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Title
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Permalink
https://escholarship.org/uc/item/62w32317

Journal
Science and Technology for the Built Environment, ahead-of-print(ahead-of-print)

ISSN
2374-4731

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Publication Date
2026

DOI
10.1080/23744731.2026.2744613

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Field-Measured Energy Savings Performance of Guideline 36 in Retrofit Implementations

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Field-Measured Energy Savings Performance of Guideline 36 in Retrofit Implementations

Recognized as a best-in-class advanced building controls sequence for commercial buildings, the voluntary ASHRAE Guideline 36 (G36) is gaining traction in new construction HVAC controls but has seen slow adoption in retrofit cases. One explanation is that stakeholders for energy retrofit projects 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 decisionmakers to invest resources without a real-world value proposition based on field-measured energy performance data. This paper presents the largest known multi-site field study of G36 performance, drawing on measured results from 38 projects across diverse building types and climate zones.

The analysis disaggregates outcomes by the most widely adopted G36 strategies, including trim-and-respond approaches to supply air temperature (SAT) and duct static pressure (DSP) reset, economizer controls and VAV airflow minimums and dual maximum controls. Results for controls re-programming implementations are encouraging, with HVAC savings ranging from 2% - 49%, with a median of 19%. The range aligns with simulation study findings showing 1% - 46% savings through these three strategies. We then present a case study from one of our 38 identified projects, detailing stakeholders' motivating factors, implementation process by the controls team, and lessons learned.

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. In addition to the results giving practitioners and decisionmakers a reference point on expected energy savings benefits, the case study provides a concrete example of what a successful retrofit project may look like and provide a blueprint for implementation. Finally, utility program developers may also benefit from these findings in restructuring qualifying measures for retro-commissioning programs.

Keywords: Guideline 36; AHU-VAV; energy efficiency; retrofit; building automation; controls

1.Introduction

1.1.Purpose, Literature Review, and Findings from Simulation Studies

More than one quad per year of energy is wasted in the United States as a result of inadequately specified and inconsistently implemented control sequences across the majority of commercial building projects (Wetter et al. 2021). Historically, HVAC control sequencing practices have lacked a uniform, referenceable structure, leading to project-specific interpretations. This complicates their verification, commissioning, and scalable deployment, and may lead to inconsistent performance. ASHRAE Guideline 36 (G36) was developed to close this gap by providing rule-based, high-performance control sequences of operation for HVAC systems. The guideline aims to improve energy efficiency, control stability, and commissioning consistency across projects. It also promotes interoperability and clearer coordination among designers, contractors, and operators (ASHRAE 2018).

G36 is a compilation of energy efficient sequences, deemed by HVAC controls and mechanical engineering practitioners as the best-in-class for commercial building systems. These sequences are available for voluntary adoption by owners nationwide. Although the G36 was first formalized in 2018, with revisions published in 2021 and 2024, contents can trace their lineage back to strategies developed in the early 2010s (Liu et al. 2014; Lin and Lau 2014; Arens et al. 2015; Hydeman and Eubanks 2015). G36 provides optimized sequence of operations for a variety of multi-zone, air-handling unit, variable air volume (AHU-VAV) systems. The sequences, developed for multi-zone AHUs and terminal units, dynamically adapt to changing loads and zone level demand, most evident in its AHU supply air temperature and supply duct static pressure trim-and-respond (T&R) reset control logic. As described in a 2015 study

(Taylor 2015), this T&R control logic is designed to modulate the AHU supply air temperature and supply duct static pressure setpoints in response to zone air conditioning requests, which are triggered by the zone air temperature exceeding the zone air temperature setpoint and the zone airflow setpoint exceeding the zone airflow respectively. The logic allows the system to 'trim' - i.e., raise supply air temperature or reduce duct static pressure when the demand is low, and 'respond' in the opposite direction when a predetermined number of zones are starved. For the airside economizer, G36 stipulates a dynamic minimum outdoor airflow setpoint that would minimize mechanical cooling when outdoor air is cooler and drier than return or mixed air while ensuring minimum ventilation requirements are met based on CO_2 sensors. G36 also covers VAV-level control logic, aimed at modulating the terminal unit's capacity based on zone demand. Dual max logic (Taylor et al.2012) and reduced minimum airflow (Arens et al. 2015) recommendations are two examples of sequences that enable these systems to run more efficiently than status quo control sequences. Dual max is a VAV box logic that uses a higher cooling max airflow setpoint and a separate, lower heating max airflow setpoint (instead of one shared maximum), so heating doesn't over-ventilate the zone while cooling still gets full airflow capacity. The VAV minimum airflow is set to match the specific zone's outdoor air intake requirement rather than an arbitrary 30% to 50% box design assumption. Despite the wide scope of the guideline, many perceive the guideline as too complex and arduous to implement, resulting in practitioners only implementing certain components of the guideline. In a survey of 488 controls contractors across the country, only 29% had one or more G36 project implementations (Singla and Paliaga 2022). Table 1 shows key strategies from the full scope of Guideline 36 sequence of operations. For the purposes of this study, we focused on characterizing the benefits of G36 sequences to four main air-side sequences

that were most frequently implemented in the dataset we collected.: 1.AHU T&R SAT/DSP 2. Economizer 3. VAV Dual max and 4. VAV Minimums.

Table 1. Full scope of ASHRAE Guideline 36 2021 edition including addenda till 2024

Side	Level	Strategies
Airside	AHU	Supply air temperature & duct static pressure reset, integrated economizer control, optimal start-stop and morning warm-up, occupied-unoccupied and other operating modes, AHU-level automated fault detection and diagnostics, hierarchical alarm suppression, etc.
	VAV/ zone	Dual -max logic, VAV minimums, discharge air temperature rests, demand-controlled ventilation, occupied-standby mode, zone humidity limiting
Waterside	Chilled water plant	Chilled water supply temperature reset (trim and respond), chilled water

		differential pressure rest, chiller staging/sequencing, condenser water temperature reset, cooling tower fan control
	Hot water plant	Hot water supply temperature reset (trim and respond), boiler staging, primary/secondary pump control

A growing body of simulation-based research has demonstrated the performance advantages of G36 control sequences compared with traditional control practices. For example, a parametric, whole-building simulation research using EnergyPlus-Modelica hybrid models found that G36 control logic can deliver average HVAC energy savings of approximately 31 % relative to baseline control sequences across climates in California (Zhang et al. 2022). In another recent study of a large office building in Chicago, G36 control strategies retrofitted to replace conventional sequences yielded modelled energy savings of up to 41 % in the heating season, 18 % in the shoulder season, and 20 % in the cooling season while maintaining thermal comfort, highlighting the benefits of coordinated air- and plant-side control improvements over baseline practice (Lu and Chen 2024). Prior to the publication of Guideline 36, multiple simulation-based studies evaluated advanced HVAC control strategies that are consistent with what is now formalized in the guideline and that directly informed its development, demonstrating total HVAC energy savings of up to 30 % across varied

building typologies and climate conditions (Pang et al. 2017; Fernandez et al. 2017). Several other simulation-based studies (Wetter et al. 2018; Faulkner et al. 2023; Elehwany et al. 2024) have evaluated G36 control strategies and consistently report substantial energy performance improvements relative to conventional control approaches. With the addition of the water-side strategies introduced in G36 in 2021, these analyses now span more than 70 modelled scenarios, representing a wide range of G36 strategy combinations and implementation configurations under idealized conditions. These investigations are conducted using energy simulation and therefore evaluate the impact of control sequences on energy performance, but do not assess the impact of physical control system infrastructure upgrades or retrofits, that in practice may be implemented alongside the sequence updates. This approach enables evaluation of G36 performance across a wide range of scenarios but may not necessarily capture the constraints or opportunities associated with real-world implementations. Despite the breadth of simulation-based evidence supporting the performance potential of Guideline 36, published field-based evaluations remain comparatively limited.

To date, fewer than twenty buildings (18 total) have been reported in the literature with measured post-retrofit performance of G36-aligned control sequences, primarily across three studies (Arens et al. 2012; Zhou et al. 2017; Paliaga et al. 2019). This limited field evidence for retrofit applications is attributed to multiple factors: 1) implementers are not regularly disseminating findings into the academic literature rather reporting energy savings directly to their clients, 2) retrofit rates are relatively low due to the challenges associated with implementing G36-aligned control sequences in existing buildings, where deployment must occur within the constraints of legacy equipment and control architectures. While new construction allows these constraints to be addressed at

the design stage, the predominance of existing buildings in the U.S. commercial stock, with the majority constructed before 2010 and annual building turnover rates below 2% (Chaney 2022; US EIA 2021), highlights the importance of understanding G36 performance in retrofit contexts.

In addition to the sparse field reported energy savings, no one has compiled these studies in a comprehensive analysis. Thus, the contributions of this study are four-fold: 1) the first-ever large scale compilation of G36 field studies, 2) a unified savings analysis across all installations organized by strategy, 3) a case study demonstrating efficacy and savings of a software-based G36 retrofit project, and 4) a comparison of savings from the field with simulation study findings.

2. Methodology

2.1. Data Collection Methods

The data collection process involved two main components:

1. Literature review of field implementations from journal articles or government-funded studies from 2010 to present
2. Identification of projects implemented by industry with pre and post energy data availability

For component 1, there were 20 projects identified funded by a collection of peer-reviewed papers, reports funded by the federal government (Zhou 2017) or state energy offices (Cheng et al. 2022). For component 2, we reached out to more than 20

industry practitioners, many of which were involved in the early development of the guideline or preceding ASHRAE-funded research projects. These conversations yielded an additional 18 field studies with energy savings data. All were asked to provide basic information on their projects, including building square footage, location, strategies implemented, nature of the retrofit (full hardware and software retrofit, or software-only retrofit), and either sub-system or whole-building pre/post retrofit weather normalized energy consumption.

Data collection and savings quantification for this study were conducted using a combination of direct measurement and engineering estimation approaches based on data availability at each site. Reported data and savings calculations were provided by individual site implementers, and while reviewed for internal consistency, they were not independently verified.

Given substantial variation in metering infrastructure across participating facilities, multiple measurement and verification options were applied. These were reported by project engineers to be generally consistent with the International Performance Measurement and Verification Protocol (IPMVP) (Efficiency Valuation Organization 2022). Option A (Retrofit Isolation, - Key Parameters) was used in buildings where only select HVAC variables were metered for limited durations, such as fan power or daily cooling tonnage, with non-measured parameters estimated using assumptions. Option B (Retrofit Isolation, - All Parameters) was applied in facilities with HVAC submetering that captured all - fan, cooling, and heating energy, allowing direct calculation of pre- and post-retrofit HVAC loads. Option C (Whole Facility) was used in cases where only whole-building utility data was available, with HVAC energy estimated from

whole-building electricity and gas consumption in combination with HVAC end-use fractions. Assumptions are documented in the section 2.3

2.2. Characterization of the Dataset

The study dataset includes 38 facilities spanning multiple building types, climate zones, and U.S. states, with varying levels of G36 strategy implementation (Tables 2-5). Eight building types were represented, with the majority comprising offices and mixed use buildings. The sample covers five climate zones, with about half from warm marine locations. Similarly, projects from California are most common in the data set, likely attributable to the thriving building energy efficiency ecosystem in that state. The trim and respond reset strategies were most commonly implemented, although demand-controlled ventilation and VAV sequences were also quite common across the data set.

Table 2. Building Type in the G36 Dataset

Building Type	**Count**
Office	19
Mixed Use Office	7

Medical - Outpatient	4
Laboratory	3
University	2
Medical - Inpatient	1
Data Center	1
Retail	1

Table 3. ASHRAE Climate Zones in the G36 Dataset

ASHRAE Climate Zones	**Count**
Warm Marine (3C)	20
Warm Dry (3B)	5
Cool Humid (5A)	7
Mixed Humid (4A)	3
Cool Dry (5B)	3

Table 4. States covered in this G36 Dataset

States	**Count**

CA	25
OH	2
IA	5
NJ	3
CO	3

Table 5. G36 strategies implemented in this dataset

G36 Strategies	Count
SAT Trim and Respond	25
DSP Trim and Respond	29
Demand Control Ventilation	12
VAV Minimum	18
Dual Max	13

2.3. Methodology for Unified HVAC Savings

The buildings in the dataset had substantial variation in both metering infrastructure and HVAC system configuration, and therefore reported savings using different quantities and metrics, e.g., combined vs. disaggregated fuels, whole-building vs. HVAC, vs.

heating, cooling and fan energy, etc. Accordingly, it was necessary to unify the dataset into a common metric across each of the 38 building sites. Given the diversity in data reported for each site, seven calculations were used to express savings in the common metric used in the study - total HVAC savings as a percent of total HVAC energy use.

To ensure consistency, all measured electric and fuel consumption was converted to a common thermal basis (kBtu) using standard conversion factors for electricity, fossil fuels, and chilled water. Heating, cooling, and fan energy were converted to plant input energy using documented engineering assumptions; unless site-specific data were available, a default boiler efficiency of 80% (Praprost 2025) and a default chiller performance of 1 kW/ton (Kim and CaraDonna 2025) were applied. 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. Where HVAC submetering was unavailable, end-use distributions were estimated using the 2018 Commercial Buildings Energy Consumption Survey (CBECS) database (US EIA 2021). CBECS data was used to determine the national median end-use breakdown based on the project's principal building activity and census region. Where sample sizes permitted, data was further refined by census division.

Total HVAC energy is defined as follows:

$$E_{HVAC} = \frac{E_{fan} + \left(\frac{E_{cool,in} \times \eta_C}{3.517}\right) + \left(\frac{E_{heat,in}}{\eta_B}\right)}{A_{floor}} \quad (1)$$

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.)

Retrofit performance was consistently evaluated as the percent reduction in total HVAC energy between pre- and post-retrofit periods:

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

Where:

- $E_{HVAC,pre}$: Total HVAC energy intensity (kBtu/sf/yr) before G36 implementation
- $E_{HVAC,post}$: Total HVAC energy intensity (kBtu/sf/yr) after G36 implementation

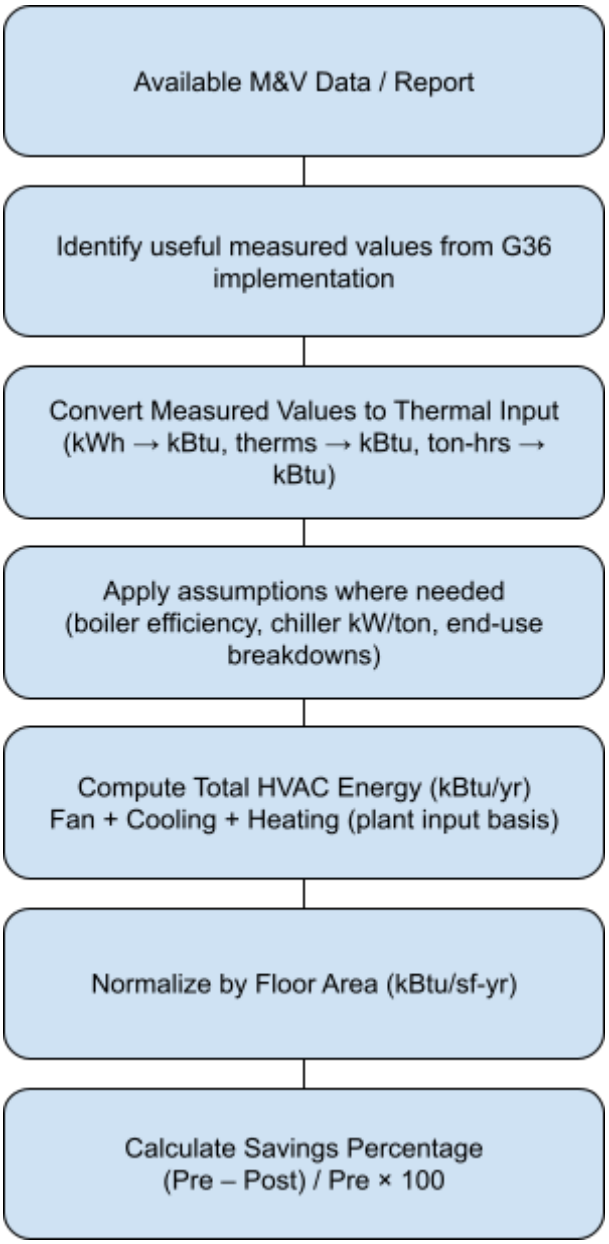


Figure 1. Illustration of steps to arrive at percent HVAC savings from implementer provided data and assumptions

Table 6. Methods for deriving HVAC percentage savings from provided data and assumptions

Method	Measured / Provided Inputs	Assumptions / Defaults	Core Calculation Steps
Method 1	Fan kWh/yr; Cooling kBtu/yr; Heating kBtu/yr	• Boiler efficiency (a) • Chiller efficiency (b)	• Convert fan energy to kBtu • Use Eq(1) and Eq(2) with assumptions (a) and (b) for % HVAC savings
Method 2	HVAC kWh/yr; Gas therms/yr	• Boiler efficiency (a) • Chiller efficiency (b) • Fan and Cooling energy as a fraction of HVAC electric based on CBECS for associated building types and climate zones (c)	• Convert heating energy to kBtu • Calculate fan energy from HVAC electric with assumption (c) and convert to kBtu • Calculate cooling energy from HVAC electric with assumption (c) and convert to kBtu • Use Eq(1) and Eq(2) with assumptions (a) and (b) for % HVAC savings
Method 3	• Whole-building kWh/yr; • Gas therms/yr	• Boiler efficiency (a) • Chiller efficiency (b) • Fan and Cooling energy as a fraction	• Convert heating energy to kBtu • Calculate HVAC electric as a fraction of whole-building

Method	Measured / Provided Inputs	Assumptions / Defaults	Core Calculation Steps
		of HVAC electric based on CBECS (c) ● HVAC electric as a fraction of whole building electric from CBECS (d)	electric with assumption (d) and convert to KBtu ● Calculate fan energy from HVAC electric with assumption (c) and convert to kBtu ● Calculate cooling energy from HVAC electric with assumption (c) and convert to kBtu ● Use Eq(1) and Eq(2) with assumptions (a) and (b) for % HVAC savings
Method 4	Weather normalized Whole-building kBtu/yr	● HVAC as a fraction of whole-building energy (d)	● Calculate non-HVAC load from whole-building energy using (d). ● Subtract this non-HVAC load from pre and post whole-building energy to get pre and post HVAC energy. ● Use Eq(2) to calculate total HVAC savings

Method	Measured / Provided Inputs	Assumptions / Defaults	Core Calculation Steps
Method 5	Fan kWh/yr	None, since savings were solely from fan energy	Convert fan kWh directly to kBtu (×3.412)
Method 6	HVAC kWh/yr	Electric boiler efficiency assumed to be 100%	Convert electric HVAC energy to kBtu (×3.412)
Method 7	• Post-retrofit fan electric energy (kWh/day) • Fan energy savings % • Post-retrofit cooling energy (tons/day) • Cooling energy savings % (total, including water-side G36) • Post-retrofit heating energy (therms/day) • Heating energy savings % (total,	• Fan = 100% air-side; • Cooling air-side = 40% *(author-provided)*; Heating air-side = 30% *(author-provided)* • Cooling plant efficiency: 3 kW/ton • Boiler efficiency: 82% (Building A), 88% (Building B)	• Annualize daily values for fan, cooling , and heating by multiplying per day values by 365; • Calculate pre-retrofit fan, cooling, and heating values from % savings and post-retrofit values. Note that these savings include waterside savings. • Isolate air-side G36 savings from total using assumptions • Use Eq(2) for %HVAC savings from air-side G36 strategy implementation.

Method	Measured / Provided Inputs	Assumptions / Defaults	Core Calculation Steps
	including water-side G36)		

3.Results

3.1.Field Study Findings

The total HVAC energy use savings across all 38 facilities ranged from 2%-60% with a median of 21%. Figure 2 shows the plot of savings across all facilities ranging from the highest to the lowest

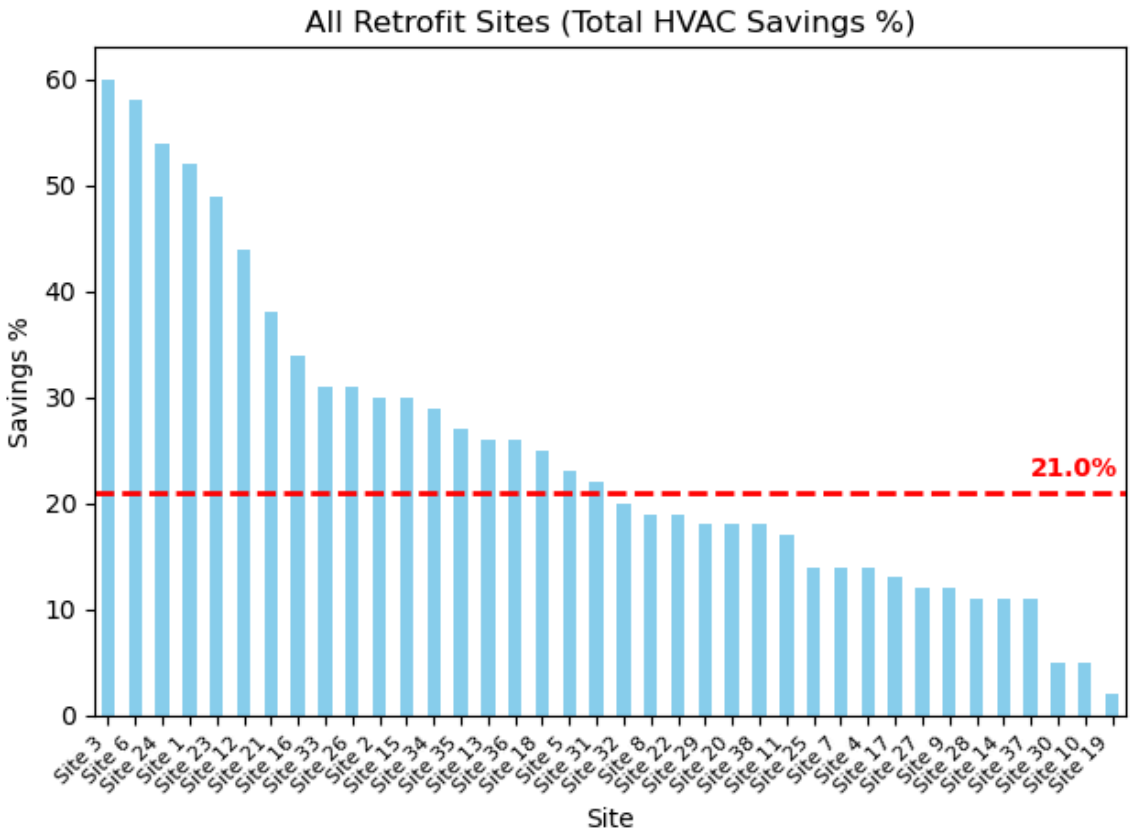


Figure 2. HVAC savings across all 38 projects with designation of the median

Six of the 38 projects required both hardware and software upgrades, such as converting from pneumatic to direct digital control (DDC), or single speed fan motors to variable frequency drives (VFDs). In this paper, these six projects are referred to as 'full retrofit'. The remaining projects only included software updates to the control logic and sequences. These thirty-two projects are referred to as 're-programming only'. Shown in Figure 3, the median total HVAC energy savings for the full retrofit projects was found to be 31% while that for re-programming only was found to be 19%.

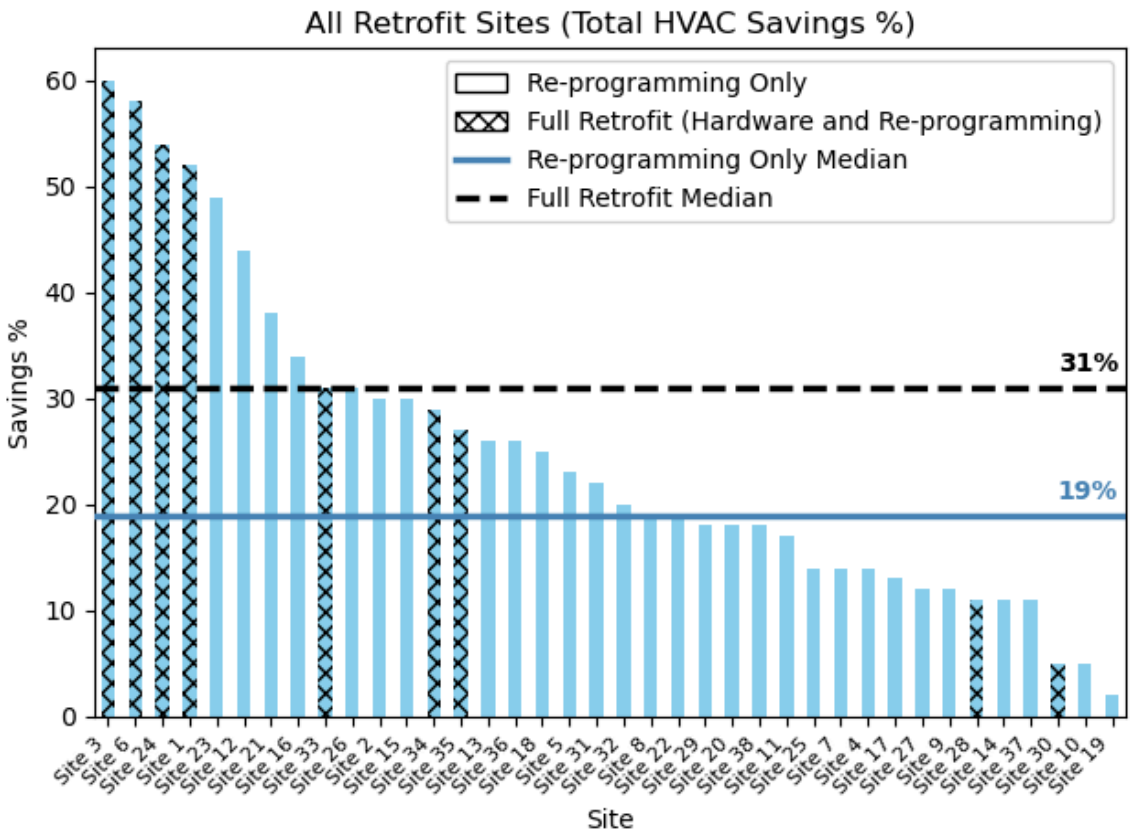


Figure 3. HVAC savings from full retrofit, and re-programming only projects

Full retrofit projects may have resulted in higher savings for multiple reasons. They often start from a worse baseline, and aging hardware creates inefficiencies that

software optimization alone cannot fully overcome e.g., pneumatic controls or single speed equipment. This limits how thoroughly new setpoints can be implemented across the HVAC system. Hardware replacement also addresses accumulated degradation e.g., failed damper actuators, drifted sensors, etc. The observed savings in full retrofit projects reflect the combined effect of controls optimization and infrastructure improvements and cannot be attributed to G36 implementation alone. This makes G36 specific energy savings from full retrofit results difficult to attribute. In this analysis the savings from hardware upgrades were found to be at the 78th percentile across all projects and tended to skew any aggregate conclusions. Hence, the remainder of this analysis focuses on re-programming only projects, where the controls infrastructure was already functional and the savings are more directly tied to different combinations of G36 sequence implementations and how these field-observed savings compare to simulated savings.

Software-only projects implemented varying combinations of G36 control sequences across facilities. Table 7 reports the frequency of each sequence combination.

Table 7. Frequency of G36 control sequence combinations implemented in software-only projects

Sequence / Combination	**Count**
SAT + DSP Reset	7
DSP Reset Only	5
VAV Minimum Only	5

All 5 Sequences	5
SAT + DSP + Economizer	3
SAT Reset Only	2
SAT + DSP + VAV Min + Dual Max	2

Figure 4 shows the of observed savings for re-programming only projects with different implemented combinations of G36 sequences .

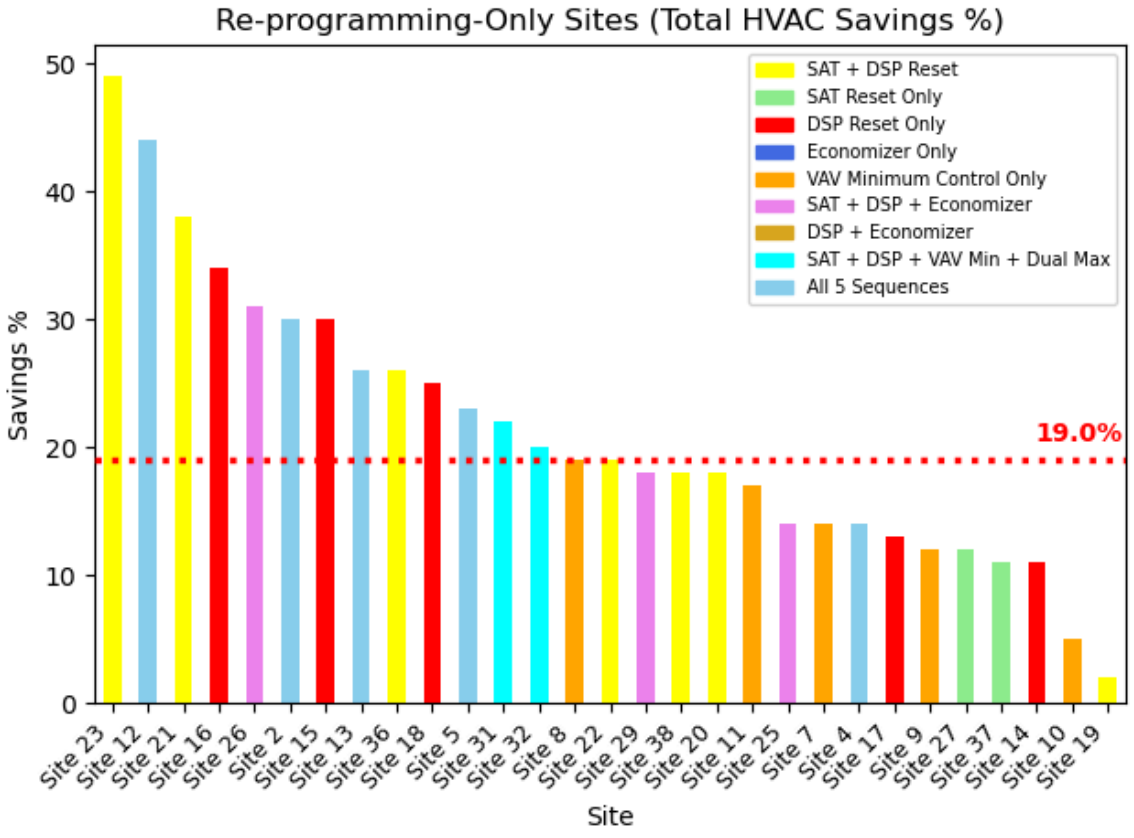


Figure 4. HVAC savings across re-programming only G36 sequence combinations

Because many sequence combinations were implemented at only a small number of sites, comparison of resulting savings across these combinations focuses on the

following four most frequently implemented cases avoid over-interpreting sparsely represented strategies: 1) SAT + DSP reset 2) DSP Reset Only 3) All five sequences 4) VAV Minimum Only.

Figure 5 compares the four most frequently implemented G36 sequences or sequence combinations. Strategies are ordered by median HVAC savings from highest to lowest. Within each strategy, individual projects are sorted by savings magnitude.

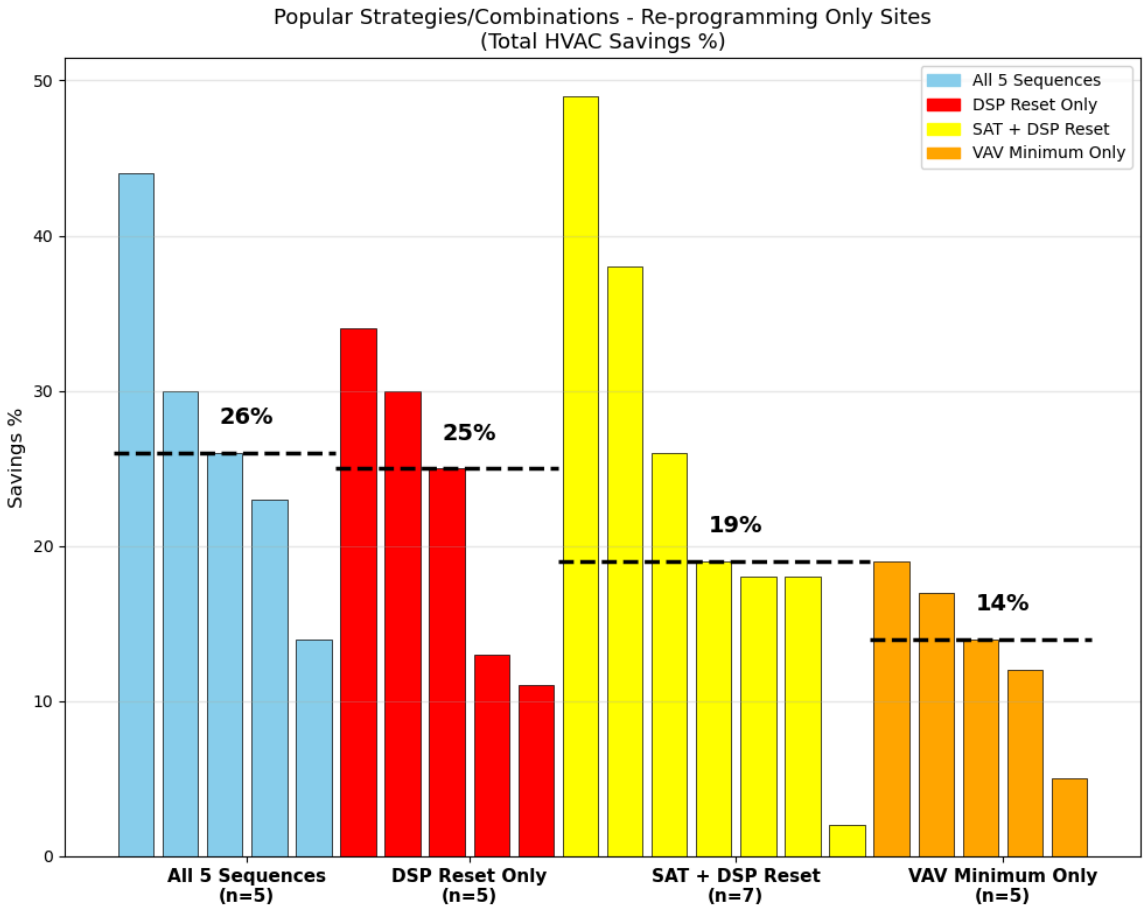


Figure 5. HVAC savings disaggregated for the sequences or combinations of sequences

As expected, projects that implemented all five air-side sequences showed the highest savings. Similarly, the projects that implemented T&R reset strategies together or in

isolation generated higher savings than projects that implemented only a VAV minimum. However, it is also observed that the DSP-only strategies demonstrated *higher* savings compared to the combined SAT and DSP reset approach. This anomalous result is likely attributable to site-specific factors such as variability in baseline HVAC system attributes, presence of operational faults that can compromise performance, and potentially variability in implementation of 'the same sequence' across different sites and engineering team.

3.2. Comparison with Simulation Findings

The field-measured savings from these strategies were compared against results reported in prior simulation studies (Pang et al. 2017; Fernandez et al. 2017; Wetter et al. 2018; Zhang et al. 2022; Faulkner et al. 2023; Elehwany et al. 2024). Figure 6 presents a comparison of median savings for the four most commonly implemented strategies based on field data. For DSP reset only and VAV minimum only, the field results are consistent with the simulation results, with the field results with only slight differences. In contrast, simulation studies indicate greater savings potential when all five sequences are implemented simultaneously, and when the two reset strategies are implemented together, as documented in [4]. This difference is more pronounced for the combined reset strategies, however, with small sample sizes, it cannot be determined whether these differences and similarities are significant in a statistical sense.

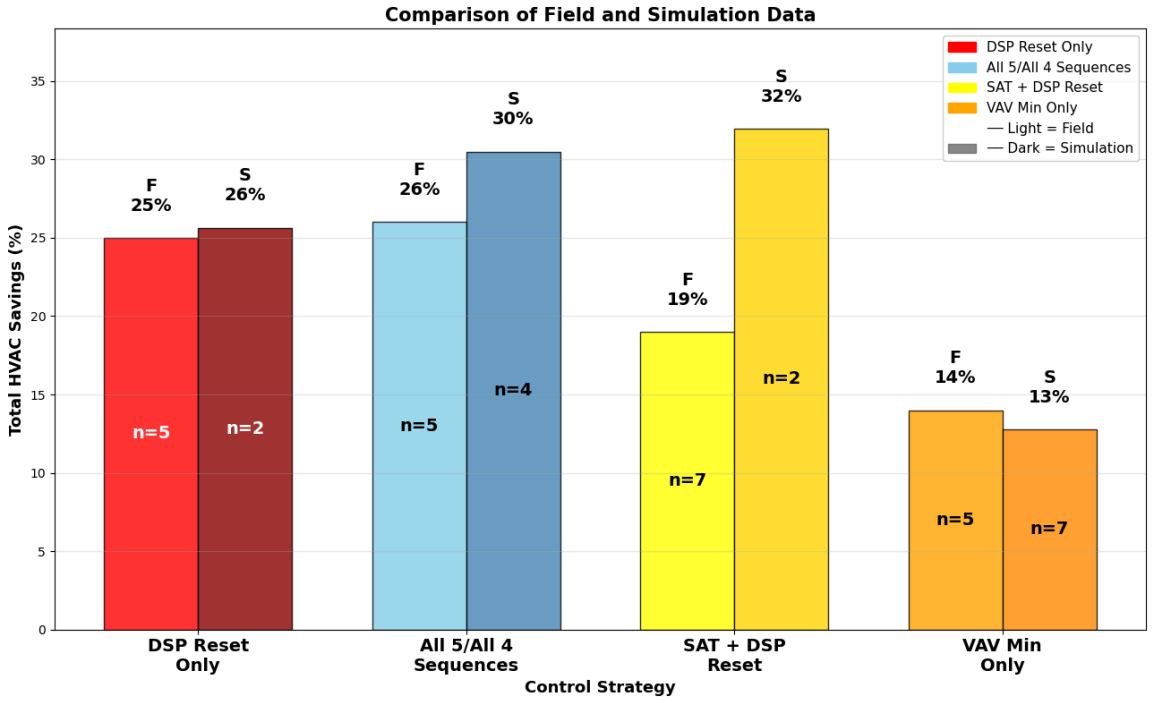


Figure 6. Comparison of field data and simulation study findings

While the field and simulation findings show no outright contradictions, savings for the SAT+DSP reset strategy diverge noticeably between the two. The simulation results derive from a high-fidelity virtual testbed of a Chicago, IL building (ASHRAE climate zone 5A), reported separately for cooling and heating seasons; the field data, by contrast, come exclusively from California sites. This climate mismatch may partly explain the divergence, though the small sample size (n = 2) for this strategy group likely contributes as well. A larger, climate-diverse dataset would help yield more definitive conclusions.

4. Case Study

4.1. Building Description

To illustrate a G36 retrofit project in much further detail, a case study is presented. The case study building is a 120,000 square foot outpatient and office building located in Columbus, Ohio. The building is served by a series of AHU-VAV systems, consisting of

nine AHUs across two wings. The outpatient wing is 30,000 square feet served by 1 AHU, while the office wing is eight stories, each served by an AHU. The building automation system (BAS) is a Delta controls system which includes fully programmable DDC hardware at the AHU (DSC-1616) and VAV (DVC-304) level. The outpatient wing's HVAC utilities are metered with the main building while its electrical loads are served by an adjacent facility. Figure 7 shows a schematic of the AHUs, their capacity, and the floors they serve.



Figure 7. Schematic of the case study medical office building

4.2. Baseline Operations

Before the G36 retrofit, at baseline operation, the site was found to have an average monthly site energy use intensity of 240 kbtu/sqft, which is more than double the national median site EUI for a medical office building of 98 kbtu/sqft (U.S. Environmental Protection Agency 2024). The main underlying reasons for the higher-than-normal EUI were found to be: 1) High VAV minimum airflow setpoints, 2) Underperforming AHU SAT and DSP resets, and 3) Overridden occupancy schedules and after-hours operational policies. These three problems resulted in an HVAC system that ran far less efficiently than possible. At the AHU level, fans were found to operate

at a higher speed than needed, and the SAT setpoint was well below zone requirements. At the VAV level, this led to higher quantities of overcooled air being delivered. Not only did this result in discomfort due to overcooling, it also led to the spaces calling for terminal reheat, resulting in simultaneous heating and cooling. Moreover, the VAV airflow minimums were found to be set too high, leading to high cooling energy of the VAVs in the deadband operation. This also drove the space temperature down to the heating setpoint creating false heating loads at this facility. Table 8 shows the setpoints across a select set of AHU and VAV level control loops before and after G36 implementation.

Table 8. Pre and post-retrofit setpoints for 5th Floor AHU SAT, DSP and VAV airflow. Note that the minimum airflow apples to both heating and cooling

Equipment	**Pre-retrofit Setpoints**		**Post-retrofit Setpoints**		
AHU System	**Supply Air Temperature (degF)**	**Duct Static Air Pressure (in of w.c.)**	**Supply Air Temperature (degF)**	**Duct Static Air Pressure (in of w.c.)**	
AHU 7	55	1.5	55 - 65	0.5 - 1.5	
VAV Systems	**Min Airflow (CFM)**	**Cooling Max Airflow (CFM)**	**Min Airflow (CFM)**	**Cooling Max Airflow (CFM)**	**Heating Max Airflow (CFM)**
VAV 7-1	126	315	63	315	126

VAV 7-2	70	175	35	175	70
VAV 7-3	112	280	56	280	112
VAV 7-4,7-7, 7-10,7-12, 7-16	400	1000	200	1000	400
VAV 7-5	236	590	118	590	236
VAV 7-6, 7-14	200	500	100	500	200
VAV 7-8	400	1200	200	1200	400
VAV 7-9	500	1250	250	1250	500
VAV 7-11	192	480	96	480	192
VAV 7-13,7-15	312	780	156	780	312

4.3. Implementation of G36 Strategies

The baseline operational state of the HVAC system made the site a strong candidate for G36 implementation. The underperforming resets called for demand based T&R while the simultaneous heating and cooling could be mitigated with reduced VAV minimums and dual-max logic. Additionally, the facility also leveraged two other G36 capabilities - 1) importance multipliers, which allow certain zones (e.g., specialized patient care

areas) to be prioritized in the comfort-driven logic and 2) rogue zone detection which flags zones that are driven by faults or undersized VAVs and consistently request for maximum heating or cooling leading to overall inefficiency of the system by holding the setpoints at suboptimal values. With the exception of a few VAV controllers, the existing control infrastructure was found with sufficient memory and scan rate capability to implement the new G36 control strategies without requiring any hardware retrofits.

Prior to the retrofit, most occupancy schedules had been overridden to continuous operation in response to complaints from staff occasionally present during nights and weekends. To restore schedule-based control without reintroducing these complaints, the retrofit team interviewed floor and department managers to characterize actual occupancy patterns, then grouped zones accordingly: 24/7 occupied areas, Monday-Saturday daytime patient-care areas, and Monday-Friday daytime office areas. Each group received off-hours setback tailored to its occupancy profile: 24/7 zones retained normal V_{min} and temperature setpoints around the clock, while the remaining zones had V_{min} reduced to minimum controllable flow and temperature deadbands relaxed during unoccupied periods. Where feasible, the number of ignores allowed in trim and respond reset logic was also increased off-hours, letting setpoints relax further while zones were unoccupied.

After reviewing existing control sequences and available performance data, the site's retrofit team developed a staged retrofit plan summarized in Table 9. The retrofit was completed over a 6-month period. The retrofit team consisted of the internal BAS controls technicians, with external help from consulting engineers, commissioning agents and controls contractors. First, system operations were reviewed relative to the

current energy and ventilation codes, then the VAV controllers were updated with the necessary logic including dual max, VAV minimum airflows and rogue zone detection. Problematic zones highlighted by the newly implemented rogue zone logic were addressed before finally updating the AHU controllers.

Table 9. Step-by-step retrofit plan to implement G36 strategies

Step #	**Activities**	**Parties in charge**
Step 1	- Reevaluate VAV min airflow setpoints according to latest adopted energy and ventilation codes. Reevaluate AHU min ventilation according to latest adopted ventilation codes	Consulting engineer to perform calculations
Step 2	- Incorporate G36-based sequences at VAV controllers, including: - Dual-max logic - T&R reset requests - Rogue zone detection - Unoccupied setback strategies	BAS shop or controls contractor
Step 3	- Address rogue zones - Use BAS to generate biweekly or monthly reports that identify problem zones	Engineer or CxA working in collaboration with BAS shop or controls contractor

Step 4	- Incorporate G36-based sequences at AHU controllers - Given location in climate zone 4A, include modifications for stable dehumidification control	BAS shop or controls contractor. Leverage engineer or CxA to validate system performance

4.4. Resulting Site HVAC Savings

The EUI of the building was monitored before and after the retrofit activities, consistent with Method 4, as described in Table 5. In addition to the EUI, total HVAC energy was derived from CBECS estimated percentage of total building site energy consumption associated with HVAC loads. Table 10 shows the HVAC energy savings that resulted from the retrofit of the site control sequences.

Table 10. Weather normalized energy savings

HVAC Pre Retrofit (Baseline)	**HVAC Post Retrofit**	**HVAC Energy Savings**	**% HVAC Energy Savings**
21,621,587 kBTU	16,579,575 kBTU	69.3x10e6 kBTU	41%
135.8 kBTU/sqft	80.2 kBTU/sqft	55.6 kBTU/sqft	

4.5. Implementation Lessons Learned

Despite the success of this implementation, there were a number of noteworthy

challenges and insights gained through the process, summarized in major themes in the following sections.

Insights from rogue zone logic

The rogue zone detection logic provided in the Guideline enabled the team to automatically identify previously undetected performance faults across multiple VAV zones. VAV boxes in multiple zones appeared to be starved of airflow and triggered rogue zone faults. Investigation of the duct static pressure at the inlet and downstream of the reheat coils with dampers at the fully open position revealed that accumulation of airside debris in the coils across these boxes was the main cause of the faults. Following coil cleaning, the affected zones no longer exhibited ‘rogue’ behavior. This example demonstrates the advantages of G36’s automated rogue zone detection logic. Before implementing it, the operations team required several days to manually identify each rogue zone across the site. With the G36 logic, this process was streamlined, reducing the effort from days to minutes allowing the team to focus directly on diagnostics and repairs. Over time, the logic continued to provide additional value by automatically detecting newly triggered rogue zones caused by mechanical failures, such as malfunctioning VAV damper or reheat valve actuators.

Floor by floor implementation

The operations team took a floor-by-floor approach and designated a low-risk floor for beta-testing. This floor was selected on occupant receptiveness and work-hours. This allowed the team to monitor comfort and energy performance via virtual energy

metering (i.e. trending of calculated rather than directly measured values) closely before further rollout. Issues were addressed as they arose, making scaling across the site easier. Programming of the G36 sequences was then staged across the remaining AHUs in the building one at a time. This approach reduced uncertainty and risks, while the virtual metering allowed for immediate energy savings results rather than waiting for the monthly utility report. Performance tracking and system isolation for simplified troubleshooting allowed the team to build confidence and promote buy-in before committing to site-wide changes.

Logic living locally vs in supervisor:

The AHU and VAV controllers were retrofitted with G36 programming locally. This was preferred by the facilities team, but yielded a slower implementation process, especially when copying programs or databases over an MS/TP trunk. VAVs usually lived on MS/TP networks that fed up to a BACnet/IP device, often the AHU controller. The AHUs typically had an IP connection to a network switch that was managed by IT. Allowing some logic to live in a supervisory-level controller may have sped up implementation time.

Control memory and scan rate limitations:

Despite the vast majority of the controllers having adequate memory and scan rate, a small number of the controllers (i.e., fewer than 5 out of nearly 200) had notable limitations. The scan rate limitation was documented by the manufacturer and was validated through some early trial-and-error. Typical causes for poor scan rate include saturated/near-saturated memory, inefficient programming practices (e.g., running loop functions constantly, instead of every 2 minutes or so), and ineffective network communication methods (e.g., sending individual data packets for each data point from

a single VAV, rather than combining them into consolidated packets that could reduce network congestion). While 127 KB of memory was sufficient in this retrofit project, it is noteworthy that additional memory was required for some applications in other buildings that had more granular trending and additional pressure and humidification programming.

5. Discussion

The median total HVAC savings of 19% observed across the 32 re-programming only G36 retrofit projects demonstrates that significant energy reductions are achievable through controls updates alone. However, this does require that the building's existing control infrastructure can accommodate the sequences.

The disaggregation analysis results demonstrate that savings outcomes vary with the specific combination of sequences implemented. DSP reset trim-and-respond was the most frequently implemented sequence, appearing in 29 of 38 projects, and delivered a median savings of 25% as a standalone measure, notably higher than the 19% observed when combined with SAT reset. This difference may be attributed to the fact that all of these DSP reset results (5 out of 5) stem from a study (Zhou et al. 2017) that implemented a tiered-trim-and-respond (TTR) strategy. Rather than applying uniform adjustment rates, TTR modulates its response across multiple tiers based on how far the damper position strays from a target range, representing a more adaptive approach than standard G36 T&R.

At zone level, the VAV minimum strategy was the most popular with 18 of 38 projects implementing it either in isolation or in combination with others. More broadly, the dataset confirms that the full set of airside strategies in G36 are rarely implemented all

together. Rather, facilities selectively applied sequences, likely based on existing infrastructure, system performance, and operational priorities, with the resulting savings reflecting that variability.

The case study offers several generalizable insights about the baseline conditions observed - high VAV minimums, simultaneous heating and cooling, etc. are consistent with fault patterns commonly observed in existing buildings while providing some meaningful examples of trial and error in leveraging existing controller infrastructure. The implementation strategy illustrated in the case study highlights an incremental controls retrofit approach, starting from low-risk spaces and scaling through gradual improvements. This allows for incremental validation, resulting in increased buy-in from the operations and controls team with virtual metering shortening the feedback loop by demonstrating energy savings much sooner than waiting for monthly utility reports.

The field verification study presented has limitations to address. For many of the implementations providing field-measured savings, rigorous research-grade monitoring and reporting was not the original intent. Without oversight or control over how field measured savings were measured and recorded, our study relied on a series of assumptions to estimate savings, which introduces a level of uncertainty in the range of HVAC savings. Geographically, the climate zones represented in the study are skewed towards California sites, which limits the generalizability of these results. This is due primarily because of California's longer history of energy efficiency retrofit programs and the high number of firms in the state with expertise to deliver these advanced strategies with positive outcomes. The range in observed savings (from 2-50% HVAC

savings), is not thoroughly explained in our analysis, and is a function of the strategies implemented and each implementation's baseline performance and operational state. The magnitude of savings achieved is also shaped by factors outside the sequences themselves: how closely the existing HVAC configuration matches G36's design assumptions, the rigor with which the controls contractor executes the sequence logic, and how much custom programming is needed as a result of non-standard equipment with G36's standard sequence architecture. Despite the 38 instances of G36 implementations compiled here, the sequence-specific savings analyses meant disaggregation of the results into significantly smaller sample sizes reducing the statistical significance of the conclusions. The smaller sample sizes led to inconclusive findings for certain individual measures and in other cases were confounded by the inclusion of G36 variant strategies such as the tiered trim and respond. Despite the limitations, it is encouraging to see alignment between field-measured and simulation-predicted savings – with DSP, VAV mins, all 5 sequences implementations within 1-4% of each other – lending credence to the magnitude of expected results.

6. Future Work

This study provides the largest-known compilation of field-measured HVAC savings from implementation of ASHRAE Guideline 36, comprising 38 projects that span a diverse range of building types, climate zones, and strategy implementation combinations. For decision-makers, it provides a realistic benchmark for what to expect, what savings are plausible, and how implementation choices influence outcomes. Future work will seek to expand the dataset across a broader range of climate zones and building types to strengthen the generalizability of these findings and better characterize

the spectrum of energy savings performance achievable across diverse building configurations. Given the high level of savings that resulted from these implementations, there is opportunity to explore how these best-in-class advanced sequences can be incorporated into retro-commissioning services and programs for broader deployment.

In order to continue lowering the barrier of entry to these advanced sequences, more efforts to enhance workforce capacity for effective control delivery are needed including software solutions to automate the configuration and deployment across disparate building systems. Finally, future R&D should focus on developing automated processes to identify buildings that are good G36 retrofit candidates and estimate expected energy savings.

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