Enter the AHU (36th Chamber of ASHRAE): A Multi-site Field Study of ASHRAE G36

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ABSTRACT

Despite being recognized as the best practice for advanced building controls, ASHRAE Guideline 36 (G36) has seen slow adoption in retrofit cases. Decisionmakers lack credible field evidence to justify the time and person-power investment. Most prior analyses have relied on software simulations, which overlook implementation challenges and fail to persuade owners to move from models to real-world deployment. This paper presents a multi-site field study of G36 performance, drawing on measured results from 17 projects across diverse building types and climate zones.

The analysis disaggregates outcomes by the most widely adopted air handling unit (AHU) based G36 strategies, including trim-and-respond approaches to supply air temperature (SAT) and duct static pressure (DSP) reset, and economizer controls. Results for controls re programming implementations are encouraging, with HVAC savings ranging from 2% - 49%, with a median of 18%. The range aligns with simulation study findings showing 1% - 46% savings through these three strategies.

These findings show that even without capital investment in control infrastructure upgrades, existing building owners are reaping significant benefits from updating HVAC sequences of operation to industry best-practice solutions. The results give practitioners and decisionmakers a reference point on what to expect, which strategies deliver, and how field performance may compare to simulation.

Introduction

Published modeling analyses indicate that individual HVAC control measures, such as wider temperature deadbands, and night setbacks, can yield up to 7.7% site energy savings at the national scale when aggregated across building types and climate zones (Fernandez et al. 2017). However, HVAC control sequencing practices have historically been project-specific, leading to variability in design, programming, commissioning, and operational performance. ASHRAE Guideline 36 (G36) was developed to standardize high-performance sequences of operation by providing rule-based control logic that coordinates supervisory and equipment-level actions. By moving beyond custom control measures, G36 aims to enable consistent energy performance, improved system reliability, and scalable deployment across commercial building portfolios (ASHRAE 2024).

The control sequences defined in G36 cover both airside and waterside strategies. The airside sequences were released first and have broader early adoption providing guidance for air handling units (AHUs) and variable air volume (VAV) systems. The sequences dynamically adapt to changing loads and zone-level demand, as evident in its three primary AHU-level control strategies: (1) supply air temperature (SAT) setpoint reset, (2) supply duct static pressure (DSP) setpoint reset, and (3) economizer control.

The SAT and DSP setpoint reset sequences employ a trim-and-respond (T&R) control logic (Taylor 2015). Rather than maintaining fixed setpoints, this logic continuously modulates the AHU SAT and DSP setpoints in response to zone-level air conditioning requests, which are generated when zone conditions deviate from their respective setpoints. When there aren't sufficient requests, the active setpoint is incrementally trimmed, increasing for SAT and decreasing for DSP, at a prescribed rate. When the number of requests exceeds a threshold, the setpoint responds by adjusting incrementally to satisfy zone-level requirements. This demand-based approach ensures that the AHU operates at the least energy-intensive conditions, leading to significant reductions in both fan and cooling energy compared to conventional fixed-setpoint control. The third primary AHU-level strategy, economizer sequence which modulates the outdoor air, return air, and relief damper positions subject to outdoor air and enthalpy limits to minimize fan energy when outdoor conditions permit.

A report published by the Environmental Security Technology Certification Program (ESTCP) (Zhou et al. 2017) documented energy savings ranging from 11% to 34% from implementation of a G36-aligned DSP T&R reset strategy across five buildings at the Iowa Army National Guard facilities. A limited number of other studies (Arens et al. 2014; Cheng et al. 2022) have examined the implementation of G36 air-side strategies, though these analyses typically include VAV-level controls and report combined HVAC savings ranging from 5% to 60%. VAV-level strategies, while impactful, are outside of the scope of this paper. Published field measurements of G36-aligned AHU-level control sequences remain limited.

In this paper, we present a compilation of field-measured results from deployments of two G36 T&R strategies and the economizer control strategy. We further compare these empirical findings with simulation-based studies that evaluate these AHU-level strategies individually and in combination, providing a focused assessment of their real-world performance.

Data – Collection and Characteristics

Data Collection

In addition to compiling findings from the five buildings in the aforementioned ESTCP report, data was also compiled through outreach to industry-led implementations with pre and post energy measurements, resulting in 17 total projects. Collected variables included building characteristics, retrofit scope (software-only or hardware and software), implemented strategies, and subsystem or whole-building energy consumption.

Measurement and verification (M&V) approaches differed across projects depending on available metering and data infrastructure. Methods were documented as provided by implementers and while consistent with the principles of the International Performance Measurement and Verification Protocol (IPMVP) (EVO 2012), reported project-level savings were not independently assessed by the authors.

Table 1 summarizes the M&V approaches used across case studies. Approaches were selected based on site-specific metering infrastructure and were broadly aligned with IPMVP concepts but were not implemented as formal IPMVP-compliant studies.

Table 1. M&V Approach for Data Collection

M&V approach	Description	Example data sources
Option A-like (Retrofit Isolation, Key Parameters)	Used when only key HVAC variables were metered, with others estimated using engineering assumptions.	Fan power measurements or cooling load, with non-measured parameters such as default boiler or chiller efficiency estimated using assumptions
Option B-like (Retrofit Isolation, All Parameters)	Used when comprehensive HVAC submetering allowed direct calculation of pre- and post-retrofit HVAC energy.	Submeters for chillers, boilers, AHUs, and pumps, BAS trends for temperatures and flows, direct fan and pump kWh.
Option C-like (Whole Facility)	Used when only whole-building utility data were available, with HVAC energy inferred via disaggregation or engineering estimates.	Interval or monthly utility data, benchmarking models, HVAC end-use fractions from simulations or prior audits.

Characteristics of the Dataset

The 17 facilities included in this dataset span three states. The dataset consists of six mixed use office buildings, eight offices spaces, and one of each – lab, medical outpatient, and university. Table 2 shows the sequences or combination of sequences implemented across the 17 facilities. Across the 17 facilities, duct static pressure trim and respond resets were most commonly implemented, followed by supply air temperature trim and respond resets. Economizer controls strategy was less frequent, with only three instances in the dataset.

Table 2. G36 Strategies Implemented in this Dataset

Strategies implemented	Count
Supply Air Temperature Trim and Respond	12
Duct Static Pressure Trim and Respond	15
Economizer Controls Strategy	3

Methodology

Energy savings results were expressed differently across the data set. For example, some projects reported combined fuels while others disaggregated by fuel type, and some quantified HVAC-level savings while others reported at the whole-building level. Three estimation methods were used to synthesize and unify the results to the principal metric used in this study - total HVAC energy savings. Energy consumption from electricity and fuels was standardized to kBtu using established conversion factors. Heating, cooling, and fan energy were added and converted to plant input energy or total HVAC energy (kBtu/year) by using documented engineering assumptions, with default values of 80% boiler efficiency (Parker et al. 2023) and 1 kW/ton chiller performance (Kim and CaraDonna 2025) where site-specific parameters were unavailable. While 80% reflects rated full-load efficiency and standard industry practice, field measurements have documented annual thermal efficiencies as low as 33–50% for non-condensing boiler plants, driven by oversizing and short-cycling at low part loads (Raftery et al. 2018; Cheng, Raftery, and Wendler 2024); these real-world effects were not captured in this analysis. Electric boiler efficiency is assumed to be 100% at the equipment boundary, consistent with standard industry practice. In cases without HVAC submetering, end-use allocations were derived from the 2018 Commercial Buildings Energy Consumption Survey (CBECS) (EIA 2023) median distributions by building type and census region, with further refinement by census division where larger sample sizes from CBECS were available. This total HVAC energy value for pre and post sequence implementation was then normalized by floor area.

Total HVAC energy was determined as defined in Equation 1:

$$E_{HVAC} = \frac{E_{fan} + (E_{cool,in} \times \eta_C) + (\frac{E_{heat,in}}{\eta_B})}{A_{floor}} \text{ .... Equation (1)}$$

Where:

- E_{HVAC}: Total HVAC energy intensity (kBtu/sf/yr)
- E_{fan}: Annual fan energy consumption (kBtu/yr)
- $E_{cool,in}$: Annual cooling energy input (kBtu/yr)
- η_C: Chiller efficiency (kW/ton)
- η_B: Boiler efficiency
- $E_{heat,in}$: Annual heating energy input (kBtu/yr)
- A_{floor}: Floor area of impacted space (sq.ft)

Figure 1 shows sample steps to convert data received in the form of cooling energy to plant energy input

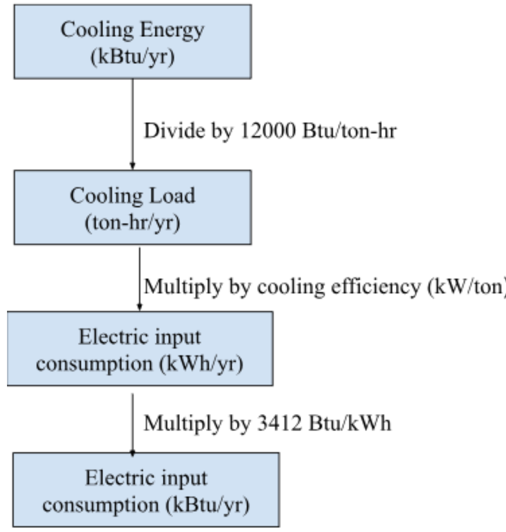

Figure 1. Illustration of the steps to convert air-side cooling energy into water-side electricity consumption

Savings from sequence implementation were evaluated as the percent reduction in total HVAC energy between pre- and post-retrofit periods as shown in Equation 2.

$$E_{savings} = \frac{E_{HVAC,pre} - E_{HVAC,post}}{E_{HVAC,pre}} \times 100 \quad \ldots \text{ Equation (2)}$$

Where:

- $E_{savings}$ Percent reduction in total HVAC energy (%) between pre- and post-retrofit periods
- $E_{HVAC,pre}$: Total HVAC energy intensity (kBtu/sf/yr) before G36 implementation
- $E_{HVAC,post}$: Total HVAC energy intensity (kBtu/sf/yr) after G36 implementation

Table 3 provides the details of the three methods used in this paper to arrive at a HVAC percentage savings value for all 20 sites.

Table 3. Methods for Deriving HVAC percentage savings from provided data and assumptions

Method	Measured / provided inputs	Assumptions / defaults	Core calculation steps	Sites associated with method
Method 1	HVAC kWh/yr; Gas therms/yr	• Boiler efficiency (a) • Chiller efficiency (b) • Fan and Cooling energy as a	• Convert heating energy to kBtu • Calculate fan energy from HVAC electric with assumption (c) and convert to kBtu • Calculate cooling energy from HVAC	Site7 through Site 15

Method	Measured / provided inputs	Assumptions / defaults	Core calculation steps	Sites associated with method
		fraction of HVAC electric based on CBECS (c)	electric with assumption (c) and convert to kBtu ● Use Eq(1) and Eq(2) with assumptions (a) and (b) for % HVAC savings	
Method 2	Fan kWh/yr	● None, since savings were solely from fan energy	● Convert fan kWh directly to kBtu (×3.412)	Site 1 through Site 5
Method 3	HVAC kWh/yr	● Facility has electric boiler - efficiency assumed to be 100%	● Convert electric HVAC energy to kBtu (×3.412) ● Use Eq (2) for % HVAC savings	Site 6, Site 16, Site 17

Results

Field Implementation Findings

The HVAC savings in the 17 reprogramming only projects analyzed ranged from 2%-49%. The median HVAC energy savings for these projects were found to be 18% as shown in Figure 2.

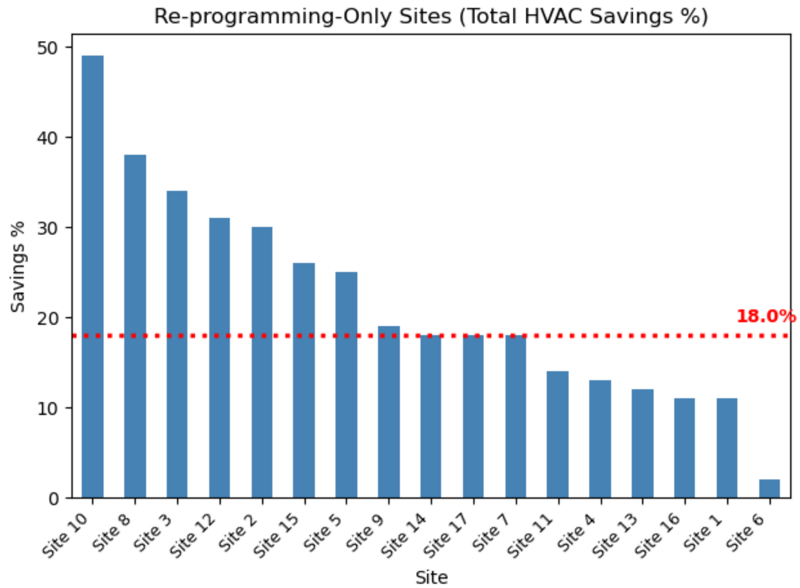

Figure 2: Overview of HVAC savings across reprogramming only sites with AHU-level G36 strategies implemented

Figure 3 shows the sequences or combinations of sequences implemented at each site. The highest savings implementation occurred at two sites that implemented both SAT and DSP T&R sequences.

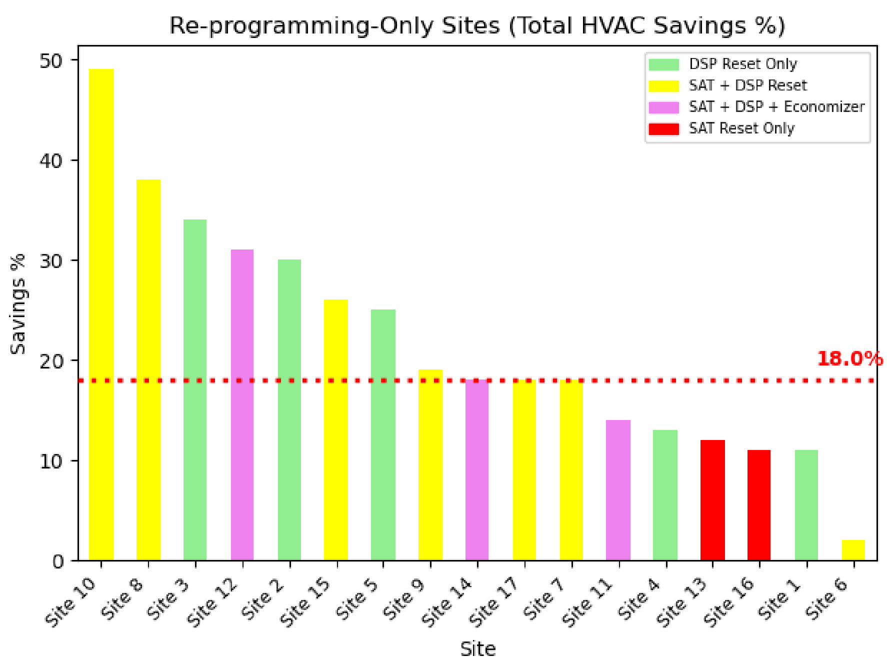

Figure 3: Distribution of HVAC savings across software-only G36 sequence combinations

Figure 4 further disaggregates these facilities into the groups of sequences implemented to compare trends across these groups. The most frequently encountered retrofit implemented was SAT and DSP T&R resets combined, with median savings of 19%. Duct static pressure resets was the second most frequently implemented with a median of 25% followed by SAT+DSP resets combined with economizer at an 18% median. The median savings through DSP reset-only were found to be higher than those for SAT and DSP reset combined, and this may be a result of differences in baseline operating conditions across buildings, variations in system configuration and control tuning, or other implementation-related factors that influenced realized performance.

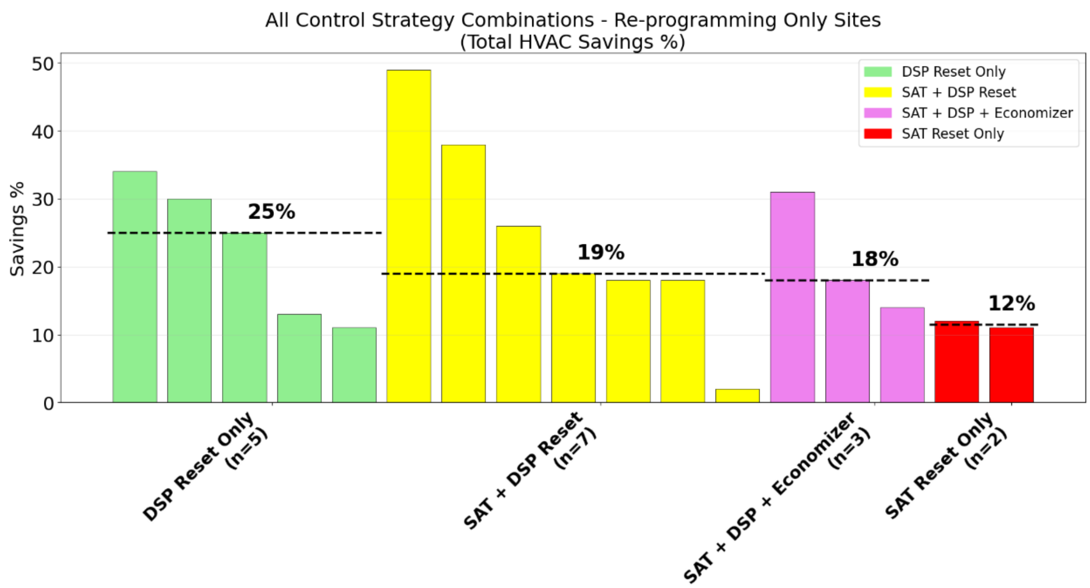

Figure 4: HVAC savings disaggregated for the sequences or combinations of sequences

Comparison with Simulation Findings

Median savings from field-measured implementations were benchmarked against values reported in previously published simulation studies (Lu and Chen 2024; Pang, Piette, and Zhou 2016; Fernandez et al. 2014; Elehwany 2024). Figure 5 illustrates this comparison for the three AHU-level G36 control strategies for which simulation data were available in the reviewed literature. For the DSP reset-only strategy, field-measured median savings were marginally higher than simulation-predicted values. The SAT and DSP reset combination, however, showed the opposite trend, with simulations predicting greater savings than those observed in the field; given that this comparison rests on just two field data points (n = 2), these findings should be treated with caution. A similar caveat applies to the SAT reset-only comparison, where simulation results appear to underestimate field savings by approximately 5%, though the field sample again comprises only two data points. The SAT + DSP reset + Economizer combination was absent from the reviewed simulation literature and is excluded from Figure 5.

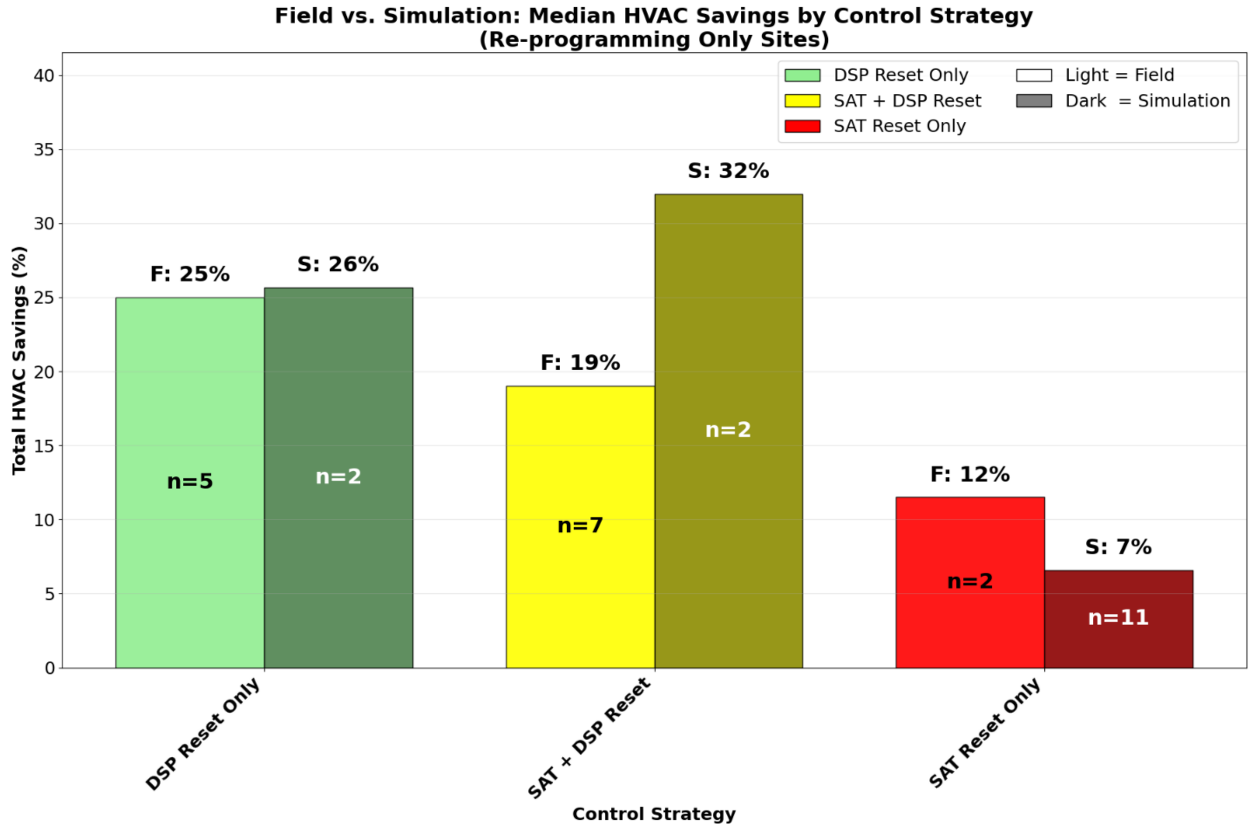

Figure 5: Comparison of field data and simulation study findings

Conclusion and Next Steps

Conclusions

This study presents a multi-site compilation of field-measured performance data for AHU-level control sequences based on ASHRAE Guideline 36, encompassing 17 projects in total. Across these software-only sites, the three core G36 AHU sequences: SAT reset trim-and-respond, DSP reset trim-and-respond, and economizer controls, achieved a median total HVAC savings of 18%, showing that energy reductions are achievable through controls reprogramming alone, requiring only contractor programming labor, without investing in hardware.

DSP reset trim-and-respond was the most widely implemented strategy, appearing in 15 of the 17 projects either as a standalone measure or in combination with other sequences. As a standalone strategy, DSP reset yielded a notably higher median savings of 25%, compared to 19% for the combined SAT and DSP reset strategy. This difference may be partly attributable to the fact that the standalone DSP reset results draw from a prior study (ESTCP 2017) that employed a tiered trim-and-respond (TTR) variant of the standard G36 DSP reset sequence. Unlike the conventional trim-and-respond approach, the TTR method introduces multiple tiers of adjustment rates that respond to how far the maximum damper position deviates from a target range. This difference may have contributed to the higher savings observed for standalone DSP reset implementations. A broader observation from this dataset is that while G36 is a comprehensive guideline, facilities frequently implement only a subset of its sequences, or combine them in ways that reflect site-specific constraints and priorities.

Despite representing a larger multi-site synthesis of field data, this study has limitations worth acknowledging. The projects skew geographically with majority of the data from implementations in California, which means the findings may not translate cleanly to different climate zones. Moreover, once sites are disaggregated by the specific combination of sequences implemented, the groups become too small to draw further conclusions as to the savings associated with these different combinations. A richer dataset would also strengthen comparisons with simulation-based predictions, with the current analysis constrained by limited overlap between field-measured and simulated data combinations.

Future Work

This work points to several directions for future research and dissemination. First, while this study focuses on AHU-level sequences, VAV-level airside strategies such as dual-maximum control and VAV minimum flow reset, provide significant opportunity to explore G36 airside strategies further. Expanding the field dataset to include these sequences among others found in the guideline would provide a more complete picture of the energy savings achievable through full G36 airside implementation.

Second, continued data collection remains a priority. As noted above, grouping sites by strategy combination quickly shrinks the available sample, and more projects across diverse climates, building types, and occupancy patterns would allow for more conclusive findings and stronger comparisons with simulation predictions.

Beyond data collection, G36 adoption depends on addressing several practical barriers. Controller programmability, available memory, and network traffic constraints such as where to host request aggregation logic or when to upgrade controllers, all shape how G36 sequences can be implemented. More work remains in developing and disseminating guidance to help practitioners assess infrastructure readiness. Documenting implementation experiences across varied environments would help the field move toward clearer, replicable deployment strategy for G36.

Finally, fault awareness before implementation is critical. Certain faults may be outright blockers, preventing G36 from being implemented at all, while others such as sensor drift, if more pervasive, will undermine savings if left unaddressed. Developing a tiered framework that distinguishes disqualifying faults from those that matter only when widespread would give practitioners clearer screening criteria. Pre-implementation fault screening should be a standard part of the deployment process, and EMIS tools can play a useful supporting role in identifying and tracking these issues before and after implementation. Tying fault screening workflows into EMIS-based deployment is a logical next step toward making this practical at scale.

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References

Arens, E., H. Zhang, and T. Hoyt. 2015. "Effects of Diffuser Airflow Minima on Occupant Comfort, Air Mixing, and Building Energy Use (RP-1515)." *Science and Technology for the Built Environment* 21 (8): 1101–1114.

ASHRAE (American Society of Heating Refrigerating and Air Conditioning Engineers). 2024. *Guideline 36–2024. High-Performance Sequences of Operation for HVAC Systems.* Atlanta, GA: ASHRAE.

Cheng, H., R. Singla, and G.Paliaga. 2022. *Demonstrating Scalable Operational Efficiency Through Optimized Controls Sequences and Plug-and-Play Solutions.* California Energy Commission.

Cheng, H., P. Raftery, and P. Wendler. 2024. "Are We Prioritizing the Right Thing? Cutting Carbon Emissions in California's Large Office Buildings Before Installing a Heat Pump." *Proceedings of the 2024 ACEEE Summer Study on Energy Efficiency in Buildings*.

EIA (Energy Information Administration). 2023. *2018 Commercial Buildings Energy Consumption Survey (CBECS)*. Washington, DC: U.S. Energy Information Administration. eia.gov/consumption/commercial/data/2018/.

Elehwany, H., B. Gunay, M. Ouf, N. Cotrufo, and J.-S. Venne. 2024. "Evaluating Common Supply Air Temperature Setpoint Reset Strategies with Varying Occupancy Patterns and Behaviours." *Building and Environment* 266: 112129.

ESTCP (Environmental Security Technology Certification Program), U.S. Department of Defense. 2017. "Demonstration of Energy Savings in Commercial Buildings for Tiered Trim and Respond Method in Resetting Static Pressure for VAV Systems." *2017 Cost and Performance Report.* Ames, IA.

EVO (Efficiency Valuation Organization). 2012. *International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings. Volume 1*. Washington, DC: EVO.

Fernandez, N., S. Katipamula, W. Wang, Y. Huang, and G. Liu. 2014. "Energy Savings Modelling of Re-Tuning Energy Conservation Measures in Large Office Buildings." *Journal of Building Performance Simulation* 8 (6): 391–407.

Fernandez, N., S. Katipamula, W. Wang, Y. Xie, M. Zhao, and C. Corbin. 2017. *Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction*. Pacific Northwest National Laboratory. PNNL-25985. www.pnnl.gov/main/publications/external/technical_reports/PNNL-25985.pdf.

Lu, X., and Y. Chen. 2024. "Energy Saving Estimation of ASHRAE Guideline 36 Supervisory Setpoint Reset Controls in a Commercial Large Office Building." *ASHRAE Transactions* 130: 148–156.

Pang, X., M. Piette, and N. Zhou. 2016. "Characterizing Variations in Variable Air Volume System Controls." Energy and Buildings 135: 166–175.

Parker, A., H. Horsey, M. Dahlhausen, M. Praprost, C. CaraDonna, A. LeBar, and L. Klun. 2023. *ComStock Reference Documentation: Version 1*. Golden, CO: National Renewable Energy Laboratory. nrel.gov/docs/fy23osti/83819.pdf.

Kim, J., and C. CaraDonna. 2025. *ComStock Measure Scenario Documentation: Chiller Replacement*. Golden, CO: National Renewable Energy Laboratory. www.nrel.gov/docs/fy25osti/95003.pdf.

Raftery, P., A. Geronazzo, H. Cheng, and G. Paliaga. 2018. "Quantifying Energy Losses in Hot Water Reheat Systems." *Energy and Buildings* 179: 183–199.

Taylor, S. T. 2015. “Resetting Setpoints Using Trim & Respond Logic.” *ASHRAE Journal 57(11):52-57*.