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FINAL PROJECT REPORT

Demonstrating Scalable Operational Efficiency Through Optimized Controls Sequences and Plug-and-Play Solutions

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Best in Class: Demonstrating Scalable Operational Efficiency through Optimized Controls Sequences and Plug-and-Play Solutions is the final report for the Best in Class project (Contract Number: EPC-17-001) conducted by Taylor Engineering with TRC, Lawrence Berkeley National Lab, and Integral Group. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov.

ABSTRACT

Existing commercial buildings in California account for roughly 40 percent of total electricity sales in the service territories of the state's three primary investor-owned utilities: Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison. Successful design and operation of building automation and control systems can reduce energy consumption by heating, ventilating, and air conditioning equipment, but there are many barriers to upgrading existing building automation systems. This project demonstrated the cost effectiveness and energy savings potential of installing optimized control sequences based on American Society of Heating, Refrigerating and Air-Conditioning Engineers Guideline 36 in existing commercial buildings. Replacing building control systems achieved between 26 to 35 percent electricity savings with 6- to 8-year simple paybacks, while updating software in buildings that already had modern control systems provided electricity savings of 11 to 17 percent with 2- to 7-year simple paybacks.

Besides improving system performance for individual projects, standardization around Guideline 36 can improve scalability and streamline the value delivery chain, reducing first costs and improving quality in the process. Using extensive stakeholder engagement and lessons learned from field demonstrations, the project's research team identified technical and market barriers before developing and testing strategies to overcome these barriers and accelerate successful market adoption. Anticipated outcomes from the completed activities:

- Project results will raise industry awareness of the value of Guideline 36.
- A best practices guide will help increase industry stakeholder understanding and improve the design, installation, and operation of systems using Guideline 36.
- A pilot tool to quickly screen sites for potential energy savings and a utility incentive program design concept can help with initiating retrofit projects.
- Software tools can streamline implementation and improve quality control.
- Potential codes and standards improvements may increase measure adoption.
- Outreach to industry stakeholders and key market actors can accelerate industry awareness and adoption of this new guideline and opportunity.

The estimated statewide potential benefits of implementing Guideline 36 and networked lighting controls in existing commercial buildings in California over the next 15 years include reducing electricity use by 2,387 gigawatt hours, which will save Californians $373 million in energy costs and eliminate 1,742 million pounds of carbon dioxide emissions.

Keywords: Advanced HVAC controls, controls retrofits, building automation systems, ASHRAE Guideline 36

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EXECUTIVE SUMMARY

Introduction

Existing commercial buildings in California account for roughly 40 percent of total electricity sales in the service territories of the state's three largest investor-owned utilities: Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison. In most existing buildings, building automation systems have sub-optimal control programming that can cause excessive energy consumption by heating, ventilating, and air-conditioning (HVAC) equipment. Exacerbating this problem is the current ad-hoc process of specifying and implementing control programming for individual buildings, which is often based on partial and fragmented information. This cumbersome current practice sets the stage for risks and problems at every stage in complex controls installation and operations processes, from poor understanding of control fundamentals to misinterpreted designs to insufficient quality control—in other words, in the very foundation of these processes. This project specifically addresses these challenges; it is no less than an opportunity to address the entire value delivery chain: from design through implementation, commissioning and testing, and ongoing system maintenance and long-term fault detection. The sequences of operation spelled out in the American Society of Heating, Refrigerating and Air-Conditioning Engineers Guideline 36 provide much-needed direction for the coordinated control of heating, ventilating, and air conditioning equipment based on best practices, the latest energy efficiency research, and current energy standards. Compared with current practices, the advanced sequences of operation built into Guideline 36 offer the opportunity to significantly improve energy efficiency and indoor environmental quality in commercial buildings. Standardization around these high-performance sequences further provides the opportunity for scaling these improvements across the industry, ultimately overcoming current workflow inefficiencies and high-risk steps in the value delivery chain. Industry alone is unable to advance its processes due to the inherent resistance to change, lack of standardization, and cost and schedule pressures on individual projects. This research project demonstrates the strong value proposition of optimized building controls, offers resources to support industry participants, and kick starts key industry partners to initiate broad changes that will ultimately benefit everyone involved in this process.

Project Purpose

The research team developed this comprehensive demonstration project to overcome technical, structural, and market barriers to maximizing long-term energy savings by improving technology applications and market transformation strategies. More effective building controls provide the opportunity to significantly reduce energy consumption in existing buildings and reduce transactional costs. These controls provide the technologically mature and cost-effective means to contribute to California's ambitious mandates to reduce statewide energy consumption and greenhouse gas emissions from commercial buildings.

The project focused on the following goals:

1. **Technological Innovation:** Demonstrate the commercial viability (ease, practicality, and cost effectiveness) of controls retrofits in existing commercial buildings that integrate heating, ventilating, air conditioning, and lighting controls to achieve greater energy efficiency and better indoor environmental quality.

2. **Market Innovation:** Demonstrate a new delivery mechanism (the use and standardization around Guideline 36 for control sequences of operation and programming) for control system upgrades, in close collaboration with utilities and other industry partners to satisfy California's mandates for cost-effective scalable energy and carbon reductions.

The project focused on three main objectives:

1. Demonstrate energy savings and improved occupant comfort from control upgrades based on Guideline 36 sequences and other advanced solutions such as fault detection and diagnostics and networked lighting controls.
2. Investigate potential technological advancements that streamline and support successful deployment of controls retrofits in commercial buildings.
3. Recommend strategies, tools, and initiatives that address market barriers to wider acceptance and adoption of these scalable technology packages through best practice guidelines, case studies, utility program ideas, and energy code improvements.

These goals and objectives would together promote rapid market adoption and increased energy savings from the optimized building control technologies examined in this study. Project results support a cost-efficient and technically-sound shift from current standards to an improved approach for existing commercial buildings.

Project Approach

The research team included Taylor Engineering, TRC Energy Services, Lawrence Berkeley National Laboratory, and Integral Group. Product vendors included Enlighted and Clockworks Analytics, as well as the large controls manufacturers Siemens, Trane, Automated Logic, and Alerton (a division of Honeywell). Demonstration efforts were supported by site partners Kaiser Permanente, Contra Costa College, and California State University, Dominguez Hills.

The team developed the technical approach to meet project goals and objectives, which included a combination of technical tasks (such as bench-scale testing, field demonstrations, and data collection) and market-connection activities (technology and knowledge transfer, tools, and market pathways).

The purpose of the field demonstrations was to demonstrate energy savings and improved occupant comfort from control upgrades based on Guideline 36 sequences and other advanced solutions (such as fault detection, diagnostics, and networked lighting controls) at several demonstration sites. Project objectives focused on:

- Evaluating the technology's energy savings and cost effectiveness.
- Evaluating the technology's indoor environmental quality effects like thermal comfort and ventilation.
- Evaluating the technology's impacts on stakeholders, including value proposition and influences on workflow and market share.
- Conducting knowledge and technology transfer activities.

Field demonstrations included two building types that represent typical building baselines: buildings without modern direct digital control systems where the control systems were completely retrofitted, including hardware and software replacements; and buildings with modern direct digital control systems where only the software controls were upgraded. In the existing buildings stock, buildings without modern controls are far more common and represent a more conventional retrofit opportunity. However, energy savings may be partly due to the hardware control system upgrade itself and the resolution of deferred maintenance issues, rather than from the new software technologies demonstrated in this project. The second building type, with existing modern controls, allowed researchers to isolate energy savings from the new technologies. The demonstrations included multiple buildings of each type to provide robust results and reduce site-specific influences.

A subset of demonstration buildings considered fault detection and diagnostics and networked lighting controls technologies to compare various packages of measures.

The project also focused on controls software validation and optimization that addressed the project’s second objective: to investigate potential technological advancements of optimized controls retrofits. The team evaluated the performance of previously untested portions of Guideline 36 through building energy simulations. As part of the field demonstrations, the team developed new control strategies and proposed advancements for adoption in the guideline. The team also developed and piloted new software tools to streamline the use of Guideline 36.

Technology and knowledge transfer were major components of project efforts to meet the project’s third objective: accelerating market transformation. The project focused on scaled market adoption of new delivery mechanisms that promote widespread industry acceptance of this new streamlined approach to designing and installing building automation systems. The market assessment and feasibility analysis describe the deployment potential, opportunities, and barriers associated with the new control solutions. The team conducted research on market segmentation, explored building automation system delivery channels and methods, and studied stakeholder impacts through extensive engagement and interviews with engineers, installers, building operators, and building automation manufacturers. The team developed market transformation pathways including a utility program concept design, potential codes and standards improvements, and a best practices guide. The findings of the market analyses were combined with the field demonstration results to create a series of market resources to streamline technology and knowledge transfer.

Project Results

Optimized control solutions were successfully implemented, and energy savings evaluated at four demonstration sites. Two sites underwent full-control retrofits (both hardware and software), and two sites underwent software-only retrofits. Though each demonstration site presented unique conditions, from building usage and occupancy to pre-existing equipment-control configurations, the energy savings and cost effectiveness were generally consistent.

The project achieved whole-building electricity savings of 26 to 35 percent, with 6- to 8-year simple paybacks at the two full-control retrofit sites. Combining electricity and natural gas, the sites achieved 35 to 45 percent whole-building energy savings. The software-only retrofits achieved whole-building electricity savings of 11 to 17 percent, with 2- to 7-year simple paybacks, and 8 to 16 percent whole-building energy savings, including natural gas. The latter result clearly demonstrates that control sequences in modern buildings substantially affect building energy consumption, and that control systems in existing buildings can be cost-effectively upgraded to achieve significant energy savings. Moreover, given that most of the measures associated with these software-only retrofits have been prescriptively required by the California Building Energy Efficiency Standards (Title 24) for more than 10 years, this result indicates the tangible energy benefits of greater future compliance with Title 24 in typical heating, ventilating, and air-conditioning designs.

One demonstration site did not proceed as planned because of implementation challenges with the designer, installer, and owner. Although energy and indoor air quality improvements could not be evaluated at this site, lessons learned from this effort, as well as from the other demonstration sites, were invaluable and mirror many of the following technical and market barriers identified elsewhere throughout the project:

- **Designers are unfamiliar with technical aspects of controls best practices**. The design documents are often missing key elements and details required for a successful project: complete equipment schedules with all necessary inputs for Guideline 36, clear delineation of contractor scope with respect to existing equipment to either be replaced or remain, and clear outlining of required procedures.
- **A high level of effort and existing market barriers make it difficult to develop control programs that follow Guideline 36**. Many installers do not expect detailed sequences of operation from designers and do not expect the extensive effort required to develop new programming.
- **Project success is dependent on more than merely providing accurate and clear construction documents**. Active construction administration and commissioning are critical to ensure that projects are built according to their design intent. Comprehensive testing of control functionality is essential.
- **Building owners and property managers must better understand the value and importance of following direction from designers and commissioning agents**. Enforcement of project specifications ultimately rests with the owner or property manager. If key design elements are not enforced during construction, the subsequent installation is unlikely to achieve the design intent.
- **The optimized controls solution and Guideline 36 are complex and challenging to successfully deploy**. Though Guideline 36, industry standardization, and software tool development will ultimately streamline future implementation, this is not yet a plug-and-play solution. Rather, it requires diligent and careful design and sufficient technical understanding to adapt to unique project circumstances, particularly in retrofit applications. Control sequences are just one aspect of comprehensive controls design; other components must also be designed and installed appropriately to ensure successful implementation.
- **Data quality and accessibility are critical.** With advanced control implementations, active monitoring of system performance is required to verify and ensure correct operation. Recording trend data, calibrating key energy meters, and end-to-end checkout of monitoring between the native building automation systems and third-party analytics are not routinely emphasized, but monitoring cannot be effective without these steps.
- **Building operators are key stakeholders who are often insufficiently considered and involved during typical design and construction efforts**. Operator understanding of the design intent and key aspects of the control functionality, particularly with the complex logic of an optimized controls solution, is

critical to ensure that building systems are operated correctly and according to design intent.

The original project design anticipated many of these challenges, but lessons learned as part of the field demonstration efforts helped the research team more fully understand these barriers, identify possible solutions, and in many cases pilot or develop solutions. The project successfully developed proof of concept tools (a simplified energy savings calculator and an automated method of test for Guideline 36 programming) to support market adoption that were well received but require further work to develop into market ready tools.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

Market innovation was one of two primary goals of this study. The team designed project tasks to examine scaled market adoption potential and initiate steps for development of knowledge transfer and new delivery mechanisms for optimized building control solutions.

The team developed and disseminated materials to facilitate knowledge transfer, accelerate market adoption, and increase awareness of project results. Throughout the project, the team distributed both information on Guideline 36 and early research findings through more than 20 presentations and trainings at conferences, industry events, and other organizations. The research applies to all stakeholders in the building automation industry including facility managers, building owners, design engineers, controls contractors, controls manufacturers, and commissioning agents.

The team identified specific market transformation pathways to leverage opportunities and barriers to transform the market through a series of market-facing resources that includes:

- Utility program concept designs for utilities and implementers to develop and implement incentive programs.
- Best practices guides for building owners and operators, engineering and controls firms, and portfolio property management companies to successfully specify and implement optimized building controls.
- Codes and standards for investor-owned utilities and municipalities to advance code requirements relating to optimized control solutions.

The team also promoted market adoption by collecting data on early adopters of Guideline 36 implementations and tracking the progress of building automation system manufacturers.

Benefits to California

The highly efficient building controls demonstrated in this project would provide energy savings to utility customers and reduce greenhouse gas emissions. The estimated annual energy-savings potential for investor-owned utility ratepayers at full implementation is 2,387 gigawatt-hours of electricity. These measures result in both initial and ongoing operational optimization, resulting in deep energy savings with long-term persistence. Cost-competitive and scalable advanced building automation technologies also ultimately support California’s energy efficiency industry. Controls technologies also benefit ratepayers with improved comfort and satisfaction and support occupant customization—all factors that can lead to increased productivity and building valuation. Such occupant benefits are increasingly important to the market and can be significant drivers of the market adoption of this emerging technology.

CHAPTER 1:
Introduction

Background

According to the California Energy Commission's (CEC) consumption database, existing commercial buildings consume approximately 40 percent of California's total electricity sales in investor-owned utility (IOU) territory. Heating, ventilating, and air-conditioning (HVAC) equipment account for a substantial portion of commercial building energy consumption. In most buildings, sub-optimal control programming in building automation systems (BAS) leads to excessive energy consumption by HVAC systems and poor control of indoor environmental quality (IEQ). Exacerbating this problem is the current ad-hoc process of specifying and implementing control programming for individual buildings, which is additionally often based on partial and fragmented information. Designers often lack a deep understanding of control systems, deferring that responsibility to contractors, and they are generally slow to keep up with industry best practices and increasingly complex building energy code requirements. Installing contractors are pressured to minimize costs by the competitive, price-driven industry, and to work quickly as one of the last steps in the construction process prior to occupancy.

This cumbersome current practice sets the stage for risks and problems at every stage in complex controls installation and operations processes, from poor understanding of control fundamentals to misinterpreted designs to insufficient quality control—in other words, in the very foundation of these processes. The result is too often that buildings are constructed with deficient ventilation and temperature control capabilities and unnecessarily high energy consumption.

Upgrading existing systems to operate more efficiently by updating the controls sequence of operations presents a prime opportunity to achieve cost-effective, persistent, and measurable savings. However, due to high transaction costs and the need for custom analysis and programming for each project, the current retrofit/upgrade model is a real barrier for building owners and operators to effectively scale installation of advanced controls measures.

This project specifically addresses these challenges; it is no less than an opportunity to address the entire value delivery chain: from design through implementation, commissioning and testing, and ongoing system maintenance and long-term fault detection. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 36 (G36) High-Performance Sequences of Operation for HVAC Systems provides much-needed direction for the coordinated control of HVAC equipment based on best practices, the latest energy efficiency research, and current energy standards. Compared with current practices, the advanced sequences of operation built into Guideline 36 offer the opportunity to significantly improve energy efficiency and IEQ in commercial buildings. Standardization around these high-performance sequences further provides the opportunity for scaling these improvements across the industry, ultimately overcoming current work-flow inefficiencies and high-risk steps in the value delivery chain. Streamlining the value delivery process reduces implementation costs and improves cost effectiveness of this energy efficiency opportunity.

This project demonstrates the validity of installing upgraded control solutions for the commercial building sector in a unique way that overcomes these challenges and barriers.

Project Goals and Objectives

The project focused on two research goals:

1. **Technological Innovation:** Validate the commercial viability (such as ease, practicality, and cost effectiveness) of optimized controls retrofits in existing commercial buildings that integrate HVAC and lighting controls to achieve energy efficiency and better IEQ.
2. **Market Innovation:** Demonstrate a new delivery mechanism (the use and standardization around ASHRAE G36 for control sequences of operation and programming) for control system upgrades in close collaboration with utilities and other industry partners to address California’s need for cost-effective scalable energy and carbon reductions.

The project focused on three main objectives:

- Demonstrate energy savings and improved occupant comfort resulting from Best-in-Class control upgrades based on G36 sequences and other advanced solutions, such as fault detection and diagnostics (FDD) and networked lighting controls (NLC), at several demonstration sites.
- Investigate potential technological advancements to streamline and support the successful deployment of optimized controls retrofits in commercial buildings.
- Recommend strategies, tools, and initiatives to address market barriers to wider acceptance and adoption of these scalable technology packages through best practice guidelines, case studies, utility program ideas, and energy code connections.

CHAPTER 2:
Project Approach

Overview

The team developed a technical approach to meet the project's goals and objectives, which included a combination of technical tasks (testing, validation, field demonstrations, data collection) and market connections activities (technology and knowledge transfer, tools, and market transformation pathways).

One of the key technical tasks was to validate and improve optimized control solutions (OCS) and G36. Another key technical task was to conduct field demonstrations at buildings that represented two types of typical baselines: buildings without modern direct digital control (DDC) systems where the control systems were completely retrofitted, including hardware and software replacements, and buildings with modern DDC systems where only the software controls were upgraded. A subset of demonstration buildings was retrofitted with FDD and NLC technologies to isolate savings and compare various packages of measures. The project market connection activities paved the way for accelerated market uptake through market analysis, tools, deployment plans, and codes and standards, which significantly enhanced technology and knowledge transfer activities. Keys to the overall project success were participation from the technical advisory committee (TAC) and the commission agreement manager (CAM).

The objective of the field demonstrations was to meet the first project objective: to demonstrate energy savings and improved occupant comfort resulting from control upgrades based on G36 sequences and other advanced solutions (for example, FDD and NLC) at several demonstration sites. The project also focused on the following field demonstration objectives:

- Evaluating the technology's energy savings and cost effectiveness.
- Evaluating the technology's IEQ effects like thermal comfort and ventilation.
- Evaluating the technology's impacts on stakeholders, including value proposition and influences on workflow and market share.
- Conducting knowledge and technology transfer activities.

The project team pursued each of these steps at the field demonstration sites.

In the existing buildings stock, the first type of building (without modern controls) is far more common than the second building type (with modern controls) and represents a more conventional retrofit opportunity. However, any resulting energy savings could be partly from the hardware control system upgrade itself and the resolution of deferred maintenance, rather than the implementation of the software technologies. The second building type (with existing modern controls) generated energy savings solely from the technologies studied. These demonstrations included multiple buildings of each type and provided a robust set of demonstration results that reduced any site-specific influences.

Technology and knowledge transfer activities were a major component of project efforts to meet the third objective: to accelerate market transformation. The project focused on facilitating the scaled market adoption of new delivery mechanisms for OCS and encouraging widespread industry use of a new streamlined approach to designing and installing BASs. The market assessment and feasibility analysis helped provide understanding of deployment potential, opportunities, and barriers associated with OCS. The team conducted research on market segmentation, explored BAS delivery channels and methods, and studied stakeholder impacts through extensive engagement and interviews with engineers, installers, building operators, and BAS manufacturers. The team developed market transformation pathways including a utility program concept design, potential codes and standards improvements, and a best practices guide. The findings of the market analyses were combined with field demonstration results to create a series of market resources to facilitate technology and knowledge transfer. Table 1 below summarizes market analysis and market transformation pathways activities.

Table 1: Technology Transfer Project Tasks

Market Assessment and Feasibility Analysis	Market Transformation Pathways
• **Assess Market Potential** by defining applicable market segments, developing robust estimates of market size, and assessing the potential market penetration of Best-in-Class. • **Conduct Cost and Payback Analysis** and collect vendor input to demonstrate that technology implementation costs will yield a reasonable customer payback period. • **Identify Market Barriers** for widespread implementation such as savings uncertainty perceptions, limited professional expertise, regulatory oversight challenges, and codes and standards deficiencies. • **Determine Market Adoption Feasibility** through engagement of industry players to evaluate their gains, losses, market disruption, and solutions.	• **Facilitating Market Adoption** by working with BAS manufacturers and dealers to improve their G36 offerings • **Utility Program Concept Design** for utilities and implementers to develop and implement incentive programs. • **Codes and Standards** for investor-owned utilities and municipalities to advance code requirements related to best-in-class solutions. • **FDD Functional Specifications** to help building owners make informed decisions about the purchase of FDD/Continuous Commissioning (CCx) software • **Best Practices Guides** for building owners and operators, engineering and controls firms, and portfolio property management companies to specify and implement Best-in-Class appropriately.

Source: Taylor Engineering and TRC

The following subsections further describe the project approach:

- **Demonstration Site Selection:** Describes the selection criteria that the team developed and implemented to select demonstration sites.
- **Field Demonstration Sites and Activities:** Describes the demonstration sites and activities at each site including site descriptions, measures implemented, and measurement and verification (M&V) activities.
- **Market Outreach:** Describes the market sources the team used to inform market potential and assess adoption feasibility.
- **Market Acceleration:** Describes efforts by the team to increase awareness and understanding of G36.

Results from the field demonstrations and from the market transformation activities are further described in Chapters 4 and 5.

Demonstration Site Selection

General Site Selection Criteria

The project team developed criteria to evaluate each potential site, requiring, at a minimum, that:

- Electrical service must be provided by a California IOU.
- Most of the building must be served by variable air volume (VAV) air handling units (AHU).
- There must not be any other significant retrofits, renovations, or changes in occupancy planned between the start of the demonstration and early 2020.

The project team preferred facilities with existing whole-building interval energy metering for electricity, gas, and chilled and hot water use and more than one year of historical utility data.

The demonstration sites fall into two primary types: 1) full hardware and software retrofit or 2) software-only retrofit sites. A subset of the demonstration sites featured additional FDD and/or NLC technologies.

Building Type 1: Guideline 36 Hardware + Software Retrofit Site Selection Criteria

To demonstrate the impacts of a full DDC controls upgrade with G36 OCS, the project team selected a minimum of three sites with existing pneumatic controls at the zone level, a planned zone level DDC retrofit, and flexibility to change the design and installation of the controls system.

The selected sites were Kaiser Permanente (KP) Vallejo Medical Office Buildings (MOB) and MOB Addition, KP Whittier MOB, California State University (CSU) Dominguez Hills LaCorte Hall, and KP Fresno MOB.

Building Type 2: Guideline 36 Software-Only Retrofit Site Selection Criteria

A software-only upgrade isolates the energy savings of G36 OCS without the influence of pneumatic-to-DDC conversions, deferred maintenance, and impacts from other activities associated with the full control retrofits. The project team selected three sites with existing modern DDC systems down to the zone level that were fewer than eight years old.

The selected sites were KP Pleasanton Data Center, KP Oakland Specialty MOB, and Contra Costa College (CCC) Student and Administration Building.

Fault Detection and Diagnostics Retrofit Site Selection Criteria

A subset of the Type 1 and Type 2 demonstration sites totaling 400,000 to 500,000 square feet (ft²) incorporated an FDD platform. There were no prerequisites for FDD demonstration sites other than a BAS with BACnet communication protocols. The selected sites were KP Vallejo MOB and MOB Addition, KP Oakland Specialty MOB, and CSU Dominguez Hills LaCorte Hall.

Networked Lighting Controls Retrofit Site Selection Criteria

A subset of the Type 1 and Type 2 demonstration sites was retrofitted with the Enlighted NLC. The prerequisite for this site selection was existing fluorescent lighting. LaCorte Hall at CSU Dominguez Hills was selected.

Field Demonstration Sites and Activities

Kaiser Permanente Vallejo Medical Office Building

The MOB and MOB Addition buildings in Vallejo, California, are a conjoined two-story facility totaling roughly 200,000 ft² (Figure 1 below). The facility primarily houses offices, exam rooms, procedure rooms, and outpatient surgery, as well as nursing stations, waiting rooms, and a pharmacy for a wide range of medical departments. The MOB wing was constructed in 1990, and the MOB Addition wing was constructed in 1992. The MOB buildings are part of a large medical campus, which also include a central plant facility.

Figure 1: Kaiser Permanente Vallejo Medical Office Building

Source: Google Maps

The buildings are served by 12 VAV and one constant air volume (CAV) air handlers, which provide cooling via airside economizers and chilled water coils fed from the adjacent campus chiller plant. VAV reheat boxes provide heating using hot water coils fed from the campus hot water plant. Building pressure is controlled by relief fans.

The existing BAS consisted of a DDC system controlling the air handlers with pneumatic controls at the zone level. As part of the demonstration retrofit, the facility underwent a full hardware and software DDC retrofit, including replacement of the pneumatic zone controls.

Kaiser Permanente Whittier Medical Office Building

The two-story medical office building in Whittier was built in 1990 and totals 33,640 ft² (Figure 2 below). A central double-height lobby space splits the building into two equally sized wings, which feature waiting areas, exam rooms, procedure rooms, private offices, and a conference room.

Figure 2: Kaiser Permanente Whittier Medical Office Building

Source: Google Maps

The facility is conditioned by two VAV air conditioning (AC) units with direct expansion (DX) cooling and airside economizing, which serve VAV cooling-only and reheat boxes. A gas-fired boiler, primary pump, and two constant-speed secondary pumps provide heating hot water to zone reheat coils.

VAV boxes had pneumatic controls, and the boiler plant and AC units operated with stand-alone controls. As part of the demonstration retrofit, the facility underwent a full DDC retrofit, with all zonal controls replaced with DDC hardware. The boiler plant and AC units were integrated with the new Alerton DDC network.

California State University Dominguez Hills LaCorte Hall

Constructed in 1978, LaCorte Hall is a three-story 67,800 ft² (55,000 ft² conditioned) classroom and office building on the CSU Dominguez Hills campus in Carson, California (Figure 3 below). The lower two above-grade levels contain classrooms, workshops, music rooms, offices, a gallery, and an auditorium. The third story houses faculty offices and additional classrooms.

Figure 3: California State University Domininquez Hills LaCorte Hall

Source: Taylor Engineering

A single VAV air handler with fan walls on both the supply and return serve VAV reheat boxes. An airside economizer and chilled water coil fed by the campus chiller loop provide cooling. Heating is provided by zone hot water reheat coils served by the campus boiler plant.

The air handler and some VAV boxes were controlled by an existing DDC system. The remaining VAV boxes were equipped with pneumatic controls. As part of the demonstration retrofit, all existing pneumatic controllers were replaced with DDC controllers.

Existing fluorescent 2x4 troffer fixtures throughout the building were replaced with light emitting diode (LED) retrofit kits to provide additional energy savings and enable greater dimming and occupancy controls. Fluorescent-strip fixtures in lower-level shop spaces were replaced with new LED fixtures. Additionally, the Enlighted NLC system was incorporated to reduce lighting energy in response to occupancy and daylighting. Integration between the NLC system and the BAS allowed for ventilation and airflow to nearly every zone to be reduced when unpopulated based on occupancy sensing.

Kaiser Permanente Fresno Medical Office Building

The Fresno MOB campus consists of three, four-story buildings totaling 120,000 ft² (Figure 4 below). Space types in the facility include offices, exam rooms, procedure rooms, nursing stations, waiting rooms for a wide range of medical departments, and a pharmacy. The MOB buildings are connected to the hospital facility and are served by a central plant.

Figure 4: Kaiser Permanente Fresno Medical Office Building

Source: Google Maps

As part of a campus-wide HVAC upgrade, the MOB complex was planned to undergo a retrofit that included new AHUs, VAVs and DDC controls. The construction project was delayed for reasons out of the team's control, and it did not proceed beyond the development of construction documents and permitting during the course of the team's study. As the project was not implemented, this site is not included in the project results.

Kaiser Permanente Oakland Specialty Medical Office Building

The KP Specialty Medical Office Building (SMOB) in Oakland is a 225,000 ft² facility built in 2012 (Figure 5 below). The project controls demonstration covers approximately 178,000 ft², and it did not include the day surgery facility on the second floor. SMOB is adjacent to KP's hospital facility, and includes offices, exam rooms, procedure rooms, nursing stations, waiting rooms for a wide range of medical departments, as well as a cafeteria and a pharmacy.

Figure 5: Kaiser Permanente Oakland Specialty Medical Office Building

Source: Kaiser Permanente

Four VAV rooftop AHUs with both hot and chilled water coils serve the lower level and floors one, three, four, and five. Zones include VAV reheat boxes, VAV cooling-only boxes, CAV reheat boxes, and CAV cooling-only boxes.

As part of the demonstration retrofit, the team updated the control programming for the multizone VAV air handler and VAV reheat boxes and the single-zone VAV air handler to employ G36 sequences of operation.

Contra Costa College Student and Administration Building

The Student and Administration building is located on the CCC campus in San Pablo, California (Figure 6 below). Constructed in 2017, the building is approximately 50,000 ft^2 and is composed of office space, commercial kitchens for educational training, a cafeteria, and a student store.

Figure 6: Contra Costa College Student and Administration Building

Source: Taylor Engineering

The building is served by four multi-zone VAV air handlers with VAV-reheat terminal units and two single-zone VAV air handlers. Air handlers have an economizer, hot water coil, chilled water coil, and return fan. A water-cooled chiller provides chilled water to the air handler coils. A gas-fired condensing boiler generates heating hot water that is distributed to both the air handler coils and the VAV-reheat box coils.

The BAS was already DDC. As part of the demonstration retrofit, the team updated the control programming for the multizone VAV air handler, VAV reheat boxes, and the single-zone VAV air handler to employ G36 sequences of operation.

Kaiser Permanente Pleasanton Data Center

The Pleasanton Data Center is a two-story data center and office building constructed in 1999, which is located in Pleasanton, California (Figure 7 below). The floor area totals 76,000 ft², but the scope of the field demonstration only involved 23,700 ft² of office space. The first floor contains a lobby, break rooms, conference rooms, and private offices. Some private offices and a large conference room are located on the second floor. The remainder of the building is occupied by data halls, process spaces, and equipment rooms.

Figure 7: Kaiser Permanente Pleasanton Data Center

Source: Google Maps

A chilled water VAV air handler with airside economizer serves VAV terminal units that supply ventilation air to process rooms and data halls. Hot water for VAV boxes with reheat coils is provided by a natural-gas boiler plant located onsite. The water-cooled chiller plant is also located onsite and supplies chilled water to both the air handler serving the demonstration area and to an air handler providing cooling for the mechanical room and to computer room air handling units conditioning the data halls.

As part of the demonstration retrofit, the air handler and all VAV terminal units serving the demonstration area were upgraded with new G36 sequences of operation.

Measures at Each Demonstration Site

Table 2 below summarizes the measures at each demonstration site:

- Multi-zone VAV AHU and single-zone VAV AHU OCS, which are complete sequences for controlling these equipment types
- Low VAV box minimums OCS, which are sequences that minimize zone airflow
- Adapted for DX cooling OCS, which are modified sequences for multi-zone VAV AHU for DX cooling instead of chilled-water cooling
- Cost-based supply air temperature (SAT) reset OCS, which are sequences that optimize SAT based on energy cost
- Time-averaged ventilation OCS, which are sequences that allow for zone airflows to effectively be controlled to values below the VAV box controllable minimum value
- T24 occupied standby OCS, which are sequences that disable zonal ventilation and airflow in occupied-standby mode
- NLC, which are lighting controls to reduce lighting energy in response to occupancy and daylighting
- FDD, which is logic that detects equipment and programming faults in the operation

Table 2: Demonstration Site Measures

	Full retrofit sites			Software-only sites		
	KP Vallejo MOB	KP Whittier MOB	CSUDH LaCorte	KP Pleasanton	KP Oakland SMOB	CCC SAB
OCS						
Multi-zone VAV AHU	Y	Y	N	Y	Y	Y
Single zone VAV AHU	N	N	N	N	N	Y
Low VAV box minimums	Y	Y	N	Y	Y	Y
Adapted for DX cooling	N	Y	N	N	N	N
Cost-Based SAT Reset	N	Y	N	Y	N	Y
Time-Averaged Vent.	N	N	N	Y	N	N
T24 Occupied-standby	N	N	N	Y	N	Y
Enlighted NLC	N	N	Y	N	N	N
FDD	Y	N	Y	N	Y	N

Source: Taylor Engineering and TRC

Measurement and Verification

The team installed metering at each site to measure electrical and gas HVAC energy use. The team conducted an M&V analysis to estimate energy savings associated with each retrofit. Savings were determined following the "Option (B) Retrofit Isolation: All Parameter Measurement" based on the International Performance Measurement and Verification Protocol. The annual savings were weather normalized against the typical meteorological year data to eliminate any biases from differences in pre-retrofit and post-retrofit weather.

Table 3 below summarizes the monitoring period at each site.

Table 3: Monitoring Period at Each Site

	Pre-retrofit	Post-retrofit
KP Vallejo MOB	Jun 2017 – Jun 2018	Jan 2019 – Dec 2020
KP Whittier MOB	Aug 2018 – Jan 2019	Oct 2020 – May 2021
CSU Dominguez Hills LaCorte Hall	July 2019 – March 2020	September 2020 – May 2021
KP Pleasanton Data Center	Jan 2018 – Jan 2019	Oct 2019 – Oct 2020
KP Oakland Specialty MOB	Oct 2019 – Mar 2020	Dec 2020 – July 2021
CCC Student & Administration Building	Oct 2018 – May 2019	Sep 2019 – Mar 2020

***Note that the team monitored multiple energy streams at each site, and each energy stream may have a different monitoring period. What is shown in the figure is the time when most of the data streams at a site were monitored.**

Source: Taylor Engineering

In addition to measuring energy-use differences, the project team explored how the retrofits affected IEQ—including thermal comfort and ventilation. This is an important aspect for investigation since it is critical to provide at least the same, if not better, occupancy comfort and health.

The team investigated IEQ through:

- Conducting pre- and post-retrofit temperature, relative humidity, and carbon dioxide (CO_2) (in a sampling of sites) measurements.
- Conducting pre- and post-retrofit occupant surveys to assess their thermal comfort, perceived indoor air quality, satisfaction with lighting, and other IEQ indicators.

Note that for both types of data collection, the project team was restricted in post-retrofit data collection at many sites because of changes in occupancy due to COVID-19.

The IEQ investigations explored the following research questions:

- How does the retrofit impact thermal comfort?
    - At each site, is thermal comfort improved, degraded, or does it remain about the same?
    - Because the retrofit reduces minimum airflow rates (compared with standard practice), does the retrofit reduce over-cooling during the summer?
- How does the retrofit impact ventilation rates and perceived IEQ?
    - The retrofit will likely increase operating hours of the economizer but delivered ventilation rates may decrease. In aggregate, how do the combined effects of the retrofit impact ventilation, as measured by CO_2 rates and perceived air quality by occupants?

Market Outreach

There are several primary data sources that the team used to inform the market potential and assess adoption feasibility. The team collected information on market barriers and potential solutions through formal and informal interactions with stakeholders during interviews, conferences, meetings, and other events. The team also convened a TAC comprised of industry experts including designers, commissioning agents, utility managers, manufacturers, and building owners.

Stakeholder Interviews

The team conducted formal interviews with BAS manufacturers, dealers, building operators, building owners, design engineers, and commissioning agents. The team interviewed market actors to address the following research questions:

- What are current processes for getting controls into buildings and operating them?
- How could G36 improve upon current processes?
- What is the value proposition of G36 to the industry?
- What are the barriers to implementing G36?
- How could the barriers to implementing G36 be addressed?
- What is the overall market appetite and awareness of G36 and to broader concepts like optimized control sequences?

A summary of the stakeholder interview findings is presented in Appendix A.

Technical Advisory Committee

The TAC included designers, researchers, commissioning agents, utility managers, manufacturers, and building owners. The TAC met as a group three times during the project. In the first TAC meeting, the team presented an overview of the project scope and objectives and solicited feedback on the project's technical approach. The team also gathered input on market pathways and barriers. The TAC validated the team's approach to the research project. In the second TAC meeting, the team presented preliminary results from the demonstration-site findings from the G36 energy savings calculator development and identified market barriers. The TAC provided input on prioritizing activities. In the third TAC meeting, the team presented energy and cost savings and lessons learned from the demonstration sites. The team also presented work in progress to address key market adoption barriers and other work needed beyond the research project.

Dealer Surveys

The team observed that while all the major BAS manufacturers committed to implementing ASHRAE G36 factory application libraries, there were still significant barriers to adoption by BAS dealers (also known as controls contractors). To better understand these barriers and market demand for G36, the team worked with manufacturers to develop a dealer survey. The survey included questions to better understand awareness of G36, interest in G36, implementation of G36, current dealer processes, and the types of retrofits they typically encounter. There were 488 respondents to the survey, which were distributed through four different manufacturers

The survey responses showed that 68 percent of respondents had heard of G36, the majority through communication from their manufacturer or from an industry publication, such as the ASHRAE Journal. Respondents who had heard of G36 also indicated how many of their teams' projects had implemented G36—the choices were none, 1 to 5, 6 to 10, or more than 10. Of the respondents, 43 percent had implemented it on at least one project, while 7 percent had implemented it on more than 10 projects. Linking these responses with their reported zip codes, the team estimated around 450 unique G36 implementations, many of which could be partial implementations. When asked to rate the overall success of completed G36 projects, half of the respondents indicated that the projects were either *extremely successful* or *very successful*, with most other respondents indicating that the projects were *somewhat successful*. A small group of respondents indicated that the projects were *not so successful*, though no respondents rated the projects as *not at all successful*.

The survey asked how dealers most often start programming for a new job and allowed respondents to select up to two options. The most frequent to the least frequent responses follow.

- Copy from a previous job
- From own dealer library
- From a manufacturer library
- Program from scratch to match specified sequences of operation
- From a library for a customer

The survey results indicated widespread awareness of G36, many more implementations than the team was previously aware of, and that projects have been overwhelmingly successful. The survey results also re-enforced a barrier that the team had hypothesized: that only a minority of dealers use manufacturer libraries as part of their normal process.

The complete survey results are presented in Appendix B.

Market Acceleration

Throughout the project, the team conducted activities to accelerate market adoption of G36. These included presentations and trainings related to G36 and developing a value proposition to highlight the benefits of G36 across the industry.

Knowledge Dissemination

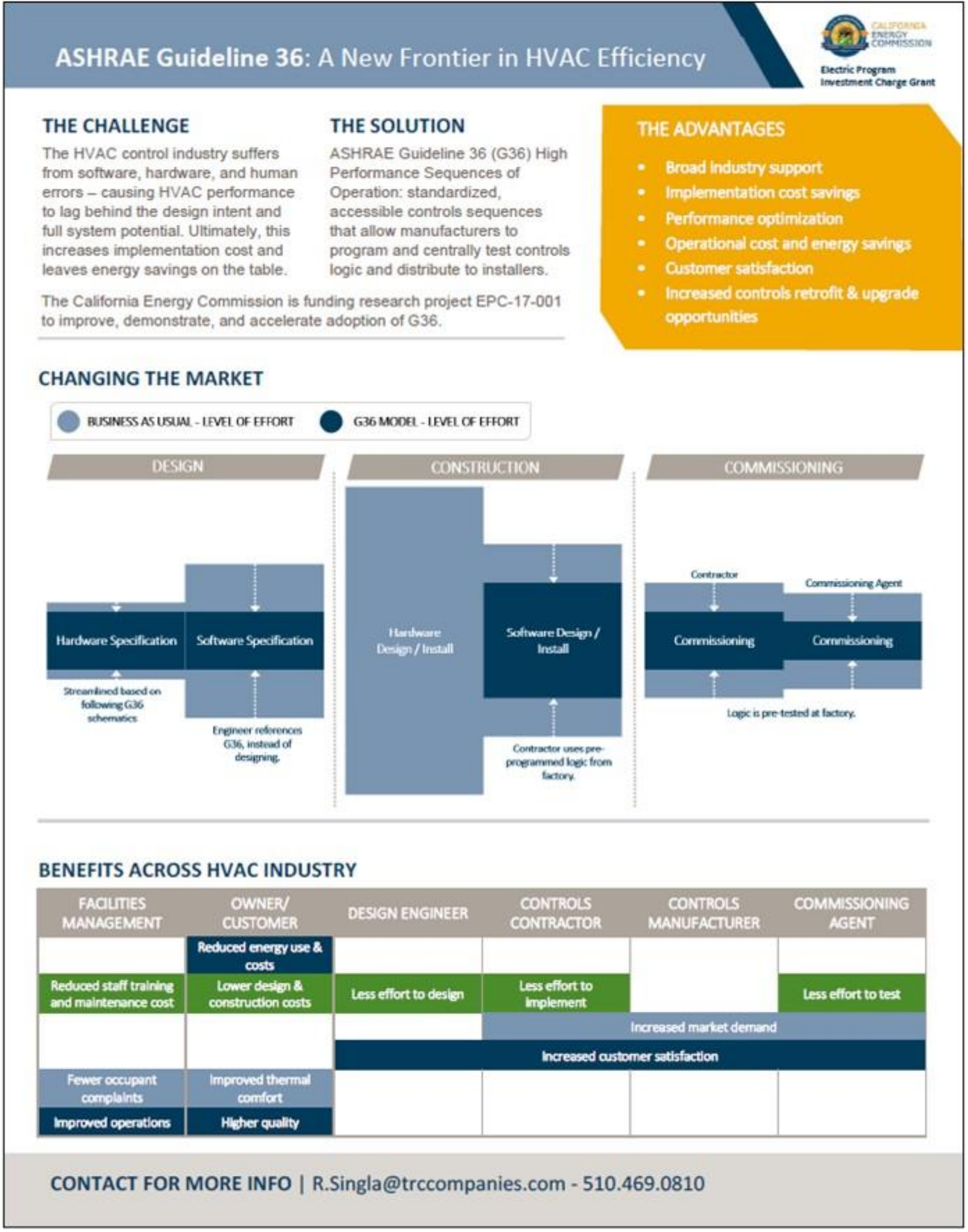
The team has developed and widely disseminated materials to facilitate knowledge transfer, accelerate market adoption, and maximize the impact of these demonstration projects. This section describes related activities completed by the team.

During the course of this research project, the team conducted 17 presentations and trainings at both ASHRAE national and local chapters, BAS manufacturers, U.S. Department of Energy's Energy Exchange, American Council for an Energy-Efficient Economy, U.S. Green Building Council, Better Buildings Summit, Energy as a Resource, BEST Center, Pacific Energy Center, City of Palo Alto utilities facilities managers, and the University of California Berkeley Center for the Built Environment.

Value Proposition

The team developed a value proposition for G36, showing how effort expended at each design and construction phase could be reduced with G36 when compared with a business-as-usual approach, and additionally how individual stakeholders could benefit from G36. The team developed a one-page document summarizing the value proposition, shown in Figure 8 below, which was shared widely with building owners, controls contractors, utility program managers, and designers.

Figure 8: Value Proposition Flyer



ASHRAE Guideline 36: A New Frontier in HVAC Efficiency

Electric Program Investment Charge Grant

THE CHALLENGE

The HVAC control industry suffers from software, hardware, and human errors – causing HVAC performance to lag behind the design intent and full system potential. Ultimately, this increases implementation cost and leaves energy savings on the table.

THE SOLUTION

ASHRAE Guideline 36 (G36) High Performance Sequences of Operation: standardized, accessible controls sequences that allow manufacturers to program and centrally test controls logic and distribute to installers.

The California Energy Commission is funding research project EPC-17-001 to improve, demonstrate, and accelerate adoption of G36.

THE ADVANTAGES

- Broad industry support
- Implementation cost savings
- Performance optimization
- Operational cost and energy savings
- Customer satisfaction
- Increased controls retrofit & upgrade opportunities

CHANGING THE MARKET

● BUSINESS AS USUAL - LEVEL OF EFFORT ● G36 MODEL - LEVEL OF EFFORT

DESIGN

Hardware Specification

Software Specification

Streamlined based on following G36 schematics

Engineer references G36, instead of designing.

CONSTRUCTION

Hardware Design / Install

Software Design / Install

Contractor uses pre-programmed logic from factory.

COMMISSIONING

Contractor

Commissioning Agent

Commissioning

Commissioning

Logic is pre-tested at factory.

BENEFITS ACROSS HVAC INDUSTRY

FACILITIES MANAGEMENT	OWNER/ CUSTOMER	DESIGN ENGINEER	CONTROLS CONTRACTOR	CONTROLS MANUFACTURER	COMMISSIONING AGENT
	Reduced energy use & costs				
Reduced staff training and maintenance cost	Lower design & construction costs	Less effort to design	Less effort to implement		Less effort to test
			Increased market demand		
		Increased customer satisfaction			
Fewer occupant complaints	Improved thermal comfort				
Improved operations	Higher quality				

CONTACT FOR MORE INFO | R.Singla@trccompanies.com - 510.469.0810

Source: Taylor Engineering and TRC

CHAPTER 3: Controls Analysis and Development

Though most of the control approaches in G36 have been vetted and improved over many years, the guideline itself is relatively new. There are still bugs to fix, gaps to fill, and approaches that can be further improved. From a market perspective, awareness of G36 is rapidly growing, and there are many related research and development efforts, but additional tools may be required to streamline and support broad and successful industry adoption. The project included several technical tasks beyond field demonstrations that enhance and support successful market adoption of G36. These tasks include validating some portions of G36 that have not been previously studied, developing new sequences of operation to improve G36, and developing proof of concept software tools to help streamline future industry use of G36.

Specifically, this chapter summarizes the approach and results for the following activities:

- The G36 Performance Validation Method is proof of concept of an automated test of controller programming to confirm adherence to G36. Applied to manufacturer application libraries, this method supports a shift toward the centralization of G36 programming by ensuring quality and building confidence among key stakeholders.
- The G36 Energy Savings Calculator is proof of concept of a software tool that helps building owners quickly and easily screen for cost-effective retrofit opportunities. There are currently few tools that accurately predict the energy impact of a G36 retrofit. In the future, the G36 Energy Savings Calculator may support broad deployment of G36 in existing buildings by streamlining this process.
- Simulation studies validated improved energy performance of existing (and potentially future) portions of G36, compared with conventional practices. These analyses provide confirmation of G36 approaches, demonstrate the value of applying these approaches, and enhance future versions of this guideline.
- Development of new sequences of operation improve on existing sequences and address equipment and conditions not currently represented in G36.

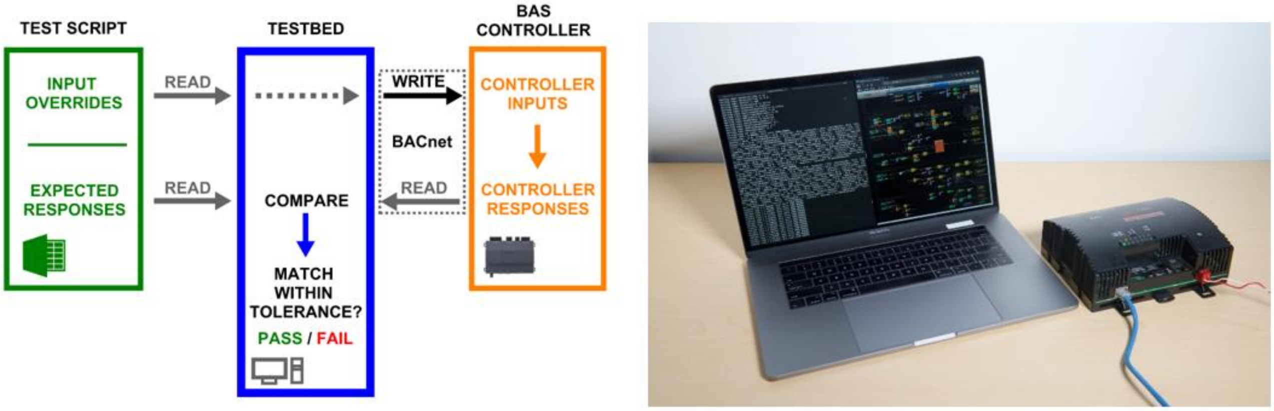
Guideline 36 Performance Validation Method

This section summarizes a method developed and piloted by the project team to test G36 control programming and validate its adherence to the intended performance.

A broader impact of the publication of G36 is the opportunity for industry standardization of G36 sequences of operation. Rather than have the sequences programmed repeatedly for specific projects, with the associated process inefficiency and risk of errors, standardization allows sequences to be programmed centrally by each BAS manufacturer at the factory. Centralized application libraries can be preprogrammed and pretested to ensure quality and reduce field implementation times. The objective of the G36 performance validation method is to provide automated and objective confirmation that BAS manufacturer programming conforms to G36 requirements.

The team evaluated potential approaches and developed a pilot testbed that provides a mechanism for automated, objective, and repeatable testing of control programming. The testbed interfaces with control programming loaded on a physical controller through a network connection, simulates a carefully scripted series of conditions to test the programming, and assesses whether the control responses match expectations (Figure 9 below). This bench-scale approach allows the test to focus on the programming alone and provides an agnostic method that can be used with controllers and control environments from different manufacturers.

Figure 9: Automated Guideline 36 Programming Testbed



Diagrammatic view of Automated G36 Programming Testbed (left), and photo of testbed software and BAS controller (right)

Source: Taylor Engineering and LBNL

The team successfully demonstrated the testbed concept for a small portion of G36 logic that was loaded on a physical BAS controller provided by Automated Logic Corporation (Figure 9 above). The testbed platform was effectively deployed to communicate with the BAS controller, execute the scripted conditions, and monitor controller reactions for comparison against expected responses. This proof of concept represents a promising strategy for automated and objective testing of G36 control programming.

The project identified several key considerations for future efforts to expand the platform:

- Mapping control points between the testbed script and programming must be carefully coordinated during the test setup, and required control points must be exposed over the network.
- Test scripts must be modularized so individual portions of the test may pass or fail, so that a single failure does not require retesting the entire program.
- Though the sequences in G36 are written in fine detail, they nevertheless leave room for interpretation and differing implementations, which may meet the intent of the guideline. By contrast, this testing approach is objective and contains a binary outcome: pass or fail. The development of the associated test script may result in a narrow interpretation for what programming is compliant with G36 sequences.

The pilot test concept and results were presented to groups of key stakeholders, with positive reception. When fully developed, this testbed could be the basis for a test standard or certification process that provides independent validation that factory application libraries are robust and accurately follow G36 sequences. Stakeholders representing different segments of the industry have shown strong interest in its development and support the need for a test platform. Though the pilot tests were successful, the testing was only completed for a small portion of logic on one manufacturer's controller. Further development is required to expand the scope of the test scripts, confirm compatibility with other manufacturers, develop a robust user interface and reporting mechanism, and assemble a coalition of stakeholders to consider organizing an independent entity that could oversee and administer third-party testing and certification of manufacturer programming libraries.

A detailed report of the performance validation method appears in Appendix C. The open-source testbed logic is available online at: https://github.com/LBNL-ETA/guideline36_conformance_test.

Guideline 36 Energy Savings Calculator

This section provides a summary of the project task to develop and pilot test a simplified tool to estimate energy savings from retrofitting existing buildings with G36.

Retrofitting existing HVAC system controls to G36 sequences has great potential for energy savings in buildings. However, it is difficult to accurately estimate the energy savings of the control retrofits, and the process of doing so can be costly. Moreover, the costs of both determining retrofit opportunities and implementing the retrofit itself need to be justified by energy and cost savings. An early screening tool that allows building owners, design engineers, and utility incentive program designers to quickly assess the value of a potential retrofit before embarking on project design would, therefore, reduce barriers to identifying promising retrofit sites. To this end, the project team designed the G36 Energy Savings Calculator (Savings Calculator) as a screening tool. The team also identified parameters that influence estimated savings and analyzed their relative impacts.

The prototyped Savings Calculator is a Microsoft Excel© spreadsheet, and it is made up of a user interface at the front end (Figure 10 below) and data processing at the back end. The user interface allows selection of building design and operational characteristics for several factors that impact energy savings with a G36 control retrofit. These factors included currently used conventional control strategies, climate, hours of operation, internal load density, floor area, and central plant efficiency. Variations in conventional control strategies targeted a sample of common control methods including duct static pressure reset, SAT reset, and zone airflow control. Once selections are made to most closely represent an application's baseline condition, the data processing back end determines energy savings using results from pre-run simulations of retrofitting each baseline condition to full G36 controls. For a user, this design allows quick estimates of energy savings without the need for significant expertise in building energy simulations or setups of complex simulation software.

Figure 10: Guideline 36 Energy Savings Calculator

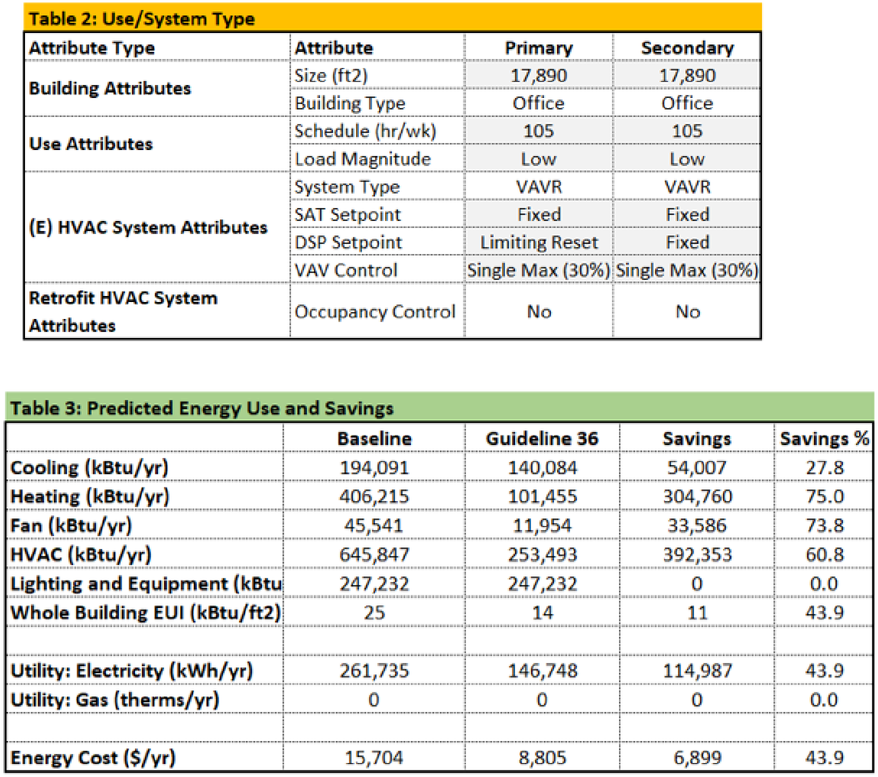


Table 2: Use/System Type

Attribute Type	Attribute	Primary	Secondary
Building Attributes	Size (ft2)	17,890	17,890
	Building Type	Office	Office
Use Attributes	Schedule (hr/wk)	105	105
	Load Magnitude	Low	Low
(E) HVAC System Attributes	System Type	VAVR	VAVR
	SAT Setpoint	Fixed	Fixed
	DSP Setpoint	Limiting Reset	Fixed
	VAV Control	Single Max (30%)	Single Max (30%)
Retrofit HVAC System Attributes	Occupancy Control	No	No

Table 3: Predicted Energy Use and Savings

	Baseline	Guideline 36	Savings	Savings %
Cooling (kBtu/yr)	194,091	140,084	54,007	27.8
Heating (kBtu/yr)	406,215	101,455	304,760	75.0
Fan (kBtu/yr)	45,541	11,954	33,586	73.8
HVAC (kBtu/yr)	645,847	253,493	392,353	60.8
Lighting and Equipment (kBtu	247,232	247,232	0	0.0
Whole Building EUI (kBtu/ft2)	25	14	11	43.9
Utility: Electricity (kWh/yr)	261,735	146,748	114,987	43.9
Utility: Gas (therms/yr)	0	0	0	0.0
Energy Cost ($/yr)	15,704	8,805	6,899	43.9

Simplified user interface for G36 savings calculator. User inputs are shaded in gray in Table 2 (top), and predicted energy use and savings are summarized in Table 3 (bottom)

Source: Taylor Engineering and LBNL

The pre-run simulations were completed in the state-of-the-art Modelica-EnergyPlus co-simulation developed by the Spawn of EnergyPlus project (Wetter, et al., 2020). Where conventional building energy simulation tools lack the computational capability for detailed modeling of HVAC control sequences, Modelica allows for direct modeling of conventional and advanced control sequences in the Control Description Language developed by the OpenBuildingControl project (Wetter, Hu, Grahovac, Eubanks, & Haves, 2018).

Modeling a modified medium office building in California climates exhibited a large range of savings potential, with minimum savings of 1.8 percent, maximum savings of 76.2 percent, and median savings of 29.7 percent.

Potential applications for the Savings Calculator include screening eligibility and incentives for utility programs, supporting building energy policy, codes and standards, and allowing individual building owners and managers to make informed decisions on retrofit opportunities. Additional work would be required to refine the tool to better characterize the savings estimated by the cases in this study; longer-term next steps include exploring other factors and cases that could influence energy savings potential.

A detailed report of the savings calculator is included in Appendix C. The open-source prototype Savings Calculator is available at https://github.com/LBNL-ETA/G36SavingsCalculator.

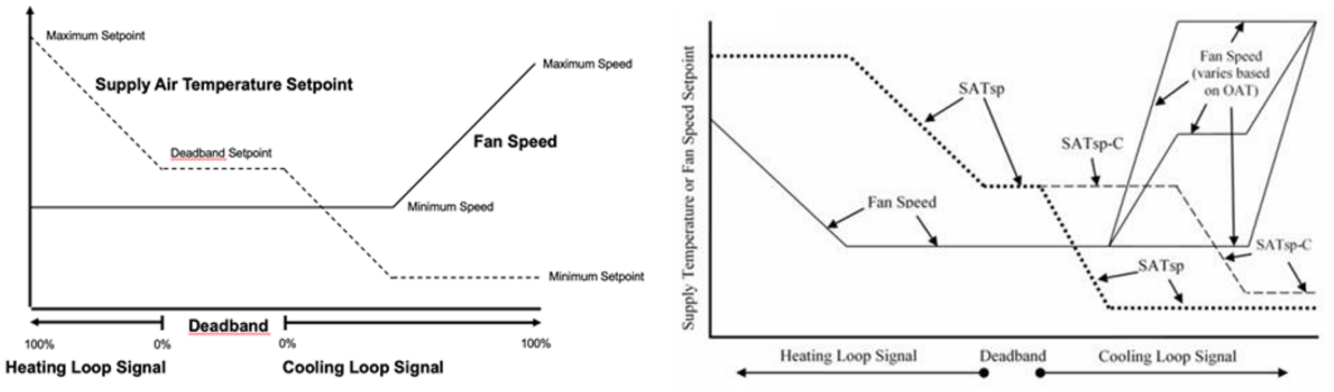
Single Zone Variable Air Volume Energy Simulations

The following is a summary of the team’s simulation analysis that evaluates the energy performance of the novel G36 approach for controlling single zone variable air volume (SZVAV) systems, compared with conventional practices.

SZVAV systems are common HVAC systems capable of modulating both SAT and airflow rates to maintain temperature control in a single thermal zone. Conventional SZVAV control strategies have evolved over the past two decades, but ASHRAE G36 introduced a new approach that improves energy performance by balancing fan and cooling energy and maximizing airside economizer cooling. This advanced control strategy had not previously been either simulated or field tested.

This effort directly simulated the new SZVAV strategy in Modelica, leveraging the Control Description Language developed by the OpenBuildingControl project (Wetter, Hu, Grahovac, Eubanks, & Haves, 2018), to evaluate its performance against a baseline representing conventional practice. The control schemes for the baseline and G36 approaches are shown in Figure 11 below.

Figure 11: Single Zone Variable Air Volume Control Strategies



Control diagrams for Single Zone Variable Air Volume strategies, baseline (left) and Guideline 36 (right).

Source: Taylor Engineering

The results showed that the G36 approach saved 5.7 percent annual HVAC energy in the Sacramento climate and 21.7 percent in the Oakland climate. The G36 approach saved energy by taking better advantage of economizing potential through the simultaneous reset of SAT and fan speed.

A detailed report of the SZVAV analysis appears in Appendix C.

Cost-Based Supply Air Temperature Reset

The optimal control of SAT setpoints in a VAV reheat systems balances fan, cooling, and reheat energy. The cost-based SAT reset approach is a practical strategy that estimates the real-time cost of HVAC energy end-uses and uses that cost feedback to reset the SAT setpoint. In previous studies, the cost-based approach was found to save nearly 30 percent HVAC energy costs in a field demonstration (Raftery, et al., 2018) and an average of 8.5 percent whole building energy cost in simplified simulation analyses (Bauman, et al., 2017) (Cheng, 2020). The goal of this effort was to confirm the earlier simulation results using a more rigorous simulation approach that directly models the advanced cost-based SAT approach using the EnergyPlus simulation platform with its energy management system feature.

The simulations were run for the Oakland and Sacramento climates based on a building model with realistic zoning and stochastic internal gains schedules. A parametric analysis evaluated the impact of a range of factors around building occupant usage, HVAC equipment performance and control, and utility rate structures. Across the simulated conditions, the cost-based approach consistently achieved the lowest energy use and lowest energy cost, compared to other SAT reset strategies, with only a few exceptions. The cost-based SAT reset strategy yielded an average of 13.1 percent lower HVAC energy use and 9.5 percent ($0.140/ft^2) lower whole building energy cost compared to the warmest SAT reset strategy.

A detailed report of the cost-based SAT simulation analysis is included in Appendix C.

Control Sequence Development

The team developed several new control sequences as part of field demonstrations to address equipment and conditions not currently represented in G36, as well as to improve existing sequences in G36. The new strategies either improve or expand on current approaches by enhancing energy and operational performance and were developed and field tested at one or more demonstration sites. Several of the sequences developed were proposed and adopted by the ASHRAE standing guideline project committee as addenda to G36-2018 through the continuous maintenance process. Other newly developed control sequences may be considered for future G36 adoption but may also require further study.

Newly developed sequences adopted for G36 include:

- **Occupied-standby control for Title 24.** This sequence disables zonal ventilation and airflow in occupied-standby mode when spaces are sensed to be unpopulated but otherwise scheduled to be in an occupied period; it is consistent with the mandatory requirements introduced in the 2019 version of Title 24.
- **Revised return fan control.** This sequence revises aspects of the control of return fans in G36 to avoid building pressurization issues and the risk of unintentionally introducing excess outdoor air in some modes of operation.
- **Improved G36 alarming.** This addendum to G36 revised the definition of several alarms to reduce the frequency of nuisance alarms, so alarm notifications are more focused and effective for building operators.

Newly developed sequences that were field tested but require further study include:

- **Cost-based SAT reset.** This control sequence improves a strategy previously developed to adjust SATs to reduce energy cost, based on real time estimates of HVAC energy costs. Though this strategy has been demonstrated in simulation and limited field testing to significantly reduce energy costs, further study is required to develop a simplified control strategy that can be more easily implemented.
- **SAT control with DX.** The control sequences for air handlers in G36 currently only apply to systems served with chilled water for cooling. This control sequence adapted the existing G36 logic and applied it to a packaged AC unit with DX cooling. Because of the range and variability in the ways that packaged AC units interface with BASs, further study is required to develop a generic control sequence for DX systems that is more broadly applicable.

- **Cost-based SAT Reset for DX systems.** This control sequence integrates aspects of the two control strategies just described to adapt the cost-based SAT reset approach for use with AC units with DX cooling. Further study is required to develop a simplified control strategy that can be more easily and broadly implemented at scale.

A detailed report of the new control sequence development appears in Appendix C.

CHAPTER 4: Project Results

Field Demonstrations

The field demonstration plan originally included seven sites: four sites planned for full retrofits and three sites planned for software-only retrofits. Most of the sites were successfully completed; however, the COVID-19 pandemic beginning in March 2020 aligned heavily with the expected post-retrofit monitoring periods for many of the sites. Shelter-in-place orders left buildings completely or largely vacant, and many buildings remained vacant or with only reduced occupancy for some time even once the shelter-in-place orders were relaxed. Two sites (Vallejo and CCC) had sufficient post-retrofit data to evaluate prior to the onset of the pandemic. Two sites (Whittier and KPPDC) had post-retrofit periods fully during the later stages of the pandemic and reported savings may be partially influenced by reduced occupancies. The impact of reduced building occupancy and possible adjustments to M&V results were explored at these two sites but adjustments were not ultimately implemented due to lack of occupancy data and uncertainty about the impact given the complexity of the HVAC interactions. For KPPDC, review of data from the extended implementation period against the post-retrofit COVID period showed minimal year-over-year differences in energy use, suggesting that COVID had minimal impact on the M&V analysis. For Whittier, the post-retrofit monitoring period was delayed as long as possible to allow the occupancy levels to return closer to normal pre-pandemic levels. Implementation at two sites was also severely impacted by the pandemic: LaCorte Hall remained vacant throughout the project period, preventing meaningful M&V, and Oakland SMOB was heavily delayed.

A full description of the results of the field demonstrations appears in Appendix D.

Energy and Cost Results

Energy savings across the demonstration sites ranged from 11 to 35 percent whole building electricity savings. Table 4 below shows the annualized normalized energy use and cost savings at each site.

Many factors impacted the energy savings results across the demonstration sites, including whether the G36 retrofit included hardware or was software-only, whether the existing controls were pneumatic or DDC, whether there were any concurrent retrofits where savings could not be isolated, and the existing sequences of operation. In general, higher savings were from projects that included hardware retrofits where existing zone-level controllers were pneumatic, the existing sequences had fixed or limited reset ranges for static pressure and SAT, and the VAV terminal units had single-maximum sequences with high minimums.

Table 4: Annual Normalized Energy Use and Cost Savings

Building	Retrofit	Retrofit Isolation (kBtu/ft^2)			Whole Building Electricity (kBtu/ft^2)			Cost Savings \$/ft^2
		Pre-Retrofit Energy Use Intensity (EUI)	Post-Retrofit EUI	Savings %	Pre-retrofit EUI	Post-retrofit EUI	Savings %	
KP Vallejo MOB	Hardware + Software	87.9	35.6	60%	53.3	39.2	26%	\$1.06
KP Whittier MOB	Hardware + Software	133.9	55.7	58%	93.2	60.9	35%	\$1.74
CSUDH LaCorte Hall	Lighting	6.8	2.1	69%	N/A	N/A	N/A	\$0.21
CCC SAB	Software-only	25.4	22.3	12%	22.6	20.3	11%	\$0.14
KP Pleasanton Data Center	Software-only	104.5	80.9	23%	67.0	55.6	17%	\$0.63

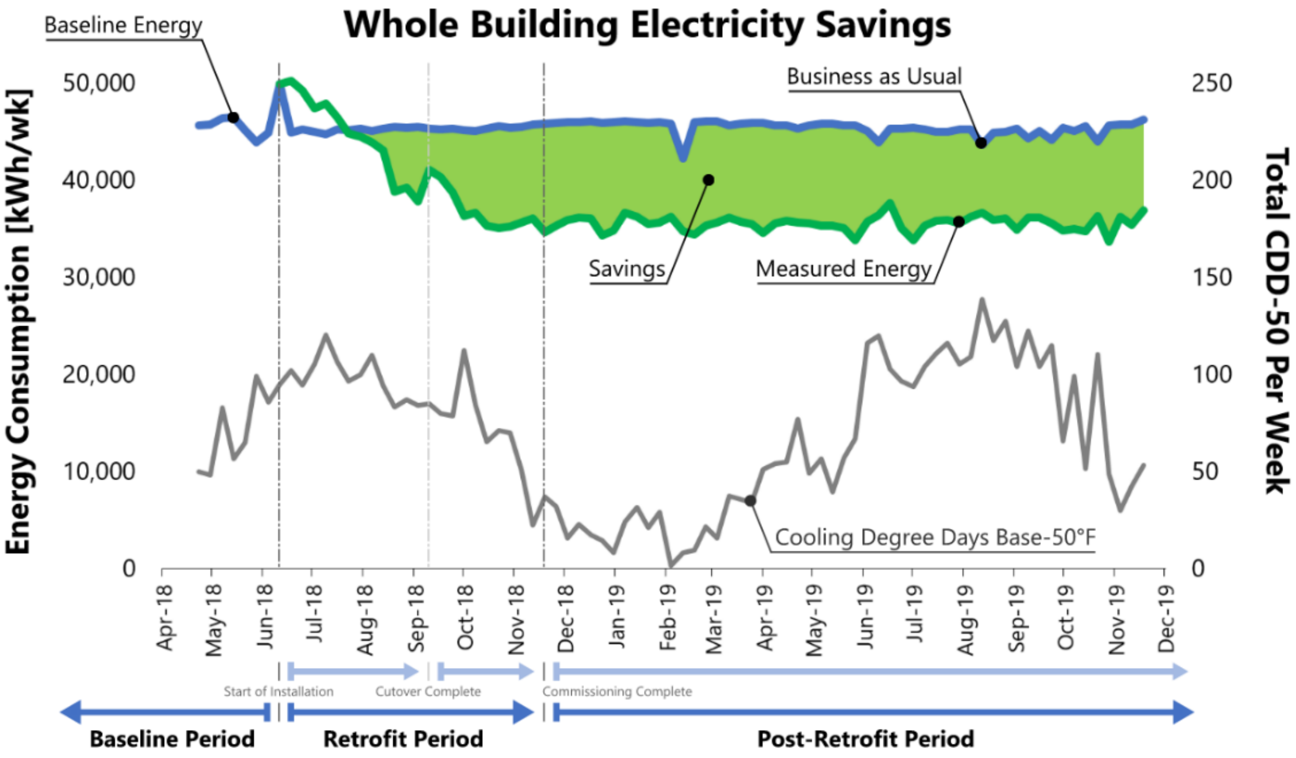
Retrofit isolation EUI values (kBtu/ft^2) for G36 retrofits are reported for HVAC end-uses only.

The Whittier and Pleasanton post-retrofit periods occurred during the COVID-19 pandemic; no adjustments could be made to account for the impact on changes in building occupancy. See accompanying text for further details.

Source: Taylor Engineering

Figure 12 below illustrates whole building electricity savings at Kaiser Vallejo MOB, along with cooling and heating degree days for reference. The pre-retrofit baseline energy consumption is represented by the blue lines and is extended as the *business as usual* consumption through the retrofit period, based on regression analysis with outdoor air temperature and schedule as independent variables. The measured post-retrofit energy consumption is represented by the green lines, with savings indicated by the shaded light-green areas. The HVAC zones and air handlers were progressively retrofitted starting in June 2018 with substantial completion in September 2018. Annual energy savings were evaluated based on normalized metered energy consumption methods to adjust for typical weather conditions and allow for estimated annual savings.

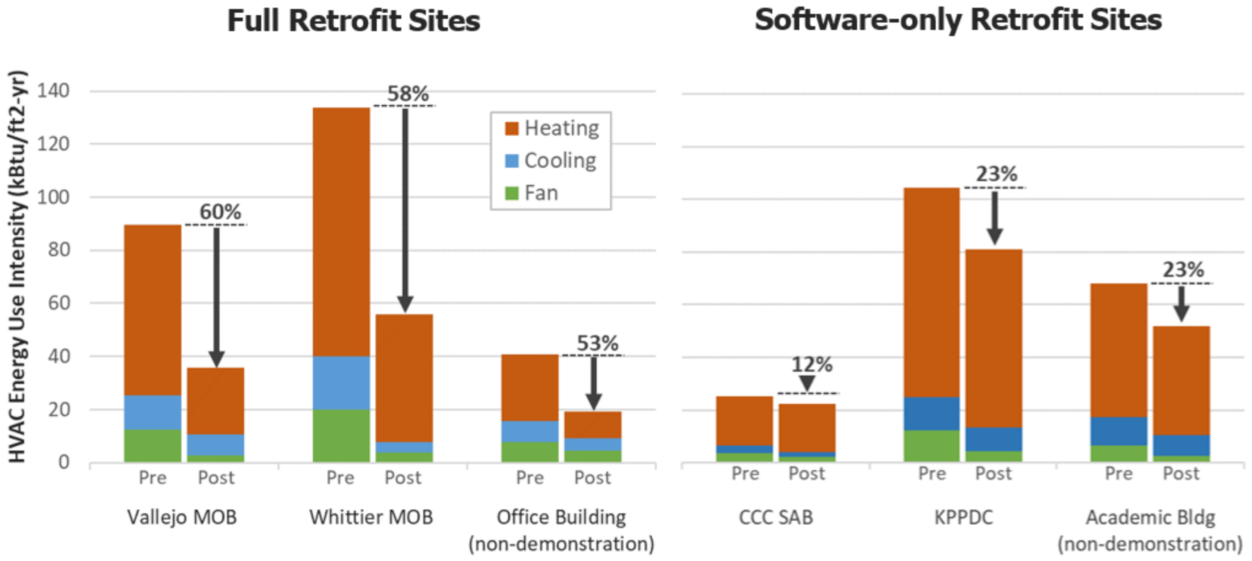
Figure 12: Whole Building Electricity Savings at Kaiser Vallejo Medical Office Building



Source: Taylor Engineering

Figure 13 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. Given the consistency in results across the two types of retrofits and that only two of the sites reported had monitoring during COVID-19, the team expect that changes in occupancy patterns due to the pandemic likely do not have a significant impact on energy results.

Figure 13: HVAC Energy Savings Across Retrofit Sites

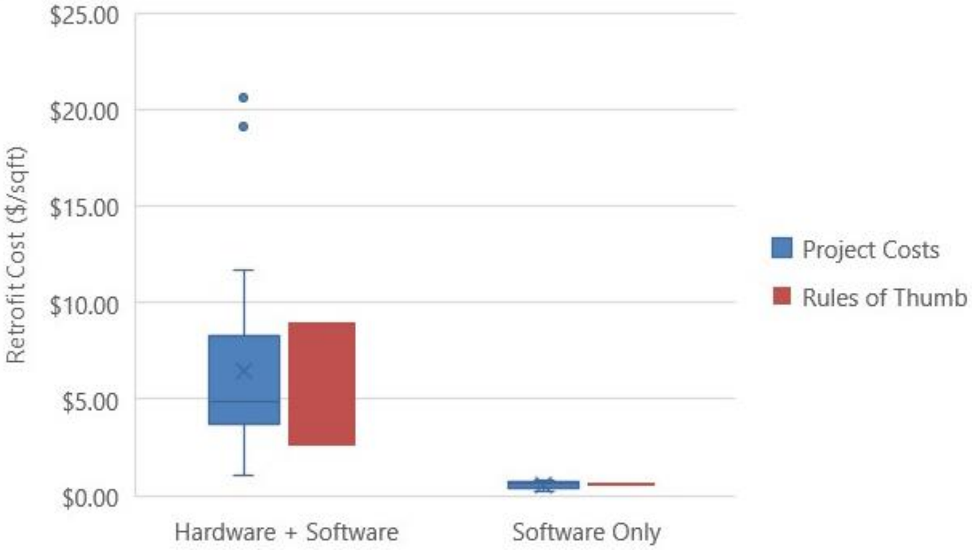


Source: Taylor Engineering

For each retrofit type, two demonstration sites are shown, along with a similar project that was not part of the demonstration. The full retrofit sites each achieved about 50 to 65 percent reduction in HVAC energy intensity. Note that the MOBs generally have a much higher energy intensity than non-MOBs. The roughly 80 percent fan savings at both Vallejo and Whittier are striking, shown in the reduction of green bars. Among the software-only retrofit sites in Figure 13, savings were also consistent within a range of 10 to 25 percent. Although overall savings were lower when compared with the full retrofit sites, the first costs and levels of disruption are also much lower. All the retrofits shown had simple paybacks of eight years or less.

The project team compiled first-cost data from the demonstration projects and other similar projects to provide guidance to industry on what to expect with G36 projects. Costs are heavily dependent on project-specific conditions, differences in regional construction labor rates, construction market conditions, and the bidding nature for each project (negotiated or competitively bid). The project team reached out to designers, BAS manufacturers, controls contractors, building owners, and researchers to gather cost data. Contributors provided a total of 27 data points for hardware and software retrofits and 7 data points for software-only retrofits. In addition to providing data points from actual projects, some contributors also provided ranges of costs based on rules of thumb. Figure 14 below shows the retrofit cost data that the team collected, which shows that the average retrofit cost for a hardware and software retrofit is $6.40 per square foot, and the average software-only retrofit is $0.65 per square foot.

Figure 14: Retrofit Cost per Square Foot



Source: Taylor Engineering and TRC

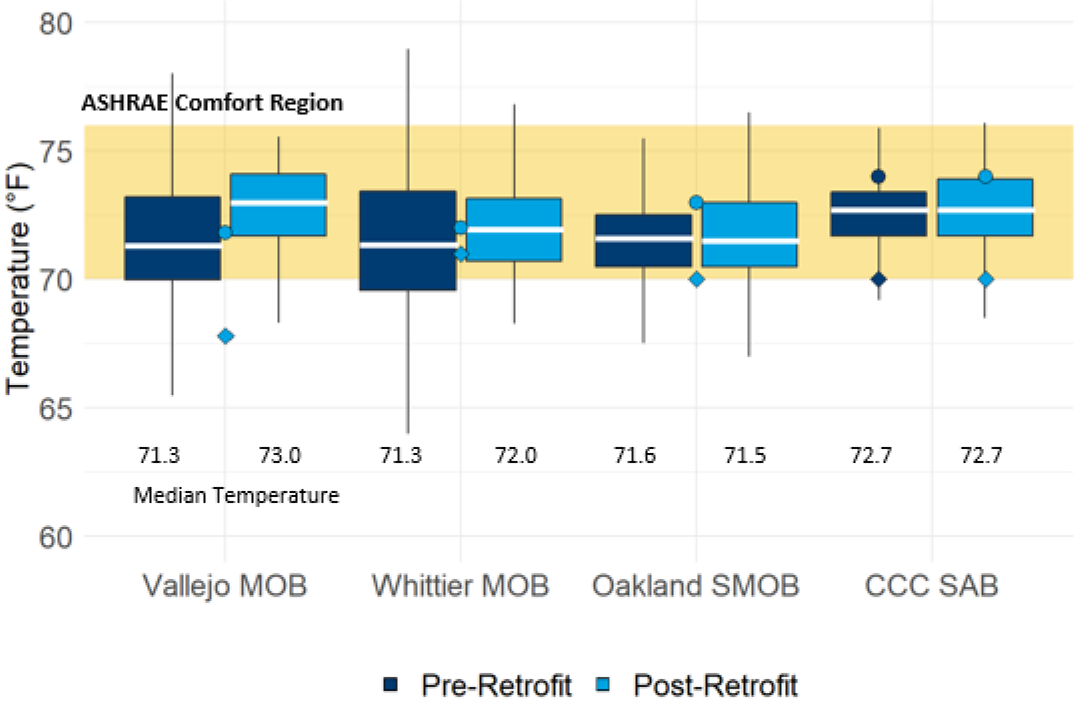
Combining expected energy savings with expected retrofit costs resulted in a 6- to 8-year payback period for hardware-plus-software retrofits and 2- to 8-year payback periods for software-only retrofits.

Indoor Environmental Quality Results

In general, the IEQ conditions of temperature and relative humidity were similar pre- and post-retrofit at all sites evaluated. On average, post-retrofit office space temperatures increased at KP Vallejo MOB and KP Whittier MOB, and were unchanged at CCC SAB and KP Oakland SMOB. The project team expected that the retrofits would lead to decreased summer over-cooling due to improved system resets and lower zone airflow minimums, and therefore, lead to improved occupant thermal comfort. There was a reduction in over-cooling at KP Vallejo MOB and KP Whittier MOB, where the office space temperature increased on average from pre-retrofit to post-retrofit by 1.7°F and 0.7°F, respectively. The average temperature of office spaces at all four sites remained within the range suggested by ASHRAE for the cooling season (70°F to 76°F) in the pre-retrofit and the post-retrofit. An ASHRAE research project (Arens, et al., 2015; Paliaga, Zhang, Hoyt, & Arens, 2019) found that even an average space temperature increase of 0.4°F in the summer within the ASHRAE comfort region cut occupant cold discomfort in half, suggesting that the difference in average space temperatures seen at KP Vallejo MOB and KP Whittier MOB likely resulted in improved occupant thermal comfort in those areas. Average office space temperatures at CCC SAB and KP Oakland SMOB had only very slight changes from pre-retrofit to post-retrofit. Relative humidity and CO_2 typically remained within acceptable ranges in both the pre-retrofit and the post-retrofit periods in the locations evaluated.

Figure 15 below illustrates pre- and post-retrofit space temperature trends of office spaces during the normally-occupied periods of the cooling season across the demonstration sites.

Figure 15: Space Temperature Trends During Normally-Occupied Periods in Cooling Season, all Office Spaces



Source: TRC

Due to COVID-19 reduced occupancy, the project team was not able to conduct post-retrofit occupant surveys at several sites. At KP Vallejo where post-surveys were conducted, satisfaction with the temperature decreased significantly and satisfaction with indoor air quality decreased slightly. But those responses represent only about two percent of total building occupants, so it is unclear whether those responses represent most occupants. At CCC SAB, satisfaction with thermal comfort and air quality remained about the same pre- and post-retrofit.

Overall, IEQ conditions either improved or did not appear to vary considerably from the pre- to post-retrofit periods. Combined with the energy savings results, these case studies illustrate how energy savings can be achieved without decreasing thermal comfort.

Guideline 36 Implementation Lessons Learned

The team has identified challenges, lessons learned, and keys to success for G36 implementation. A summary of these findings follows.

The following were critical for this project's success: detailed design and project specifications (contract requirements that dictated contractor responsibilities) and detailed construction administration and commissioning (construction processes that ensured contract requirements were met and that design intent was achieved). For at least one demonstration site, major controls commissioning phases included limited software simulation of functional tests, demonstration testing, and extensive trend reviews.

Another key to success was focused commissioning. The following elements were part of the focused commissioning.

- The lead design engineer performed detailed functional testing and trend reviews.
- There was limited software simulation of functional tests, demonstration testing, and extensive trend analysis.
- An active punch list was maintained and reviewed weekly.
- The commissioning agent offered extensive services to assist the controls contractor in writing, troubleshooting, and condensing the controls logic.

Building operations after the post-retrofit activities are critical to the project's long-term success. Involving building engineering staff in the design and participating in training on the BAS design (not just how to operate the interface) ensures that operators are better positioned to monitor and adjust the control systems. Additionally, the front-end graphics complement G36 and provide clear communication of the system and allow operators to make any necessary adjustments. Lastly, FDD, hierarchical alarm suppression, and rogue zone identification logic all aid the building operator in efficiently operating the building.

The team also identified challenges related to G36 implementation at each stage in the process. During design, the format of G36 is a challenge. The PDF format of the 2018 version is challenging to edit and incorporate into a project specification, while a Microsoft Word© version of G36 may also be challenging for designers who are not familiar with the guideline and/or advanced features in Word©. Another challenge for designers is that G36 currently only covers a limited set of HVAC systems and does not cover every possible design scenario. Lastly, while G36 primarily represents sequences of operation, there are numerous other facets of control system design that are critical for successful implementation, including hardware and graphical requirements and commissioning.

During contractor procurement, control contractors often do not read the control sequences carefully when bidding on jobs. G36 is significantly more complex and detailed than the sequences that most controls contractors experience. During construction, uninitiated programmers may be initially confused by the level of detail and the organization format. Additionally, the complexity of logic required for zonal control in G36 may exceed capacity limitations of many lines of zone-level controllers. Also, controller compatibility may be an issue where configurable-only controllers are used—these are controllers that incorporate built-in logic but do not provide the flexibility of customized programming.

G36 includes features intended to provide more flexibility for operators to adjust settings to optimize operational and energy efficiency. However, there is also a lack of training materials and guidance for operators on how best to take advantage of these capabilities.

The market transformation work described in Chapter 5 addresses some of these challenges.

CHAPTER 5: Technology Transfer and Market Transformation

Market innovation is one of two primary goals in this study. A key component focused on understanding the market potential for OCS across California by conducting a market assessment and feasibility analysis. Based on insights gained from the market assessment and feasibility analysis, the project team developed five market transformation pathways. The following sections describe both the outcomes of the market assessment and feasibility analysis and those market transformation pathways. The Technology and Knowledge Transfer Report is available in Appendix E.

Market Assessment and Feasibility Analysis

The team characterized the BAS industry based on data collected, as described in Chapter 2. This characterization led the team to several findings:

- The current BAS controls industry workflow is inefficient and error prone. G36 can help address some of these inefficiencies and errors, but the workflow itself is a key barrier to G36 adoption.
- BAS dealer and manufacturer use of application libraries varies across the industry, which also presents a key G36 adoption barrier.
- Demonstration sites and stakeholder insights revealed additional G36 adoption barriers.

Key findings and the resulting barriers are described detail below. For complete details, please refer to Appendix F.

Building Automation System Industry Workflow

The team analyzed current controls industry workflows. Through this analysis, the team identified challenges and issues in the current market, which G36 helps address. Figure 16 below summarizes the existing industry process for BAS software installation and highlights specific areas that are *high risk*, indicated by warning symbols. The team defined high risk as steps that consume much time and cost and are often customized for each building. This scenario is prone to errors and often results in energy waste since these are manual processes. In addition to its energy-savings potential, a key benefit of G36 is that it addresses many of these high-risk steps inherent in the industry today.

The industry workflow analysis highlighted one major barrier that the team characterized as the existing business model barrier: leveraging the full potential of a modern BAS and G36 requires several tools and processes that, once completed, could transform the market. The team's vision of the next step is in G36 Model 2.0 (Figure 17 below). In this scenario, the G36 selection software generates a G36 model number corresponding to the HVAC system based on the designer's selection from a simple set of menu options. The controls contractor can then feed that model number into the BAS manufacturer's software and automatically generate programming. These automated processes eliminate multiple manual steps that are frequently prone to misinterpretation and errors. There are currently several high-risk steps, and G36 and the described future market products reduce risk in all of them. With future market innovation, there will be more automation and significantly less risk. Many of these high-risk areas have not already been resolved due to implementation barriers, particularly with control contractors.

Barriers

The project team characterized the BAS industry and identified market barriers and the adoption feasibility of G36.

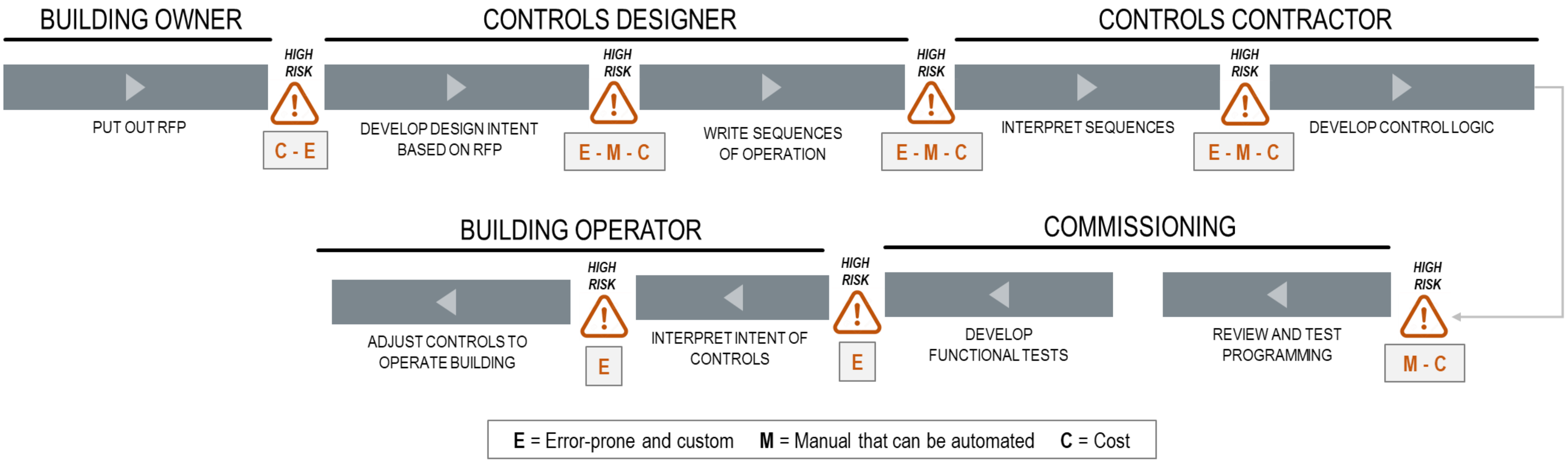
One major barrier identified through analysis of the BAS controls industry workflow is the existing business models of manufacturers and dealers. In the existing model, programming is customized for each building. This is the expectation of manufacturers, dealers, designers, commissioning agents, building owners, and building engineers. The controls industry requires a disruption to change this customized approach into a standardized approach. One component of this barrier is a *chicken and egg* problem; some industry players do not want to make changes unless specifically requested, but stakeholders may be reluctant to do so until they are confident that those requests can be fulfilled.

The team identified several industry barriers to widespread adoption of G36 control sequences. Many of these barriers were highlighted in the field demonstration and include the complexity of G36, that G36 is not comprehensive, the lack of awareness of G36, the lack of understanding of G36, and that the benefits of G36 are unknown.

The team has identified several barriers related to G36 industry implementation including lack of manufacturer commitment to pre-program libraries (dealers' existing processes do not involve utilizing manufacturer libraries), equipment limitations, BAS hardware incompatibility, and a perception of added cost.

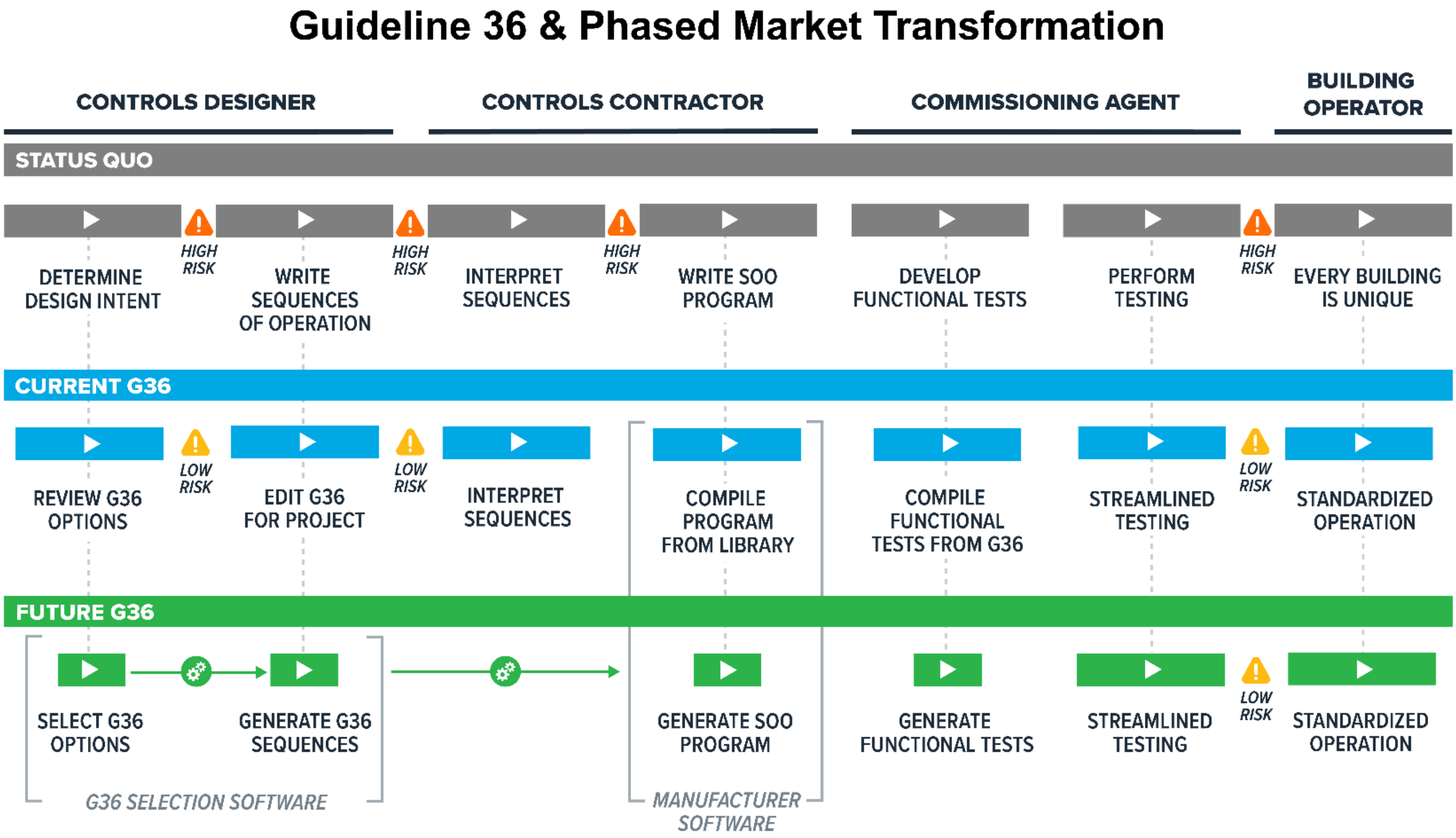
The research team identified several barriers related to building operation including lack of operator guidance and inadequate user interfaces, which are required by building operators to address occupant comfort complaints. Buildings with G36 require less building operator intervention; however, there is a lack of training materials and guidance for operators on how best to utilize these capabilities. In current processes, building operators have assumptions about controls system functionality and the level of interaction required to keep it working. Building operators often thus override setpoints when responding to occupant complaints or other problems as they arise, often due to lack of understanding of how the automatic controls should respond.

Figure 16: Business-as-Usual Building Automation System Controls Industry Workflow



Source: Taylor Engineering and TRC

Figure 17: Potential Future Building Automation System Controls Industry Workflow



Source: Taylor Engineering and TRC

Market Transformation Pathways

Based on insights gained from the market assessment and feasibility analysis, the project team developed five market transformation pathways:

- Facility market adoption
- Utility program design
- Codes and standards enhancement
- FDD specifications
- Best practices guide

These pathways address the barriers and would push market adoption from multiple angles. No single pathway will address all barriers, but the pathways together could drive market adoption.

Facilitating Market Adoption

The team collected data on early adopters (e.g., commercial building owners, designers, and installers) of G36 implementations. The team identified early adopters through its own projects, ASHRAE G36 committee members, and industry contacts. Through the team's early adopter tracking, the team identified 28 buildings (not including the demonstration sites in this project) where G36 has been or is being implemented. This may be an underestimate, since the research team identified these buildings through word-of-mouth with industry contacts, and G36 users may be reluctant to publicly state their use of the guideline.

Furthermore, the team held discussions with major BAS manufacturers regarding their efforts to implement G36, including Automated Logic Corporation, Siemens, Johnson Controls, Distech, Trane, Alerton, and Schneider Electric. All of these manufacturers have made a commitment in some form to implement G36 in their factory application libraries. The team tracked manufacturer progress including what G36 libraries they have released to their dealers, as well as which legacy and current hardware and software offerings from the manufacturer are compatible with G36.

Though manufacturers have begun releasing G36 libraries, the manufacturers still need to complete and validate the quality of their libraries and encourage their dealers to use them. Because these steps will not be completed in the immediate term, the team proposed two intermediate solutions that dealers could use in the near term to help implement G36 before pre-programmed libraries are fully available:

- BAS contractor sharing (peer to peer)
- Portfolio owners sharing pre-tested logic with BAS contractors on new projects

For BAS contractor sharing, contractors could develop G36 control programming and incorporate it into an internal library leveraged for future projects, as is common practice for control programming in general. Some contractors also have access to information-sharing platforms for a particular BAS product line. For example, Automated Logic hosts a website called ALCshare[1], which allows its dealers to exchange information, share solutions, and even get application programming from other dealers. Where these dealer networks and sharing

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[1] http://alcshare.com/

mechanisms exist, the first dealer to undergo the process can share the experience with other dealers who would benefit from shared G36 programming.

Utility Program Design

This project developed utility program design concepts that leverage OCS for HVAC controls in G36.

The team identified market barriers that impede deep energy savings from BAS retrofits in custom incentive and traditional retro-commissioning (RCx) programs and developed a new BAS retrofit model that addresses these barriers. The research team proposes a revolutionary new approach that bridges the gap between traditional RCx and custom programs and maximizes energy savings with *BAS modernization* of both hardware and software retrofits. Many buildings suitable for RCx can achieve deeper savings through this BAS modernization approach, while also gaining additional non-energy benefits. This approach leverages standardized high-performance control sequences from G36 to save energy, reduces transaction costs and risks, and improves occupant comfort.

This new utility program design model leverages market enablement through open standards, BAS industry partnerships, and tools for cost-effective scaling that include tools for project screening, savings calculations, and M&V. The project also proposes a new incentive program model: the BAS Modernization Program, which bridges the gap between traditional RCx programs and custom incentive programs.

The team wrote a paper on this new utility program design concept for the American Council for an Energy-Efficient Economy 2020 Summer Study on Energy Efficiency in Buildings Virtual Conference, included in Appendix G.

The team also investigated opportunities for incorporating G36 into current utility programs by reviewing existing programs and savings calculator tools across the country. The opportunities identified were shared informally with various program managers and through conferences across the country. This review is included in Appendix H.

Codes and Standards Enhancement

One of the primary goals of this project was market innovation, specifically to demonstrate a new delivery mechanism for control systems upgrades that features plug-and-play solutions that address California's need for cost-effective energy and carbon reductions.

One pathway to meet this goal is through codes and standards enhancements. The team's objective, with respect to codes and standards, was to examine current building code requirements to identify the feasibility, impediments, and opportunities for OCS. The team focused on code change opportunities in the California Building Energy Efficiency Standards (Title 24).

Title 24 is designed to ensure that new and existing buildings meet minimum energy efficiency and IEQ requirements. The standards are updated on a triennial basis by the CEC to allow consideration and possible incorporation of new energy efficiency technologies and methods. Title 24 contains building energy efficiency requirements that apply to most residential and non-residential buildings throughout California.

The team identified the following change opportunities and the steps needed to provide more effective enforcement of control requirements for both new construction and alterations. Table 5 below provides a summary of code change opportunities.

Table 5: Code Change Opportunities

Opportunity	Scope of change
Advanced lighting integration	New construction Title 24 mandatory rule
SAT reset	New construction and alteration; prescriptive requirement and ACM rule change
DDC system requirements	New construction and addition and alteration; mandatory requirements
Controls retrofit code trigger	Alterations permit process
Compliance and enforcement	Acceptance testing form improvement
Certifying programming	Compliance credit
FDD	New construction and alteration; prescriptive requirement

Source: Taylor Engineering and TRC

The team also recommends code readiness in the following areas.

- **Certified G36-Compliant Controllers:** Field demonstrations and modeling to establish a baseline and determine energy savings associated with certified G36-compliant controllers
- **FDD:** Field demonstrations and modeling to establish savings from FDD market offerings

A detailed report on these recommendations is included in Appendix I.

Fault Detection and Diagnostics Functional Specifications

The team leveraged project results and Lawrence Berkeley National Laboratory's work to develop recommended functional specifications for FDD and CCx. Specifications guide future software analysis features and capabilities, organizational operational practices, high-value data points and frequency, and other integration recommendations. The guide specifically addresses a major gap where interested building owners may be interested in FDD but are unsure about the range of capabilities and how best to evaluate and select a platform and options among available products. These functional specifications help building owners make informed decisions about the purchase of FDD/CCx software by detailing key performance metrics, help product manufacturers improve functionality of their technologies to align with specifications, and inform future projects to replicate solutions demonstrated in this project. The FDD functional specifications have been distributed through the DOE Better Buildings program and are included in Appendix J.

Best Practices Guide

The publication of G36 was a significant advancement in the building automation industry, not only for disseminating technical content in high-performance sequences of operation, but also for establishing a pathway to industry standardization. This standardization provides an opportunity for streamlining market delivery processes that are currently labor-intensive, error-prone, and ultimately subject to failure.

The team developed a best practices guide for a broad range of stakeholders including building owners, property managers, designers, installers, and operators. This guide:

- Expresses the value proposition for Guideline 36, including energy cost savings and cost effectiveness data from demonstration sites.
- Highlights and describes the intent of key sequences of operation.
- Provides supporting information about critical considerations that impact building automation system performance beyond the sequences of operation, including important control sensors and graphics requirements.
- Provides a troubleshooting guide that is tailored to building operators to help ensure that buildings are operated appropriately and according to the design intent.

This document serves as a key technical resource for industry users, compiling into a single document information from a wide range of existing resources and new data generated from the demonstration and market transformation activities. The guide is freely available on the Taylor Engineers website and has been frequently announced across multiple media (email newsletters, ASHRAE conference seminars and related technical committee meetings, in controls-related continuing education classes, and peer-to-peer communications).

The Best Practices Guide appears in Appendix K.

CHAPTER 6: Conclusions/Recommendations

The project successfully demonstrated the energy savings potential and cost effectiveness of two retrofit types. Savings of 26 to 35 percent for whole-building electricity were achieved with 6- to 8-year simple payback when control systems were fully replaced. At buildings with existing modern control systems where only software updates were performed, whole-building electricity savings of 11 to 17 percent were achieved with 2- to 7-year simple payback. These results were strengthened through their replication across multiple sites. With existing commercial buildings in California accounting for roughly 40 percent of the total electricity consumed in the service territories of the state’s three major IOUs, more efficient control sequence retrofits utilizing G36 represent a major opportunity to achieve significant energy savings and reduce greenhouse gas emissions. Estimated statewide benefits through deployment in commercial buildings over the next 15 years are a reduction in electricity use by 2,387 gigawatt-hours, saving Californians $373 million in energy costs and reducing carbon dioxide emissions by 1,742 million pounds.

In addition to demonstrating this energy savings potential, the project supports widespread adoption of this technology through technical advancements, knowledge transfer, and market transformation efforts. These activities each target major adoption barriers identified through market research, including interviews and surveys of a wide range of industry stakeholders:

- **Lack of Awareness and Understanding of the Value of G36:** The team developed a series of market-facing resources promoting the value proposition and energy and IEQ benefits. Any type of retrofit causes disruptions to building users and requires financial investment, and decision makers need to feel confident that the investment is worth it. Significant and cost-effective energy savings were demonstrated through both field study and simulation analyses. Throughout the course of the project, team members disseminated information on G36 as well as research findings through more than 20 presentations and trainings at conferences, industry events, and various other organizations. Results were also shared through peer-reviewed publications including a paper highlighting the national ASHRAE technology award for the retrofit at the KP Vallejo MOB demonstration site. See Appendix E for full listing of dissemination activities.
- **Challenges With Identifying Appropriate Retrofit Opportunities:** The scope of G36 addresses a limited (but growing) set of HVAC equipment types. The opportunity for achieving energy and operational improvements in existing buildings is a function of both existing equipment types and how they are operated. Identifying appropriate and cost-effective retrofit opportunities is made challenging by a lack of understanding of these key factors and the difficulty of evaluating savings opportunities through simulations alone; complex HVAC control strategies cannot be easily modeled in conventional building energy simulation tools. To address these challenges, the project developed plain language descriptions of key G36 measures and a qualitative screening guide for retrofit opportunities in the best practices guide, and piloted a simplified energy savings calculator that allows users to quickly estimate energy-savings opportunities.

- **Challenges With Understanding and use of G36:** The control strategies in the guideline are complex and require advanced understanding of HVAC systems and controls. Many concepts are unfamiliar to market players and inaccessible due to the sheer size of the document. To address these challenges, the team delivered trainings and presentations at conferences, as well as trainings for individual project stakeholders, to describe an approach that better conveys the design intent to both installers and operators. The best practices guide serves as a key resource for a broad audience to highlight and explain key concepts in G36 and provide guidance on other important issues beyond the scope of the guideline. The team has also coordinated closely with industry stakeholders and separate research efforts to develop software tools that simplify and streamline the use of G36.
- **Difficult to Program Accurately:** Sequences of operation are English-language instructions on how mechanical components operate in tandem to maintain thermal comfort and provide necessary ventilation in an energy-efficient way. Those sequences need to be translated and implemented in a control programming language by installers, but this translation step is onerous due to the complexity and high level of detail in G36. Early projects employing G36 must overcome these difficulties on a project-by-project basis. Standardization around G36 allows for centralized programming by manufacturers and incorporation into libraries that are available for individual installers and projects instead of requiring installers to *reinvent the wheel* on each project.
- To support this end goal:
    - The team shared the concept of manufacturer pre-programmed libraries with key industry leaders throughout the value delivery chain: manufacturers, regional sales, and individual installers, as well as other key users to create demand for this new research and development. The team monitored and compiled the status of manufacturer G36 library development to increase momentum and apply pressure to competing manufacturers. All major manufacturers have now released programming libraries for at least a portion of G36; at the start of this project none had even indicated any plans to do so.
    - The team piloted an automated test method that could be used for independent certification of programming to confirm adherence to G36. Interviews with manufacturers and installers universally confirmed that existing manufacturer programming libraries are seldom used, for various reasons: they are out-of-date, do not work well, do not accommodate regional climate needs, or are simply programmed in a different style that does not match individual user preference. Independent certification of the programming quality would instill confidence in building owners, designers, and installers that the programming libraries are robust and accurate, and that use of the libraries would improve both processes and operational efficiency (compared with installers developing the programming for in-house libraries or for individual projects).
- **Risk and First-Cost Barriers:** Undertaking a control retrofit entails the operational risk that systems will not be operated correctly, as well as the risk of financial investment. The field demonstrations provided strong evidence that significant energy savings can be achieved with OCS retrofits in a cost-effective manner. Technology transfer efforts (including trainings, presentations, publications, reports, and guides)

reduce these risks by increasing understanding of key issues and lessons learned. The simplified energy savings calculator allows decision makers to easily screen buildings for energy savings opportunities that help reduce financial risk. The utility program design concept also provides a mechanism to help incentivize these types of control retrofits and reduce the first-cost barrier.

- **Persistence of Savings:** Maintaining the high performance of commercial HVAC systems with OCS requires that building operators monitor BAS and understand system operations. Without these, there is a risk of performance degradation from normal device failures and improper operator overrides and adjustments. The FDD demonstrated that G36 system monitoring can help identify and prioritize issues for operators. The G36 trainings and best practices guides will assist with improving operator understanding of G36 design intent and best practices for adjusting and tuning systems.

Though many of the strategies in G36 have been tested and improved over decades, the guideline is relatively new. Improving the successful use of G36 on typical projects, rapidly encouraging widespread use, and realizing the full potential benefits of G36 through industry standardization will require major changes from existing practices. Further work is required to continue to improve the applicability of G36 and support successful industry adoption.

The research team further recommends:

- **Further development of G36 to expand the scope of its applicability to more equipment types, particularly for packaged AC systems, which are used over most of commercial building stock.** For existing buildings, much of the benefit of G36 might be more easily achieved with only a subset of the components within G36. Development of a simplified version of G36, a "G36-lite," would support broader deployment through lower first costs, reduced disruptions and reliance upon highly-trained experts, and better compatibility with existing equipment and control functionalities. Such development, because of the scale of work required, needs to be supported by grant funding.
- **Further development of the energy savings calculator.** This project developed a simulation workflow capable of modeling complex control strategies through the co-simulation of EnergyPlus and Modelica, as well as a simplified spreadsheet user interface that draws upon data from pre-run parametric simulations. The pilot energy savings calculator is an open-source software tool. However, further refinement and expansion of the tool's capabilities are required for its broad usability. Potential applications include screening retrofit opportunities for energy savings potential and utility use to determine eligibility or estimate incentives.
- **Further development of automating the G36 programming testbed.** The team evaluated test approaches and developed and piloted a workflow and software interface for automated testing of G36 programming on a physical controller through an open communication protocol. The pilot test was only evaluated for a short portion of the programming and only tested with programming from one manufacturer. With the rapid development of manufacturer programming libraries, there is an urgent need for independent confirmation of programming quality and conformance with G36. Further development of the testbed strategy will be critical and should include stakeholder outreach to ensure compatibility and broad buy-in from a majority of manufacturers,

comprehensive development of the test scripts and user interface, and research into developing an independent certification body to administer testing.

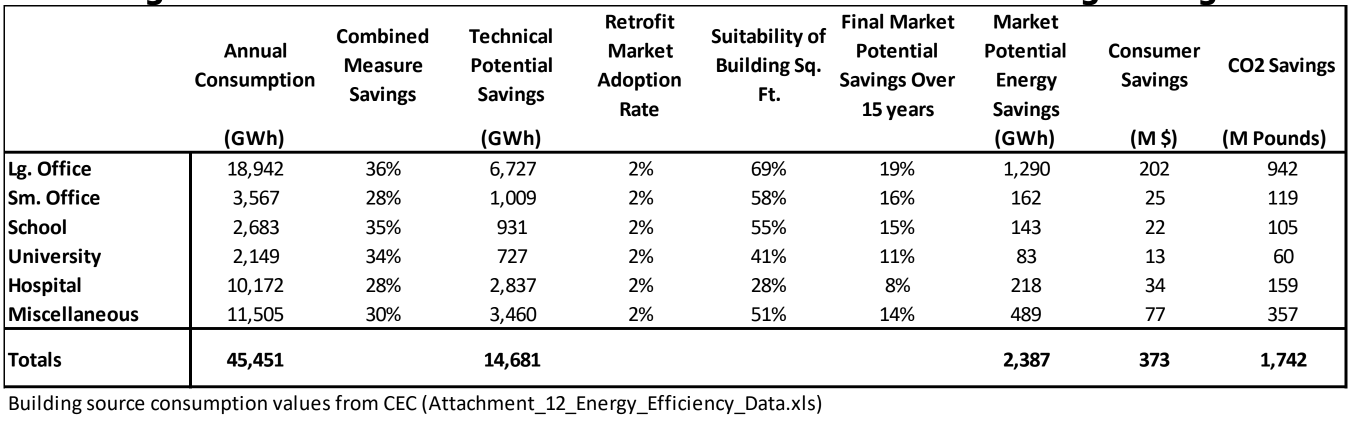
- **Utility savings programs.** Retrofits employing OCS and G36 may meet cost-effectiveness thresholds for utility programs but are generally not practically applicable to existing programs. The utility program design concept should be piloted by a California IOU. This effort should be closely monitored and considered for deployment by California IOU programs to encourage more widespread adoption.
- **Codes and standards improvements.** Many key energy measures in G36 are already either mandatory or prescriptively required, at least in concept, in Title 24 and ASHRAE Standard 90.1. G36 provides additional specificity on how to implement each of these requirements. More work is needed with code enforcement and to educate industry on these requirements and the resources available to facilitate their implementation. The Codes and Standards report in Appendix I provides specific recommendations of other opportunities to incorporate additional energy measures into Title 24, including expanding alterations scopes to cover control retrofits
- **Workforce training.** HVAC control is generally an advanced topic that is not very well understood by most HVAC designers and building operators. There are relatively few classes on this topic available at universities and continuing learning institutions. Moreover, many BAS programmers are not trained in software development and lack university degrees; most programmers instead transition from roles as technicians and other trades. The lack of formal education and sophistication in these subdisciplines is a major barrier to expanding successful use of advanced HVAC controls. These challenges were echoed in interviews with consulting engineering companies and building automation contractors, which expressed the difficulty of recruiting qualified candidates into this field. More funding is also needed to support continuing learning opportunities for HVAC controls education.

CHAPTER 7:
Benefits to Ratepayers

OCS provide greater energy security and reliability, along with energy savings and emission reductions, for IOU electricity ratepayers. Figure 18 below shows significant potential statewide savings over the next 15 years: 2,387 GWh, $373M, and 1,742 million pounds of CO2 emissions. Cost competitive, scalable OCS and plug-and-play technologies will also support a competitive energy efficiency industry in California. The controls technologies offer improved comfort and satisfaction for building occupants. The findings of this study could importantly help accelerate statewide energy and cost savings and improve indoor environments.

The statewide annual energy savings for the technologies included in this study at full implementation is 2,387 GWh (Figure 18 below) through a combination of savings from DDC controls using G36 and NLC. These measures result in both initial and ongoing operational optimization and deep energy savings, with long-term persistence. The integration achieves higher energy savings through the synergistic operation of various systems. The savings potential in a typical large office building is estimated to be 36 percent of total large office building energy consumption. These control strategies would together reduce peak electric load, and both the NLC and G36 are demand-response ready for further load shedding.

Figure 18: Statewide Technical and Market Potential Building Savings



	Annual Consumption (GWh)	Combined Measure Savings	Technical Potential Savings (GWh)	Retrofit Market Adoption Rate	Suitability of Building Sq. Ft.	Final Market Potential Savings Over 15 years	Market Potential Energy Savings (GWh)	Consumer Savings (M $)	CO2 Savings (M Pounds)
Lg. Office	18,942	36%	6,727	2%	69%	19%	1,290	202	942
Sm. Office	3,567	28%	1,009	2%	58%	16%	162	25	119
School	2,683	35%	931	2%	55%	15%	143	22	105
University	2,149	34%	727	2%	41%	11%	83	13	60
Hospital	10,172	28%	2,837	2%	28%	8%	218	34	159
Miscellaneous	11,505	30%	3,460	2%	51%	14%	489	77	357
Totals	**45,451**		**14,681**				**2,387**	**373**	**1,742**

Building source consumption values from CEC (Attachment_12_Energy_Efficiency_Data.xls)

Source: Taylor Engineering and TRC

The project team estimates a moderate early adoption rate, but concerted efforts by utilities and contractors can achieve a saturation of 66 percent of the retrofit market. The calculations assume a retrofit rate of 3 percent of the existing building stock each year with a proposed measure saturation rate of 66 percent, resulting in an adoption rate of 2 percent of the full market, per year. This would result in realized annual savings (after 15 years for large and small offices, schools, universities, hospitals, and miscellaneous buildings) of 2,378 GWh, energy cost reductions of $373M, and a reduction of 1,742 million pounds of CO2, as shown in Figure 18.

For these energy savings estimates, the team estimated market penetration over the next 15 years of existing building stock in California for applicable building types, including 19 percent for large offices, 16 percent for small offices, 15 percent for schools, 14 percent for miscellaneous, 11 percent for universities; and 8 percent for hospitals.

The technologies examined in this project could save energy without negatively impacting or potentially even improving occupant comfort and satisfaction. Occupant benefits are increasingly important to the market and can be a significant driver of market adoption of emerging energy efficiency technology.

LIST OF ACRONYMS

Term	Definition
AC	Air conditioning
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	Building automation system
CAM	Commission agreement manager
CAV	Constant air volume
CCC	Contra Costa College
CCx	Continuous commissioning
CDL	Control description language
CEC	California Energy Commission
CO2	Carbon dioxide
CRAH	Computer room air handler
CSU	California State University
DDC	Direct digital control
DX	Direct expansion
FDD	Fault detection and diagnostics
Ft^2	Square feet
GWh	Gigawatt-hour
G36	Guideline 36
HVAC	Heating, ventilating, and air conditioning
IAQ	Indoor air quality
IEQ	Indoor environmental quality
IOU	Investor owned utilities
IPMVP	International Performance Measurement and Verification Protocol
KP	Kaiser Permanente
LED	Light emitting diode
LBNL	Lawrence Berkeley National Laboratory
MOB	Medical office building
M&V	Measurement and verification
N/A	Not applicable

Term	Definition
NLC	Networked lighting controls
OCS	Optimized control solutions
PDF	Portable document format
SAT	Supply air temperature
SMOB	Specialty medical office building
SZVAV	Single zone variable air volume
TAC	Technical advisory committee
Title 24	California Building Energy Efficiency Standards
TMY	Typical meteorological year
VAV	Variable air volume

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APPENDIX A:
Stakeholder Interview Findings

APPENDIX B:
Dealer Survey Results

APPENDIX C:
Final Report on Controls Software Validation and Optimization

APPENDIX D:
Field Demonstration Report

APPENDIX E:
Technology and Knowledge Transfer Report

APPENDIX F:
Market Assessment and Feasibility Analysis

APPENDIX G:
Utility Program Design

APPENDIX H:
Utility Program Opportunities

APPENDIX I:
Codes and Standards Enhancement Report

APPENDIX J:
Functional Specifications for Fault Detection and Diagnostics

APPENDIX K:
Best Practices Guide for Advanced Building Automation Systems