Simplified HVAC Control Retrofits

Final Report

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Executive Summary

Existing commercial buildings represent a significant opportunity for energy savings and emissions reductions, yet many continue to operate with outdated or inefficient heating, ventilation, and air conditioning (HVAC) control strategies. Although American Society of Heating, Refrigeration, and Air-Conditioning Engineers Guideline 36 (G36) provides a proven framework for high-performance HVAC controls, its complexity, implementation requirements, and compatibility challenges with existing building systems have limited its adoption in retrofit projects. Building owners, engineers, controls contractors, and utility program administrators need practical guidance that translates advanced control concepts into solutions that can be applied cost effectively in existing buildings.

To address this need, this project developed the Simplified HVAC Control Retrofits Design Guide, a practical tool intended to help practitioners identify, evaluate, and implement high-impact HVAC control improvements in existing commercial buildings. The guide focuses on retrofit applications where full G36 implementation may not be feasible, providing a structured approach for selecting control strategies that deliver meaningful energy savings while accommodating the operational and technical constraints commonly found in existing facilities.

The project pursued four primary objectives:

- Identify HVAC control measures with the highest energy-saving potential for existing commercial buildings.
- Evaluate how key G36 sequences can be adapted for retrofit applications.
- Develop a user-friendly design guide that supports the planning, design, and implementation of HVAC control retrofits.
- Assess opportunities to integrate these measures into utility energy efficiency programs and broader market transformation efforts.

The project combined literature review, technical analysis, industry engagement, and market assessment. The team reviewed published research, evaluated documented retrofit case studies, examined common HVAC system configurations and control deficiencies, and assessed the applicability of G36 strategies across a variety of existing-building conditions. Stakeholder engagement activities included discussions with design engineers, controls contractors, commissioning professionals, researchers, utility representatives, and other industry experts. This feedback helped ensure that the guide reflects real-world implementation challenges and industry needs.

A key finding of the project is that many of the benefits associated with advanced HVAC controls can be achieved through a focused set of retrofit measures that are both practical and cost effective. The resulting design guide emphasizes strategies such as dual-maximum variable air volume control, duct static pressure reset, supply air temperature reset, optimal start and stop sequences, demand-controlled ventilation, occupied standby operation, dynamic outdoor air control, and chilled- and hot-water temperature reset. The team selected these measures because they offer a strong combination of energy-saving potential, operational benefits, and feasibility for implementation in existing facilities.

Stakeholder feedback reinforced both the importance of the opportunity and the challenges facing the market. Participants consistently identified HVAC controls as a major source of untapped energy savings but noted several barriers to broader adoption, including limited familiarity with G36, perceived implementation complexity, lack of standardized guidance, control-system constraints, missing field instrumentation, and workforce training needs. Stakeholders responded positively to the concept of a simplified retrofit-focused resource and emphasized the value of practical implementation guidance, decision-support tools, and educational materials that can be applied across a wide range of building types and system configurations.

Based on the findings, the team recommends expanding the use of simplified advanced control strategies in existing building retrofit programs, increasing workforce training and technical assistance related to HVAC controls, and developing standardized approaches for evaluating and verifying control-based energy savings. Utility programs should consider incorporating these measures into commercial energy efficiency offerings, particularly through Strategic Energy Management and other programs focused on operational improvements. Continued promotion of commissioning and retro-commissioning practices is also recommended to ensure that control improvements achieve and maintain their intended performance.

The significance of this project lies in its ability to bridge the gap between advanced HVAC control theory and real-world retrofit implementation. By translating complex control sequences into practical guidance that can be applied in existing buildings, the Simplified HVAC Control Retrofits Design Guide reduces barriers to adoption and supports broader deployment of high-performance control strategies. The design guide provides a valuable resource for engineers, controls contractors, commissioning providers, building owners, and utility program implementers seeking to improve building performance without requiring extensive equipment replacement.

Ultimately, the project demonstrates that significant energy savings, operational improvements, and occupant comfort benefits can be achieved through thoughtful HVAC control retrofits. By enabling wider adoption of proven control strategies across the existing building stock, the guide has the potential to reduce operating costs, improve building performance, advance utility energy-efficiency objectives, and support long-term decarbonization goals.

Abbreviations and Acronyms

Acronym	Meaning
AHU	Air handling unit
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BAS	Building automation system
BRO	Behavioral, retro-commissioning, and operational
Cal TF	California Technical Forum
CAV	Constant air volume
CEC	California Energy Commission
CMC	Custom Measure Characterization
CMG	Custom Measure Guidance
CPUC	California Public Utilities Commission
DDC	Digital direct controls
EE	Energy efficiency
EUL	Effective useful life
G36	ASHRAE Guideline 36
GHG	Greenhouse gas
GSA	General Services Administration
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
MOB	Medical office building
M&V	Measurement and Verification
OAT	Outside air temperature
PG&E	Pacific Gas & Electric Company

Acronym	Meaning
PNNL	Pacific Northwest National Laboratory
RCx	Retro-commissioning
SAT	Supply air temperature
SEM	Strategic Energy Management
SOO	Sequence of operation
TSB	Total System Benefit
VAV	Variable air volume

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Introduction

More than 80 percent of buildings that will exist in 2050 are already built. Addressing energy efficiency (EE) in today's existing buildings is a key component to reducing overall energy consumption in the building sector. Detailed instructions for how to control heating, ventilation, and air conditioning (HVAC) systems efficiently in new construction are provided by American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Guideline 36 (G36) "High-Performance Sequences of Operation for HVAC Systems." Applying these strategies to existing buildings offers the potential for cost-effective energy savings and significant decarbonization. This project focuses on the development of a guide for identifying low-cost, high-impact control retrofit measures, and a package of recommended control sequences that are adapted from G36 to address typical conditions in existing buildings.

For full control system replacements, previous demonstration projects have cost effectively achieved up to 50 percent to 60 percent HVAC energy savings through applying G36 control sequences, but these efforts have involved costs and complexities that create barriers for scaling. For retrofits, the existing control infrastructure is often incompatible with G36 in its original form, so either the hardware must be upgraded to fully accommodate G36, or the sequences of operations (SOO) must be adapted to conform with the hardware limitations. Most practitioners do not have experience with G36, do not know which SOOs are most effective for energy savings, and do not know how best to adapt the SOOs to match typical existing HVAC control conditions.

The project focuses on the development of a simplified version of G36 targeted to retrofit projects in existing buildings. G36 Lite focuses on measures that can be implemented easily and economically, including ones that have often been overlooked by retro-commissioning (RCx) providers. The G36 Lite approach will promote the application and adaptation of key portions of G36 to the existing building stock to help achieve rapid and cost-effective energy savings. Similar past projects have achieved over 20 percent HVAC energy savings through simple programming and setpoint changes with short simple paybacks. Through this project, the final outcome of a new guide will help practitioners apply high-impact measures to retrofits and support scaling these concepts from G36 to reduce energy use and emissions in the existing building stock.

For utility programs supporting existing commercial buildings in California, G36 Lite strategies will help set the bar for implementers, utilities, and regulators regarding what is achievable in existing buildings and how proposed improvements can be both estimated and verified. The results of this work will support future program design.

This report lays out the background of the project, describes the methodology and approach, and reports on findings and recommendations. The Simplified HVAC Control Retrofits Design Guide is provided in Appendix A.

Background

Documented Challenges with HVAC Controls

Even though most building HVAC systems are generally similar, the current standard industry practice with modern direct digital control (DDC) systems is to develop custom sequences and control programming for each application or to adapt logic from a similar recent project. In addition to the process inefficiency of reinventing the wheel for each project, this practice also introduces the risk of problems and operational inefficiencies, such as poorly written sequences or incorrectly implemented programs. G36 offers opportunities for industry to streamline these processes by following standardized control sequences and leveraging centralized programming libraries that can be pre-tested and applied at scale.

Many aspects of G36 are already required conceptually in building energy standards (ANSI/ASHRAE/IES 2022) (International Code Council 2024) (California Energy Commission 2025). However, these long-standing code requirements have been found to have poor compliance rates in the field. For example, a Pacific Northwest National Laboratory (PNNL) study with similar code requirements for HVAC control measures found a 60 percent compliance rate for newly constructed buildings in the Pacific Northwest (Rosenberg, et al. 2017). In California, variable air volume (VAV) dual maximum control has been required by the Title 24 Building Energy Efficiency Standard since 2008 (California Energy Commission 2025), yet a 2023 review of a sampling of designs found VAV minimum airflows averaging 30 percent, far above the required limit, which typically ranges from 10 percent to 15 percent (Singla, et al. 2023). Anecdotally, the project team has also observed dozens of buildings constructed since 2008 that have not complied with this requirement. In field studies, this one issue has been found to impact HVAC energy use by up to nearly 20 percent (Arens, et al. 2015). A 2002 literature review of 40 case studies found that over one-third of 450 documented controls-related faults across 70 buildings could be attributed to faulty or incomplete programming (Barwig, et al. 2002).

While HVAC controls have significant impacts on building energy usage, the controls are often overlooked as EE measures in utility incentive programs due to the system risks and complexities, as well as concerns about performance persistence. Building staff sometimes override poorly performing controls, sacrificing EE in an effort to maintain occupant comfort.

Potential Benefits with G36

A large demonstration study funded by the California Energy Commission (CEC) evaluated the impact of retrofitting existing buildings with G36. Two types of retrofits were evaluated: full control retrofits where building automation system (BAS) hardware and programming were replaced, and software-only retrofits, which focused only on reprogramming the control logic (Cheng, Singla and Paliaga 2022). Figure 1 below shows the HVAC energy use intensities pre- and post-retrofit for full retrofit and software-only retrofit sites, with energy end uses broken out. For each retrofit type, two demonstration sites are shown, as well as another similar project that was not part of the demonstration. The full retrofit sites each achieved about 50 percent to 60 percent reduction in HVAC energy intensity.

Note that the medical office buildings (MOB) generally have a much higher energy intensity than non-MOBs. The roughly 80 percent fan savings at the MOB projects (both full retrofits) are striking, shown

in the reduction of the green bars in Figure 1. As a result, ASHRAE awarded the Vallejo project a national technology award in 2021 (Kiriu and Stein 2021). Among the software-only retrofit sites in Figure 1, the HVAC energy savings are also consistent within a range of 10 percent to 25 percent. Although the overall savings are lower than at the full retrofit sites, the first costs and level of disruption are also much lower, and all the retrofits shown had simple paybacks of eight years or less. A survey of G36 control retrofits across 38 existing buildings reported median HVAC energy savings of 42 percent in full retrofits and 19 percent in reprogramming-only projects (Deshpande, et al. 2026).

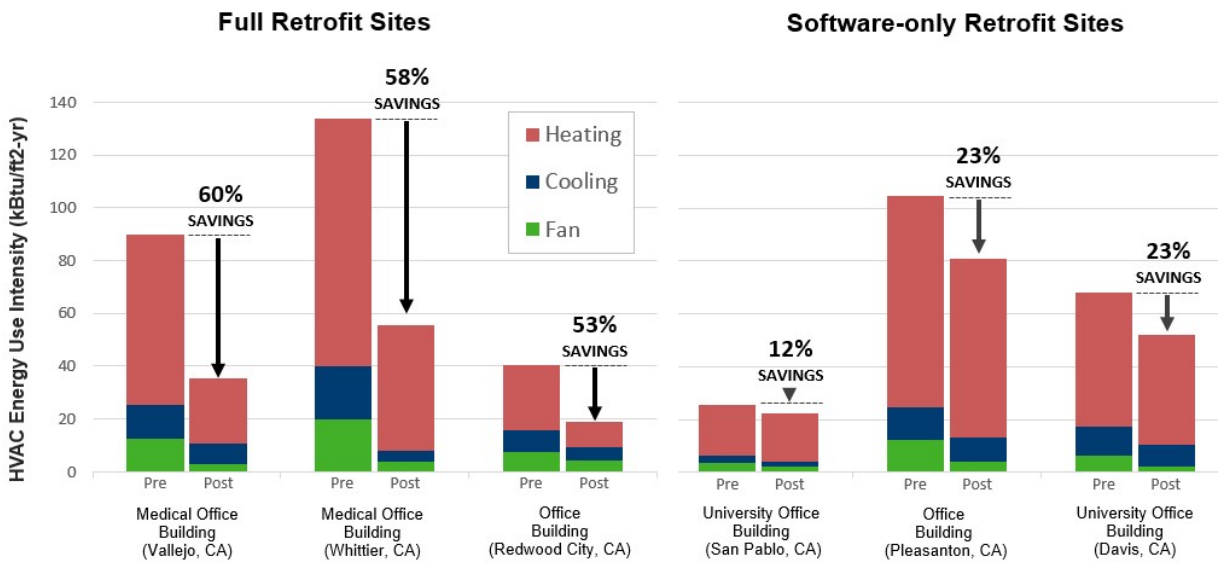

Figure 1: Guideline 36 retrofit energy savings.

An earlier field demonstration study conducted prior to G36's release modified a single software variable at each thermal zone (the zone minimum airflow) and reported 4 percent to 19 percent natural gas savings (an overall HVAC savings of 5 percent to 19 percent) across 5 commercial buildings in California (Arens, et al. 2015).

Results from simulations show the impact of control strategies on building energy use. An EnergyPlus study found that using different control strategies for common measures—like supply air temperature (SAT) reset, zone minimum airflow control, economizer control, and others—could vary HVAC energy use up to approximately 65 percent (Pang, Piette and Zhou 2017). A Spawn-of-EnergyPlus simulation of G36 controls retrofits shows similarly positive savings to the field studies above. For a medium-sized commercial building, using G36 sequences could provide an average savings of 31 percent compared to baseline control sequences representing existing practices (Zhang, et al. 2022).

Growing Awareness

G36 continues to gain awareness and traction, including its adoption in the General Services Administration (GSA) P100 Facilities Standard (U.S. General Services Administration 2024). The GSA is one of the largest holders of real estate in the United States, and its standards for buildings require that SOOs must follow the most recently published version of G36. Other building portfolios

have standardized on the use of G36, including higher education campuses such as the Contra Costa Community College District and Foothill–De Anza Community College District.

The 2015 version of the Washington State Energy Code included G36 as part of a prescriptive compliance option, even before the initial publication of G36 (Washington State Building Code Council 2015). That requirement was later removed in the 2018 version but was replaced by specific individual control requirements that derive from G36 strategies. ASHRAE Standard 90.1 includes informative references to G36 where there are related prescriptive control requirements (ANSI/ASHRAE/IES 2022). California's 2025 edition of Title 24 specifically references G36 as a prescriptive requirement for complying with many aspects of the code (California Energy Commission 2025). Though code compliance still falls short in many areas, the increased visibility and standardization of G36 in California will increase familiarity for designers and programmers, as well as building operators and owners.

Control manufacturers have developed pre-programmed libraries from which programmers can write sequences, cutting down on programming errors and time. Many manufacturers have also actively promoted the benefits of G36 through trainings, webinars, and white papers.[1,2,3] Additionally, there are a dozen or more synchronous training courses offered annually that focus on G36 through the ASHRAE Learning Institute, PG&E Energy Centers, and other programs.

Challenges with Scaling and Applying to Retrofits

Despite the success of field studies and simulations in implementing G36 in existing buildings, there have been challenges in using G36 at scale in existing buildings based on several real and perceived reasons.

There is a perception that G36 is too difficult or complex, which hinders its acceptance at multiple project levels, from the building owner to the programmer. The sequences in G36 are significantly longer and more detailed than conventional practice, and G36 is also primarily viewed as only being applicable to new construction, though numerous field studies have demonstrated the implementation of G36 in retrofit applications, as seen in Figure 1. Both of these factors can be remedied by manufacturer libraries of G36 sequences, but stakeholders must be aware of and trust these libraries for projects to be completed successfully.

In its current state, G36 may not be able to be implemented in some HVAC system types without modifications. While correctly modifying G36 sequences is a real challenge that requires advanced understanding of HVAC controls, there is also a perception by many practitioners that G36 controls cannot or should not be modified. Many existing sequences in G36 can be adapted or modified for use with HVAC equipment that are not directly covered in G36. For example, G36 provides sequences for VAV systems, but not constant air volume (CAV) systems. While VAV sequences such as duct static pressure control would not apply to a CAV system, SAT control sequences would apply and could be adapted for use with a CAV system to improve HVAC efficiency in existing buildings.

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[1] https://jcienus.qalive.jci.com/Building-Insights/Thought-leadership/Top-5-Benefits-of-ASHRAE-36

[2] https://www.trane.com/commercial/north-america/us/en/about-us/newsroom/blogs/system-controls-for-applying-ashrae-guideline-36.html

[3] https://resources.sw.siemens.com/en-US/video-improving-efficiency-ashrae-guideline-36/

Many users also do not recognize that some control sequences require that specific design information or sensors/devices be provided to operate effectively. Instructions on each of these required elements in G36 may go unnoticed due to lack of understanding in general and users being overwhelmed with the amount of information and detail in G36.

Limits to Retro-Commissioning Measure Portfolio

RCx involves evaluating an existing building's systems and may often result in HVAC control measures for improved efficiency, which is one potential point during which G36 controls could be implemented. However, this process tends to skip zone-level measures in favor of building-level measures because of lack of awareness. Conventional practice overlooks one of the most impactful energy measures in G36: dual maximum VAV control logic with low minimums. This simple measure has a cascading effect in that it tends to reduce not only zone-level airflow and reheat, but also system-wide fan, heating, and cooling energy all the way up to the air handler unit (AHU) and central heating and cooling plants. Also, as many G36 sequences involve zone-level feedback or setpoints, this limits the scope of measures that can be pursued for a building.

When control programming changes are made as part of RCx interventions, the strategies used often rely on simpler logic that less intelligently responds to building needs. For example, RCx efforts will commonly encounter a fixed supply air temperature setpoint in an existing building, where the conventional energy measure is to reset the setpoint linearly based on the outdoor air temperature (OAT). Cooling loads generally correlate well with OAT and this is a relatively easy programming change to make. However, it is an open loop control strategy with no feedback mechanism to consider whether the building's cooling demands are being satisfied. Furthermore, some thermal zones may have loads that do not correlate with the ambient weather conditions, such as interior conference or classrooms. If occupant comfort issues arise, this logic may be disabled via manually overridden equipment control. The G36 approach to SAT reset is more complex to implement but directly considers cooling demand to help ensure that thermal loads are satisfied.

Another limitation is the impact of ineffective controls programming that is either unchecked or undetected during an RCx implementation. Ineffective controls programming creates a negative feedback loop where operators and owners lose confidence in automated controls and opt for less efficient strategies that allow them to better manage comfort. This makes implementing future control changes harder.

Utility Program Landscape

As part of California's EE portfolio, various utility programs focus on improving HVAC controls as a resource allocation through BAS upgrades and RCx interventions. Some programs offer no- or low-cost HVAC control enhancements targeting specific market segments, such as hospitals or government buildings. Others are structured around the delivery models, such as Custom programs or commercial Strategic Energy Management (SEM). Other downstream program delivery models include Deemed, Hybrid (custom lite), and Direct Installation.

Historically, HVAC control measures have been primarily supported through Custom EE programs available to all large commercial and industrial customers—a universal approach that created significant administrative and implementation problems for HVAC control projects.

Key challenges with this one-size-fits-all model include:

- Determining accurate baselines, which includes distinguishing between existing conditions and mandated code requirements.
- Burdensome measurement and verification (M&V) requirements needed to verify pre- and post-performance for numerous and diverse measure types and sizes.
- Misalignment between program milestones and typical project development and implementation schedules.
- Difficulties in consistently quantifying program influence, incremental costs, and overall project cost effectiveness.

These difficulties prompted specific statewide policies and program guidance documents that targeted only no- or low-cost RCx opportunities within the existing Custom framework; this only partially resolved the issues. The most recent effort to improve support for these measures involves adopting the SEM model, which has shown considerable success in the industrial sector in recent years.

As a next step in program enhancement, this G36 retrofit guide serves as a common stakeholder reference to assess, implement, and report energy savings from advanced HVAC control strategies. This structure can help implementers effectively identify and respond to diverse market needs (e.g., full BAS upgrade, partial BAS upgrade, or key measure sequences). Increased stakeholder consensus and regulatory alignment on achievable G36 performance in real-world conditions can help existing programs realize deeper and more persistent energy savings and support the development of future innovative and responsive EE program models, possibly resulting in new Deemed, Hybrid, and Direct Installation offerings.

Integrating G36 resources into existing EE programs supports knowledge transfer and drives market transformation. The advanced control sequences outlined in G36 necessitate a level of programming expertise that may exceed the capabilities of some program teams and controls contractors. Improper implementation, commissioning, and operator training can lead to manual overrides or incorrect settings, undermining potential energy savings. Targeted outreach and education, which are a great fit for commercial SEM programs, can leverage the G36 retrofit guide to boost industry awareness of the standard's proven advantages and accelerate broader adoption.

Objectives

The objective of this project is to support the scaling of HVAC control EE measures in ASHRAE Guideline 36 to existing buildings. This effort will help users prioritize key energy measures in G36, as well as adapt G36 to the existing building stock in retrofit and RCx applications.

The project achieved these objectives by developing a design guide that will help direct the industry in how to apply G36 measures. Specifically, the design guide:

- Identifies the key energy measures in G36 and provides brief summaries that introduce each measure and highlight important considerations.
- Provides summaries of energy savings data from field and simulation studies.

- Includes guidance on how to evaluate control retrofit opportunities and recommendations for retrofit approaches.
- Provides recommendations for how to apply and adapt G36 strategies to different HVAC system types and control configurations that are common in existing buildings but not directly supported by G36.

The design guide is based on a compilation of information from published research, as well as feedback from subject matter experts. The primary target audience for the guide is energy analysts, RCx providers, design engineers, and building owners.

The project objective is also achieved through utility program recommendations such that G36 measures can proliferate, continuing to bring more awareness to G36.

Methodology and Approach

The project scope is divided into three major tasks.

Task 1: Review Existing Project Data

To better understand the range of typical existing HVAC systems and their overlap with systems covered in G36, the team gathered information from completed projects. This included compiling data on typical existing HVAC system conditions and HVAC control retrofit measures from past projects to understand the range of typical existing system types beyond what is covered in G36. In addition, the team compiled HVAC energy savings data to understand the cost impacts of control measures in existing buildings, informing the prioritization of recommended measures.

The team also coordinated with PNNL on modeling work that was outside the scope of this project to evaluate the energy savings impact of key measures.

Findings from this task were reviewed through discussions with outside stakeholders—including design engineers, energy auditors, and controls contractors—to confirm the list of system types and key measures, as well as gather input on key barriers.

Task 2: Develop Controls Retrofit Guide

The project team developed a design guide to help stakeholders identify key measures and effectively apply them to varying existing system and project conditions.

Based on work completed in Task 1, the team compiled a list of key measures. This work relied upon literature, as well as past project work and engineering judgement. Furthermore, the team adjusted the list of recommended measures based on findings from the PNNL simulation analysis.

In addition to key G36 measures, the team developed a list of adapted G36 measures for different HVAC system types not currently covered by G36. This list allows for application of G36 control concepts to common HVAC system types that are not directly referenced in G36.

The team also developed a list of adapted G36 measures based on different HVAC control configurations and the project budget and level of effort, which included developing guidance and decision matrices to assist decision-makers with evaluating opportunities and determining

recommended control retrofit approaches. For buildings with a mix of DDC and pneumatic controls or controllers that are not fully programmable, users will be able to understand which measures can be implemented with or without tweaks. Some measures may require hardware upgrades, while others can still achieve savings using the existing infrastructure.

The design guide is included in Appendix A. The technical content from the design guide will also be integrated into an existing chapter on retrofit applications in the Advanced Building Automation System Best Practices Guide (Cheng, Eubanks and Singla 2022), a guide that was developed in 2022 as a part of a CEC project. The Best Practices Guide is available online for free[4] and has high visibility, with over 4,000 views since it was initially posted in 2022.

Task 3: Program Characterization and Development

In support of the Task 2 effort, the team used a mixed-methods approach to characterize program opportunities. The project team integrated a literature review of program policies and implementation plans—combined with interviews and discussions with program implementers, controls contractors, and RCx providers—to determine where G36 can most effectively support existing and future EE programs. Collectively, these methods yield both qualitative and quantitative insights into stakeholder needs and the potential advantages of integrating G36.

The literature review guided the design of program interviews. By synthesizing recurring themes and gaps identified in existing demonstration projects, market studies, and program evaluations, the project team developed tailored questions for different market actors, including program implementers, program engineers, controls contractors, and utility program representatives. The team also reviewed and presented EE program delivery types and G36 applicability.

The interviews with program implementers were designed to achieve several key objectives. Primarily, they helped validate our understanding of current program offerings, G36 experience, evaluation tools, and market barriers, confirming that the challenges the project team has identified align with real-world conditions. Furthermore, the interviews offered critical insight into the decision-making processes and motivations of program implementers and the customers they support. Refer to Appendix B for an example interview guide.

Findings

Overview

The findings section presents a summary of market research, design guide development results, and the utility program characterization. This section also provides a summary of stakeholder feedback on the project findings and design guide materials.

Market Research

Published research reports on G36 largely focus on the potential benefits and advantages of G36, but there is much less documentation of challenges faced when deploying G36. However, anecdotal

[4] https://tayloreng.egnyte.com/dl/phXTDfFQb8/2022-06-13_BAS_Best_Practices_Guide_v1.0.pdf_

feedback from individual project experiences and other unpublished information (when considered collectively) provides an indication that the industry faces some broader challenges when applying G36 at scale, particularly in retrofit applications. Understanding the barriers is key to identifying and developing solutions to help overcome them. This section summarizes some of the challenges that have been encountered and expressed in various G36 applications.

Government Building Control Retrofit

A government building underwent a control retrofit as a pilot project for using G36 control sequences. The project faced several challenges in design, installation, and project execution, stemming from project team inexperience with G36 and lack of rigor in the project delivery approach.

- **Vague scope of work:** The retrofit was performed by an installer with a negotiated contract, who developed the scope of work in a report style rather than a detailed set of drawings and specifications that might have been required for a competitively bid project. Submittals were not a required project element but could have helped to ensure that project requirements were met. The scope included excerpts of control sequences from G36, but they were disorganized (not following the logical organizational structure in G36), poorly edited with gaps and conflicts, and some detailed sequences were incorrectly modified.
- **Overlooked measures:** The project scope focused on the AHUs, specifically excluding zone-level controllers, because of budget and other external factors. The project designers unnecessarily omitted key energy measures (i.e., SAT and duct static pressure resets) that require feedback from the zone level, not realizing that there are approaches to implementing these measures without making programming changes at the zones.
- **Required sensors missing:** The project scope included control sequences from G36 but did not include the addition of sensors required for those control strategies—specifically, a building static pressure sensor for building static pressure control and a return fan discharge pressure sensors for return fan speed control.
- **Incorrect ventilation calculations:** A secondary goal of the project was to verify that required ventilation airflow rates were provided, which can be both an indoor air quality and an EE measure to ensure that minimum required rates are met but not excessively exceeded. Because the project scope did not include zone-level work, the designer chose to omit zone-level ventilation calculations, overlooking the fact that the ventilation requirements in ASHRAE Standard 62.1 cannot be correctly calculated without these inputs.
- **Lack of effective commissioning:** The building owner chose to self-perform the commissioning process rather than engage a professional commissioning provider. Commissioning processes that were thus omitted from the project included peer review, submittal reviews, and functional performance testing.

Library Control Retrofit

A control retrofit of a library building in Minnesota served as a G36 demonstration project (Zhou, et al. 2025). The building owner covered costs for the end-of-service-life control retrofit and agreed to apply G36 control sequences. The role of the demonstration project team was largely limited to measurement and verification. The demonstration project encountered several issues with the implementation of G36 and, as a result, largely failed to achieve the desired EE improvements. Several of the factors that impacted G36 implementation are summarized below.

- **No design engineer on board:** The demonstration was implemented as a hands-off retrofit with no design engineer involved, and the research team was led by a project engineer who had limited HVAC control experience. The contractor had no previous experience with G36 but was responsible for adapting the sequences to the project requirements and determining information that a designer would normally provide.
- **Existing HVAC system deficiencies:** Over the course of the project implementation, the team discovered numerous issues with the existing mechanical equipment. The project scope only included budget to upgrade the controls and did not resolve the mechanical issues, which significantly hampered the effectiveness of some of the control system measures. It is common to encounter deferred maintenance issues in retrofit projects.
- **Required sensors not provided:** The project did not include installation of an outdoor airflow monitoring station or building static pressure sensor in order to align with the control sequences in G36. Without a means to measure outdoor airflow, the contractor was forced to resort to controlling minimum outdoor air with a fixed minimum damper position. This approach does not meet current building code requirements and best practices but is a common occurrence. The return fan control sequence in G36 also could not be implemented without a building static pressure sensor.

Round Table Discussion on G36

A large building portfolio owner that has required the use of G36 convened a discussion with its team of consultants to solicit feedback on experiences with G36. Though there were some positive comments on the potential benefits of standardization and improved energy and comfort performance, many of the consultants expressed frustration and described implementation challenges.

- The owner required the use of G36 verbatim without modifications, which most consultants found too strict. Many of the HVAC system types in this building portfolio are outside of the range of types directly supported by G36, which necessarily requires some level of adaptation.
- There were repeated complaints about the complexity of G36, difficulty with using the long Microsoft Word document, and lack of contractor experience with G36, all of which contributed to projects expending more time and effort using G36 rather than realizing the promise of reduced cost by streamlining and standardizing on a single approach.
- Many consultants expressed that the G36 requirement made sense for new construction but should be relaxed for existing buildings and projects where only a portion of a system is being upgraded. One consultant recommended that the G36 requirement be removed altogether.
- Many consultants assumed that G36 was a turnkey solution and could be successfully applied with little additional work beyond conventional practice by the designer. Rather than editing and adapting the sequences in G36 to just the elements applicable to a specific project, many designers simply required the use of G36 or included the full set of G36 sequences in their specifications, which did not provide clear scopes of work for the installers.

Other Feedback

- One engineer specified G36 by referencing required sections but did not create a set of conformed sequences to give the project team a coherent overview of how the systems were to be controlled. The contractor refused to do this, which meant the responsibility fell on the commissioning agent, who needed clear sequences to be able to conduct their testing. The lack of conformed sequences earlier on in the project timeline led to confusion and missed requirements that could not easily be overcome later on in the commissioning process.
- On one project, the occupied-standby measure was applied as a code-required measure with occupancy sensors at each of the zones. However, the designer failed to provide zone-level ventilation requirements to accompany the sequences, which meant that the contractor could not implement the code-required reset of the system-level outdoor air intake based on the zone sensing.
- When provided an edited copy of G36 sequences that were adapted for a specific building application, a control programmer repeatedly did not recognize the document to be the project-specific sequences, misunderstanding the document to instead be the full guideline. Conventional sequences consist of a paragraph or two for each equipment that express the very basic control intent, whereas the equivalent sequences in G36 may consist of 10 pages of detail that aim to explicitly describe all of the required control logic. For those that have not used G36 before, this is such a departure from conventional practice that it can be unrecognizable as control sequences.
- A building was updated with G36 control sequences in conjunction with an AHU replacement. Rather than extending the update to the zone controllers, the existing configurable (non-programmable) zone controllers were instead retained and left out of the scope. The project did not take advantage of the significant energy savings available with implementing zone-level G36 measures, such as dual maximum VAV logic. The project team also did not recognize that dual maximum performance could largely be achieved simply by adjusting the configuration settings, without requiring any controller replacements or reprogramming. These missed opportunities were discovered and implemented as part of a separate subsequent project.

Summary

Below, we have summarized some of the key market research findings that this CalNEXT effort aims to help address.

- There is considerable lack of experience and understanding of G36. More workforce training and supporting materials are needed to help users understand how to successfully use G36.
- Some of the most effective energy measures are overlooked or improperly implemented. Guidance is needed to help identify these key measures and highlight important design considerations.
- Many users attempt to apply G36 without providing comprehensive design requirements to accompany the G36 sequences, particularly in retrofit applications where additional sensors or devices may be needed.

- Many users can be overwhelmed by the length and detail in G36 compared to conventional sequences. Additional guidance may be beneficial as introductory training for new users.

Design Guide Development

The adoption of G36 in new and existing buildings across California and the United States has been hindered by its complexity, system applicability constraints, and contractors that often lack familiarity. These market conditions create substantial obstacles for utility program interventions and successfully applying G36 in general. Some of the specific barriers include:

- G36 is over 300 pages long, which makes it difficult for new users to get familiarized.
- G36 is written in a control sequence language style that describes control logic, rather than plain language descriptions, which may be difficult for some users to understand.
- There are dozens of distinct EE measures in G36 that are well known to experienced users of the guideline. However, the sequences in the guideline are organized by equipment and function, not by energy measure. Some of the key energy measures span multiple sections of the guideline (e.g., morning warmup), which may make them difficult for new users to identify, and some of the key measures are not even referenced by their common names in the guideline (e.g., dual max VAV logic and optimal start).
- Attempting to apply all of G36 to a project may be challenging and new users in particular may not know what areas to focus attention on to provide the best value and effectiveness for their projects.
- Each G36 control sequence requires specific control infrastructure (i.e., control inputs and outputs) and design values, but many users select sequences from G36 without detailed consideration of the physical hardware and information needs.

Retrofit applications of G36 offer an enormous opportunity to provide energy savings in the existing building stock but face additional barriers, including:

- EE projects in existing buildings are often led by energy auditors and RCx providers rather than design engineers, who may have less experience writing and editing control sequences or managing comprehensive control retrofits.
- G36 is focused on best practices, so it specifically addresses best-practice HVAC system types (i.e., VAV). Many existing buildings have older HVAC system types (e.g., CAV, single fan dual duct) that are no longer common in new construction and that are not directly supported by G36. Nevertheless, there are many sequences in G36 that may still apply to these older system types, or that can be adapted to improve energy performance.
- Each G36 control sequence requires specific control infrastructure (i.e., control inputs and outputs), some of which are not typical in existing buildings. In these cases, judgment needs to be applied whether to modify the physical control infrastructure or to modify the control sequence to match the physical infrastructure.
- There is a wide range in options for control upgrades for existing systems, from complete replacements of hardware and software to targeted sensor/device replacements to programming or setpoint changes only. In addition to the energy savings opportunities, there are myriad considerations that may influence recommendations on what type of upgrade to pursue, such as remaining service life for the HVAC and associated control

equipment, project budget and economic criteria, tolerance for disruption in occupied buildings, operational performance, etc.
- Many projects are driven by economics, but it is difficult to accurately evaluate both the energy savings opportunities and the project implementation costs for control retrofits.

To overcome some of these challenges, the design guide provides guidance that is intended to lower barriers to becoming familiar with G36 and identifying applicable G36 strategies to existing building conditions (Appendix A). Specifically, this guide aims to provide a roadmap that:

- Identifies and summarizes main factors for key measures in G36.
- Adapts SOOs to variants of modern typical HVAC equipment configurations.
- Adapts SOOs to existing system constraints.
- Provides guidance on determining appropriate project scopes for different existing conditions.

An additional barrier echoed by many stakeholders is the difficulty in evaluating the energy savings potential with G36 retrofits and providing decision-makers with economic justification. Various efforts have aimed to develop simplified savings calculators to serve this purpose, but none so far are ready for full-scale deployment. Though a savings calculator was beyond the scope of this project, the design guide also includes a summary of available energy savings data from past field and simulation studies, including detailed simulations of individual measures, to help users understand the energy savings potential in retrofit applications.

This G36 retrofit guide provides utility programs with a standardized reference for best practices, benefiting utility program managers, third-party program implementers, regulators, controls contractors, and RCx providers. Fostering a shared understanding of the path toward G36 adoption, barriers to implementation, and potential solutions can help streamline existing program delivery, project assessment and review, measure implementation, and savings verification.

Utility Program Characterization and Development

An investor-owned utility (IOU) program manager must navigate California's complex and evolving EE regulations, which is primarily set by the California Public Utilities Commission (CPUC). These regulations are designed to achieve the state's ambitious clean energy and greenhouse gas (GHG) reduction goals by prioritizing energy efficiency as the state's “first resource.” This section explores how the G36 retrofit guide can benefit the IOUs’ resource acquisition programs by helping them navigate RCx program delivery barriers, realize greater verifiable and cost-effective energy savings in existing buildings, as well as serve as a steppingstone in market education and adoption.

There are multiple stakeholders involved with utility program projects; the specific stakeholders involved with an EE project can vary depending on the EE program delivery type. EE RCx measures normally fall within five primary program delivery types:

- Custom
- Commercial Strategic Energy Management (SEM)
- Custom-Lite
- Direct Install
- Deemed

The following subsections describe the program delivery types, associated key roles, EE project workflows, and considerations relevant to the EE measures in the G36 retrofit guide. The final subsection summarizes key takeaways and provides program delivery guidance.

Custom Approach

Under the Custom approach, EE programs pay an incentive to a commercial business based on the amount of energy that a specific project saves. Custom measures are designed for unique energy efficiency projects and require detailed engineering and energy savings analysis. This pathway is ideal for complex retrofits, specialized equipment upgrades, or process improvements that cannot be addressed with standardized savings estimates. A Custom EE project workflow tends to follow a step-by-step process, described as follows:

Energy Audit → Baseline Verification → Pre-Application Approval → Installation → M&V Review → Payment

1. **Energy Audit:** Customers are either identified through program marketing and outreach or are introduced as project leads by IOU account representatives and HVAC contractors. A program implementer then evaluates a facility and models savings potential.
2. **Baseline Verification:** The program implementer works with the customer and/or a controls contractor to evaluate existing baseline data and conditions, identify potential measures, calculate energy savings, and prioritize and incentivize implementation. These findings are then submitted to the program administrator and CPUC for review and approval. It is at this stage that insights contained in the G36 retrofit guide can help program engineers identify opportunities in the discovery process and communicate real-world situations and solutions for implementing G36 measures in existing buildings.
3. **Pre-Application Approval:** The customer, in collaboration with the program implementer, submits a project feasibility study. This pre-installation submittal contains engineering plans, baseline data, energy savings calculations, and a proposed M&V plan for IOU and CPUC review and approval. If approved, the IOU will issue a formal notice to proceed, which must be received prior to signing vendor contracts or purchasing any equipment/upgrades or implementing any proposed measures.
4. **Installation:** The customer then purchases, installs, and commissions the pre-approved RCx measures.
5. **Measurement and Verification (M&V):** The program implementer conducts a field inspection and reviews data logs to confirm actual post-implementation energy reduction, consistent with the Pre-approved M&V plan.
6. **Payment:** The program administrator reviews and approves the final incentive estimates based on verified performance data and releases the funds.

Custom EE projects in CA have faced significant hurdles, leading to a decline in program participation and associated energy savings statewide. Key challenges include:

- **Regulatory Uncertainty:** Requirements and guidance are often unclear, out-of-date, dispersed across multiple sources, and inconsistently applied.
- **Administrative Burden:** Projects are hindered by extensive, duplicative, and time-consuming documentation requirements.

- **Review Timelines:** Project review timelines are frequently lengthy, costly, and unpredictable, which discourages customer and market actor participation.
- **Inconsistent Attribution:** There are often multiple and inconsistent assessments for project "influence" and attribution, creating further uncertainty.

To address these challenges, the California Technical Forum (Cal TF) and the CPUC have developed a suite of priority solutions to revitalize these site-specific projects. Key priority solutions include:

- **Centralized Rulebook:** Establish a single statewide library for clear, consistent, and up-to-date guidance for custom projects.
- **Streamlining and Standardization:** Simplify processes to eliminate unnecessary costs, using standardized custom project review guidelines and templates for improved efficiency.
- **Customer-centric Design:** Focus policies on the needs of market actors to increase project adoption.

Even though the CPUC has taken steps to address program barriers through their Custom Project Review Continuous Improvement effort, there are still structural policy requirements that impede the Custom program delivery approach. For example, RCx measures involving HVAC controls have traditionally been faced with a lower effective useful life (EUL) of three years, thereby inhibiting cost effectiveness. Also, the pre-approval "notice to proceed" requirement delays implementation of RCx measures that can be easily and immediately implemented, resulting in delayed energy and cost savings for the customer. For custom EE measures, the G36 retrofit guide may serve as a common stakeholder reference to assess, implement, and report energy savings from advanced HVAC control strategies. Refer to the Guidance to Program Implementers and Administrators subsection for additional information and forward-looking utility program guidance.

Commercial Strategic Energy Management (SEM)

Commercial SEM programs are a new program offering recently added to IOU portfolios that allow greater flexibility via their verification processes, delivery approach, and extended customer engagement. Until recently, SEM programs had been limited to the industrial sector. However, due to their success, they were expanded to the commercial and institutional sectors given the diminishing returns of equipment-based incentives, the potential for low-cost operational savings, and favorable regulatory and savings parameters (i.e., a net-to-gross ratio of 1.0 and five-year EUL).

Unlike traditional Custom programs that offer a one-time incentive, SEM programs are structured as a multi-year partnership (i.e., typically one to three years), where the primary goal is to capture low-cost or no-cost operational savings supported by a gradual reduction in total building energy use (e.g., 3 percent to 5 percent per year). Successful SEM program implementation requires commitments from both the utility and different tiers of the customer's organization. An SEM program workflow tends to follow a step-by-step process, described as follows:

Onboarding and Policy Setup → Team Formation → Energy "Treasure Hunt" → Baseline Modeling → Implementation and Tracking → Performance Payout

1. **Onboarding and Policy Setup:** SEM programs enroll participants through outreach methods, such as via shared workshops that target several non-competing businesses. Prospective

businesses must sign an agreement with the utility and issue an internal energy policy to validate the program's authority.

2. **Team Formation:** A designated energy champion builds out the cross-functional internal energy team.
3. **Energy "Treasure Hunt":** The SEM coach guides the internal energy team through a thorough onsite walkthrough to identify energy waste. The team records findings into a centralized opportunity register and ranks items by cost, ease of implementation, and energy impact. As with Custom, it is during this phase of system and site assessment that the G36 retrofit guide educates and informs SEM program stakeholders of the potential for implementing G36 measures, with key considerations, workarounds and cautions.
4. **Baseline Modeling:** A utility technical expert pulls historical consumption data and uses linear regression modeling to account for external variables like weather conditions and building occupancy to predict what the building will use without intervention.
5. **Implementation and Tracking:** The facility executes low-cost and no-cost operational adjustments from their register. The energy team meets regularly with the SEM coach and participates in cohort workshops to track progress against the regression model. At agreed milestone periods (e.g., end of the program year), the utility compares actual energy bills against the baseline model to calculate avoided energy consumption.
6. **Performance Payout:** The utility pays out incentives based on a fixed rate for every verified unit of utility savings achieved through behavior and operational changes.

Commercial SEM programs can immediately benefit from the information and resources contained in this report. As previously mentioned, the Guidance to Program Implementers and Administrators subsection contains additional information and forward-looking utility program guidance. Other program delivery types that can benefit from the G36 retrofit guide and offer a deeper solution to these challenges include custom-lite and direct installation.

Custom-Lite Approach

A custom-lite (hybrid) program delivery framework optimizes RCx by merging the site-specific flexibility of custom projects with the speed and consistency of standardized Deemed measures (discussed in a later subsection). Championed by the Cal TF Hybrid Measure Subcommittee, this model directly targets the high administrative overhead and lengthy review cycles that typically bottleneck traditional RCx initiatives. To operationalize this approach, Cal TF developed a Custom Measure Characterization (CMC) template designed to serve as a collaborative platform for stakeholders to share measure-specific information and vet custom analysis tools. Their effort relies on the principle that a unified understanding of measure characteristics, combined with simplified evaluation tools, will mitigate savings uncertainty and streamline the management of real-world implementation challenges across all program levels.

Unlike traditional RCx, which is often processed as a fully Custom project with unique and complex calculations for every building, the technical requirements for custom-lite RCx measures are designed to provide a "partially deemed" path where standard engineering formulas are applied to equipment-specific data. To qualify for this pathway, building systems may have to meet specific operational or eligibility criteria. Custom-Lite RCx projects are not "hands-off"; they still require rigorous verification to ensure the restoration and improvement of energy performance. However, the custom-lite delivery streamlines program workflow by:

- **Standardizing engineering calculations:** Instead of creating a new model for every site, a custom-lite RCx program could use pre-vetted, standardized engineering formulas from the Custom Measure Guidance (CMG) library. The library currently includes an HVAC RCx tool that evaluates airside, waterside, and boiler systems improvements; example measures include scheduling, sequencing, pressure and temperature resets, economizer operations, and VAV minimum settings.
- **Simplified site inputs:** Users only need to provide specific site data into a fixed formula rather than building a custom simulation from scratch. Simplified 36-Lite can be added to the RCx CMG package as a resource used to improve RCx site assessments, identify best-practice solutions, maximize program impacts, and lower program administrative costs.
- **Predictable pre-approvals:** Because the underlying calculation methodology is "pre-deemed" by the program administrator, CMG tools and guidelines can make the review process faster and more predictable for implementers. Custom-Lite programs would benefit from the G36 retrofit guide by aligning policies and processes to support customers and market actors in the development and implementation of G36 measures.

A custom-lite program workflow tends to follow the same step-by-step process outlined previously for a traditional Custom program—often with the exception of the pre-approval requirement, given a clear understanding of the baseline data requirement needed for the post-installation submittal and final-incentive IOU review and approval. This offers reduced administrative burden and faster review cycles for candidate EE projects where potential incentive levels (e.g., <$25,000) may only require low-rigor M&V, or where standard tools and partially deemed input assumptions can be agreed upon. To take full benefit from a custom-lite approach, custom policy exceptions requests may require CPUC review and approval, either as a program modification or new program proposal/pilot. Program implementers and administrators should consider the following:

- Approval of a proposed CMC and its described methodology, including eligibility, project prerequisites, data collection required, and its streamlined M&V plan. As previously mentioned, an RCx CMC and tool already exist, and a CalNEXT report and tool enhancement are forthcoming.
- Approval of how RCx energy savings are determined and their estimated values using the proposed calculation tool.
- Waiver from the pre-installation and CPUC parallel review process, thereby deferring CPUC review until after installation.

For an existing custom program, these accommodations would require the submittal of an early opinion request to the CPUC for their review and approval. New program solicitations can simply incorporate these features into their program proposal.

Direct Installation Approach

Direct Install program delivery, often referred to as a "turnkey" approach in the context of RCx, streamlines building optimization by removing the primary financial and administrative barriers that typically stall custom projects. For example, by providing RCx services at no upfront cost to the customer, program administrators can rapidly deploy standardized energy-saving measures across a broad portfolio. The direct install model can transform RCx from a complex, multi-stage custom project into a simplified service via:

- **Elimination of upfront costs:** Unlike traditional rebate programs that often require customers to pay for upgrades and seek reimbursement, direct install programs provide and directly install energy efficient measures at minimal or no cost.
- **Pre-approved expert networks:** Programs can use a network of qualified service providers to conduct screenings, scoping, and deep-dive investigations at no charge to the owner. The G36 retrofit guide could provide deeper savings and greater consistency in program delivery.
- **Faster implementation:** Because the program implementer might oversee the contractor selection and payment, the implementation phase—where repairs, replacements, and revisions occur—can be completed more quickly, often within mandated timelines.

Deemed Approach

Under the Deemed (or "Prescriptive") approach, programs offer a set incentive based on an approved equipment or energy upgrade purchase. Deemed measures rely on predefined savings estimates based on historical data, prior program projects, program evaluations, and industry standards, making them ideal for simple, standardized projects like lighting upgrades, where savings can be easily predicted. A Deemed EE project workflow tends to follow a step-by-step process, described as follows:

Purchase and Install → Submit Application and Receipt → IOU Desk Review → Payment

1. **Purchase and Install Equipment/Upgrade:** The customer purchases an approved item or service listed on the program's active Deemed rebate catalog. A licensed contractor performs the installation or service at the commercial facility.
2. **Submit Application and Receipt:** The customer completes and submits an application to the program with attached proof of purchase, and all other data requirements specified by the Deemed workpaper.
3. **IOU Desk Review:** A utility engineer reviews application data (e.g., invoice model numbers) to verify program eligibility.
4. **Payment:** The program implementer awards the funds to the customer.

For an RCx measure to become a Deemed measure listed on a program's Deemed rebate catalog, a Deemed workpaper must first be developed, then reviewed and approved by the utility. Deemed workpapers for RCx measures typically contain thorough analysis of baseline conditions, supporting field evidence to justify assumptions, and detailed energy savings estimations. For reference, examples of existing behavioral, retro-commissioning, and operational (BRO-RCx) workpapers include Economizer Controls, Commercial (SWSV010-04); Economizer Repair, Commercial (SWSV005-04); and Supply Fan Controls, Commercial (SWHC009-05).

Deemed approaches have historically excluded RCx measures, which involve complex savings calculations, large variability of existing conditions, and insufficient market data to justify workpaper stipulations. However, recent and active field demonstrations of specific G36-based RCx measures—combined with ongoing energy modeling studies (Lu, et al. in press)—may offer data sources to support deemed measure development in the future. More information is available in the Guidance to Program Implementers and Administrators subsection below.

Guidance to Program Implementers and Administrators

ASHRAE G36 establishes a standardized framework for high-performance HVAC control sequences, replacing custom, site-specific programming with universally applicable, optimized logic. While a standard RCx retrofit saves energy by fixing HVAC control problems that return a system to its original design performance, upgrading to G36 delivers deeper, systematic advantages. However, program implementers and administrators can be faced with internal and external challenges related to communicating sequence complexity, overcoming fear of the unknown, addressing control limitations of legacy systems and controllers, and managing engineering skill gaps. The intent of the G36 retrofit guide is to provide a reference tool for current and future program stakeholders that brings awareness to the benefits and features of key G36 measures, identifies potential implementation and commissioning workarounds, and highlights potential pitfalls.

MEASURES: GOING BEYOND TRADITIONAL RCX

The G36 retrofit guide presents a set of 10 focused G36 measures that demonstrate the greatest energy savings with the least amount of implementation burden. The 10 measures include:

- Dual Maximum VAV with Low Minimums
- Duct Static Pressure Reset with Trim & Respond Logic
- Supply Air Temperature Reset with Trim & Respond Logic
- Optimal Start and Morning Warmup
- Demand Controlled Ventilation
- Occupied Standby
- Zone Heating and Cooling Setpoints with Demand Levels and Limits
- Dynamic Minimum Outdoor Airflow Setpoint
- Chilled Water Supply Temperature Reset with Trim & Respond Logic
- Hot Water Supply Temperature Reset with Trim & Respond Logic

To utility program stakeholders, many of these measures will appear familiar. However, some key points and differences are worth highlighting:

- Dual Maximum VAV with Low Minimums:
  - Can be applied in many existing VAV controllers, and workarounds are included to address common perceived field challenges like limited controller configuration capability and challenges with DX cooling equipment.
  - Are anticipated to offer a high EUL (i.e., > three years), as the control system settings targeted are unlikely to be modified by building owners and tenants.
  - Have shown a positive impact on occupant comfort, thereby removing motivations to override the associated control system settings (Arens, et al. 2015).
- G36 Trim and Respond Reset strategies offer key advantages over traditional resets. G36 Trim and Respond Reset strategies:
  - Are demand-based and feature an “importance multiplier,” which is a weighting or prioritization factor that can be user-adjusted to ensure that critical zones will not be starved for colder air or more airflow when needed. This factor can even be set to zero for

noncritical zones where the user chooses to prioritize energy efficiency over precise, local temperature control.
  - Automatically track rogue zones, which are otherwise cumbersome to track via traditional reset implementations.
  - Are anticipated to offer a moderate EUL, as they allow the user to balance energy efficiency and comfort without overriding setpoints.

Refer to supporting documentation in in Appendix A for further information.

In order to streamline retrofit implementation and minimize complexity, the G36 retrofit guide omits many "bonus" features of native G36, which may otherwise be infeasible due to existing controller limitations or may extend the project schedule and labor. Some of the omitted features include alarming, controller embedded automatic fault detection and diagnostics, hierarchical alarm suppression, and time-based suppression.

PROGRAM DESIGN CONSIDERATIONS FOR G36

Utility program stakeholders in California who seek to leverage the G36 retrofit guide should understand the Total System Benefit (TSB) metric and associated interactions with G36. The CPUC recently adopted the TSB metric to assess the cost effectiveness of IOU programs. This test moves beyond simple energy savings to include broader system benefits like GHG reduction, avoided costs, and enhanced grid reliability, which can all better align EE programs with state climate policy. The TSB metric highly values energy projects that reduce natural gas consumption and have a long measure life. This poses a couple of challenges for RCx projects, but those challenges have the potential to pair well with G36 opportunities, as described in the following paragraphs.

The first challenge-opportunity pairing is related to the EUL of EE measures. Under current state policy, G36 upgrades in existing buildings would qualify as RCx measures, which fall under the BRO measure type. The default EUL of a BRO measure is 3 years, which limits the TSB value of a retrofit. Implementing specific G36-based control sequences that have shown greater performance persistence compared to traditional HVAC control RCx measures may warrant a higher EUL, and thus, greater TSB. For example, the control system settings targeted by the Dual Maximum VAV with Low Minimums measure (i.e., one of the key measures highlighted in Appendix A) are unlikely to be modified by building owners and tenants. The initial values used to program the associated VAV box controller logic are established by technicians during the implementation process and tend to remain intact for the controller's lifespan. Also, as demonstrated by past research studies, this measure has shown a positive impact on occupant comfort, thereby removing motivations to override the associated control system settings (Arens, et al. 2015). One of the features of commercial SEM programs is that they are allowed to use a higher EUL of five years for RCx measures.

The next challenge-opportunity pairing involves missed opportunities with zone-level HVAC equipment. Stakeholder feedback has shown that most control improvements involving RCx tend to focus on the major central HVAC systems serving the building, such as air handlers, pumps, chillers, and boilers. Zone-level controls are often overlooked by owners, designers, and RCx providers due to lack of awareness of zone control impacts on energy consumption, lack of resources to assess zone limit conditions, and/or a bias toward comfort over energy efficiency. This often results in excess air supply, ventilation, and reheat. Proper VAV box control has the potential to yield significant gas

savings, which would increase a project's TSB, incentivizing programs and customers to further pursue G36.

For future Deemed opportunity consideration, additional research and IOU support in the development of RCx deemed workpapers is recommended. For example, a Deemed offering for Dual Maximum VAV with Low Minimums—an often-overlooked RCx measure—could provide a timely and easily estimated rebate for customers and RCx providers currently engaged or interested in implementing advanced HVAC controls at the zone level. Since Dual Maximum VAV with Low Minimums are fixed setpoint changes, this measure has the characteristics of predictability and verifiable energy savings necessary for workpaper development. However, Deemed workpapers still require sufficient data collection and energy modelling to support baseline conditions and to demonstrate a normalized unit savings (e.g., therms or kilowatt-hours per 1,000 cubic feet per minute reduction). This needs to be repeated for various HVAC system types, Database for Energy Efficient Resources building types, and climate zones. Future research for Deemed G36 should focus on measure level persistence (i.e., VAV Minimums versus SAT Reset, and Standard RCx versus G36) and measure-specific baseline data collection to support workpaper development.

In parallel with developing Deemed workpapers for specific RCx measures, there is a need to address broader program design gaps that limit the deployment of advanced, G36-based control strategies in existing buildings. Existing utility programs may promote some level of HVAC control upgrades, but they often miss major opportunities to achieve persistent energy savings. While a complete G36 implementation has been shown to achieve significant energy savings, such an implementation is often impractical in existing systems due to combination of application complexity, legacy equipment, and integration constraints. As a result, significant savings opportunities are left untapped because programs lack clear pathways for applying G36-inspired strategies in RCx contexts. The G36 retrofit guide addresses this gap by providing simplified, retrofit-ready control approaches that align with utility objectives while being feasible and cost-effective for existing buildings. Key areas where program delivery can benefit from the G36 retrofit guide include:

- Improved site assessments
- Refined energy-savings opportunity identification
- Improved post-implementation performance
- Enhanced project oversight and stakeholder review
- Greater performance persistence (i.e., longer EUL)

CURRENT PROGRAM OPPORTUNITIES

At this time, the program pathways readily able to adopt EE measures in the G36 retrofit guide are the custom and commercial SEM pathways. As previously discussed, these guidelines can provide deeper and more resilient energy savings that are often overlooked due to a knowledge gap of key G36 measures, lack of real-world experience, and unfamiliarity with potential workarounds required for existing buildings, systems, and control limitations. To reap the above benefits, the G36 retrofit guide needs to be disseminated to the appropriate stakeholders. This can be accomplished via:

- Posting the guide to the Cal TF website as part of the RCx Custom Measure Library, which the project team is collaborating with Cal TF staff on.
- Distributing through the CalNEXT project to key program stakeholders, including program implementers and commercial SEM energy coaches. The project team will distribute the

retrofit guide to PG&E and Southern California Edison SEM program managers and program implementers.
- Sharing through web-based training programs (e.g., PG&E Energy Centers)
- Delivering to key industry professionals, including via ASHRAE committee-participating practitioners and through RCx certification training and education

FUTURE PROGRAM OPPORTUNITIES

Based on the market research conducted through this project, California third-party implementers do not currently offer standalone Custom-Lite or Direct Install RCx programs for large commercial building optimization because of the financial and logistical challenges under current CPUC rules. As part of the shift to third-party program implementation and as an effort to simplify the project approval process, the CPUC and IOUs have been focused on developing more standardized Deemed measures. Prior custom-lite and direct install program models have been replaced by Deemed measures, to the exclusion of many RCx measures.

The project team recommends that additional research and program development be conducted to obtain a broader and more accurate registry of data relevant to the RCx measures promoted in the G36 retrofit guide, including:

- Development of future Deemed workpapers for select G36 key measures. The Dual Maximum VAV with Low Minimums measure is the readiest measure to become a Deemed offering. The following is a summary of the key information required for Deemed workpapers, what information is already available for that measure, and what needs to be done to collect the rest of the required information:
    - Market potential
        - Reference metastudy conducted by LBNL across hundreds of buildings, which revealed that this measure is rarely implemented in utility programs. (Crowe, Mills and Poeling 2020)
        - Barriers include: Lack of awareness among building owners about the energy-saving potential of zone control measures, utility programs prioritizing system-level measures over zone-level strategies, and controls contractors often replicating existing inefficient control logic during upgrades, perpetuating inefficiencies
    - Base case
        - Define by existing average VAV box minimum percentage. Define three different base-case conditions: poor (average >40 percent); low (average 25 percent to 40 percent); and moderate (<25 percent)
    - Applicable standards and requirements
        - California Title 24 requires this measure for new construction and upon system replacement
    - Parameters impacting energy savings potential
        - Savings vary by climate zone, building type, building vintage, and existing VAV box minimums.
    - Energy savings and demand reduction
        - Need to conduct energy simulations with each of the combinations defined above. May be able to leverage energy modeling done by PNNL.

    - Costs and cost-effectiveness
        - Need more cost data collection to isolate design and implementation costs for this measure.
- Demonstration of EULs greater than three years for specific G36-based RCx measures.
- Collection of representative baseline data for specific RCx measures (e.g., existing VAV airflow minimums and prevalence of high minimums).
- Collaboration with other research and modeling efforts focused on G36 to enhance site screening, predict G36 energy impacts, and develop program delivery models to meet customer and utility needs, while complying with regulatory requirements.

Stakeholder Feedback

The project team presented the project scope and draft guidance throughout the course of the project to a range of stakeholders, including mechanical designers, energy engineers, building science researchers, and utility program managers. The team also presented summaries at periodic ASHRAE G36 project committee meetings, which also include manufacturers, contractors, and commissioning agents. Feedback on the effort was consistently positive. Multiple individuals echoed the challenges described above with G36 in general and in applying it to existing buildings.

Multiple stakeholders were interested in seeing the list of key measures and liked the format of the two-pager summaries.

Stakeholders consistently reported the challenge of justifying measures to be economical in retrofit applications given that it is generally not practical to develop detailed energy models and there are not currently simplified tools that can accurately predict the performance of control retrofit measures. This work does not overcome this barrier, but the compiled reference studies provide generalized support for the energy and economic benefits of each of the measures.

One contractor commented on the challenge of convincing other project stakeholders (developers, building engineers, and building owners) that the new G36 approaches will work and should be used over conventional practices, even for issues that are directly required by code and that have been well established in numerous applications. While making educational materials and trainings available is useful, it may nevertheless be difficult to convince many stakeholders to accept change.

The project team conducted three interviews with six SEM program stakeholders (i.e., two interviewees per interview, with two program managers and four program implementers). Interviewees emphasized the importance of education, simplified tools, and clear communication to overcome delivery challenges. Common RCx measures discussed tend to focus on system-level measures, such as duct static pressure and SAT reset, central plan resets, and off-hour setback strategies. Zone-level measures are not typically prioritized for multiple reasons, including concerns of cascading system impacts (e.g., ventilation rates no longer comply with local codes or rooftop HVAC units no longer achieve minimum airflow for stable operation).

Gradual performance back-sliding combined with demands for comfort feed into low EULs, but also favor the continuous RCx approach of SEM. The program managers shared that TSB calculations have hindered many RCx projects, highlighting a need for higher gas savings, RCx measures with longer EULs, or both. Persistent strategies, such as standard operating procedures and increased awareness of G36, are seen as critical for achieving long-term energy savings and customer

engagement. The flexibility and focus on low-cost measures make SEM a current and valuable program offering in California for promoting G36.

One Custom program implementer who we interviewed found RCx projects that did not have significant gas savings potential were often not cost effective, aligning with feedback from the commercial SEM program managers mentioned prior. This is due to the negative impact of low RCx EULs and positive impact of gas savings on TSB estimates, which is the basis for the project incentives and program performance payments. In Decision 16-08-019, the CPUC allowed RCx measures to use a three-year EUL; the decision also states this may be revisited when future evidence that supports longer EULs becomes available.

Cal TF expressed interest in promoting and hosting the G36 retrofit guide under the HVAC RCx CMG. Integration of this guide into the CMG library will be discussed with Cal TF prior to and in coordination with updates scheduled this year for the HVAC tool as part of the CalNEXT PG&E HVAC Tool Validation Phase 2 study (ET25WSW0045).

Recommendations

The following steps are recommended to help transfer this knowledge into industry workflows and to support the successful scaling of G36, particularly to existing buildings:

- **Present key findings to industry through seminars, publications, and associations.** A seminar that includes the findings from this study will be presented at the American Council for an Energy Efficient Economy 2026 Summer Study, along with the associated proceedings. A manuscript has also been prepared and submitted for publication to the ASHRAE Journal, a seminar has been proposed for the 2027 ASHRAE Winter Conference, and the project team expects to present the key findings at future ASHRAE committee meetings.
- **Integrate new content into existing resources on G36, including classes and seminars and the Advanced Building Automation System Best Practices Guide** (Cheng, Eubanks and Singla 2022). Members of the project team can address the former through classes that they teach on G36 and advanced HVAC controls through the PG&E Energy Centers and ASHRAE Learning Institute. The latter is a popular free guide that has been accessed over 4,000 times since its initial posting in 2022. The content in Appendix A generated by this project has been added to the Best Practices Guide.
- **Distribute the design guide to the primary target audience of RCx providers, energy auditors, and energy service companies for addressing the existing building market.** A network of contacts has been built from existing contacts and outreach as part of this effort to help expand a distribution network of interested parties. Continue to leverage word-of-mouth tech transfer to help identify other means for disseminating project findings to the target stakeholder groups.
- **Promote the G36 retrofit guide as a best practice for existing and future Custom and SEM commercial programs.** Key measures can be integrated into Cal TF's HVAC tool CMG package with additional instructions on use of the tool for G36 measures.

- **Pilot a Custom-Lite or Direct Install RCx program using the G36 retrofit guide and the HVAC tool.** These two program delivery types could reduce high administrative overhead and lengthy review times that can make RCx projects cost-prohibitive from a program perspective.
- **Program implementers should request using higher EULs for G36 measures that are known to have persistence greater than three years designated for standard RCx measures.**

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Appendix A: Simplified HVAC Control Retrofits Design Guide

1.0 Introduction

Many studies have highlighted the energy savings potential with using heating, ventilation, and air conditioning (HVAC) control sequences from American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Guideline 36 (G36) though many practitioners perceive the applicability of G36 to be limited to new construction. G36 is long and complex, and it is often not directly applicable to typical existing HVAC and control system conditions. Existing buildings may use older HVAC systems that are not as efficient as modern systems and that are not directly supported by G36. Even for common variable air volume (VAV) reheat systems, G36 often requires sensors or devices that may not commonly be provided in standard practice. Users may also be overwhelmed by the scale and detail in G36, not recognizing what energy conservation measures within G36 provide the largest energy savings potential.

Nevertheless, the existing building stock represents an overwhelming opportunity to realize significant energy savings in the building sector through control system improvements. This design guide is intended to address some of the main barriers to applying key energy measures in G36 as part of retrofits of existing buildings. This guide identifies and describes the key energy measures in G36, those with significant energy savings potential and relative ease of implementation. It provides guidance on evaluating the opportunity for each measure in retrofit applications, and direction on what retrofit approach to take for different situations. Where existing HVAC system types and control configurations may not match those expected in G36, this guide describes what sequences may apply and adaptations to some of the sequences to better fit typical existing conditions. Lastly, case studies of different G36 retrofit applications are provided to provide tangible reference points for what past approaches have been successful or not.

2.0 Key Energy Measures

Overview

G36 contains high performance sequences of operation for variable air volume HVAC systems but the presentation of those sequences may make it difficult for many users to identify and understand individual energy measures. G36 is written in a control sequence language style that describes control logic, rather than plain language descriptions, which may be difficult to understand for those not accustomed. Also, the sequences in the guideline are organized by equipment and function, not by energy measure. Some of the key energy measures span multiple sections of the guideline (e.g., morning warmup), which may make them difficult to identify for new users, and some of the key measures are not even referenced by their common names in the guideline (e.g., dual maximum VAV logic and optimal start).

This section provides a summary of some of the most impactful energy measures based on energy savings potential and relative ease of implementation. The measures focus primarily on airside systems because of the broader applicability, but the list of measures does include two waterside measures. Quick Reference Guides for each measure are provided as Attachments to this document.

- Dual Maximum VAV with Low Minimums

- Duct Static Pressure Reset with Trim and Respond Logic
- Supply Air Temperature Reset with Trim and Respond Logic
- Optimal Start and Morning Warmup
- Demand Controlled Ventilation
- Occupied Standby
- Zone Heating and Cooling Setpoints with Demand Levels and Limits
- Dynamic Minimum Outdoor Airflow Setpoint
- Chilled Water Supply Temperature Reset with Trim and Respond Logic
- Hot Water Supply Temperature Reset with Trim and Respond Logic

Key Measures

Dual Maximum VAV with Low Minimums

Dual maximum VAV control logic sets a low minimum airflow limit in deadband equal to the zone ventilation requirement and then ramps up the flow in both heating and cooling modes. The minimum is often as low as 10-15 percent of the maximum. Compared to traditional single max logic, this approach significantly reduces simultaneous heating and cooling and reduces the risk of overcooling of spaces with low cooling loads. Dual max logic also controls the reheat to maintain the discharge air temperature at setpoint, with a maximum limit to prevent stratification in heating. It has been required in some building energy standards since 2008 but is still often overlooked in designs for new construction and in RCx despite being one of the most impactful measures in VAV systems.

Duct Static Pressure Reset with Trim and Respond Logic

Duct static pressure (DSP) reset is an approach that reduces AHU supply fan energy to the minimum required to satisfy zone airflow demand. Where VAV reheat systems inherently have some inefficiency with fans generating pressure and VAV dampers “chewing up” excess pressure, static pressure reset can significantly reduce the wasted energy compared to operating with a fixed setpoint. The setpoint is increased, or responds, when there are requests from associated zones above a minimum threshold, otherwise the setpoint decreases, or trims, when there are few or no requests.

Supply Air Temperature Reset with Trim and Respond Logic

Supply air temperature reset (SAT) is a control strategy that adjusts the temperature setpoint to minimize HVAC energy. The strategy in ASHRAE G36 resets the SAT setpoint based on zone demand as well as an outdoor air temperature limit to help ensure that zone cooling loads are satisfied and to avoid the fan penalty with resetting too much.

Optimal Start and Morning Warmup

Optimal Start and Morning Warmup/Cooldown are two related energy measures that aim to recover space temperatures from setback to comfortable temperatures as efficiently as possible. Optimal start is a machine learning strategy that predicts when an HVAC system must be started in order to recover from setback in time for the start of occupancy based on weather conditions, deviation from setpoint, and mass capacity factors. Morning Warmup and Cooldown are specific modes of system operation for recovering from setback.

Demand Controlled Ventilation

Demand controlled ventilation (DCV) is an energy efficiency measure that reduces ventilation rates when zones are below design occupancy levels. Applied to zones with high design occupant densities, DCV generally uses zone CO2 concentration as an indicator for occupancy level. When CO2 concentrations are low, zone ventilation can be reduced to the area-based ventilation requirement. When CO2 concentrations increase above threshold limits, G36 increases zone primary airflow and outdoor air rates.

Occupied-Standby

Occupied-standby is an energy efficiency measure that reduces ventilation and space conditioning during periods of scheduled occupancy but when sensors indicate that a space is vacant. Occupied-standby is allowed for most space types by ventilation standards and required by building energy efficiency standards.

Zone Heating and Cooling Setpoints with Demand Levels and Limits

This is a collection of zone temperature setpoint attributes that allow for temperature control to be maintained within a set of constraints that ensure efficient system operation. Rather than a single temperature setpoint with a fixed deadband, G36 defines separate heating and cooling setpoints that can be independently adjusted, allowing for wider or narrower deadbands where appropriate. G36 also prescribes default setpoint adjustment limits to prevent setpoints from being adjusted to unachievable values that may negatively impact other aspects of system operation (i.e., create rogue zones).

Dynamic Minimum Outdoor Airflow Setpoint

This measure dynamically adjusts the minimum outdoor airflow setpoint at the air handling unit based on real-time sensing at the zone level and scheduling of zone groups. Where conventional practice is to determine a design ventilation rate and consistently control the minimum outdoor airflow to that value at all times, this energy measure recognizes that buildings are often only partially occupied and that ventilation rates can be reduced accordingly based on real-time sensing and scheduling.

Chilled Water Supply Temperature Reset with Trim and Respond Logic

Chilled water supply temperature reset is a control strategy that adjusts the temperature setpoints to minimize HVAC energy while still satisfying demand from associated chilled water coils. The strategy in G36 resets the CHWST setpoint based on valve demand using trim and respond logic.

Hot Water Supply Temperature Reset with Trim and Respond Logic

Hot water supply temperature reset is a control strategy that adjusts the temperature setpoints to minimize HVAC energy while still satisfying demand from associated hot water coils. The strategy in G36 resets the HWST setpoint based on valve demand using trim and respond logic.

Energy Impact

Multiple field demonstrations and simulation studies have documented significant energy savings potential with implementing G36 comprehensively but fewer studies have evaluated the impact of specific energy measures to help indicate which measures offer the largest energy savings potential.

An early simulation study using EnergyPlus evaluated the sensitivity of good vs. poor practice of various VAV system control configurations on HVAC energy performance in Chicago and Houston (Pang, Piette and Zhou 2017). Though this study pre-dated and was not specifically focused on G36, the findings indicated the relative importance of VAV box minimum airflows, minimum outdoor airflow control, zone temperature setpoints, supply air temperature reset, optimal start, and duct static pressure reset (Figure 2).

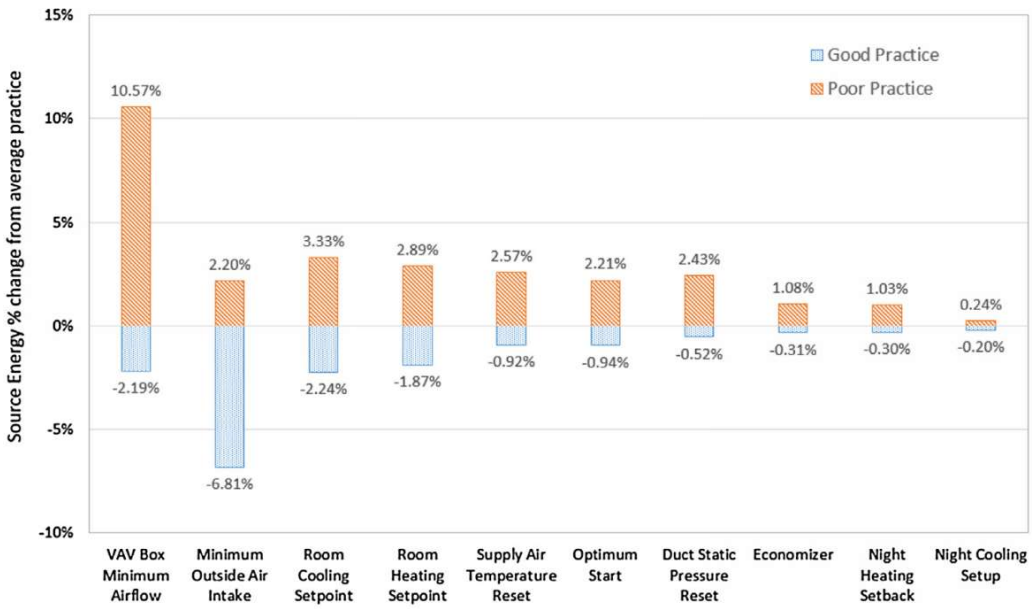


Figure 2: Simulated sensitivity analysis of VAV control measures in Chicago.

(Pang, Piette and Zhou 2017)

A few field and simulation studies have focused on individual energy measures. A field demonstration at several office buildings in the California Bay Area measured HVAC energy savings ranging from 5 to 20 percent solely from reducing VAV minimum airflows from 30 percent of the maximum down to the ventilation minimum (generally 15 to 20 percent) along with dual maximum VAV control (Arens, et al. 2015). A separate field demonstration evaluated the impact of duct static pressure reset, measuring fan energy savings from 15 to 35 percent across five buildings in Iowa compared to fixed pressure setpoints (X. Zhou 2017). Simulation analysis of medium office buildings in climate zones across the U.S. found HVAC energy savings ranging from around 20 to 45 percent (Pang, et al. 2020) and 2 to 10 percent in schools (Ye, et al. 2021).

A recent Pacific Northwest National Laboratory (PNNL) study provided the most comprehensive analysis of the energy impact of individual G36 measures using the EnergyPlus simulation engine with control strategies modeled in the Python Energy Management System (Lu, et al. in press). The analysis evaluated eleven airside measures from G36 compared to a 2004 baseline for a modified prototype medium office building in different ASHRAE climate zones (see Figure 3). On average across climate zones, the measures with the largest energy savings are: Occupied Standby, Morning Warmup/Cooldown, AHU Minimum OA Setpoint Reset, Optimal Start, Dual Maximum VAV with Low

Minimums, and SAT Reset. Notably, many of the measures provide highly variable savings depending on the climate zone. For example, in climate zone 3C, SAT Reset and Dual Max provide significantly more energy savings than in any other climate. This is attributed to the mild climate where SAT Reset can provide a large airside economizer benefit and where zones tend to spend more time at minimum airflow in deadband, compared to other climates. In contrast, the Minimum OA Setpoint measure provides minimal savings in climate zone 3C where there is a high number of economizer hours, but has a much greater impact in warmer and colder climate zones.

When all eleven of the modeled measures are implemented together, G36 reduced HVAC energy use by 29.9 percent compared to the 2004 baseline, which generally matches the average savings of 31 percent reported in an earlier analysis of key measures in G36 using a co-simulation of EnergyPlus and Modelica (Zhang, et al. 2022).

Static pressure reset is generally considered a key energy measure and this analysis reported fan energy savings of up to nearly 30 percent in some climate zones, but that only represents a small percentage on an overall HVAC site energy basis. If using energy cost as a metric, static pressure reset would generally have a larger overall impact because of the higher cost of electricity, compared to natural gas.

Figure 3: HVAC energy savings by Guideline 36 measure.

Chart based on data from (Lu, et al. in press)

Though a particular building may have existing conditions that may not match those assumed in this analysis and may have energy performance that differs from the prototype medium office building, the PNNL analysis provides a general indication of what measures are most impactful by climate

zone. Table 1 presents the top G36 energy measures as simulated in the medium office building in decreasing ranked order for each climate zone.

Table 1: Top ranked Guideline 36 energy measures by ASHRAE climate zone.

Rank	0A	0B	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
1	Min OA Reset 12.3%	Min OA Reset 8.9%	Occ-Standby 9.7%	Occ-Standby 8.5%	Occ-Standby 10.4%	Occ-Standby 13.1%	Occ-Standby 13.8%	Occ-Standby 14.7%	Occ-Standby 26.8%	Warm up/Cool down 12.4%	Warm up/Cool down 15.8%	Occ-Standby 18%	Occ-Standby 17.2%	Occ-Standby 16%	Occ-Standby 24.9%	Min OA Reset 15.5%	Occ-Standby 15.6%	Min OA Reset 16.5%	Min OA Reset 18.8%
2	Optimal Start 2.9%	Occ-Standby 5.3%	Min OA Reset 7.3%	Min OA Reset 7.3%	Min OA Reset 7.2%	Dual Max 8.7%	Warm up/Cool down 10.5%	Warm up/Cool down 13.6%	Dual Max 19.8%	Min OA Reset 11.8%	Occ-Standby 13.2%	Warm up/Cool down 16.9%	Min OA Reset 15.1%	Warm up/Cool down 14.8%	Warm up/Cool down 20.4%	Occ-Standby 14.1%	Warm up/Cool down 14.5%	Occ-Standby 13.3%	Warm up/Cool down 13%
3	Occ-Standby 2.1%	Optimal Start 4.7%	Optimal Start 6.4%	Optimal Start 5.3%	Optimal Start 6.8%	SAT Reset 7.8%	Dual Max 7.8%	Optimal Start 8.3%	SAT Reset 18.3%	Occ-Standby 11%	Optimal Start 6.7%	Min OA Reset 8.3%	Warm up/Cool down 13.1%	Min OA Reset 11.6%	Min OA Reset 12.9%	Warm up/Cool down 12.1%	Min OA Reset 13.9%	Warm up/Cool down 13%	Occ-Standby 12.5%
4	Warm up/Cool down 1.3%	Dual Max 2.8%	Dual Max 6%	Dual Max 5%	Dual Max 6.8%	Warm up/Cool down 7.7%	Min OA Reset 7%	Dual Max 6.7%	Warm up/Cool down 15.4%	Dual Max 6.3%	Dual Max 6.6%	Optimal Start 8.3%	Optimal Start 5.2%	Optimal Start 6.2%	Optimal Start 10.6%	Optimal Start 3.8%	Optimal Start 5.1%	Optimal Start 3.7%	Optimal Start 2.8%
5	DSP Reset 0.7%	DSP Reset 2.2%	SAT Reset 3.3%	SAT Reset 3.9%	SAT Reset 3.3%	Optimal Start 6.1%	Optimal Start 7%	SAT Reset 5.3%	Optimal Start 15.2%	Optimal Start 4.8%	Min OA Reset 6.3%	Dual Max 7.8%	Dual Max 3.6%	Dual Max 3.6%	Dual Max 2.8%	Dual Max 2.6%	Dual Max 2.9%	Dual Max 2%	Dual Max 1.2%
6	CO2 DCV 0.3%	Warm up/Cool down 1.9%	Warm up/Cool down 2.5%	DSP Reset 2.3%	Warm up/Cool down 3%	DSP Reset 3.1%	SAT Reset 3%	Min OA Reset 3.9%	CO2 DCV 7.2%	SAT Reset 1.6%	SAT Reset 4%	SAT Reset 4.5%	CO2 DCV 1.5%	SAT Reset 1.7%	CO2 DCV 2.3%	SAT Reset 1.5%	SAT Reset 1.7%	SAT Reset 0.9%	SAT Reset 0.6%
7	SAT Reset 0.1%	CO2 DCV 1.2%	CO2 DCV 1.9%	Warm up/Cool down 1.9%	CO2 DCV 2.1%	Min OA Reset 2.9%	CO2 DCV 2.7%	DSP Reset 2.7%	DSP Reset 3.6%	CO2 DCV 1.5%	DSP Reset 2%	CO2 DCV 3.3%	SAT Reset 1.4%	CO2 DCV 1.3%	DSP Reset 0.5%	CO2 DCV 1.1%	CO2 DCV 1.3%	CO2 DCV 0.7%	CO2 DCV 0.5%
8	TAV 0%	SAT Reset 0.2%	DSP Reset 1.8%	CO2 DCV 1.8%	DSP Reset 1.9%	CO2 DCV 2.7%	DSP Reset 2.2%	CO2 DCV 2.7%	Min OA Reset 0.8%	DSP Reset 0.8%	CO2 DCV 1.8%	DSP Reset 1.2%	DSP Reset 0.4%	DSP Reset 0.9%	TAV 0.5%	DSP Reset 0.3%	DSP Reset 0.4%	TAV 0.2%	DSP Reset 0.1%

Note: Ranking is in decreasing order based on site HVAC energy savings, based on data from (Lu, et al. in press). Modeled site HVAC energy savings data reported for each measure based on a medium office building updated to G36 from a baseline reflecting 2004 conditions.

3.0 Opportunity Evaluation

Control Retrofit Decision Matrix

The wide range of possible control retrofit approaches presents a specific challenge when applying G36 to existing buildings. Depending on project circumstances, a control retrofit may entail replacement of the entire control system including controllers, sensors, devices, and programming. Common situations that lead to a full control retrofit include end-of-service-life replacements of the control system, major HVAC equipment replacements, and large remodel projects. In other circumstances, targeted control hardware and programming changes may be more appropriate, such as when there are minor remodels or HVAC equipment replacements, known control deficiencies are being addressed, or when energy efficiency opportunities are presented. Control upgrades may also take more of a retro-commissioning (RCx) form with low-to-no cost measures implemented, such as minor reprogramming or parameter adjustments.

Designers need to consider the project circumstances and opportunities for operational and energy efficiency improvements when deciding what project approach to take. Project circumstances may include motivation (e.g., end-of-service-life, remodel, improving energy or operational performance) and project budget and tolerance for disruption. High building energy costs, high carbon emissions, building performance standards, and utility rebate programs may also be motivators for implementing a control upgrade. Finally, the opportunity to achieve energy efficiency improvements through control upgrades may be a factor.

When considering the use of G36 in a control retrofit application, the applicability of G36 to the HVAC systems and the potential opportunity for energy savings by upgrading control to G36 should be evaluated along with the project circumstances. Table 2 presents a high-level decision matrix for evaluating potential responses to a range of situations. Some actions are recommended or not for certain situations, regardless of the energy savings potential. In other cases, actions are recommended specifically when energy savings opportunities are also identified. For example, in an application with legacy controllers, where the controller product line has limited or no support from the manufacturer because a newer product line is available, and where an energy efficiency opportunity has also been identified, a full hardware and software control retrofit can leverage the synergy to support capital renewal and energy efficiency. Where the control retrofit may already be justified and budgeted as part of a capital renewal plan, there may only be minor or zero incremental costs to include G36 strategies as well.

The situations described in Table 2 are not necessarily mutually exclusive, and therefore could be considered in an additive way. For example, if the air handling units are in need of replacement and there are pneumatic zone controllers, there may be a synergy to implement a full control hardware and software retrofit since part of the controls need to be replaced and the other parts are at end-of-service-life with opportunities for energy efficiency savings by upgrading all of the controls together. The situations described in Table 2 are also not necessarily comprehensive and the recommendations are not absolute. There may be many other project circumstances that need to be weighed when deciding what project approach to take.

Table 3 presents an overview of a range of control retrofit project types and describes the relative project cost, level of effort, and energy savings potential. The table summarizes what is involved and some of the benefits of each project approach.

Ultimately, judgment and experience are required to evaluate each opportunity and project conditions to determine whether a G36 control retrofit is appropriate and justifiable. Several case studies of past projects are presented in the Attachments to this report to help users gauge what approaches have been successful in the past and what lessons have been learned from projects that struggled or missed opportunities.

Table 2: Control retrofit decision matrix.

		Possible Response				
		Full Upgrade of Control Hardware and Software	Targeted Upgrade with Minor Hardware and Software Changes	Upgrade of Control Software (Major Reprogramming)	Minor Programming or Parameter Changes	No Action
Situation	HVAC equipment failing, or HVAC equipment otherwise planned for replacement	Recommended	Consider	n/a	n/a	n/a
	Associated controller(s) failing and no longer readily replaceable/repairable	Recommended	Consider (e.g., refurbished)	n/a	n/a	n/a
	Controller operational but no longer readily replaceable/repairable	Recommended	Strongly consider	Consider	Consider	Possible
	Controller operational but legacy	Strongly consider Recommended (with energy opportunity)	Strongly consider	Consider	Consider	Possible
	Controller operational but pneumatic	Consider Recommended (with energy opportunity)	Consider	n/a	Consider	Possible
	Controller operational but configurable-only	Consider Strongly Consider (with energy opportunity)	Consider	n/a	Consider	Possible
	Controller operational and DDC (and actively supported product line)	Possible Consider (with energy opportunity)	Consider	Consider	Consider	Possible

Notes: Targeted upgrade includes replacing isolated controllers, sensors, or devices, along with associated programming. No longer readily replaceable/repairable: Controller product lines have a limited lifespan. When manufacturers release newer product lines and stop supporting older/legacy products, availability of replacement parts may become limited, often only as used and refurbished components. Repair and service of these controllers may be more difficult and impractical in this condition. This may also apply for product lines where service can only be by a single provider and costs are prohibitive and/or service quality is inadequate.

Table 3: Control retrofit approaches.

Retrofit Project Type	Relative Cost, Level of Effort, Energy Savings	Existing Control Hardware Infrastructure	Mechanical Equipment Changes	BAS Hardware / Devices	Software	Benefits
Full control system retrofit	****	Legacy DDC or pneumatic	Maybe	New BAS hardware and sensors/devices	New BAS software, including programming and graphics	Ensure adequate controller capacity Ensure adequate network bandwidth Ensure requisite sensors and devices
Full control software retrofit	***	Modern DDC, fully programmable, sufficient network and controller capacity	No	Add limited sensors/devices where needed. Largely retain existing otherwise	New BAS programming and graphics	Limited disruption and expense
Targeted control software retrofit (e.g., RCx)	**	Modern DDC, fully programmable, sufficient network and controller capacity	No	Add limited sensors/devices where needed. Largely retain existing otherwise	Revise BAS programming and graphics in high impact areas only	Limited disruption and expense Limited design and Cx required
Targeted control software retrofit (e.g., RCx)	*	Legacy DDC	No	Add limited sensors/devices where needed. Largely retain existing otherwise	Revise BAS programming (or configuration) and graphics in high impact areas only	Limited disruption and expense Limited design and Cx required

Evaluation by Measure

This section provides guidance on specific conditions to investigate when evaluating the applicability and opportunity for specific energy measures, and to consider when implementing them. These evaluations provide a subjective indication of the opportunity for energy savings potential for each measure. Though only qualitative, the opportunity for energy savings for multiple measures can potentially be coupled with modeled saving data to provide rough estimates of overall savings potential to help justify G36 applications.

Dual Maximum VAV with Low Minimums

Applicable to systems with VAV terminals, except generally does not apply to zones with very high ventilation rates such as some healthcare and laboratory applications.

- Review VAV schedules on design drawings. Existing control is likely single-max if only two airflows are provided for each VAV box, e.g., only a maximum and minimum are provided instead of three airflows. See Figure 4.
- Review airflow setpoints in the BAS directly, if accessible, since current control may not match drawings. Existing control is likely single-max if only two airflows are provided for each VAV box.
- Evaluate the ratio between max and min for a sampling of zones, in the BAS if possible. If minimums are consistently between 20 or 30 percent of the maximum, there is likely an opportunity to reduce minimums to match ventilation requirements, even if dual maximum logic is already being employed.

SINGLE DUCT VAV TERMINAL UNIT

TAG	TITUS MODEL	SIZE		CFM		STATI
		UNIT	OUTLET	MAX	MIN	INLET
VAV-C1-01	DESV	06	12x8	280	80	1
VAV-C1-02	DESV	14	20x18	1680	500	1
VAV-C1-03	DESV	09	14x13	750	225	1
VAV-C1-04	DESV	05	12x8	140	40	1
VAV-C1-05	DESV	06	12x8	280	85	1
VAV-C1-06	DESV	08	12x10	620	200	1

Figure 4: Indication of single max VAV logic.

Signs of opportunity: Heating max airflow is missing. Minimums are consistently 30 percent of maximum, not set to ventilation minimum.

- In trends, if zone temperatures are consistently maintained near the heating setpoint during warm weather, that is likely evidence of overcooling from high VAV minimums.
- Controllers are sometimes programmed with dual max logic but controlled like single max when the designer only provides two airflow setpoints on the VAV schedule (max and min). In this case, converting to dual maximum can be done simply by re-evaluating lower minimums and entering the parameters, without any reprogramming.
- Configurable zone controllers have pre-loaded logic with a limited range of configuration options but are not capable of using custom programming. Some configurable controllers are able to have separate airflow setpoints in heating and deadband, which allows them to be configured to approximate dual max logic. This can be a beneficial option when controller retrofits are not being considered, even if the reheat valve is not controlling to maintain the discharge air temperature at setpoint. Review manufacturer literature to confirm available controller settings.

- Minimums should generally be revised to match code-minimum ventilation rates. Consider using Zone Ventilation Calculation Tool, which supports both California Title 24 and ASHRAE Standard 62.1 ventilation methods. Note that the Simplified Approach in Std. 62.1 prescribes low minimum primary airflow rates that do not cause excessively high required system outdoor intake rates.
- Care must be taken when applying dual max logic to packaged VAV systems with direct expansion (DX) cooling. DX systems have minimum flow requirements for safe compressor operation, which may be in conflict with low VAV box minimums without additional logic. See discussion under Packaged Direct Expansion VAV Systems.

Duct Static Pressure Reset with Trim & Respond Logic

Applicable to multiple-zone VAV air handling units.

- Review construction documents or controls as-builts for control sequences to confirm whether the DSP is controlled to a fixed setpoint.
- Review the actual control system operation to confirm whether there is reset through the front-end graphics, programming logic, or system trends.
- Even if the DSP setpoint is reset, there may be an opportunity to improve the control if the setpoint reset is based on any factor other than damper position or if trim and respond logic is not utilized (such as a control loop maintaining the most open damper at 90 percent open).
- Even if the DSP setpoint is reset, there may be opportunities for improvement if the minimum static pressure limit is greater than the default of 0.1 inches in G36. Trim and respond logic increases the setpoint based on demand so there is no need to set an arbitrarily high minimum limit. Doing so can lead to wasted fan energy.
- Review actual operation in BAS to confirm whether the static pressure setpoint resets in practice. Even if the logic is implemented, the setpoint may effectively operate at the maximum limit if there are rogue zones preventing reset. Addressing rogue zones or allowing for some requests to be ignored may provide energy savings by improving reset effectiveness.
- Implementation of trim and respond logic for DSP reset generally involves programming at both the system and the zone level, but it can be implemented solely at the supervisory level if the zone controllers are not readily re-programmable to generate requests, such as with configurable-only, legacy or controllers with limited memory (see Non-Programmable Zone Controllers). If implementing supervisory control, consider increasing the time step to reduce network traffic.
- Trim and respond reset parameters should be visible and adjustable in graphics for tuning and cumulative request hour logic should be implemented to allow for monitoring and identification of rogue zones.

Supply Air Temperature Reset with Trim and Respond Logic

Applicable to all multiple-zone air handling units except where heating and cooling are primarily by terminals, e.g., dedicated outdoor air systems and four-pipe VAV systems.

- Review construction documents or controls as-builts for control sequences to confirm whether the SAT is controlled to a fixed setpoint.
- Review the actual control system operation to confirm whether there is reset through the front-end graphics, programming logic, or system trends.
- If the SAT setpoint is reset based only on outdoor air temperature (OAT), there may be an opportunity to improve the reset with trim and respond. Resetting based on OAT is a simple approach that is easy to implement but it is open-loop control and OAT is only a coarse indicator of cooling load. For example, interior zones may be at design cooling conditions even if the OAT is low. Though this is a common RCx solution, it is also prone to leaving cooling loads unsatisfied and often overridden by operators when there are comfort complaints in mild weather.
- If the SAT setpoint is reset based only on return air temperature (RAT), there may be an opportunity to improve the reset with trim and respond. Resetting based on RAT is a closed loop control strategy but only satisfies the average zone cooling load and can only be effective where the thermal loads are consistent across the zones that are served. When loads are variable, this approach can cause some zones to become too warm, which may lead to comfort complaints and short measure life.
- Review actual operation in the BAS to confirm whether the SAT setpoint resets in practice. Even if the logic is implemented, the setpoint may effectively operate at the minimum limit if there are rogue zones that prevent reset. Addressing rogue zones or allowing for some requests to be ignored may provide energy savings by improving reset effectiveness.
- Even if reset logic is present, the minimum and maximum limits are often adjusted by operators. Typically, a reset range of 55 to 65°F is appropriate for nonresidential systems, though higher limits may be appropriate for applications with high minimum ventilation rates, such as healthcare and laboratories.
- Implementation of trim and respond logic for SAT reset generally involves programming at both the system and the zone level, but it can be implemented solely at the supervisory level if the zone controllers are not readily re-programmable to generate requests, such as with configurable-only, legacy or controllers with limited memory (see Non-Programmable Zone Controllers). If implementing supervisory control, consider increasing time step to reduce network traffic.
- Trim and respond reset parameters should be visible and adjustable in graphics for tuning and cumulative request hour logic should be implemented to allow for monitoring and identification of rogue zones.

Optimal Start and Morning Warmup/Cooldown

Applicable to most airside systems.

- Review actual operation to confirm whether there is a fixed scheduled start time ahead of the start of occupancy, such as through reviewing trends of fan operation (see Figure 5). If the system starts at the same time every day or most days (sometimes systems are scheduled to start earlier on Mondays), optimal start likely is absent.
- Review system operation during the recovery period (prior to the typical start of occupancy) to confirm whether minimum outdoor air is provided (see Figure 5). Minimum outdoor air should not be provided during a proper Warmup/Cooldown mode since it

occurs prior to occupancy, but many systems are simply often operated in "normal" mode with fixed early start times. This can significantly increase energy use and extend the recovery period.

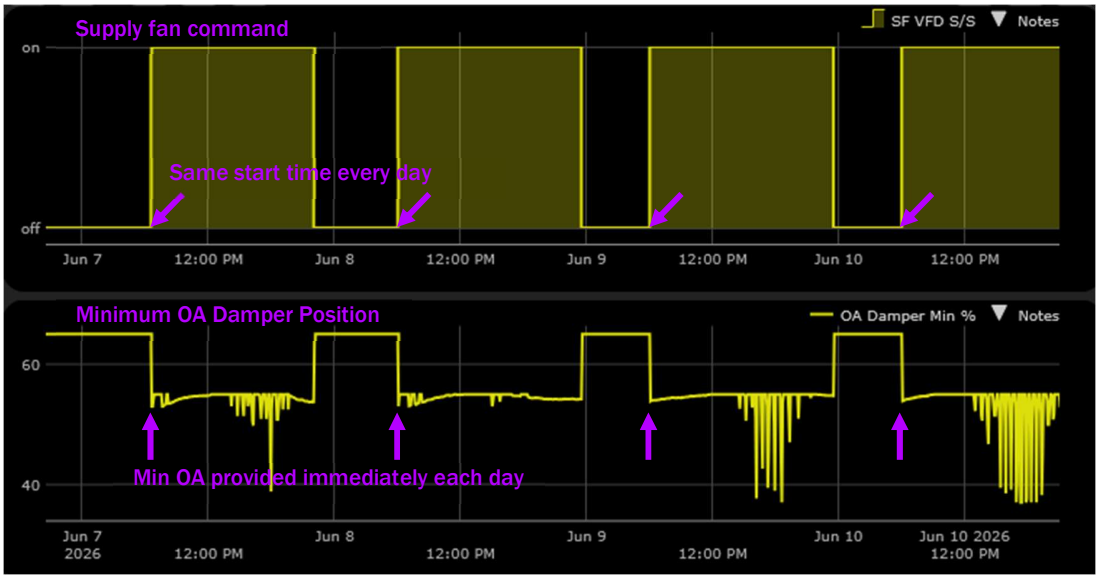


Figure 5: Indication of missing optimal start and morning warmup logic.

Signs of opportunity: System starts at same time every day (Optimal Start is missing) and immediately maintains minimum ventilation (Warmup Mode is missing)

- If optimal start is not observed in operation, often the logic exists but is disabled. For many systems, the logic is integrated into the default programming but isn't configured or tuned properly during installation. For example, when installation and startup of a system occurs in summer, the project team would not typically have an opportunity to tune the optimal start for Morning Warmup under challenging winter conditions. Optimal start must be tuned to the characteristics of building thermal mass and HVAC system capacity to work effectively. Without tuning, optimal start is frequently disabled by installers and operators when it fails to recover on time.
- The maximum duration for Warmup/Cooldown modes needs to be long enough to allow for recovery in cold/hot climates. G36 lists a default 3 hour maximum duration but this should be adjusted for each building's needs.

Demand Controlled Ventilation

Applicable to spaces with high design occupant density, such as classrooms, conference rooms, breakrooms, etc.

- Review construction documents or control as-built drawings to verify whether CO2 sensors are provided in spaces with high design occupant densities, such as on VAV schedules or floorplans (see Figure 6).
- Confirm that CO2 sensors are installed directly in the space. DCV is a zone-level energy measure and, when implemented using CO2 sensors, the sensors must be installed in each zone in order to increase ventilation appropriately during periods of high occupancy. A common mistake is to install a CO2 sensor in the common return duct. A sensor in that

location can only sense an average CO2 concentration and cannot adequately detect periods of high occupant density in individual spaces because of dilution effects. That approach is not code compliant.

- Where CO2 sensors are absent from spaces with high design occupant densities, a simple solution is to replace the existing room temperature sensor with one that includes an integrated CO2 sensor, which most BAS manufacturers offer as an option. Programming would also be required but this approach avoids the need for an additional standalone sensor and re-wiring.

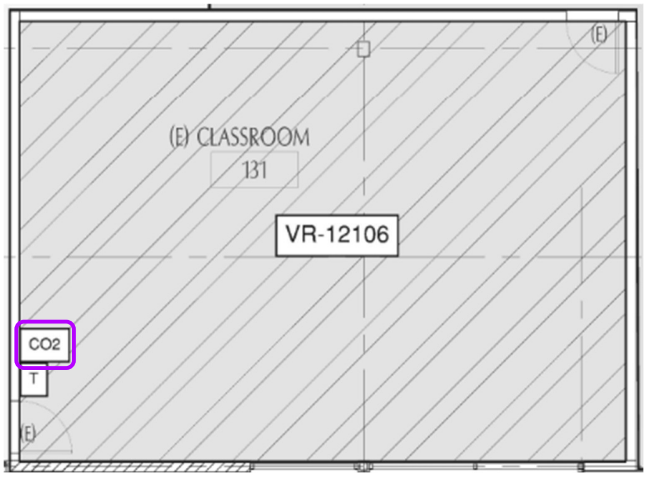


Figure 6: CO2 Sensor shown on mechanical floorplan.

- Minimum ventilation requirements consist of area-based and occupant-based components. DCV allows for the occupant-based component to be reduced to zero when CO2 levels are low. However, the area-based ventilation component must be maintained regardless of CO2 levels.
- CO2-based DCV and occupied standby can be implemented together within a single zone. Though the energy savings potential of each measure is not fully additive, occupied-standby allows for additional energy savings when the "last person" leaves by reducing the area-based ventilation requirement to zero and setting back the zone temperature setpoints.
- When CO2 levels are elevated, the DCV response in G36 is divided into two stages. First the zone airflow is increased to 100 percent of design flow. The goal is to try to address the high CO2 concentrations with dilution to the impacted zone without impacting energy use to other zones. If the first stage is not sufficient, the second stage increases the system ventilation airflow by the amount associated with the zone occupant-based ventilation component. Regardless of how high the CO2 concentration is, DCV does not require increasing ventilation beyond the design value (as if the zone were at the design occupant loading). DCV does not require increasing the outdoor air fraction to 100 percent! Energy performance of implementations that do this can be improved using G36.
- In spaces with lower design occupant densities (e.g., less dense than 100 ft^2 per person), DCV is not required and may not provide any energy savings depending on the ventilation standard. In California, zone ventilation requirements under Title 24 use the larger of the area- and occupant-based components, so DCV cannot provide any airflow reductions in spaces with low design occupant densities because the area-based requirement is already the limiting factor. In other states that follow ASHRAE Standard 62.1, the area- and occupant-based zone ventilation components are additive so DCV can provide energy savings even in spaces with lower design occupant densities. However, the energy savings

are lower and DCV may not be cost effective, which is why the building energy standards only require the use of DCV in spaces with high occupant densities.

- Typical CO2 sensors used in commercial building applications use an infrared light source to measure CO2 concentrations. These light sources fade over time leading to drift and early CO2 sensors were known for inaccuracy because of this issue. If existing CO2 sensors consistently read concentrations significantly above 500 ppm, the sensors may be due for replacement with the potential for DCV energy savings. Most BAS manufacturers now use automatic-background calibration (ABC) sensors that automatically recalibrate themselves on a periodic basis to background levels to overcome the issue with fading light sources.

Occupied Standby

Applicable to all spaces where allowed by ventilation standards.

- Occupied standby is a relatively new energy measure that was first allowed by ASHRAE Standard 62.1 in 2016, therefore it is relatively non-existent except in recent new construction.
- Review construction documents or control as-built drawings to verify whether occupancy sensors are provided in spaces, such as on VAV schedules or floorplans (see Figure 7). Occupancy sensors from networked lighting control systems can sometimes be used for occupied standby, so the sensors may not be shown on mechanical drawings. Review of the BAS graphics or trends may be more conclusive where there is uncertainty or if drawings are not available.

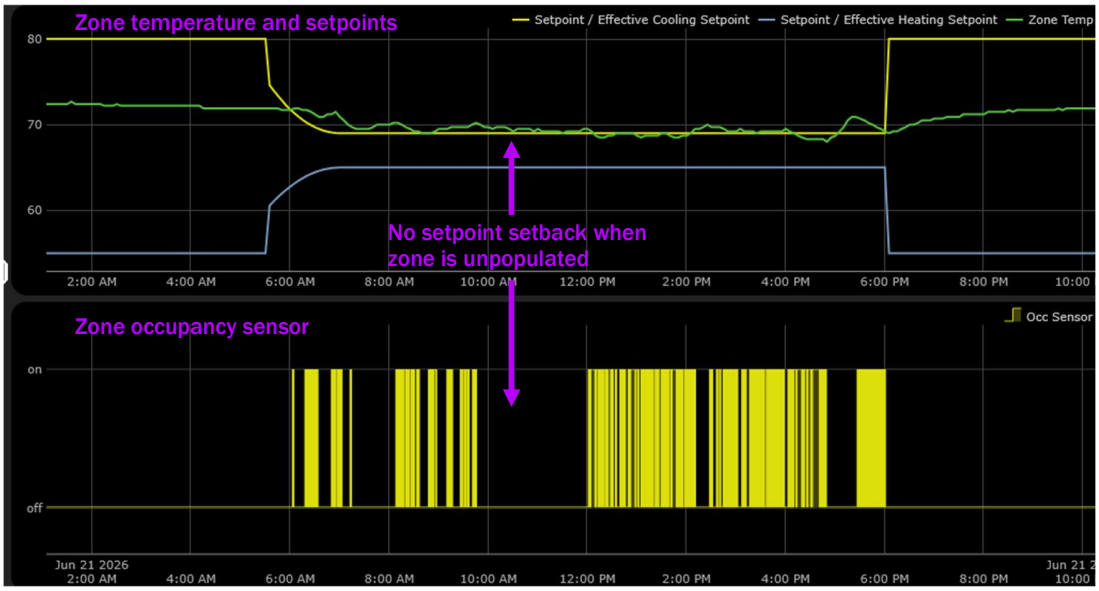


Figure 7: Indication of missing occupied standby.

Signs of opportunity: Occupancy sensor is installed but zone temperature setpoints are not setback when zone is unpopulated

- CO2-based DCV and occupied standby can be implemented together within a single zone. Though the energy savings potential of each measure is not fully additive, occupied-standby allows for additional energy savings when the "last person" leaves by reducing the area-based ventilation requirement to zero and setting back the zone temperature setpoints.
- Where absent, dedicated occupancy sensors can be installed in zones but this can be expensive depending on the size of zones, how many sensors are needed to provide full coverage of the ventilation zone, and whether wiring is concealed in a plenum or needs to be installed in conduit. Some BAS manufacturers offer room temperature sensors with optional integrated passive infrared sensors which can be a very cost-effective strategy, however room temperature sensors are seldom installed in locations that can provide adequate coverage of an entire zone.
- Networked lighting control (NLC) systems require occupancy sensors in nearly all space types based on current codes. Where an NLC exists, or better, is being installed, a network integration to the BAS can provide occupancy feedback for occupied standby without any additional sensors. The network connection may require a physical cable connection depending on network architecture, but almost certainly requires a non-trivial software effort to map the occupancy sensors to the HVAC zones and coordination is generally required between the lighting control and BAS installers.
- Occupied standby in G36 involves zone ventilation and airflow setback, zone temperature setback, and system-level outdoor airflow setback. Often only the zone-level components of the measure are implemented or only the zone temperature setback. In those cases, expanding the measure to the full G36 approach should provide additional energy savings.
- Building energy codes and G36 only apply a mild zone temperature setback when zones are sensed to be unpopulated. The rationale is that the mild setback can provide moderate energy savings and that deeper setbacks require longer times to recover, which may cause occupant discomfort and risk having the energy measure disabled.

Zone Heating and Cooling Setpoints with Demand Levels and Limits

Applicable to any thermal zones with programmable controllers.

- Survey existing zone heating and cooling setpoints to evaluate whether any cooling setpoints are excessively low (i.e., lower than 72°F for typical comfort applications) or heating setpoints are excessively high (i.e., greater than 72°F for typical comfort applications).
- Survey existing zone heating and cooling setpoints to evaluate whether they are set equal or if the heating setpoint is ever higher than the cooling setpoint.
- Setting limits to user adjustment of zone temperature setpoints may reduce zone heating and cooling loads and also prevent extreme user adjustments from creating rogue zones that negatively impact system-level setpoint resets.
- Systems are often set up with a narrow deadband (e.g., 2°F) where wider deadbands may provide adequate comfort and improved energy performance.
- Building energy codes and G36 only apply a mild zone temperature setback for occupied-standby when zones are sensed to be unpopulated. The rationale is that the mild setback

can provide moderate energy savings and that deeper setbacks require longer times to recover, which may cause occupant discomfort and risk having the energy measure disabled.

Dynamic Minimum Outdoor Airflow Setpoint

Applicable to airside systems that are not designed to constantly provide 100 percent outdoor air.

- Evaluate current configuration to determine whether there is a fixed minimum damper position. If so, and if the system is variable flow, then minimum ventilation cannot consistently be maintained. Options to add direct flow control should be explored, such as installing an airflow measurement station or differential pressure sensor, along with control programming to dynamically reset the minimum outdoor airflow setpoint.
- Evaluate current configuration to determine whether there is a fixed outdoor airflow setpoint.
- If the outdoor airflow setpoint is not currently adjusted dynamically, there may be an opportunity to reduce the system outdoor airflow at times with a dynamic setpoint according to G36 based on occupancy or CO2 sensors at the zone level or multiple zone groups.
- If the outdoor airflow setpoint is not currently adjusted dynamically, there may be an opportunity to reduce the system outdoor airflow at times with a dynamic setpoint adapted from G36 based on CO2 sensors at the zone level or multiple zone groups. This simplified approach does not require zone-level programming changes or interaction, but it does not support adjustment based on occupancy sensors. See Minimum Outdoor Air Setpoint Determination by Zone Group for details.
- Outdoor airflow can be difficult to measure accurately and stably, particularly at low velocities and in retrofit applications where conditions may not be ideal. Evaluate the feasibility of measuring outdoor airflow with the existing physical conditions. If needed, and if there are multiple outdoor air damper sections, consider isolating sections of the outdoor air damper to be used for minimum outdoor air control in order to maintain sufficiently high velocities.
- If adding an outdoor airflow measurement station or differential pressure monitor for active measurement is not feasible, consider the workaround approach of resetting the minimum damper position with supply fan speed. This approach is fundamentally imperfect and unlikely to be compliant for permitted projects subject to current building codes, but it may be a significant improvement over fixed minimum damper position and accuracy of OA AFMSs is often far worse than in idealized lab conditions. It is not uncommon to find AFMSs installed but then disabled in favor of a fixed minimum damper position because of poor selections or other installation issues. See Minimum Outdoor Air Control by Damper Position for details.

Chilled Water Supply Temperature Reset with Trim and Respond Logic

Applicable to any chilled water system.

- Review the actual control system operation to confirm whether there is reset through the front-end graphics, programming logic, or system trends.

- If the setpoint is reset based only on OAT, there may be an opportunity to improve the reset with trim and respond. Resetting based on OAT is a simple approach that is easy to implement but it is open-loop control that may leave some loads unsatisfied.
- Review actual operation in the BAS to confirm whether the setpoint resets in practice. Even if the logic is implemented, the setpoint may effectively operate at the minimum limit if there are rogue zones that prevent reset. Addressing rogue zones or allowing for some requests to be ignored may provide energy savings by improving reset effectiveness.
- Implementation of trim and respond logic generally involves programming at both the plant and the system or zone level (where the chilled water coils are controlled), but it can be implemented solely at the supervisory level if the field controllers are not readily re-programmable to generate requests, such as with configurable-only, legacy or controllers with limited memory (see Non-Programmable Zone Controllers). If implementing supervisory control, consider increasing time step to reduce network traffic.
- Trim and respond reset parameters should be visible and adjustable in graphics for tuning and cumulative request hour logic should be implemented to allow for monitoring and identification of rogue zones.

Hot Water Supply Temperature Reset with Trim and Respond Logic

Applicable to any hot water system.

- Review the actual control system operation to confirm whether there is reset through the front-end graphics, programming logic, or system trends.
- If the setpoint is reset based only on OAT, there may be an opportunity to improve the reset with trim and respond. Resetting based on OAT is a simple approach that is easy to implement but it is open-loop control that may leave some loads unsatisfied.
- Review actual operation in the BAS to confirm whether the setpoint resets in practice. Even if the logic is implemented, the setpoint may effectively operate at the maximum limit if there are rogue zones that prevent reset. Addressing rogue zones or allowing for some requests to be ignored may provide energy savings by improving reset effectiveness.
- Implementation of trim and respond logic generally involves programming at both the plant and the zone level, but it can be implemented solely at the supervisory level if the zone controllers are not readily re-programmable to generate requests, such as with configurable-only, legacy or controllers with limited memory (see Non-Programmable Zone Controllers). If implementing supervisory control, consider increasing time step to reduce network traffic.
- Trim and respond reset parameters should be visible and adjustable in graphics for tuning and cumulative request hour logic should be implemented to allow for monitoring and identification of rogue zones.

4.0 Adapted Sequences

This section highlights relevant sequences for HVAC system types that are not directly supported in G36 and provides adapted sequences of operation to streamline application of G36 to existing HVAC and control conditions that are commonly encountered.

System Type

Packaged Direct Expansion VAV Systems

G36 only directly supports VAV systems with chilled water cooling, though packaged direct expansion (DX) air-conditioning (AC) units are generally far more common in number in commercial buildings. Most of the principles in G36 apply similarly to DX units that are integrated with DDC systems, however there are some key constraints and issues that must be considered:

- **Integration with BAS.** Different AC unit product lines have varying ways of integrating control with a BAS but generally the AC unit's internal controller is responsible for some of the functionality, particularly compressor staging. A common scenario is that the BAS provides a SAT setpoint and the packaged controls stage the compressors to maintain the temperature at setpoint. Fan speed can be controlled by the BAS or often a DSP setpoint can at least be written to the packaged controls, where both options would allow for DSP setpoint reset. The designer needs to consider the equipment control integration options when adapting G36 for each AC unit application.
- **DX minimum flow requirement.** DX systems have minimum airflow requirements to prevent coils from freezing and to help ensure that refrigerant in the coil is fully evaporated before returning to the compressor. At low airflows, the compressors are locked out. These minimum flows can conventionally be very high (e.g., 50 percent of design flow) even when there are multiple compressor stages, variable capacity control, and hot gas bypass. Often the manufacturer or representative must be contacted to determine the minimum airflow requirement as it is rarely listed on equipment product sheets or submittals. Addendum u to ASHRAE 90.1-2022 requires that packaged DX systems be capable of operating at system airflows of 15 percent or lower, though many new equipment cannot meet this requirement yet. Where the DX minimum flow requirement is higher than the sum of the VAV minimums, additional logic may be needed to allow the system flow to turndown when DX is not needed, but then ramp up airflow in order to enable DX cooling when needed. One such strategy is shown in Figure 8 and Figure 9. This logic assumes that the BAS writes the SAT setpoint and enables the DX system. When there is a need for DX cooling, a reverse acting loop outputs a scalar multiplier, VminX, when the measured airflow is less than the DX minimum flow requirement. The zone occupied minimum flow Vmin* is then modified to consider VminX. Cautions:
    - The designer must provide the DX minimum flow requirement and the sum of Vmin for all zones served by the AC unit
    - The logic adjusts Vmin at each zone to increase system airflow when needed, but additional consideration may be needed to ensure adequate airflow during Cooldown and Setup modes when the zone minimum airflow endpoint is zero. Consider adjusting those endpoints to be equal to Vmin* during these modes.
    - Where applied to cooling-only VAV zones, there is a risk of overcooling.

5.16.2.5. DX Control

a. Enable DX system when:

1. Vps exceeds the minimum allowable supply airflow for DX operation by 5% for 5 minutes; and either

i. The economizer is locked out; or

ii. The economizer is enabled, and for 5 minutes the economizer PID loop output has been 100% and SAT has exceeded active supply air temperature setpoint by 2°F.

b. When the DX system is enabled, the SAT setpoint written to the DX controller through its network interface shall equal the active SAT setpoint.

c. Disable DX system when either of the following are true:

1. Vps falls below the minimum allowable supply airflow for DX operation for 1 minute continuously; or

2. For 5 minutes, both DX stages, as read through the DX controller's network interface, have been disabled and the supply air temperature is greater than 1°F below active supply air temperature setpoint.

5.16.2.6. Minimum Supply Air for Safe DX Operation Control Loop

a. The loop shall be enabled when the supply fan is proven on, the AC unit is in Occupied Mode, and either the conditions of Paragraph 5.16.2.5.a.1.i or Paragraph 5.16.2.5.a.1.ii are true.

b. The loop shall be disabled and output set to 0% whenever any of the following is true:

1. The supply fan is proven off;

2. The AC unit is not in Occupied mode; or

3. The DX system is disabled per the conditions in Paragraph 5.16.2.5.c.2.

c. Vps shall be maintained at 120% of the minimum allowable supply airflow for DX operation by a reverse-acting control loop whose output is 0-100% as illustrated in the diagram below and described subsequently. Reset VminX from 1.0 at 0% loop output to DXmult at 100% loop output.

1. DXmult shall be equal to 120% of the minimum allowable supply airflow for DX operation divided by the sum of Vmin for all zones served by the AC unit.

i. The sum of Vmin for all zones served by AC-1 is XX CFM.

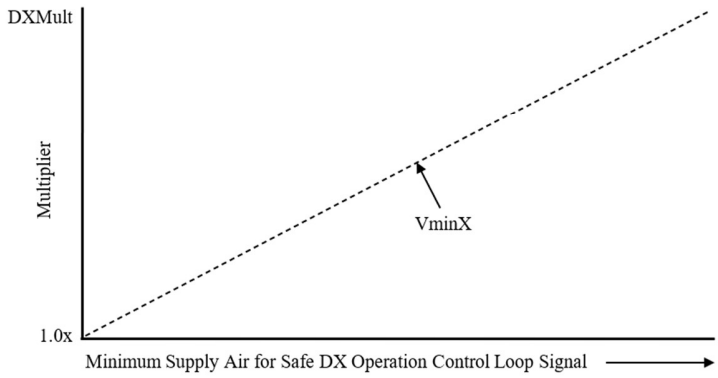


Figure 8: Zone minimum reset for DX minimum flow (AC unit logic).

5.2.1.4. For compliance with California Title 24, outdoor airflow setpoints shall be calculated as follows:

a. See Section 3.1.1.2 for zone ventilation setpoints.

b. VAV Terminal Units

1. Determine the zone minimum outdoor airflow setpoints Zone-Abs-OA-min and Zone-Des-OA-min.

i. Zone-Abs-OA-min shall be reset based on the following conditions in order from highest to lowest priority:

(a) Zero if the zone has a window switch and the window is open.
(b) Zero if the zone has an occupancy sensor and is unpopulated and is permitted to be in occupied-standby mode per Section 3.1.1.2.b.3.
(c) Varea-min if the zone has a CO_2 sensor.
(d) Zone-Des-OA-min otherwise.

ii. Zone-Des-OA-min is equal to the following, in order from highest to lowest priority:

(a) Zero if the zone has a window switch and the window is open.
(b) Zero if the zone has an occupancy sensor, is unpopulated, and is permitted to be in occupied-standby mode per Section 3.1.1.2.b.3.
(c) The larger of Varea-min and Vocc-min otherwise.

2. Vmin

i. Shall be equal to Zone-Abs-OA-min if Vmin in Section 3.1.2 is "AUTO";

ii. Else shall be equal to Vmin as entered in Section 3.1.2.

3. The occupied minimum airflow Vmin* shall be equal to Vmin times VminX (See Section 5.16.2.6 for DX unit airflow control) except as noted below, in order from highest to lowest priority:

i. If the zone has an occupancy sensor and is permitted to be in occupied-standby mode per Section 3.1.1.2.b.3, Vmin* shall be equal to zero when the room is unpopulated and VminX is equal to 1.0 for 10 minutes continuously. If VminX is greater than 1.0, Vmin* shall not be zero.

ii. If the zone has a window switch, Vmin* shall be zero when the window is open.

iii. If the zone has a CO_2 sensor:

(a) See Section 3.1.1.3 for maximum CO_2 concentration above ambient, ΔC, and ambient CO_2 concentration, Camb.
(b) Cmax = ΔC + Camb
(c) During Occupied Mode, a P-only loop shall limit CO_2 concentration to Cmax; loop output shall range from 0% at Cmax minus 200 PPM proportionally up to 100% at Cmax.
(d) Loop is disabled and output set to zero when the zone is not in Occupied Mode.
(e) For cooling-only VAV terminal units, reheat VAV terminal units, constant-volume series fan-powered terminal units, dual-duct VAV terminal units with mixing control and inlet airflow sensors, dual-duct VAV terminal units with mixing control and a discharge airflow sensor, or dual-duct VAV terminal units with cold-duct minimum control:

(1) The CO_2 control loop output shall reset the occupied minimum airflow setpoint Vmin* times VminX from the zone minimum airflow setpoint Vmin at 0% up to maximum cooling airflow setpoint Vcool-max at 50%, as shown in Figure 5.2.1.4-1. The loop output from 50% to 100% will be used at the system level to reset minimum outdoor airflow setpoint; see AHU controls.

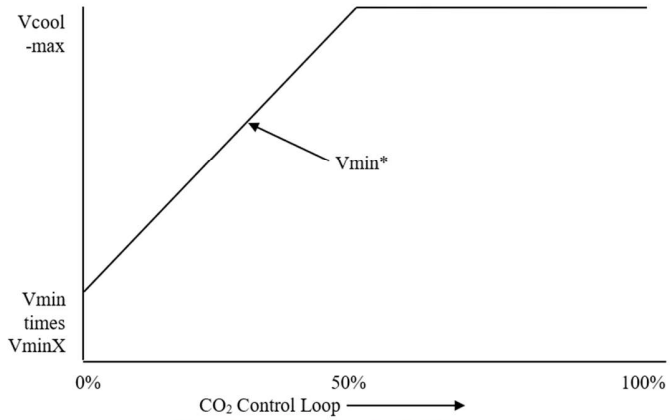


Figure 5.2.1.4-1 Vmin* reset with CO_2 loop.

Figure 9: Zone minimum reset for DX minimum flow (generic ventilation zones logic).

Text in green font represents sequence language directly in G36, where text in black font is modified for the DX minimum flow logic.

Constant Air Volume Reheat Systems

Constant air volume (CAV) reheat systems have a lot of commonality with VAV reheat systems, except that the airflow is generally held constant instead of modulating. The most common configuration is to have fixed speed supply fans without capacity control and manually balanced dampers and reheat coils at each zone. Some CAV reheat systems have variable speed drives and VAV boxes that are simply controlled to a constant airflow setpoint; these are physically similar to VAV reheat systems but are simply controlled to be constant flow. This configuration may be used in hospital applications where variable speed drives can help maintain constant flows, overcoming changes in system pressure drop from modulating economizer dampers and as filter loading varies over time.

While measures like duct static pressure reset and dual max VAV reheat logic are not applicable to CAV reheat systems, many measures in G36 are still potentially applicable. At the zone level, the zone heating and cooling setpoints can follow G36 sequences. Occupancy sensors and CO2 sensors can potentially be installed at the zone level to implement dynamic minimum outdoor airflow setpoint control. Economizer high limit controls apply.

- **Modified SAT reset using trim and respond.** SAT reset is particularly impactful for CAV reheat systems because the airflow rates are consistently high. The SAT reset approach in G36 integrates trim and respond reset logic with an outdoor air temperature limit to balance a tradeoff between cooling, fan, and reheat energy. In a VAV system, warmer SATs can reduce cooling and reheat energy but can sometimes also increase fan energy because higher airflows are required to satisfy cooling loads than with colder SATs. In a CAV reheat system, there is no tradeoff with fan energy so the optimal control approach is to provide the warmest SAT that satisfies the zone cooling loads. Figure 10 presents a modified version of the SAT reset logic for CAV systems.

5.16.2. Supply Air Temperature Control

5.16.2.1. Control loop is enabled when the supply air fan is proven ON, and disabled otherwise. When the loop is disabled, the output shall be set to deadband (no heating, minimum economizer).

5.16.2.2. Supply Air Temperature Setpoint [adapted for CAV]

a. See Section 3.1.4.1 for Min_ClgSAT and Max_ClgSAT setpoints.

b. During Occupied Mode and Setup Mode, setpoint shall be reset using T&R logic (see Section 5.1.14) between Min_ClgSAT and Max_ClgSAT.

Table 5.16.2.2 Trim & Respond Variables

Variable	Value
Device	Supply fan
SP_0	SPmax
SP_{min}	Min_ClgSAT
SP_{max}	Max_ClgSAT
T_d	10 minutes
T	2 minutes
I	See note
R	Zone cooling SAT requests
SP_{trim}	+0.1°C (+0.2°F)
SP_{res}	–0.2°C (–0.3°F)
$SP_{res\text{-}max}$	–0.6°C (–1.0°F)

Informative note: The number of ignored requests can be adjusted to balance responsiveness to demand (fewer ignores) vs energy efficiency (more ignores). The value that is set should be considered as a function of the total number of downstream zones or systems that can send requests. As a default, set the number of ignored requests to 10% of the total downstream zones or systems, rounded to the nearest integer.

Figure 10: Adapted supply air temperature reset logic for constant air volume systems.

Text in green font represents sequence language directly in G36, where text in black font is modified for this application.

Single Fan Dual Duct

Single fan dual duct (SFDD) systems (Figure 11) were common in the mid-1900s in large commercial and institutional buildings, and considered an advanced multizone system at the time because of the ability to provide good zone-level temperature control. They began to fall out of favor in the 1970s and 80s when energy costs became a bigger concern, where the constant flow and simultaneous heating and cooling were liabilities. Some SFDD systems have been converted to or originally built as variable flow with the addition of a fan capacity control (inlet guide vanes or variable speed drives), hot and or cold duct dampers, and duct pressure sensors. Nevertheless, there is still high inherent inefficiency with SFDD systems due to the large amount of simultaneous heating and cooling.

Where there is room to do so, an appealing option is to convert a SFDD system to dual fan dual duct (DFDD) by separating the hot and cold decks and installing an additional supply fan. DFDD systems are supported by G36 and can be extremely efficient with minimal reheat energy and heat recovery to the hot deck.

Many measures from G36 can still be applied to SFDD systems, whether VAV or CAV. SAT reset using trim and respond can be used for each of the hot and cold decks. For VAV systems, DSP reset using trim and respond can also be applied. Dynamic minimum outdoor airflow setpoint control can be

applicable. At the zone level, the zone heating and cooling setpoints can follow G36 sequences. Occupied standby and DCV can also be applied to VAV systems.

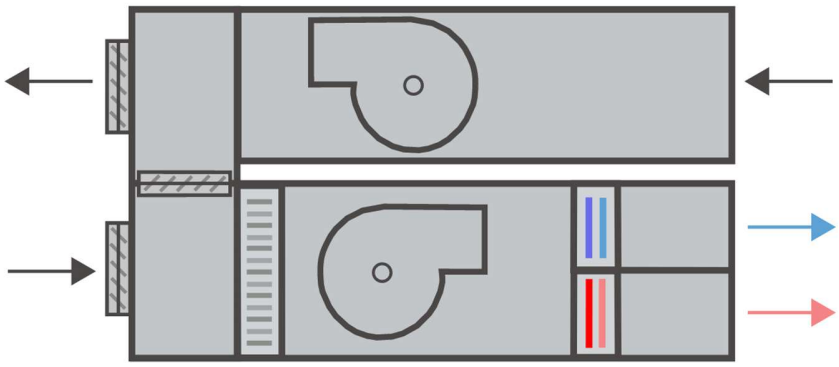


Figure 11: Single fan dual duct system schematic.

- **Economizer high limit control.** SFDD systems are often provided with airside economizers but with mixed energy performance. When an economizer is enabled during mild ambient conditions, free cooling can reduce mechanical cooling energy for the cold deck, but with the penalty of increasing heating energy for the hot deck. The optimal approach to enabling the economizer in a SFDD needs to consider the energy benefit and penalty to the cold and hot decks, in addition to the normal high limit controls for the cooling side. Figure 12 provides a sequence that evaluates whether the energy cost benefit of free cooling outweighs the hot deck penalty.

Enable SFDD economizer if: (V_cd * C_chw) / (V_hd * C_hw) > 1
And if standard high limit condition satisfied.

Where:
V_cd = cold deck supply airflow (cfm)
V_hd = hot deck supply airflow (cfm)
C_chw = chilled water energy cost ($/kBtu)
C_hw = hot water energy cost ($/kBtu)

Energy cost defaults:
C_chw = (0.65 kW/ton)*(ton / 12 kBtu/h)*($0.15/kWh) = $0.00813 /kBtu
C_hw = (0.7 boiler efficiency)*($1.2/therm)*(therm/100 kBtu) = $0.01714/kBtu

Figure 12: Supplemental economizer high limit logic for single fan dual duct systems.

Perimeter Induction

Perimeter induction systems were common in the mid-1900s, particularly in large commercial and high rise buildings where the high pressure systems reduced duct size and shaft space requirements. They began to fall out of favor in the 1970s and 80s when energy costs became a bigger concern, eventually being replaced by VAV systems. Perimeter inductions systems deliver a constant flow of primary air to zone terminals through high pressure nozzles. The induction terminals have heating or cooling coils with recirculated room air induced across the terminals. The list below describes some of the measures in G36 that can be applied or adapted to perimeter induction units.

- **DSP reset using trim and respond.** Conventional perimeter induction units are constant flow with high velocities required to induce room air across the terminal coils and with no capability of modifying zone-level flow individually. However, during mild weather conditions, airflow can potentially be reduced throughout the building. If supply fans are retrofitted with variable speed drives, trim and respond DSP reset logic can be applied with requests based on the higher of heating or cooling loop outputs for each zone.
- **SAT reset of central air using trim and respond.** Though the heating and cooling are mostly done at the perimeter induction terminals, the primary air supply air temperature can be reset using trim and respond logic based on cooling loop outputs in summer mode and heating loop outputs in winter mode.
- **Occupied standby.** Though there is no capability to shut off flow to individual zones, the zone temperature setback portion of occupied standby can be applied where occupancy sensors exist.
- **Dynamic minimum outdoor airflow setpoint reset.** Instead of a fixed minimum outdoor air damper position or fixed minimum outdoor airflow setpoint, the minimum outdoor airflow setpoint can be dynamically reset based on zone-level occupied standby and CO_2 DCV for system-level OA airflow reset (can only change ventilation at system level)

Control Configuration

Non-Programmable Zone Controllers

Zone-level control sequences are typically programmed in the zone level controllers, which may lead to the incorrect assumption that certain measures cannot be applied if the zone controllers are not able to be reprogrammed. For example, zone controllers may be configurable-only or may technically be programmable but not in practice due to controller memory, lack of vendor support, or project circumstances. However, some G36 control strategies can still potentially be implemented with workarounds:

- **Demand-based setpoint resets.** Demand-based trim and respond resets generally have the request generation logic programmed at the zone controllers and sent to the AHU controller to evaluate the setpoint. Where the zone controller cannot be programmed to generate requests, a supervisory controller can instead poll the zones (i.e., damper position, cooling loop output, or reheat valve position) with requests generated at the supervisory controller. Note that this approach increases network traffic, which may also be a limiting factor. The time step for the reset logic can be increased to help mitigate this impact.
- **Configurable-only controllers.** Configurable zone controllers have pre-loaded logic with a limited range of configuration options but are not capable of using custom programming. The standard assumption is that configurable-only controllers would need to be replaced in order to implement G36 logic, however some G36 measures may be able to be partially implemented in configurable controllers. Some configurable controllers are able to have separate airflow setpoints in heating and deadband, which allows them to be configured to approximate dual max logic. This can be a beneficial option when controller retrofits are not being considered, even if the reheat valve is not controlling to maintain the discharge air temperature at setpoint. Review manufacturer literature to confirm available controller settings.

AHU with Single Economizer Control point and Relief Fan

Though G36 controls the economizer outdoor air damper and return air damper independently with two separate control points, most conventional economizers are controlled with a single analog output control point that is mapped to both dampers so that the dampers are always complementary. Controlling the dampers independently per G36 allows for the dampers to be opened in sequence which can reduce pressure drop and fan energy. In retrofit applications with G36, this presents a challenge of deciding whether to adapt the sequences to match the existing control hardware or vice versa. Figure 13 provides a modified supply air temperature sequence for a relief fan system that supports the existing condition of a single economizer damper control point.

5.16.2.4. Supply air temperature shall be controlled to setpoint using a control loop whose output is mapped to sequence the heating coil (if applicable), outdoor air damper, return air damper, and cooling coil as shown in Figure 5.16.2.3.

a. For units with relief dampers or relief fans

1. Economizer damper minimum position MinOA-P is modulated to control minimum outdoor airflow (see Sections 5.16.4.4, 5.16.5.4 and 5.16.6.3).

b. The points of transition along the x-axis shown and described in Figure 5.16.2.3 are representative. Separate gains shall be provided for each section of the control map (heating coil, economizer, cooling coil) that is determined by the contractor to provide stable control. Alternatively, the contractor shall adjust the precise value of the x-axis thresholds shown in Figure 5.16.2.3 to provide stable control. Damper control depends on the type of building pressure control system.

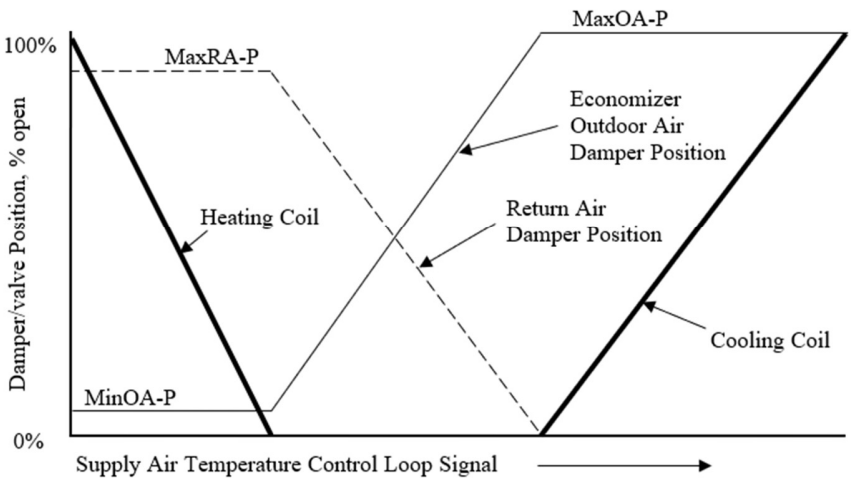


Figure 5.16.2.3 SAT loop mapping with relief damper or relief fan.

Figure 13: Economizer control with complementary dampers.

Minimum Outdoor Air Setpoint Determination by Zone Group

The dynamic reset of the minimum outdoor airflow setpoint relies on a range of zone-level parameters, sensing, and programming logic, such as for DCV, occupied-standby, window-switches, and zone air distribution effectiveness. In retrofit applications, where only zone groups are applied, the outdoor airflow setpoint logic can be greatly simplified by calculating the applicable minimum outdoor airflow requirements for each zone group, and resetting the setpoint based on the active zone groups (see Figure 14). This avoids the need to configure all of the zone level ventilation rates and then mapping and summing that logic at the supervisory level, which may be labor intensive

particularly if the values do not change. In this approach, the ventilation requirements for each zone group are instead summarized and totaled such that the active minimum outdoor air requirement can be calculated as the sum of the DesMinOA for each active zone group.

4. Minimum Outdoor Air Control

   a. Outdoor air minimum setpoints for systems with multiple Zone Groups

      1) DesMinOA design minimum outdoor air cfm for each Zone Group is as follows:

Floor	RTU-1	RTU-2
B	0	310
1	1250	2255
2	1365	1880
3	1925	1550
4	2500	1835
5	2055	1320
TDesMinOA	9,095	9,150

Figure 14: Minimum outdoor air setpoint reset by zone group.

Minimum Outdoor Air Control by Damper Position

Current building energy codes generally require measurement and control of outdoor airflow to maintain minimum ventilation rates. However, many existing VAV systems lack outdoor airflow monitoring stations (AFMS) and instead were designed to operate with a fixed minimum damper position for ventilation. That approach cannot effectively maintain constant outdoor airflow rates in VAV systems. If the minimum damper position is balanced to provide design ventilation rates at full system flow, the outdoor airflow will generally be lower at lower system flows. AFMSs can be difficult to select and install properly for accurate airflow measurement at low outdoor airflow rates in new construction, and even more so in retrofit applications. Reported airflow sensing accuracies are generally based on idealized laboratory conditions, and not particularly representative of accuracies under realistic field conditions where there may not be sufficient straight duct and readings may be impacted by wind, moisture, and dust. Installation of AFMSs in retrofits can also be expensive.

A compromise approach that improves on fixed minimum damper positions is to map the damper position inversely with supply fan speed (see Figure 15). Tests are performed at design fan speed and a lower speed to establish the damper positions that provide the required minimum outdoor airflow rate at each fan speed. This approach is an option presented in G36 for the single zone VAV system where the supply distribution has a fixed geometry and fan speed correlates with system pressure. However, this approach is known to be imperfect for multiple-zone VAV systems where VAV dampers create a variable geometry distribution system. In other words, for a given fan speed, the system pressure and airflow may vary depending on the positions of the VAV dampers. Mapping the minimum damper position to supply fan speed will not ensure that minimum ventilation rates are accurately maintained in multiple zone VAV systems (which is why it is not an available option in G36) but direct airflow measurement is also challenging and imperfect in practice, and this approach may be an improvement over a fixed minimum position.

b. Two minimum outdoor air damper positions (MinPosDes and MinPos30) required to deliver TDesMinOA at two operating percent speeds (design speed, Des%, and 30% of design speed) shall be determined based on TAB testing.

c. Minimum damper position MinPos in Paragraph 3.13H.2.c. shall be determined from the following equation:

$$MinPos = \left[\frac{DesMinOA^*}{TDesMinOA}\right]\left[\frac{(MinPosDes - MinPos30)(\%Spd - 30)}{(Des\% - 30)} + MinPos30\right]$$

Where

DesMinOA* = the sum of the design minimum outdoor air DesMinOA for all Zone Groups in Occupied Mode only. (Outdoor air is zero for Zone Groups in any mode other than Occupied Mode.)

TDesMinOA = total DesMinOA for all Zone Groups served by the system as indicated in the table above

%Spd = the current supply fan speed

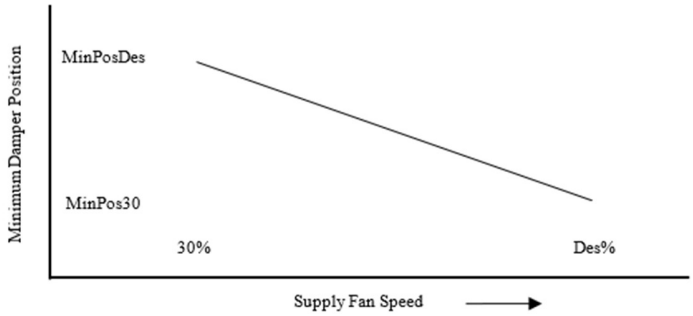


Figure 15: Minimum outdoor airflow control by fan speed mapping.

Attachments

Quick Reference Guides

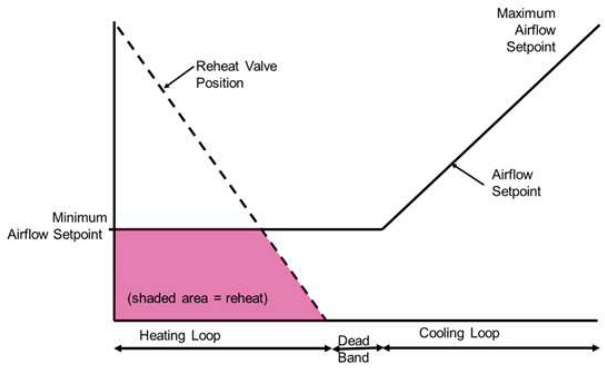
The quick reference guides are simple one- and two-page summaries of each measure that provide a brief introduction, highlight key considerations, and provide references to additional sources of information.

- Dual Maximum VAV with Low Minimums
- Duct Static Pressure Reset with Trim & Respond Logic
- Supply Air Temperature Reset with Trim & Respond Logic
- Optimal Start and Morning Warmup/Cooldown
- Demand Controlled Ventilation
- Occupied Standby
- Zone Heating and Cooling Setpoints with Demand Levels and Limits
- Dynamic Minimum Outdoor Airflow Setpoint
- Chilled Water Supply Temperature Reset with Trim & Respond Logic
- Hot Water Supply Temperature Reset with Trim & Respond Logic

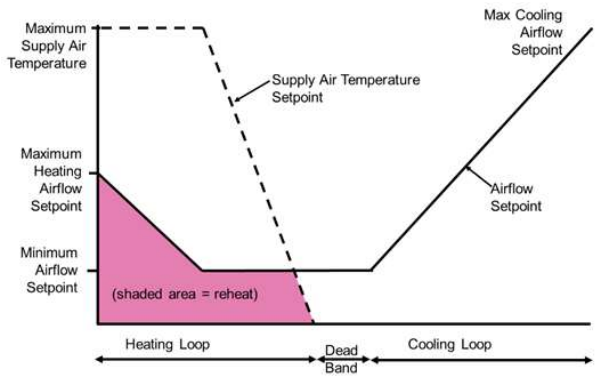
Dual Maximum VAV with Low Minimums

Dual maximum VAV control logic sets a low minimum airflow limit in deadband equal to the zone ventilation requirement and then ramps up the flow in both heating and cooling modes. The minimum is often as low as 10 to 15 percent of the maximum. Compared to traditional single max logic, this approach significantly reduces simultaneous heating and cooling and reduces the risk of overcooling of spaces with low cooling loads. Dual max logic also controls the reheat to maintain the discharge air temperature at setpoint, with a maximum limit to prevent stratification in heating. It has been required in some building energy standards since 2008 but is still often overlooked in designs for new construction and in retro-commissioning despite being one of the most impactful measures in VAV systems. (Guideline 36-2024 Paragraph 5.6.5)

Single Max Logic



Dual Max Logic



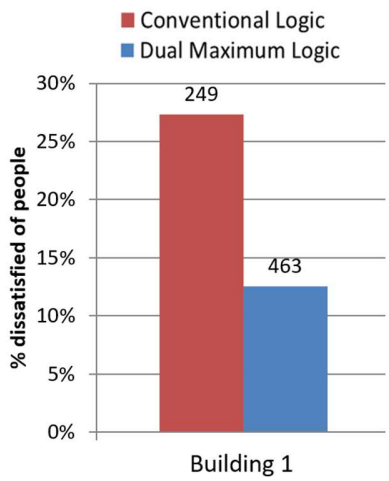
GOALS:

- Minimize simultaneous heating and cooling (reheat energy).
- Prevent overcooling of spaces with low cooling loads.
- Limit stratification of warm air in heating mode.

KEY CONSIDERATIONS:

- Careful ventilation takeoffs to determine new minimum airflow limits.
- If existing control follows single max logic with just min and max airflow limits, the original minimum can usually be taken to be the new heating max.
- Minimums can often be lowered even if the existing logic is already dual max.

"How satisfied are you with the temperature in your workspace?"



SUPPORT FOR THIS MEASURE:

- 5-20 percent HVAC energy savings measured across several field demonstration buildings[i].
- Significantly improved thermal comfort measured by occupant surveys[i].
- Shown in simulation studies to have the largest energy impact among VAV system strategies[ii].
- Required by building energy efficiency standards (ASHRAE 90.1[iii], IECC[iv], CA Title 24[v]).

WORKAROUNDS:

- Some zone programs already have dual max logic but have the minimum set equal to the heating max, because only a max and a min were included in the design. Only setpoint adjustments are needed in these cases.
- Programmable controllers not required! Some configurable VAV controllers can take separate heating and minimum airflow limits, such as the Siemens ATEC controller, which can also delay the airflow to ramp in heating until 50 percent loop output. These can closely approach dual max control without replacing controllers or needing programming.
- Dual max includes DAT setpoint control but the airflow limits can be implemented alone if DAT sensors are not available.

Tools/Resources

Zone Ventilation Calculation Tool
A free spreadsheet tool that outlines a workflow for performing ventilation takeoffs from as-built drawings and calculating ventilation requirements according to Standard 62.1 or California Title 24.

Standard 62.1 Simplified Approach
Simplified procedure for 62.1 ventilation calculations with prescribed VAV minimums. Overcomes issues with ventilation rate procedure and low VAV minimums.

UC Berkeley Screening Method
Approach for screening buildings with high VAV minimums from among large portfolios using easily accessible data encompassing building type, age, size, and monthly gas consumption.

CAUTIONS:

- Controllable minimums. VAV boxes have a low limit for stable and accurate measurement, that is a function of the flow cross in the VAV box and the pressure transducer on the VAV controller. Many DDC controllers are capable of reading velocity pressure down to 0.004 inches, which can be used with flow cross properties to calculate controllable minimums (see table for controllable minimums for various VAV box manufacturers). Actual controllable minimums are often far lower than recommended minimums published in VAV box catalogs! Guideline 36 includes logic to determine controllable minimums.
- Compatibility with direct expansion (DX). Packaged systems have minimum DX airflow requirements (often as high as 50 percent) that can be incompatible with reducing airflows through dual max and other important energy measures. Additional logic outside of Guideline 36 may be needed to allow low minimums during economizer operation and ensure adequate flow when mechanical cooling is needed.
- For spaces with zone exhaust, the minimum should be set to provide makeup airflow if needed.

Inlet Size (in)	VAV Box Controllable Minimums (cfm)				
	Titus	Krueger	Price	ETI	Greenheck
4	15	15	20	15	18
6	30	35	30	30	35
8	55	60	55	55	63
10	90	90	95	90	105
12	120	130	135	130	149
14	190	175	195	180	206
16	245	230	260	235	259
24x16	455	445	490	415	N/A

Note: Assuming transducers capable of reading down to 0.004"

[i] Arens, E. et al. (2015). RP-1515 – Thermal and Air Quality Acceptability in Buildings that Reduce Energy by Reducing Minimum Airflow From Overhead Diffusers. ASHRAE.
[ii] Pang, X., Piette, M. A., & Zhou, N. (2017). Characterizing variations in variable air volume system controls. Energy and Buildings, 166-175.
[iii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.5.2.
[iv] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.6.1.
[v] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraph 140.4(d).

Duct Static Pressure Reset with Trim & Respond

Duct static pressure reset is an approach that reduces fan energy to the minimum required to satisfy zone airflow demand. Where VAV reheat systems inherently have some inefficiency with fans generating pressure and VAV dampers "chewing up" excess pressure, static pressure reset can significantly reduce the wasted energy compared to operating with a fixed setpoint. The setpoint is increased, or responds, when there are requests from associated zones above a minimum threshold, otherwise the setpoint decreases, or trims, when there are few or no requests. (Guideline 36-2024 Paragraph 5.16.1.2)

GOAL:

- Operate fan at minimum speed needed to satisfy dynamic zone airflow requirements

KEY CONSIDERATIONS:

- Generate "requests" for increased pressure based on damper position and reset the setpoint using trim and respond logic
- Static pressure reset can be stably implemented with supply air temperature reset! Each reset responds to different feedback signals.
- Keep the minimum setpoint limit very low, e.g. the default of 0.1" in ASHRAE Guideline 36. There is no reason to make it higher. Some systems do operate at pressures this low at times and the T&R logic will reset the setpoint higher when needed.
- Even if a reset is already implemented in logic, it can often be improved if not using trim and respond, if settings are not appropriate, or if there are rogue zones that need to be addressed. A specific advantage of trim and respond logic over other approaches is the ability to identify and track rogue zones that may impede effective setpoint reset.
- Make sure the VFD minimum speed is set low.

Tools/Resources

Manufacturer Programming Blocks
Many BAS manufacturers have standardized graphical programming logic blocks for trim and respond that can help avoid the need for writing the programming from scratch.

ASHRAE Journal Paper
Taylor, S. T. 2015. Resetting Setpoints Using Trim & Respond Logic. ASHRAE Journal.

SUPPORT FOR THIS MEASURE:

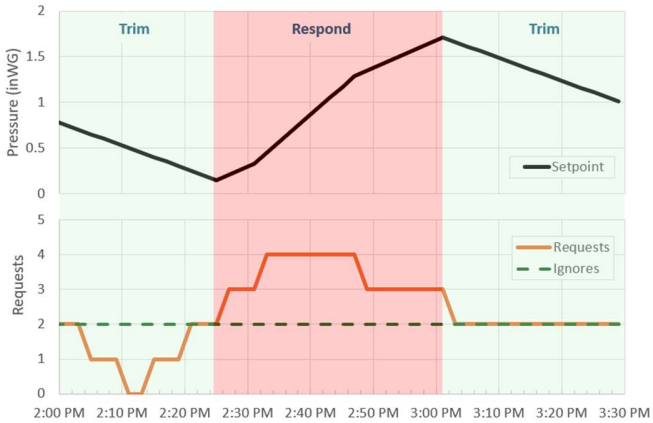
- 15-35 percent fan energy savings across several field demonstration sites[i]
- Shown in simulation studies to have significant energy impact among VAV system strategies[ii]
- Required by building energy efficiency standards (ASHRAE 90.1[iii], IECC[iv], CA Title 24[v])

WORKAROUNDS:

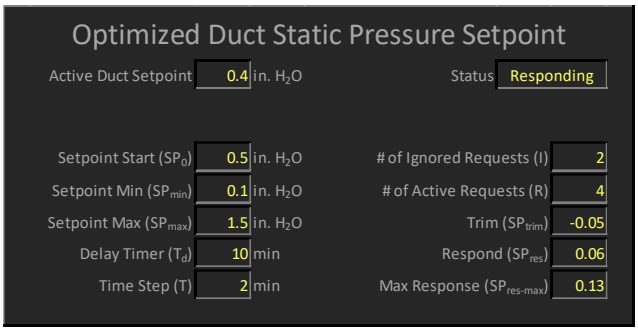
- If existing zone controllers cannot be re-programmed (e.g., legacy controllers that are not supported or not reasonably supported, or configurable-only controllers), requests can be evaluated at the supervisory level instead. The supervisory controller would poll the zones for damper position and sum the requests. The time interval may need to be increased from the default of 2 minutes to manage network traffic.

CAUTIONS:

- All trim and respond resets must be tuned. The default settings in Guideline 36 generally provide decent control stability but reset effectiveness and stability should be reviewed in trends. In particular, the "Number of Ignored Requests" should be set to balance a tradeoff between meeting demand (lower number) and maximizing energy efficiency (higher number). See Section 3.2.5 in the Advanced BAS Best Practices Guide for more guidance on tuning T&R resets.[vi]



- Ensure the trim and respond parameters are shown and adjustable in graphics, not just hardcoded in the programming, so that operators can readily review and adjust when needed.
- Rogue zones are zones that consistently generate requests and prevent the setpoint from resetting, such as a zone with a VAV damper that is consistently wide open and not maintaining airflow setpoint. There are many potential causes of rogue zones. Resets must be periodically monitored for rogue zones to ensure that setpoints can reset effectively. Guideline 36 includes logic ("cumulative request hours") that should be coupled with graphics and/or alarms to help operators identify rogue zones. See Section 4.5.5 in the Advanced BAS Best Practices Guide for more guidance.[vi]



												DSP Reset		
Zone	Operating Mode	Zone Temp (F)	Htg SP (F)	Clg SP (F)	Airflow (CFM)	Airflow SP (CFM)	Damper Pos (% Open)	HW Valve Pos (% Open)	DA Temp (F)	DA Temp SP (F)	CO2 Level (PPM)	Requests	Cumulative Req Hrs (% Req Hrs)	IM
VAV2-6	Deadband	73.3	71	74	342	330	29	0	56.9	55	n/a	0	10	1
VAV2-7	Cooling	73.9	71	74	278	280	31	0	57.2	55	n/a	0	2	1
VAV2-9	Cooling	73.8	71	74	673	675	54	0	56	55	n/a	0	13	1
VAV2-11	Deadband	73.1	70	73	275	279	24	0	57.2	55	n/a	0	1	1
VAV2-20	Deadband	72.9	71	74	245	235	16	0	57.2	55	565	0	6	1
VAV2-21	Cooling	72.3	71	74	184	180	25	0	58.7	55	n/a	0	3	1
VAV2-22	Deadband	70.8	68	71	1147	1144	45	0	57.2	55	n/a	0	23	1
VAV2-23	Deadband	73	71	74	102	100	32	0	59.1	55	n/a	0	1	1
VAV2-24	Deadband	72.9	71	74	252	250	41	0	57.5	55	n/a	0	6	1
VAV2-25	Deadband	73.1	72	75	508	500	15	0	58.4	55	n/a	0	1	1
VAV2-27	Deadband	72.4	71	74	308	300	31	0	57.2	55	n/a	0	9	1
VAV2-28	Deadband	73	71	74	290	270	32	0	58.1	55	Rogue zone	0	1	1
VAV2-30	Deadband	74.3	72	75	368	360	11	0	57.1	55	n/a	0	91	1
VAV2-31	Cooling	73.7	71	74	512	500	32	0	58.6	55	505	0	14	1

[i] Zhou, X. (2017). Demonstration of Energy Savings in Commercial Buildings for Tiered Trim and Respond Method in Resetting Static Pressure for VAV Systems, ESTCP Project EW-201408.
[ii] Pang, X., Piette, M. A., & Zhou, N. (2017). Characterizing variations in variable air volume system controls. *Energy and Buildings*, 166-175.
[iii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.5.3.2.3.
[iv] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.6.8.
[v] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraph 140.4(d).
[vi] Cheng, H., Eubanks, B., & Singla, R. (2022). Advanced Building Automation System Best Practices Guide.

Supply Air Temperature Reset with Trim & Respond

Supply air temperature reset is a control strategy that adjusts the temperature setpoint to minimize HVAC energy. The strategy in ASHRAE Guideline 36 resets the SAT setpoint based on zone demand as well as an outdoor air temperature limit to help ensure that zone cooling loads are satisfied and to avoid the fan penalty with resetting too much. (Guideline 36-2024 Paragraph 5.16.2.2)

GOAL:

- Adjust the supply air temperature setpoint to minimize HVAC energy while satisfying zone cooling loads

KEY CONSIDERATIONS:

- Generate "requests" for colder supply air based on cooling loop output (the control loop that maintains the zone temperature at the cooling setpoint) and reset the setpoint using trim and respond logic
- Supply air temperature reset can be stably implemented with static pressure reset! Each reset responds to different feedback signals.
- Warmer is not always better! Warmer temperatures can help reduce mechanical cooling loads, extend economizer operation, and reduce reheat energy, but warmer temperatures may also lead to significant increases in fan energy.
- Even if a reset is already implemented in logic, it can often be improved if not using trim and respond, if settings are not appropriate, or if there are rogue zones that need to be addressed. A specific advantage of trim and respond logic over other approaches is the ability to identify and track rogue zones that may impede effective setpoint reset.

Tools/Resources

Manufacturer Programming Blocks
Many BAS manufacturers have standardized graphical programming logic blocks for trim and respond that help avoid the need for writing the programming from scratch.

SUPPORT FOR THIS MEASURE:

- Shown in simulation studies to have significant energy impact among VAV system strategies[i]
- Required by building energy efficiency standards (ASHRAE 90.1[ii], IECC[iii], CA Title 24[iv])

WORKAROUNDS:

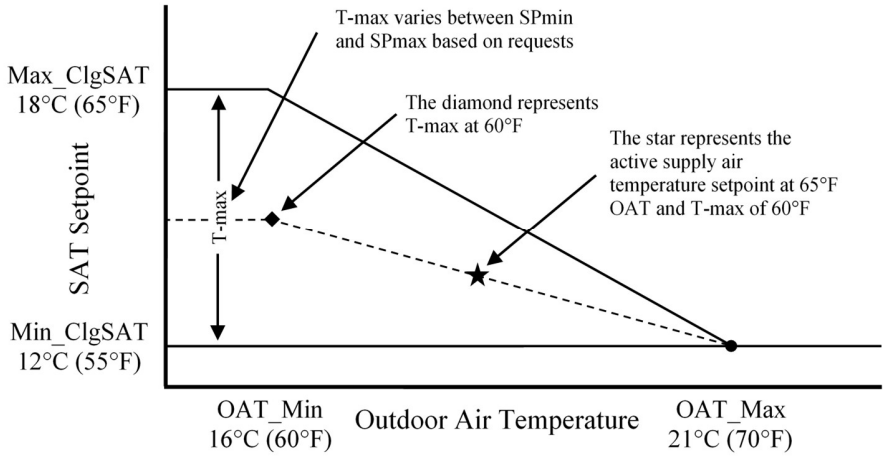
- If existing zone controllers cannot be re-programmed (e.g., legacy controllers that are not supported or not reasonably supported, or configurable-only controllers), requests can be evaluated at the supervisory level instead. The supervisory controller would poll the zones for cooling loop output and sum the requests. The time interval may need to be increased from the default of 2 minutes to manage network traffic.

CAUTIONS:

- Supply air temperature reset is often implemented solely based on outside or return air temperature. The former provides only a general proxy for load and the latter only an average proxy for load. While easier to implement, both strategies run the risk of not satisfying cooling loads in some zones (e.g., interior zones with OAT reset and high cooling demand zones with RAT reset), and are therefore likely to be disabled or overridden by operators. The Guideline 36 approach responds to demand from

associated zones to ensure that cooling needs are met.

- All trim and respond resets must be tuned. The default settings in Guideline 36 generally provide decent control stability but reset effectiveness and stability should be reviewed in trends. In particular, the "Number of Ignored Requests" should be set to balance a tradeoff between meeting demand (lower number) and maximizing energy efficiency (higher number). See Section 3.2.5 in the Advanced BAS Best Practices Guide for more guidance on tuning T&R resets.[v]
- Ensure the trim and respond parameters are shown and adjustable in graphics, not just hardcoded in the programming, so that operators can readily review and adjust when needed.



- Rogue zones are zones that consistently generate requests and prevent the setpoint from resetting, such as a zone that cannot maintain the cooling setpoint. There are many potential causes of rogue zones. Resets must be periodically monitored for rogue zones to ensure that setpoints can reset effectively. Guideline 36 includes logic ("cumulative request hours") that should be coupled with graphics and/or alarms to help operators identify rogue zones. See Section 4.5.5 in the Advanced BAS Best Practices Guide for more guidance on rogue zones.[vi]
- Supply air temperature reset can be implemented in humid climates and where zone humidity is a concern. Guideline 36 includes provisions for humidity limiting based on outdoor air, return air, and/or zone-level dewpoint.

												SAT Reset		
Zone	Operating Mode	Zone Temp (F)	Htg SP (F)	Clg SP (F)	Airflow (CFM)	Airflow SP (CFM)	Damper Pos (% Open)	HW Valve Pos (% Open)	DA Temp (F)	DA Temp SP (F)	CO2 Level (PPM)	Requests	Cumulative Req Hrs (% Req Hrs)	IM
VAV2-6	Deadband	73.3	71	74	342	330	29	0	56.9	55	n/a	0	10	1
VAV2-7	Cooling	73.9	71	74	278	280	31	0	57.2	55	Rogue zone	0	2	1
VAV2-9	Cooling	73.8	71	74	673	675	54	0	56	55	n/a	0	86	1
VAV2-11	Deadband	73.1	70	73	275	279	24	0	57.2	55	n/a	0	1	1
VAV2-20	Deadband	72.9	71	74	245	235	16	0	57.2	55	565	0	6	1
VAV2-21	Cooling	72.3	71	74	184	180	25	0	58.7	55	n/a	0	3	1
VAV2-22	Deadband	70.8	68	71	1147	1144	45	0	57.2	55	n/a	0	6	1
VAV2-23	Deadband	73	71	74	102	100	32	0	59.1	55	n/a	0	1	1
VAV2-24	Deadband	72.9	71	74	252	250	41	0	57.5	55	n/a	0	6	1
VAV2-25	Deadband	73.1	72	75	508	500	15	0	58.4	55	n/a	0	1	1
VAV2-27	Deadband	72.4	71	74	308	300	31	0	57.2	55	n/a	0	9	1
VAV2-28	Deadband	73	71	74	290	270	32	0	58.1	55	n/a	0	1	1
VAV2-30	Deadband	74.3	72	75	368	360	11	0	57.1	55	n/a	0	3	1
VAV2-31	Cooling	73.7	71	74	512	500	32	0	58.6	55	505	0	14	1

[i] Pang, X., Piette, M. A., & Zhou, N. (2017). Characterizing variations in variable air volume system controls. Energy and Buildings.
[ii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.5.3.5.
[iii] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.6.5.
[iv] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraph 140.4(d).
[v] Cheng, H., Eubanks, B., & Singla, R. (2022). Advanced Building Automation System Best Practices Guide.

Optimal Start and Morning Warmup/Cooldown

Optimal Start and Morning Warmup/Cooldown are two related energy measures that aim to recover space temperatures from setback to comfortable temperatures as efficiently as possible. Optimal start is a machine learning strategy that predicts when an HVAC system must be started in order to recover from setback in time for the start of occupancy based on weather conditions, deviation from setpoint, and mass capacity factors. Morning Warmup and Cooldown are specific modes of system operation for recovering from setback. (Guideline 36-2024 Paragraphs 5.3.2.3, 5.3.7, 5.4.6, 5.6.4, 5.16.2.2, 5.16.3, and others)

GOAL:

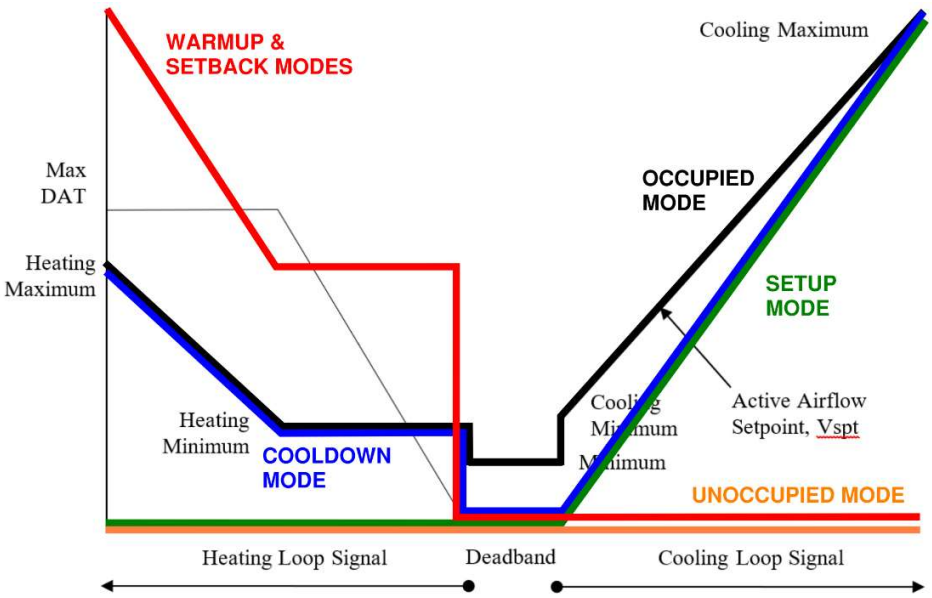
- Reduce system run time to only what is needed to recover space temperatures by the start of occupancy. Avoid starting too early, which can lead to energy waste, or starting too late, which can lead to thermal comfort complaints.
- Recover space temperatures as efficiently as possible.

KEY CONSIDERATIONS:

- Guideline 36 does not provide a sequence for optimal start (nor does it even mention it by name!), rather it describes a performance-based requirement. In practice, each BAS manufacturer tends to have its own optimal start strategy.
- Ventilation is only required during Occupied mode, the scheduled period when occupants are normally expected to be present. As Warmup and Cooldown occur prior to Occupied Mode, ventilation should not be provided during these modes of operation. Unnecessarily ventilating during Warmup and Cooldown modes wastes energy through the additional conditioning of outdoor air and potentially by prolonging recovery times.
- VAV box airflow setpoints vary in different operating modes. Setpoint is zero in deadband because ventilation is not required and heating airflow setpoints increase in warmup mode because there is no reheat.
- Cooling-only VAV boxes can provide heating in Warmup Mode if there is a central heating coil at the air handling unit!

Air Handling Unit Control by Mode

Supply Air Temperature Setpoint
Setpoint is 95°F in Warmup and Setback Modes, design SAT temperature in Cooldown, and resets in all other modes.
Minimum Outdoor Airflow Setpoint
Determined based on ventilation calculations in Occupied Mode, zero in all other modes.



SUPPORT FOR THIS MEASURE:

- Shown in simulation studies to have significant energy impact among VAV system strategies[i]
- Optimal start is required by building energy efficiency standards (ASHRAE 90.1[ii], IECC[iii], CA Title 24[iv])

CAUTIONS:

- Optimal start must be tuned for the applicable seasons to work effectively. Optimal start is often disabled by operators when not appropriately tuned because it does not consistently recover spaces temperatures in time.
- Each zone may have different recovery times, depending on capacity and envelope loads. Guideline 36 evaluates warmup and cooldown needs at every zone but some manufacturers' optimal start logic only evaluates a single zone or a sampling of representative zones, which may lead to comfort issues for other zones.
- The Morning Warmup and Cooldown logic extends across multiple equipment and control functions so the associated sequences in Guideline 36 are dispersed in several sections, which makes them difficult to see as comprehensive measures.
- The Warmup logic in Guideline 36 aims to recover as fast as possible to reduce system runtime. However, new research suggests that recovering at a more measured pace may be more efficient with equipment with modulating capacity control.[v]

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[i] Pang, X., Piette, M. A., & Zhou, N. (2017). Characterizing variations in variable air volume system controls. Energy and Buildings, 166-175.
[ii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.4.3.3.3. (optimal start)
[iii] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.4.2.3. (optimal start)
[iv] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraph 140.4(d).
[v] Cheng, H., Raftery, P., and Wendler, P. (2024). Re-Optimizing Optimal Start and Morning Warmup. ASHRAE Journal.

Demand Controlled Ventilation

Demand controlled ventilation (DCV) is an energy efficiency measure that reduces ventilation rates when zones are below design occupancy levels. Applied to zones with high design occupant densities, DCV generally uses zone CO2 concentration as an indicator for occupancy level. When CO2 concentrations are low, zone ventilation can be reduced to the area-based ventilation requirement. When CO2 concentrations increase above threshold limits, G36 increases zone primary airflow and outdoor air rates. (Guideline 36-2024 Paragraphs 5.2.1.3.b.5.iv and 5.2.1.4.b.3.iii)

GOAL:

- Reduce ventilation rates to spaces with high design occupant densities during periods of lower occupancy

KEY CONSIDERATIONS:

- CO2 sensors should be installed in the breathing zone in spaces with high design occupant density (California: 40 square feet per person or less, threshold requirement varies elsewhere).
- Many manufacturers have room temperature sensors with optional integrated CO2 sensors, which can reduce installation cost of adding demand controlled ventilation.
- When CO2 concentrations are high in particular zone, Guideline 36 first aims to increase primary airflow to that zone, rather than increasing the outdoor air fraction to all zones.

SUPPORT FOR THIS MEASURE:

- Simulation studies showed 10 to 30 percent HVAC energy savings in office buildings[i].
- Required by building energy efficiency standards (ASHRAE 90.1[ii], IECC[iii], CA Title 24[iv])

CAUTIONS:

- DCV is a zonal energy conservation measure. CO2 sensors are often mistakenly installed in the return air duct at the system-level where they cannot provide an effective indication of occupancy.
- Building energy codes only require the use of DCV in spaces with high design occupant density (e.g., classrooms, conference rooms) but some projects install CO2 sensors in all zones.
- CO2-based DCV is compatible with occupied-standby though the savings from the two measures will not be fully additive.
- When CO2 concentrations are high, system outdoor air rates can only be increased up to the design level, not to 100 percent outdoor air.
- Standard 62.1-2025 prescribes different CO2 concentration limits for different space types[v].

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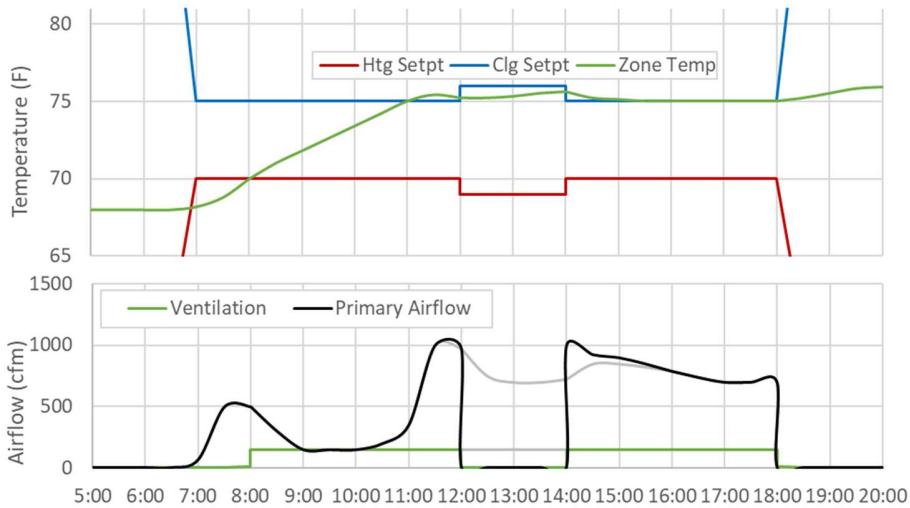
[i] O'Neill, Z., Li, Y., Cheng, H., Zhou, X., and Taylor, T. 2019. Energy Savings and Ventilation Performance from CO_2-Based Demand-Controlled Ventilation: Simulation Results from ASHRAE RP-1747. Science and Technology for the Built Environment
[ii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.4.3.8.
[iii] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.7.1.
[iv] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraphs 120.1(d)3 and 120.1(d)4.
[v] ANSI/ASHRAE. (2025). Standard 62.1 Ventilation and Acceptable Indoor Air Quality.

Occupied Standby

Occupied-standby is an energy efficiency measure that reduces ventilation and space conditioning during periods of scheduled occupancy but when sensors indicate that a space is vacant. Occupied-standby is allowed for most space types by ventilation standards and required by building energy efficiency standards. (Guideline 36-2024 Paragraphs 5.2.1.3.b.5.ii, 5.2.1.3.b.3.i, and 5.3.2.9)

GOAL:

- Reduce zone ventilation to zero when a space is sensed to be vacant.
- Reduce zone primary airflow to zero when a space is sensed to be vacant and is in deadband.
- Setback zone heating and cooling setpoints when a space is sensed to be vacant.
- Reduce system outdoor airflow when associated spaces are sensed to be vacant.



KEY CONSIDERATIONS:

- Occupancy sensors can be stand-alone devices, integrated into room temperature sensors, or part of a networked lighting control (NLC) system.
- Leveraging occupancy sensors in an NLC avoids the need for additional hardware but completing the network integration to the building automation system can be challenging in practice.
- Many manufacturers have room temperature sensors with optional integrated motion sensors, which can reduce installation cost, but see caution below.
- Default temperature setbacks are mild (1-2°F) to ensure that zones can recover in a reasonable amount of time when occupants return.

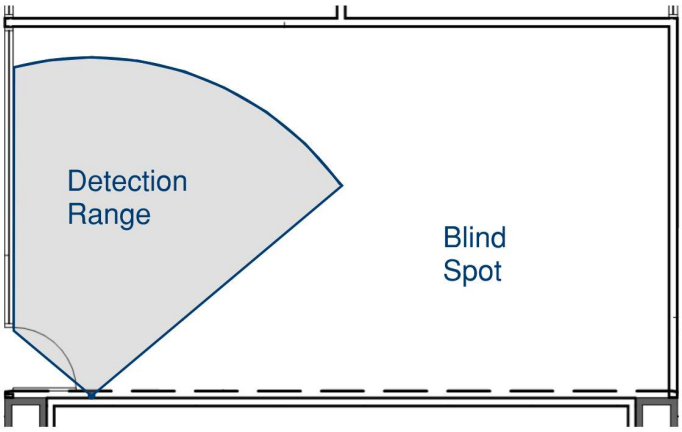
SUPPORT FOR THIS MEASURE:

- Simulation analysis of buildings in climate zones across the U.S. found HVAC energy savings ranging from around 20 to 45 percent of medium office buildings[i] and 2 to 10 percent in schools[ii].
- Required by building energy efficiency standards (ASHRAE 90.1[iii], IECC[iv], CA Title 24[v])

CAUTIONS:

- Occupied-standby is not permitted by ventilation standards for space types where contaminants are dominated by sources other than people, such as K-12 classrooms, retail, restaurants, barbershops, and gyms where there may be chemicals, cooking, stored materials, etc.

- Designers need to provide zone-level ventilation requirements to implement this measure fully.
- The system-level outdoor air setpoint should be reduced accordingly when associated zones are in occupied-standby mode.
- Occupancy sensors must have full visibility over the associated zone. Multiple sensors may be required for large zones and zones serving multiple spaces. Sensors integrated with room temperature sensors often do not have adequate coverage of a zone.



- CO2-based DCV is compatible with occupied-standby though the savings from the two measures will not be fully additive. Where both are provided occupied-standby can provide additional savings by disabling area-based ventilation when the last occupant leaves and through the zone temperature setbacks.

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[i] Pang, Z., Chen, Y., Zhang, J., O'Neill, Z., Cheng, H., and Dong, B. 2020. Nationwide HVAC Energy-Saving Potential Quantification for Office Buildings with Occupant-Centric Controls in the U.S. Applied Energy.
[ii] Ye, Y., Chen, Y., Zhang, J., Pang, Z., O'Neill, Z., Dong, B., and Cheng, H. 2021. Energy-Saving Potential Evaluation for Primary Schools with Occupant-Centric Controls. Applied Energy.
[iii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.5.3.9.
[iv] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.7.8.
[v] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraphs 120.1(d)5 and 120.2(e)3.

Zone Heating and Cooling Setpoints with Demand Levels and Limits

This is a collection of zone temperature setpoint attributes that allow for temperature control to be maintained within a set of constraints that ensure efficient system operation. Rather than a single temperature setpoint with a fixed deadband, Guideline 36 defines separate heating and cooling setpoints that can be independently adjusted, allowing for wider or narrower deadbands where appropriate. Guideline 36 also prescribes default adjustment limits to prevent setpoints from being adjusted by users to unachievable values that are too high or low and that may negatively impact other aspects of system operation (i.e., create rogue zones). (Guideline 36-2024 Paragraph 5.3.2)

GOAL:

- Define independent zone temperature heating and cooling setpoints.
- Establish adjustment limits for zone temperature heating and cooling setpoints, including a minimum deadband requirement.
- Establish standard setpoint adjustments for occupied standby and demand limiting.

KEY CONSIDERATIONS:

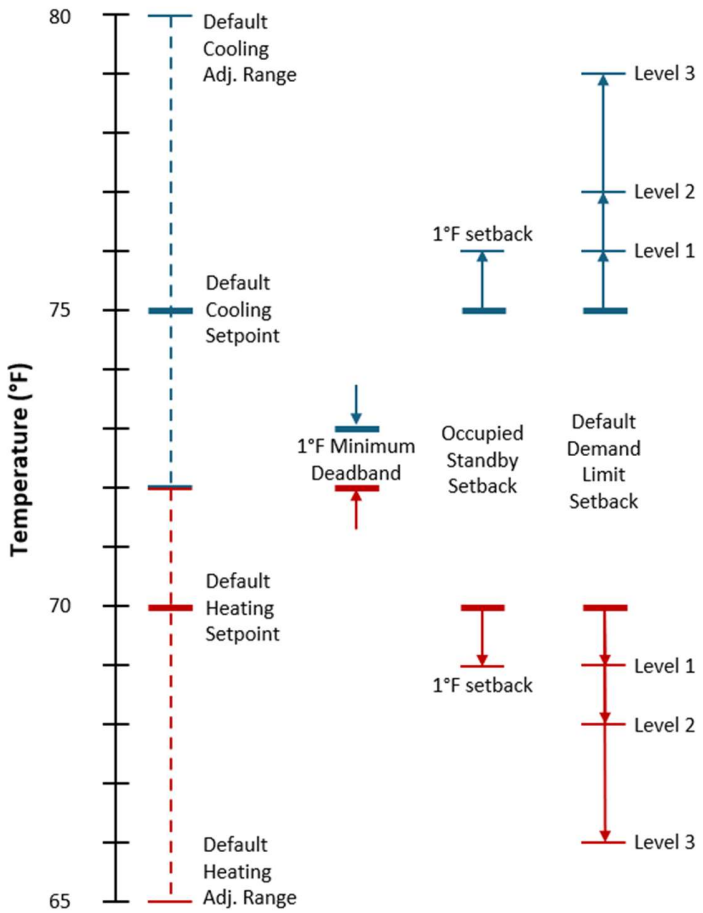
- These are best practice rules for basic zone temperature setpoints. These are best implemented when using control logic from an established library, but may be less practical to implement in control retrofits where modifying existing zone logic.

SUPPORT FOR THIS MEASURE:

- Shown in simulation studies to have significant energy impact among VAV system strategies[i]
- Required by building energy efficiency standards (ASHRAE 90.1[ii], IECC[iii], CA Title 24[iv])

CAUTIONS:

- Training for building operators is also key to maintaining reasonable zone setpoints over time.



[i] Pang, X., Piette, M. A., & Zhou, N. (2017). Characterizing variations in variable air volume system controls. Energy and Buildings, 166-175.
[ii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.4.3.1.
[iii] International Code Council. (2024). International Energy Conservation Code. Paragraphs C403.4.1.2 through C403.4.1.4
[iv] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraph 120.2(a).

Dynamic Minimum Outdoor Airflow Setpoint

This measure dynamically adjusts the minimum outdoor airflow setpoint at the air handling unit based on real-time sensing at the zone level and scheduling of zone groups. Where conventional practice is to determine a design ventilation rate and consistently control the minimum outdoor airflow to that value at all times, this energy measure recognizes that buildings are often only partially occupied and that ventilation rates can be reduced accordingly based on real-time sensing and scheduling. (Guideline 36-2024 Paragraphs 5.16.3.1 and 5.16.3.2)

GOAL:

- Minimize the conditioning of excess outdoor air beyond minimum ventilation requirements at each moment in time.

KEY CONSIDERATIONS:

- System ventilation requirement can be adjusted by zonal CO2 sensing, occupancy sensing, and window switches, as well as zone group scheduling.
- Energy savings potential varies by climate zone with larger savings in more extreme climates and lower savings in mild climates.
- The dynamic minimum outdoor airflow control logic is compliant with minimum ventilation requirements in ASHRAE Standard 62.1 and CA Title 24.

SUPPORT FOR THIS MEASURE:

- Shown in simulation studies to have significant energy impact among VAV system strategies[i], and potentially up to 15-20 percent of HVAC energy compared to a fixed setpoint (draft result)[ii].
- Required by building energy efficiency standards (ASHRAE 90.1[iii], IECC[iv], CA Title 24[v])

WORKAROUNDS:

- In control retrofits without occupancy sensors, logic can be simplified to control to ventilation rates based on zone groups, to reduce burden of zone reprogramming.

CAUTIONS:

- Designers must provide zone-level ventilation requirements in combination with the sequences in order to implement this strategy effectively.
- As the outdoor airflow setpoint can be significantly below the design value, accuracy and stability of the airflow measurement stations (AFMS) is a critical consideration. Designers should carefully consider the expected low range of outdoor airflow and the compatibility of the selected AFMS. Use of a dedicated minimum outdoor air damper section is often needed to ensure adequate AFMS performance at low flows, rather than a single, common damper section for economizer and minimum outdoor airflow.

[ii] Pang, X., Piette, M. A., & Zhou, N. (2017). Characterizing variations in variable air volume system controls. Energy and Buildings, 166-175.
[ii] Pacific Northwest National Lab (in progress 2026).
[iii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraphs 6.5.3.3. and 6.5.3.9.1.
[iv] International Code Council. (2024). International Energy Conservation Code. Paragraphs C403.6.6 and C403.7.8.1.1.
[v] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraphs 120.1(d)4.E and 120.1(d)5.B.vi.

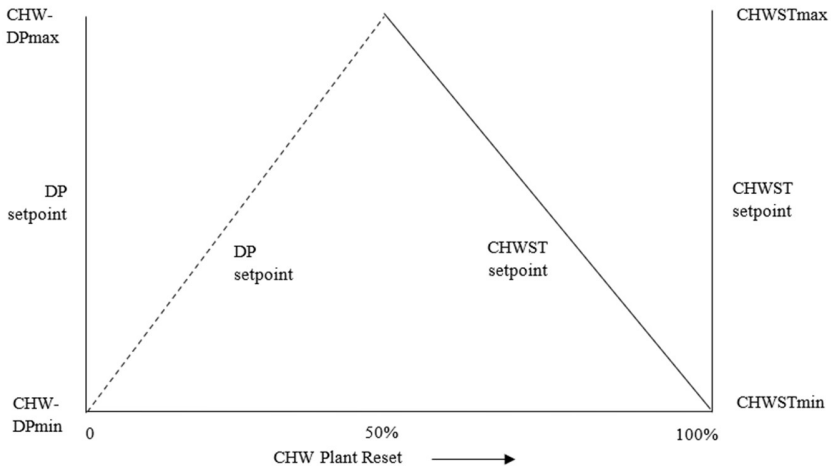
Chilled Water Supply Temperature Reset with Trim & Respond Logic

Chilled water supply temperature reset is a control strategy that adjusts the temperature setpoints to minimize HVAC energy while still satisfying demand from associated chilled water coils. The strategy in ASHRAE Guideline 36 resets the CHWST setpoint based on valve demand using trim and respond logic. (Guideline 36-2024 Paragraph 5.20.5 and 5.16.16.1, which is typical of many for request generation)

GOAL:

- Adjust the supply temperature to minimize HVAC energy while satisfying cooling loads.

KEY CONSIDERATIONS:



- Demand is indicated by chilled water reset requests which are generated when chilled water valve positions exceed a threshold.
- Increasing chilled water supply temperatures can significantly improve chiller efficiency.
- Guideline 36 uses a single chilled plant reset that is mapped to both the chilled water differential pressure and the chilled water supply temperature setpoints. As demand increases, the DP setpoint is increased then CHWST reduced.[i]

SUPPORT FOR THIS MEASURE:

- Demonstrated in a field study to provide 15 percent energy savings compared to a fixed setpoint.[ii]
- Required by building energy efficiency standards (ASHRAE 90.1[iii], IECC[iv], CA Title 24[v]).

CAUTIONS:

- All trim and respond resets must be tuned. The default settings in Guideline 36 generally provide decent control stability but reset effectiveness and stability should be reviewed in trends. In particular, the "Number of Ignored Requests" should be set to balance a tradeoff between meeting demand (lower number) and maximizing energy efficiency (higher number). See Section 3.2.5 in the Advanced BAS Best Practices Guide for more guidance on tuning T&R resets.[vi]
- Ensure the trim and respond parameters are shown and adjustable in graphics, not just hardcoded in the programming, so that operators can readily review and adjust when needed.

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[i] Taylor, S. T. (2017). Fundamentals of Design and Control of Central Chilled-Water Plants. ASHRAE.
[ii] Jayarathne, T., Singla, R., Duarte, C., Zou, A., Raftery, P., Kiriu, R., and Cheng, H. (2025). ASHRAE Guideline 36 Open-Source Supervisory Control Technology Development and Demonstration. CalNEXT Final Report. ET22SWE0039.
[iii] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.5.4.4.
[iv] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.4.1.6.
[v] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraph 140.4(k)4.
[vi] Cheng, H., Eubanks, B., & Singla, R. (2022). Advanced Building Automation System Best Practices Guide.

Hot Water Supply Temperature Reset with Trim & Respond Logic

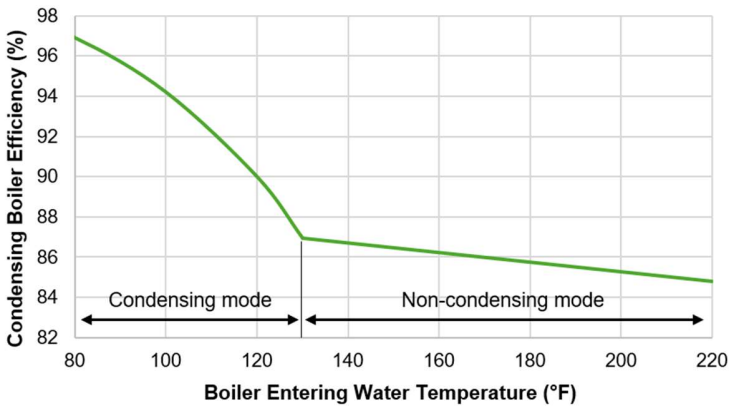
Hot water supply temperature reset is a control strategy that adjusts the temperature setpoints to minimize HVAC energy while still satisfying demand from associated hot water coils. The strategy in ASHRAE Guideline 36 resets the HWST setpoint based on valve demand using trim and respond logic. (Guideline 36-2024 Paragraph 5.21.4 and 5.6.8.2, which is typical of many for request generation)

GOAL:

- Adjust the supply temperature to minimize HVAC energy while satisfying heating loads.

KEY CONSIDERATIONS:

- Demand is indicated by hot water reset requests which are generated when hot water valve positions exceed a threshold.
- Reducing supply temperatures can significantly improve heating equipment efficiency, particularly for condensing boilers where condensing begins at return (entering) temperatures around 130°F and improves at lower temperatures, and for air-to-water and water-to-water heat pumps which operate less efficiently at high temperature (high lift) conditions.



- Energy loss through pipe distribution is largely overlooked but has been found to account for as much as 40 percent of the annual heat produced by a boiler plant[i,ii]. Fortunately, distribution losses can be reduced by operating at lower hot water temperatures.

SUPPORT FOR THIS MEASURE:

- Demonstrated in a field study to provide up to 11 percent energy savings compared to a fixed setpoint.[iii]
- Required by building energy efficiency standards (ASHRAE 90.1[iv], IECC[v], CA Title 24[vi]).

WORKAROUNDS:

- Requests are generated by associated hot water control valves. If existing zone controllers cannot be re-programmed (e.g., legacy controllers that are not supported or not reasonably supported, or configurable-only controllers), requests can be evaluated at the supervisory level instead. The supervisory controller would poll the zones for valve position and sum the requests. The time interval may need to be increased from the default of 2 minutes to manage network traffic.

CAUTIONS:

- Hot water temperature reset is often implemented solely based on outside air temperature. OAT can be a good proxy for heating load but limits must be carefully tuned to ensure that loads are met and to maximize efficiency. The demand-based strategy in Guideline 36 manages that balance automatically.
- All trim and respond resets must be tuned. The default settings in Guideline 36 generally provide decent control stability but reset effectiveness and stability should be reviewed in trends. In particular, the "Number of Ignored Requests" should be set to balance a tradeoff between meeting demand (lower number) and maximizing energy efficiency (higher number). See Section 3.2.5 in the Advanced BAS Best Practices Guide for more guidance on tuning T&R resets.[vii]
- Ensure the trim and respond parameters are shown and adjustable in graphics, not just hardcoded in the programming, so that operators can readily review and adjust when needed.
- Rogue zones are zones that consistently generate requests and prevent the setpoint from resetting, such as a zone that cannot maintain the heating setpoint. There are many potential causes of rogue zones. Resets must be periodically monitored for rogue zones to ensure that setpoints can reset effectively. Guideline 36 includes logic ("cumulative request hours") that should be coupled with graphics and/or alarms to help operators identify rogue zones. See Section 4.5.5 in the Advanced BAS Best Practices Guide for more guidance on rogue zones.[vi]

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[i] Raftery, P., Geronazzo, A., Cheng, H., & Paliaga, G. (2018). Quantifying energy losses in hot water reheat systems. Energy and Buildings.
[ii] Raftery, P., Vernon, D., Singla, R., & Nakajima, M. (2023). Measured Space Heating Hot Water Distribution Losses in Large Commercial Buildings. ASHRAE Conference Proceeding.
[iii] Jayarathne, T., Singla, R., Duarte, C., Zou, A., Raftery, P., Kiriu, R., and Cheng, H. (2025). ASHRAE Guideline 36 Open-Source Supervisory Control Technology Development and Demonstration. CalNEXT Final Report. ET22SWE0039.
[iv] ANSI/ASHRAE/IES. (2025). Standard 90.1 Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings. Paragraph 6.5.4.4.
[v] International Code Council. (2024). International Energy Conservation Code. Paragraph C403.4.1.6.
[vi] California Energy Commission. (2025). Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Paragraph 140.4(k)4.
[vii] Cheng, H., Eubanks, B., & Singla, R. (2022). Advanced Building Automation System Best Practices Guide.

Case Studies

Simple one page case study descriptions are presented for a range of past G36 projects highlighting the existing conditions encountered and how those projects proceeded.

1. Full Control Retrofit of California Office Building
2. Software-only Retrofit of California Academic Building
3. Software-only Retrofit of California Office Building
4. Partial Control Retrofit of California Office Building
5. Software-only Retrofit of New York Office Building
6. Full Control Retrofit of Minnesota Library

Case Study #1: Full Control Retrofit of California Office Building

Measure	Existing Condition	G36 Measure Applied
VAV Control Logic and Average VAV Minimum (as % of Design)	Single Maximum with 30% Minimums	Dual Maximum with 9% Minimums
DSP Setpoint Control	Fixed Setpoint	Reset with Trim & Respond
SAT Setpoint Control	Limited Reset	Reset with Trim & Respond
Outdoor Air Flow Control	Fixed Minimum Damper Position	Reset Minimum Damper Position
Optimal Start and Morning Warmup	No	Optimal Start and Morning Warmup
Demand Controlled Ventilation	No	In densely occupied spaces per G36
Occupied Standby	N/A	N/A

Building / Project Description

Space Types: Office, conference

Building Size: 140,000 ft^2

ASHRAE Climate Zone: 3C

California Climate Zone: 3

Site HVAC Energy Savings: 53%

Building EUI (kBtu/ft2): 67.0 (before), 45.5 (after)

Cost effectiveness: 6.3 year simple payback

HVAC System Description	
HVAC System Type	VAV Reheat
HVAC/BAS System Age (at time of project)	16 years
Cooling	Evaporatively-Cooled Packaged DX
Heating	Gas-fired boilers
BAS Type	DDC throughout
BAS Condition	Legacy, no longer supported
Project Initiation	Replace end-of-life BAS
Deferred Maintenance Issues	Yes, addressed in project

The control retrofit was initiated as an end-of-service-life replacement of the existing DDC system. The full control system was replaced including server, all BAS controllers, sensors, control valves, and damper actuators. The new BAS also controlled the packaged AC units and hot water plant. No lighting or mechanical changes were made but the retrofit likely addressed deferred maintenance issues. The new control programming followed G36 sequences. Though initiated as a capital renewal project, the project could have been justified based on the energy economics.

An engineer led the control retrofit design with updated VAV schedules, control schematics, and specifications. The engineer also led submittal reviews and the commissioning effort, including functional testing and trend analysis.

Case Study #2: Software-only Retrofit of California Academic Building

Measure	Existing Condition	G36 Measure Applied
VAV Control Logic and Average VAV Minimum (as % of Design)	Single Maximum with 36% Minimums	Dual Maximum with 15% Minimums
DSP Setpoint Control	Fixed Setpoint	Reset with Trim & Respond
SAT Setpoint Control	Limited Reset	Reset with Trim & Respond
Outdoor Air Flow Control	Fixed Setpoint	Dynamic Outdoor Air Setpoint
Optimal Start and Morning Warmup	No	Optimal Start and Morning Warmup
Demand Controlled Ventilation	Densely occupied spaces	Densely occupied spaces per G36
Occupied Standby	No	Yes

Building / Project Description

Space Types: Offices, cafeteria, bookstore

Building Size: 50,000 ft^2

ASHRAE Climate Zone: 3B

California Climate Zone: 3

Site HVAC Energy Savings: 12%

Building EUI: 41.5 (before), 38.3 (after)

Cost effectiveness: 7 year simple payback

HVAC System Description	
HVAC System Type	VAV Reheat
HVAC/BAS System Age (at time of project)	2 years
Cooling	Chiller (not in scope)
Heating	Gas-fired boiler (not in scope)
BAS Type	DDC throughout
BAS Condition	New
Project Initiation	Demonstration project
Deferred Maintenance Issues	No

The building was recently constructed but exhibited some HVAC control attributes that did not meet current code requirements and offered the potential for improvement. A software-only (programming) control retrofit was initiated as a demonstration of the energy savings potential using G36. The existing control system hardware was retained including server, controllers, sensors, valves, and damper actuators. The control programming for the AHU and terminals was updated to follow G36. No lighting or mechanical changes were made, nor changes to the control of the chilled or hot water plants.

An engineer led the control retrofit design with updated VAV schedules, control schematics, and specifications. The engineer also led submittal reviews and the commissioning effort, including functional testing and trend analysis.

Case Study #3: Software-only Retrofit of California Office Building

Measure	Existing Condition	G36 Measure Applied
VAV Control Logic and Average VAV Minimum (as % of Design)	Single Maximum with 28% Minimums	Dual Maximum with 7% Minimums
DSP Setpoint Control	Fixed Setpoint	Reset with Trim & Respond
SAT Setpoint Control	Limited Reset	Reset with Trim & Respond
Outdoor Air Flow Control	Fixed Minimum Damper Position	Reset Minimum Damper Position
Optimal Start and Morning Warmup	Unknown	Optimal Start and Morning Warmup
Demand Controlled Ventilation	Densely occupied spaces	Densely occupied spaces per G36
Occupied Standby	No	Yes

Building / Project Description

Space Types: Office, conference, data center

Building Size: 24,000 ft^2

ASHRAE Climate Zone: 3C

California Climate Zone: 3

Site HVAC Energy Savings: 23%

Building EUI: 146.7 (before), 123.2 (after)

Cost effectiveness: 2 year simple payback

HVAC System Description	
HVAC System Type	VAV Reheat
HVAC/BAS System Age (at time of project)	20 years
Cooling	Chiller (not in scope)
Heating	Gas-fired boiler (not in scope)
BAS Type	DDC throughout
BAS Condition	New
Project Initiation	Demonstration project
Deferred Maintenance Issues	No

The building was undergoing a limited control system retrofit to update legacy zone controllers, though other existing control system hardware including sensors, valves, and actuators were retained. Where the original project scope intended to replicate the existing control logic, the demonstration project expanded the scope to update the AHU and zone-level programming to follow G36. As the legacy DDC controllers were still operational, the project effectively represented a software-only (programming) retrofit. No lighting or mechanical changes were made, nor changes to the control of the CHW or HW plants.

An engineer led the control retrofit design with updated VAV schedules, control schematics, and specifications. The engineer also led submittal reviews and the commissioning effort, including functional testing and trend analysis.

Case Study #4: Partial Control Retrofit of California Office Building

Measure	Existing Condition	G36 Measure Applied
VAV Control Logic and Average VAV Minimum (as % of Design)	Single Maximum with 33% Minimums	Single Maximum with 18% Minimums
DSP Setpoint Control	Reset (but with very limited range)	Reset with Trim & Respond
SAT Setpoint Control	Fixed (adjusted manually)	Reset with Trim & Respond
Outdoor Air Flow Control	Fixed Outdoor Air Setpoint	Fixed Outdoor Air Setpoint
Optimal Start and Morning Warmup	No	Yes
Demand Controlled Ventilation	Densely occupied spaces	Densely occupied spaces
Occupied Standby	N/A	N/A

Building / Project Description

Space Types: Office, conference

Building Size: 120,000 ft^2

ASHRAE Climate Zone: 3C

California Climate Zone: 3

HVAC System Description	
HVAC System Type	VAV Reheat
HVAC/BAS System Age (at time of project)	14 years
Cooling	Chiller (not in scope)
Heating	Gas-fired boiler (not in scope)
BAS Type	DDC throughout
BAS Condition	Supported DDC product line + configurable zone controllers
Project Initiation	AHU retrofit and energy efficiency upgrade

The project was driven by the replacement of packaged AC units with chilled water air handling units, with associated upgrades to the controls to follow G36. However, existing configurable-only zone controllers were retained and were out of scope.

SAT and DSP setpoint resets were implemented using T&R logic though these were later found to largely be disabled or overridden. Further review found that the zone requests were incorrectly mapped to the wrong AHUs.

The project scope did not extend to the configurable zone controllers, though these were later found to be capable of partially mimicking dual maximum VAV logic with low minimums.

Case Study #5: Software-only Retrofit of New York Office Building

Measure	Existing Condition	G36 Measure Applied
VAV Control Logic and Average VAV Minimum (as % of Design)	Single Maximum with 50% Minimums	Dual Maximum with 7% Minimums
DSP Setpoint Control	Fixed Setpoint	Reset with Trim & Respond
SAT Setpoint Control	OAT-based Reset	Reset with Trim & Respond
SAT Control	Separate SAT and MAT setpoints, complementary damper control	Single SAT setpoint and sequenced dampers per G36
Outdoor Air Flow Control	Fixed Setpoint	Dynamic Setpoint
Optimal Start and Morning Warmup	Yes	Yes
Demand Controlled Ventilation	Densely occupied spaces	Densely occupied spaces
Occupied Standby	No	Yes

Building / Project Description

Space Types: Offices, conferences, locker rooms, and laundry

Building Size: 40,000 ft^2

ASHRAE Climate Zone: 4A

Energy Impact: 46% savings chilled water, 19% savings fan energy, 8% savings hot water

HVAC System Description	
HVAC System Type	VAV Reheat
Cooling	District chilled water
Heating	District steam
BAS Type	DDC throughout
BAS Condition	New controllers
Project Initiation	Demonstration project
Deferred Maintenance Issues	No

The HVAC control system had recently been replaced at end-of-service life when the software-only retrofit was initiated as a G36 demonstration project. Control programming was replaced with G36 logic, except that several functions were programmed with both baseline and G36 strategies with switching logic alternating between the two every week for M&V purposes.

A design engineer evaluated the existing HVAC and control system, adapted G36 to the project conditions, developed functional testing scripts, and provided overall project oversight. Programming was by the manufacturer and tests were executed by the campus operators. Trend analysis was led by the research team.

Documentation of significant energy savings with G36 outside of California is a key finding.

Case Study #6: Full Control Retrofit of Minnesota Library

Measure	Existing Condition	G36 Measure Applied
VAV Control Logic and Average VAV Minimum (as % of Design)	Single Maximum with 50% Minimums	Dual Maximum with 50% Minimums
DSP Setpoint Control	Fixed Setpoint	Reset with Trim & Respond
SAT Setpoint Control	Fixed Setpoint (adjusted seasonally)	Reset with Trim & Respond
Outdoor Air Flow Control	Fixed Minimum Damper Position	Fixed Minimum Damper Position
Optimal Start and Morning Warmup	No, fixed schedule	No, fixed schedule
Demand Controlled Ventilation	Densely occupied spaces	Densely occupied spaces
Occupied Standby	N/A	N/A

Building / Project Description

Space Types: Library stacks, reading room, conference room, offices

Building Size: 8,500 ft^2

ASHRAE Climate Zone: 6A

Energy Impact: 2.8% increase in electricity, natural gas impact not statistically significant

HVAC System Description	
HVAC System Type	VAV Reheat
HVAC System Age (at time of project)	28 years
Cooling	Air-cooled Chiller
Heating	Gas-fired boiler
BAS Type	DDC throughout
BAS Condition	Legacy controllers
Project Initiation	Replace end-of-life BAS
Deferred Maintenance Issues	Yes, but not addressed

The project was driven by an end-of-service life BAS replacement, with G36 added to the scope as a demonstration study. Control system hardware and software were fully replaced.

No design engineer involved, the project was led directly by the contractor with no prior G36 experience. Most of the attempted energy measures were unsuccessful for a range of reasons. Required sensors for some sequences were missing (BSP sensor) or improperly selected (OA AFMS). Dual max VAV logic was installed but the VAV minimums were not re-evaluated. SAT reset was implemented but overridden by operators in winter to address mechanical shortcomings.

A lesson learned includes the importance of a design engineer to adapt G36 to the project, provide design data, and specify required control components. In retrofits, evaluating the condition of the existing system and addressing deficiencies is also necessary.

Appendix B: Utility Program Stakeholder Interview Guide

Section A: Screening & Introduction

Interview Instructions

This interview guide is designed to apply to a variety of potential respondents. As such, the questions are written deliberately to be open-ended and flexible. The questions should be understood as concepts to explore rather than a verbatim script. In particular, the follow-up questions and probes should be considered possibilities to further explore topics but may not apply to all respondents.

Introduction

Thank you for agreeing to speak with us today. As a reminder, we are performing this work as part of a Statewide program to identify current practice and future opportunities **to help accelerate the adoption of Guideline 36 (G36) measures in existing buildings through the development of a Simplified G36 retrofit guide.** I expect this conversation to take about **45 minutes** of your time.

I want to let you know that your participation in this research is voluntary and that you may choose to end the call at any time.

Your identity and responses will be kept confidential. The information we gather today will only be reported in an anonymized and aggregated format. Under no circumstances will information you share with us be used to directly sell or market any products or services to you. **To help me capture your responses accurately, is it okay if I record this call?**

[INTERVIEWER NOTE: only begin recording if respondent gives permission to do so]

Section B: Programs and SME Questions

Background and Experience

1. **Please tell us a little bit about your Commercial SEM program with PG&E and your role.**
2. **Is implementing Guideline 36 sequences a program goal or requirement?**

   Probe: Program role in implementation of HVAC control improvements.

   Probe: What is the expectation of program participants and trade allies in implementing HVAC control improvements (std. RCx versus, full- or near-G36 opportunities)?

Program Offerings and Requirements

3. **How do you screen for potential program participants?**

   Probe: HVAC control project types – full-hardware & software upgrades, software-only or retro-commissioning? Data analytics and high summer gas usage?

4. **What are the most common standard RCx and/or Guidelines 36 measures evaluated, recommended, and implemented?**

   Probe: Flowcharts for scenarios at the system level are being considered for G36 Lite.

Probe: AHU resets, off-hour controls, DCV, Economizer Repair, VAV optimization, Chilled and Hot Water Plant. Key Guideline 36 measures, zone-level control improvements, lack of awareness of zone-level control opportunities, effectiveness at building-level impacts requires high level of zone control (>50 percent). For example, SEM does meter-level savings (>10 percent savings needed).

Probe: Existing conditions – Length of duct system (increased DSP reset potential), design velocity of duct system (+DSP reset), overcooling and high VAV minimums. Non-standard system types (constant volume).

5. **Who performs the baseline energy savings analysis for proposed HVAC control measures?**

   Probe: Design engineer involvement (input on actual/proposed VAV requirements, ASHRAE 62.1), program engineer, controls contractors. Calculation tools (Hwakong VAV spreadsheet, Cal TF HVAC Tool, etc.). Title 6 requires ventilation at time of construction, after this time the building operator can reset minimums.

6. **Who performs HVAC SOO commissioning?**

   Probe: What are the program commissioning requirements and tools (trend review, diagnostics, etc.) G36 Lite can help support these efforts.

7. **How do you coordinate M&V level of rigor and activities?**

   Probe: M&V options employed (Options A, B, and/or C), in-house staff familiarity with G36 (G36 Lite can help), eligibility and inclusion of deemed and capital projects (NMEC or SEM integration). Working with commissioning agents to coordinate this effort.

8. **In your experience, what challenges have you faced when trying to implement standard RCx (to original design conditions, HVAC control only) or Guideline 36 SOO.**

   Probe: Probe: How do they deal with limited subsystem control capabilities (e.g., VAV box memory) or non-standard HVAC system types

   Probe: Existing baselines (AOE & RCx), versus code triggers

   Probe: For example, SAT reset to prior code versus current Guideline 36 code requirement. G36 allows you to prioritize specific zones, track rogue zones. G36 Lite still offers these two features.

Trade Ally Relationships

9. **What has your experience been with customers and trade allies, and their knowledge and implementation of Guideline 36?**

   Probe: Inform and inquire how G36 Lite can help bridge the knowledge gap and build consensus in project planning and implementation.

Section C: Closing

Is there anything we have not discussed today that you feel that we should know about? That is all the questions I have for you. We appreciate you taking the time to help us with this research and hope have a nice day.