heating, ventilation, and air conditioning (HVAC) systems are commonly used in commercial buildings, but their performance varies widely, leading to a significant performance gap between best practice and typical operation. The supply air temperature (SAT) reset strategy significantly influences the energy efficiency of VAV systems. This paper presents the field implementation and validation of a novel SAT control method, Cost-Optimized Reset (CORE) in three commercial buildings in California. To evaluate the real-world performance of CORE, we conducted a measurement and verification (M&V) analysis using a randomized crossover trial approach over the course of the monitoring period. Energy consumption, HVAC operational parameters, and utility rates were analyzed and showed 5-22% energy savings in combined heating, cooling and fan energy, and 1-20% savings in related energy cost for CORE compared to the existing SAT reset strategy with no reported compromise to occupant comfort or system stability. The work also highlights implementation challenges and solutions and provides practical insights for scaling advanced control strategies across broader building portfolios. Through this field validation, CORE demonstrates its potential to serve as a cost-effective and scalable control strategy that aligns with the goals of improving energy efficiency and reducing carbon emissions in commercial buildings.

INTRODUCTION

Multi-zone variable air volume (MZ VAV) heating, ventilation, and air conditioning (HVAC) systems are commonly used in commercial buildings, but their performance varies widely, leading to a significant performance gap between the industry best practice and typical operation. The supply air temperature (SAT) reset strategy used in these systems significantly influences energy, cost and thermal comfort performance. Commonly used SAT reset strategies include fixed SAT setpoint, outside air temperature based SAT reset and warmest zone based SAT reset. Limitations of these include unnecessarily low SAT setpoints leading to wasted heating and cooling energy, not meeting zone demand or overcooled zones, and unnecessary energy cost due to not considering the interactive effect of heating, cooling, and fan energy use. A simulation based study led by Lawrence Berkeley National Lab (Granderson, et al. 2018) reported 4-15% HVAC energy consumption variation between

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different SAT reset strategies commonly used in VAV systems.

The team previously developed Cost Optimized Reset (CORE), a cost-responsive SAT reset solution for MZ VAV systems (Raftery, et al. 2018, Wang et al., 2025) to address these concerns. CORE dynamically adjusts the SAT to achieve the lowest HVAC cost considering heating, cooling, and fan energy use, as well as associated electricity and natural gas costs. Raftery et al., (2018) implemented CORE in a building in California to show 26% normalized annual energy savings that corresponds to 17% annual energy cost saving. One of the algorithm design constraints was to limit complexity so that it would be feasible to implement it in existing automation systems without requiring additional sensors other than those that are typically found in these systems. We further simplified the initial algorithm to remove the need for discharge air temperature sensors at VAV terminal boxes, evaluated the performance using EnergyPlus simulation (Wang et al., 2025), and then implemented the updated CORE strategy in three medical office buildings in California. This paper presents the details of the CORE field demonstrations including algorithm enhancement and adoption, implementation and commissioning, data collection for measurement and verification, and energy and cost savings analysis. Additionally, this paper discusses the resource requirements for implementing CORE, issues identified during the field demonstration, and how CORE may be scaled for wider adoption.

OVERVIEW OF SUPPLY AIR TEMPERATURE RESET METHODS

Existing SAT reset strategies, including conventional strategies and the current best practice strategy described in the American Society of Heating Refrigeration and Airconditioning Engineers (ASHRAE) Guideline 36 (G36) (ASHRAE, 2024), determine a SAT setpoint based on factors such as outdoor air temperature and zone heating and cooling demand. These common SAT reset strategies have three inherent deficiencies including 1) Using simplifications and assumptions about the relationship between SAT and total HVAC energy cost, 2) Requiring tuning key parameters with optimal values that differ for every building and vary over the building's life, and 3) Providing no easy way to determine what those optimal settings are and whether tuning is improving savings or not.

Conventional SAT Control Methods

SAT reset has been used in buildings and has been required by energy codes for several decades. For example, California Title 24-Building Energy Efficiency Standards have required SAT reset since 1992 and ASHRAE Standard 90.1 has required SAT reset since 2010. Historically, the easiest way to achieve this was to reset the SAT based on outside air temperature (OAT), where the system increases the SAT when OAT is cooler. Prior to this and even today, fixed SAT setpoint is commonly used in buildings. In more recent building automation systems (BAS) where zone-level data are available, zone-demand-based SAT resets have become more common. Through previous research efforts, including interviews with practitioners and reviewing published literature, the project team identified several commonly used SAT reset strategies used in buildings, along with their limitations. **Fixed SAT setpoint (no reset)** is most often used in older buildings and climates with hot, humid summers. In this strategy, there is no zone feedback, so to avoid not satisfying zone demand, implementations often have an unnecessarily low SAT, which wastes cooling and reheat energy. Additionally, operators tend to frequently override the setpoint to address specific complaints and those tend to persist for months or years and lead to inefficient operation over time. **Outside air temperature based SAT reset** controls SAT based on an OAT range where the SAT increases when outside air becomes cooler. This method also does not use zone feedback and has the risk of not meeting zone demand or unnecessarily wasting cooling and reheat energy. **Warmest zone-based SAT reset** decreases the SAT based on the zone with the most critical demand for cooling. Trim and Respond (T&R) logic (Tailor 2015) may be used for the reset. This strategy attempts to meet zone demand but does not balance between the fan, heating, and cooling energy to optimize either the energy use or the energy cost.

ASHRAE Guideline 36

ASHRAE Guideline 36, titled High-Performance Sequences of Operation for HVAC Systems (ASHRAE 2024), establishes current industry best practice standardized sequences of operations for HVAC systems. G36 provides the standardized sequence of operation of multi-zone VAV air handling units (AHU), including SAT control. It performs a two-factor SAT reset based on zone cooling demand and OAT. During Occupied Mode, it resets the SAT, determined using T&R logic. The reset limits are from the minimum cooling SAT setpoint when the OAT is at the maximum limit and above up to the maximum SAT limit when the OAT is at the minimum limit where the minimum and maximum SAT setpoints are determined by the designer (See Figure 5.16.2.2 in Guideline 36-2024, (ASHRAE 2024)). Implementing G36 in a building requires the designer to determine the SAT limits, OAT limits, and the parameters required for the T&R reset logic, though the majority of the time the guideline's default values are used. However, the true optimal SAT and OAT ranges for the reset require tuning for specific building load and occupancy conditions; G36 provides guidance, but the designer decides.

Cost Optimized Reset (CORE) Method

In multi-zone VAV HVAC systems, resetting SAT impacts heating energy, cooling energy, and fan energy required to meet the zone-level demand. Due to the interactive nature of these different energy uses, SAT reset upwards does not always decrease the total energy use or energy cost. For example, when a zone requires less cooling, resetting SAT upwards can reduce cooling energy use and reheating energy use. However, the airflow rate required to meet the zone demand increases and causes increased fan energy use. The extent to which outside air economizing is possible under these conditions also affects the optimal SAT. The total energy use and the total energy cost depend on the efficiency of the equipment, the tradeoff between the three energy uses, and their respective energy utility rates. The purpose of CORE is to optimize the HVAC energy cost while meeting the comfort requirements in the building.

As shown in Figure 1, CORE does this by first checking if there are cooling requests from the zones. If there are cooling requests beyond a specified threshold, it will reset the SAT downwards until the cooling demand is met, using the same T&R logic as G36. If no cooling requests are present, CORE dynamically calculates the HVAC energy cost for the current SAT and compares it with an estimated HVAC cost for a small increment and decrement of the SAT from the current setpoint; CORE then resets the setpoint to the lowest HVAC cost out of the three potential SAT setpoints (current SAT setpoint, small increment, and small decrement). The CORE algorithm calculates the HVAC energy cost by estimating the heating, cooling, and fan energy uses for the three potential SAT setpoints and the predefined time-of-use (TOU) utility rates for the building, which are input by the designer or user (Raftery, et al. 2018).

RESEARCH OBJECTIVES

The objective of this research is to refine the CORE algorithm for broad applicability and implement it in buildings with different HVAC systems and evaluate energy and cost savings.

The team evaluated additional features that improve the performance of CORE compared to the initial version of CORE (Raftery, et al. 2018). To improve market scalability, the team investigated different versions of CORE that can be implemented even with BAS limitations, such as when zone-level data is not available, and evaluated building system requirements, implementer requirements, feasibility criteria, and product offering requirements. The team implemented the refined CORE algorithm and compared the energy consumption and energy cost between CORE and baseline conditions in three buildings.

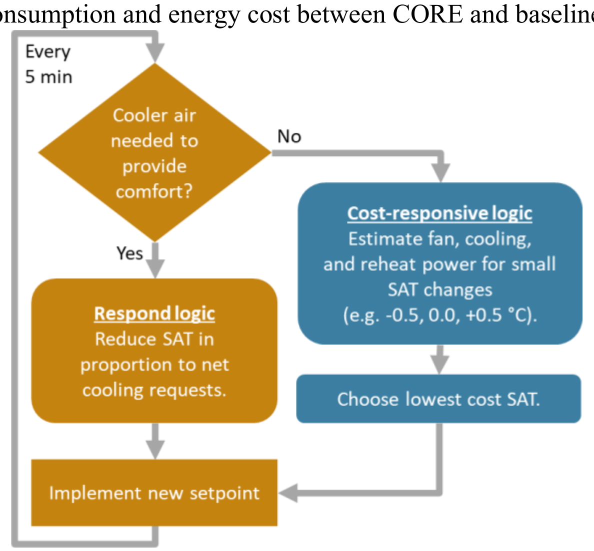


Figure 1 CORE overview schematic.

ALGORITHM IMPROVEMENT AND ENERGY SIMULATIONS

One of the objectives of this research project is to refine CORE to be broadly applicable. In the previous pilot demonstration (Raftery, et al. 2018), the team observed instability of SAT setpoint control under conditions where the SAT approaches the current outdoor temperature. Here, a small amount of mechanical cooling, like chilled water coils served by the building's chilled water plant, is needed to further reduce the SAT, and the simple algorithm often oscillates around this setpoint. In direct expansion (DX) air handling units, this could cause frequent cycling of the AHU's compressors, which reduces equipment life and reduces the stability and performance of the CORE algorithm operation. The team introduced a smoothing function for the cooling cost calculation to reduce this instability. The team also introduced a cooling power calculation equation for demonstration sites with DX cooling, as the initial version of CORE only considered cooling with chilled water. The team identified that older buildings may not have sensor availability, e.g., zone-level discharge air temperature sensors, or sufficient network bandwidth to implement the initial version of CORE. This led the team to develop a further simplified version of CORE that does not require the discharge air temperature data at VAV terminal units. Wang et al. (2025) published the updated algorithm with these features and the simplified algorithm and include the input data and output command (new SAT setpoint) from the algorithm.

We compared these refined algorithms with existing SAT reset strategies using detailed parametric energy modeling using EnergyPlus and found that for a variety of climate conditions, CORE was the best performing algorithm. It saves between 0.6 – 31% energy cost against G6 and conventional SAT reset strategies (see Fig. 4 of Wang et al., 2025), and notably the second best performing control algorithm for a given case varied widely depending on the building characteristics and weather.

CORE IMPLEMENTATION AND PERFORMANCE EVALUATION

The team selected demonstration sites based on site location, HVAC system type, HVAC system operating condition, ability to implement advanced controls and collect data at building and HVAC system level to evaluate energy and cost performance, and availability of building for the duration of the project without any major retrofit work. We selected three medical office buildings (MOB) that were either constructed or had a major HVAC system retrofit recently to ensure the ability to implement CORE. The buildings hereafter referred to as MOB-1, MOB-2, and MOB-3 each have a MZ VAV reheat system serving most of the building, and all use a Niagara system for HVAC control and SkySpark for trend data viewing and storage. MOB-1 is a 33,000 ft^2 (3,060 m^2) building served by three rooftop units (RTUs) with DX cooling and electrical resistance reheat at zone terminal units. MOB-2 is a 49,300 ft^2 (4,580 m^2) building served by three RTUs with DX cooling and natural gas boiler/hot-water heating system. MOB-3 is a 51,200 ft^2 (4,760 m^2) building served by two air handler units (AHUs) with an electric chiller/chilled-water cooling system and natural gas boiler/hot-water heating system. All three buildings currently run SAT reset based on zone demand using the T&R logic but do not take into account OAT for determining reset limits. The existing fixed reset limits for the buildings are MOB-1: 55-65 °F (12.7-18.3 °C), MOB-2: 53-58 °F (11.6-14.4 °C), and MOB-3: 55-65 °F (12.7-18.3 °C) In all three buildings, we implemented CORE and compared against the existing control strategy.

Implementation Approach

The CORE implementation process involved programming CORE and then commissioning, through functional performance testing and trend data review. CORE programming was done by a controls contractor who had recently conducted HVAC system retro-commissioning in these buildings and thus was well familiar with the controls and systems.

Programming. We shared a plain language description of CORE with the controls contractor, who then programmed CORE in an offline version of the supervisory building controls system in modular form. This approach allowed us to test the CORE operation and fix any issues before implementing the algorithm in the building. We conducted a preliminary review of the programming to ensure CORE logic was correctly programmed and then implemented the CORE algorithm in the selected sites' BASs. Unlike many MZ VAV systems in California, the MOB-1 site has electric resistance reheat at the VAV terminal units; accordingly, we updated the CORE algorithm for that site to account for electric reheat under the heating cost calculation. The project team validated CORE's performance using a two-step process. First, the controls contractor executed standardized functional performance tests (FPTs) to confirm proper operation of zone/system calculations, cost optimization, and trim-and-respond logic. After resolving identified issues though existing building commissioning (EBCx), the team conducted a trend data review using several weeks of BAS data to confirm that supply air temperature reset and energy cost behavior matched expected CORE responses. This combined FPT and trend review ensured that programming updates were verified both under controlled test conditions and during extended real-world operation.

MEASUREMENT AND VERIFICATION APPROACH

The team conducted M&V to evaluate the energy and energy cost savings of CORE compared to a baseline SAT control strategy at each demonstration site. To estimate energy and energy cost savings, we followed established International Performance Measurement and Verification Protocol (IPMVP) procedures (Efficiency Valuation Organization, 2025) and compared energy use for CORE and baseline strategy energy data. The CORE algorithm calculates heating, cooling, and fan energy use at five-minute intervals based on airside measurements. Where submetered HVAC energy use was not available, and to supplement it where it was available, the team used the calculated heating, cooling, and fan energies. The former method captures the actual metered energy use, including additional equipment energy use from pumps and cooling towers, and indicates the performance of CORE while taking equipment efficiencies into account. Isolating HVAC energy use ensures that non-HVAC loads in the building do not affect savings estimates. This is especially important in sites like the MOB-1which has large MRI scanner loads. However, MOB-2 did not have submetered HVAC energy, so we used the whole building electricity and natural gas energy use.

Randomized M&V Sampling Procedure. To capture the full range of weather conditions, M&V on research field studies typically involves running the baseline and intervention conditions in each building for up to nine months each. In randomized M&V, a sequential method of running the baseline and intervention conditions is used to significantly reduce the total M&V period (Raftery, et al. 2024) and to improve robustness by mitigating the impact that changes in the building that are unrelated to the controls being studied will have on the results. In this project, the team pre-programmed a randomization sequence in the BAS to select between CORE and baseline strategies at midnight every day and run the selected strategy for the day. Over time, this ensured that the distribution of days where either strategy ran had the same range of building operating conditions. This randomization ensured that both strategies ran roughly equal amounts and covered all types of days of the week to ensure that all events in the building, e.g., weekends, weekly seminars etc., were represented in both strategies allowing us to compare the measured energy consumption between strategies during the data collection period.

The team evaluated the existing control strategy of each site and decided to use it as the baseline condition. The existing strategy was similar to G36, where T&R logic is used to reset the SAT based on cooling requests from zones. However, the existing strategy did not use OAT to determine the SAT reset range, as prescribed in G36, and instead used fixed reset ranges.

Data Collection Plan. The controls contractor provided the project team access to the SkySpark database platform that recorded the BAS trend data for all three buildings. This allowed the team to view and download trend data of energy-related parameters such as HVAC electric energy, whole building electric energy, and whole building natural gas usage as well as temperature and flow rate data. The team reviewed energy data weekly and evaluated it for common system and data quality issues, such as missing data, unexpected values, and equipment failure. We notified and worked with the contractor and building management to address any issues identified in these reviews.

Measured Energy Consumption Comparison. We used a one-tailed hypothesis test to compare the measurement distribution of the two sampled control strategies (Montgomery and Runger, 2018). The null hypothesis is the mean daily energy usage sampled from the intervention measurement set is greater than or equal to the mean daily energy usage sampled from the baseline measurements. Statistical significance indicated by p-value less than 0.05 indicated that CORE achieved measurable energy savings.

Utility Cost Impact. The demonstration sites have time-of-use (TOU) rate plans for electricity, where the utility charges a fixed price per kWh based on the time of day and time of year, with the late afternoon and evening periods having a higher rate than other times of day, and the summer season rates being higher than the winter season rates. For this analysis, we used the calculated heating, cooling, and fan energy cost data from the CORE algorithm which uses the TOU electricity rates and the relevant natural gas rate. In addition to the hourly rates, the team recognized that the electricity peak demand charge can be significant for commercial customers, but considering these charges were outside of the project scope.

RESULTS AND DISCUSSION

Overall, all three buildings showed energy and cost savings with CORE compared to the baseline. We evaluated the energy use of heating, cooling, and fan energy to understand how overall energy saving is achieved. To illustrate this, Figure 2 below shows a histogram of the supply air temperature setpoints utilized by the baseline and CORE for AHU-1 in MOB-3. CORE uses higher supply air temperature setpoints compared to the baseline indicated by higher count towards the upper end of the reset range (55- 65°F).

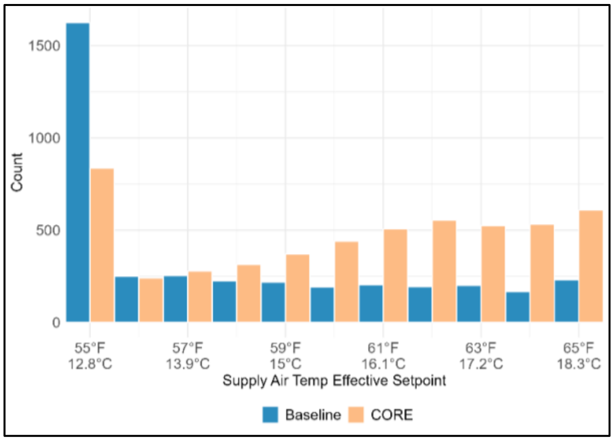
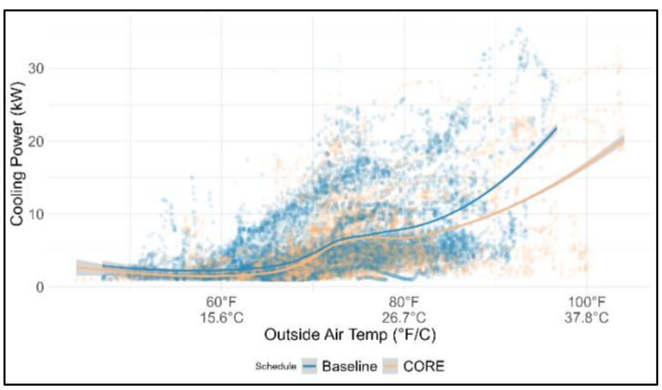


Figure 2. Comparison of supply air temperature set point distribution between baseline and CORE for MOB-3.

The implication of this is illustrated in Figure 3 where the cooling power consumption (left) and fan power consumption (right) for MOB-3 against outside air temperature is plotted. Since CORE supplies warmer air, cooling power is lower for CORE compared to baseline at all outside air temperature levels. However, to satisfy the comfort requirements, more airflow needs to be supplied indicated by higher fan power. The decrease in cooling power is more than the increase in fan power leading to an overall reduction in energy consumption.



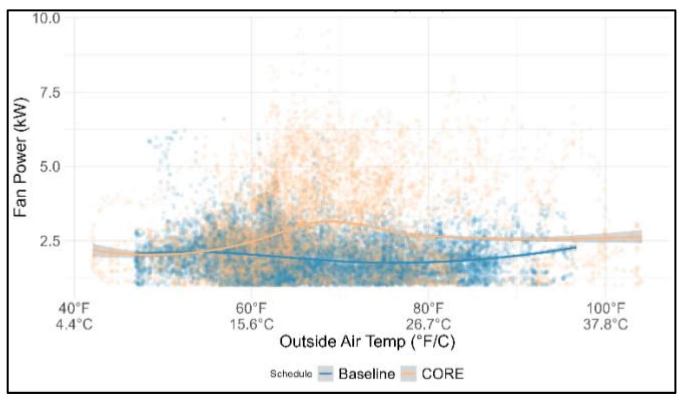


Figure 3. Comparison of cooling power (left) and fan power (right) between baseline and CORE for MOB-3

Energy and Cost Savings Analysis

Table 1 below summarizes the measured energy and cost savings for the three demonstration sites. Note that the team calculated energy cost using only the per energy unit rate and we did not add fixed or demand charges. In **MOB-1,** CORE reduces energy consumption by **5-16%** and cost by **1-18%** based on the RTU level heating, cooling, and fan (HCF) data. In **MOB-2,** CORE reduces heating, cooling, and fan energy consumption by only **2%** but the cost is reduced by 1**0%.** Electrical and gas energy consumption is reduced by **7%** at the whole building level, but all three comparisons have poor statistical evidence as indicated by p-value larger than 0.1. For the whole building level comparison, this is largely due to the additional variation in energy consumption associated with non-HVAC electrical use in the building incurred by measuring at the building level instead of submetering performance. In **MOB-3,** heating, cooling, and fan data indicate CORE reduces total energy consumption by **22%** and reduces cost by **20%** whereas the total HVAC electrical and gas energy consumption reduces by **15%**.

The magnitude of HVAC cost, especially considering the floor area normalized annual cost, between \$ 0.05 and 0.16/ft^2-

year ($ 0.54 – 1.72/m^2-year), is low compared to typical buildings in California where values around $0.5/ft^2-year ($5.38/m^2-year) would represent a well performing building. The reason for this is the low electricity rates applicable to these buildings (around $0.04/kWh). In a typical commercial building in California, these rates are higher, and CORE would have higher absolute energy cost savings.

Table 1: Energy and Cost Savings Summary

	Measured Mean Daily HVAC Energy				Measured Mean Daily HVAC Cost			
Energy type	**Baseline kWh (kBTU)**	**CORE kWh (kBTU)**	**% savings**	**P value**	**Baseline ($)**	**CORE ($)**	**% savings**	**P value**
MOB-1 HCF RTU1	167 (570)	148 (607)	11%	0.058	4.15	4.10	1%	0.469
MOB-1 HCF RTU2	97 (331)	92 (314)	5%	0.288	2.96	2.63	11%	0.265
MOB-1 HCF RTU3	227 (775)	190 (648)	16%	0.042	6.57	5.40	18%	0.156
MOB-2 Total HCF	481 (1641)	470 (1604)	2%	0.41	14.96	13.39	10%	0.154
MOB-2 Building Elec+Gas	2307 (7872)	2142 (7309)	7%	0.163				
MOB-3 Total HCF	229 (781)	178 (607)	22%	0.021	6.63	5.33	20%	0.065
MOB-3 HVAC Elec+ Gas	497 (1696)	422 (1440)	15%	0.059				

Implementation Issues and Lessons

Implementations issues, costs and barriers are often not quantified or discussed in many studies that look at implementation of advanced control strategies (Henze et al., 2024). A secondary goal of this research was to document the lessons learned and best practices for implementing CORE to inform market adoption considerations of this technology.. The team encountered a number of challenges during implementation, and we categorize them under three topics below: algorithm complexity, existing HVAC system, building design and control issues, and challenges working with an existing control system.

Algorithm Complexity. There were several issues related to the CORE algorithm programming caused by miscoordination between the implementor and the research team. One reason for this may be the complexity of the CORE algorithm compared to what implementers are used to programming, such as outside air-based SAT control or demand-based SAT control. G36 has been available as an industry best practice, specifically for SAT control, for seven years but adoption has been slow, due in part to complexity as well as a lack of familiarity among controls contractors and mechanical engineers. The G36 SAT reset logic has similar programming and sensor requirements to CORE but is less complex, and as a result, CORE may have similar market adoption barriers.

Existing HVAC System, Building Design, or Control Issues. The team conducted a detailed review of data quality and the general performance of the HVAC system of the buildings before implementation. However, several issues related to the HVAC system and controls and building design still emerged during the commissioning period, which led to CORE not operating as expected. These issues include non-functional equipment (MOB-1 – RTU1), building design that led to high outside airflow, and issues in the HVAC controller (MOB-1 and MOB-2) that made it difficult to map and update some variables. To address these issues, we recommend conducting a thorough review of the existing HVAC system, controls, and design, performing existing building commissioning (EBCx) and resolving issues identified from the review and EBCx. This process itself will yield substantial cost and energy savings in most existing buildings.

Challenges with Working with an Existing Control System. In addition to identifying HVAC system and building issues, the team discovered limitations of the existing control system. Niagara programming follows a wire diagram format that passes on calculated values and logic to the next steps. This setup was easy to observe for snapshots of time but difficult to investigate how the controller behaved over time, which was required to find the causes of issues. This was partly due to multiple rounds of programming done at the site previously, which complicated the mapping process. In addition, the team uncovered a calculation syntax error that created incorrect CORE calculations and led to CORE not optimizing cost.

The research team performed functional testing of CORE operation after implementation to ensure correct system operation. However, running these tests was restricted by the capabilities of the system, such as the ability to override variables due to equipment restrictions, which could make it difficult to identify issues. The team also found several issues by performing manual calculations of each CORE variable using downloaded measured trend data. It may be useful to do the manual calculations early on as part of commissioning. Performing a detailed review through live access to programming may help identify issues faster. Using a simpler CORE algorithm may also help, as this would require less programming and use a smaller number of variables. Additionally we recommend performing a thorough review of the control system functionality including accessibility to software for programming and configuring the control system, speaking to facility controls technicians about existing issues which can help identify problems beforehand, along with coordinating with the control system service contractor on what is needed to implement, and developing a standard pre-check of system requirements, coupled with functional testing and commissioning procedures to verify CORE operations to catch issues before it is turned over to operations.

Scalability Considerations

In terms of the market scalability considerations, a well-operating HVAC and control system is important for any improved control sequences to perform effectively. This includes functioning controls for economizers, VAV boxes, SAT controls, zone temperature control and the ability to identify rogue zones, and a control system with direct digital controls down to zone terminal units. Deferred maintenance of mechanical sensors and equipment is a common barrier for advanced control implementation and should be considered as a required make-ready step and encouraged by facility managers and utility programs. For the field implementations under this project, the controls contractor and the research team spent about 135 hours programming and deploying CORE. Programming was mostly a one-time effort since for the second and third sites, only data point mapping was required due to the supervisory layer pathway. Similarly, the controls contractor and the project team spent about 170 hours commissioning, testing and debugging but this time got progressively reduced for second and third sites. After the initial three sites, the controls contractor successfully deployed CORE at a fourth medical office building spending only a couple of hours, which highlights the scalability of the implementation method. CORE would be more cost-effective as part of a larger controls update or full retro-commissioning rather than as part of a standalone implementation. One way to potentially get around some of the existing control system usability issues and decrease CORE implementation costs would be to have the CORE algorithm in an accessible programming library, such as those commonly developed by manufacturers for G36 sequences. Manufacturers could add CORE to their HVAC software and provide it to their control installers, and then a controls contractor would configure CORE for a specific site. Additionally, providing more detailed guidance to the implementer, including an explicit description of the intention of each part of the algorithm, using the simplified CORE algorithm (Wang et al. 2025), providing an example of "what right looks like" from a programming, testing, and operations perspective can reduce these challenges. The research team is providing CORE programming in a Python script that may be useful for some manufacturers, contractors, and vendors. CORE could be marketed as an energy conservation measure for EBCx processes or as a part of a larger control system retrofit. Lastly, a simplified CORE algorithm would be easier to implement and could get around existing systems' issues with data availability or communication bandwidth restrictions.

CONCLUSION

In this field demonstration project, we refined the previously developed CORE algorithm to be adaptable for a wide range of buildings and implemented CORE in three commercial buildings to evaluate energy and energy cost savings. The savings analysis showed 5-22% savings in combined heating, cooling, and fan energy, and 1-20% savings in related energy cost across the three buildings. The field demonstration in the three medical office buildings highlighted the importance of existing building equipment and control system operation for accurate CORE functionality and its ability to optimize energy cost. The team recommends a thorough evaluation of the existing HVAC system and BAS controls, and a process to identify and resolve issues before implementing any new controls retrofits. The team also identified the importance of supporting the implementers on CORE programming and deployment in buildings so that the intention of CORE is correctly interpreted and programmed. For this purpose, the team believes that CORE may be better packaged within a programming library offered by BAS manufacturers so that it is better integrated with the other controls rather than implementers programming and deploying CORE as a standalone measure. For CORE to be consistently implemented, there will need to be standards, processes, and case studies developed to include CORE in various types of projects. We recommend developing pre-programming in coordination with control manufacturers, defining control system functionality and accessibility requirements for implementation in new and existing buildings, defining minimum HVAC operational requirements to fully utilize CORE, and accompanying implementation path through controls retrofit and existing building commissioning focused on standards and guidelines. Easing the implementation path for engineers, controls manufacturers and installers, and facility management/operations through these recommendations can help CORE be more effective and installed in more locations.

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