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Publication Date
2024-01-21

Peer reviewed

DOI 10.20357/B7NC8P

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Energy Technologies Area
August 2020

Acknowledgment:

The work was funded by Taylor Engineering through the California Energy Commission Electric Program Investment Charge (EPIC) Program, Solicitation Grant Funding Opportunity Number: EPC-GFO-16-304, entitled “Smart Building Controls and Diagnostic Upgrades for California”.

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Abstract

Most existing buildings have sub-optimal heating, ventilation, and air conditioning (HVAC) controls, resulting in wasted energy and occupant discomfort. Retro-commissioning (RCx) addresses many of these issues, but it is a lengthy and highly customized process. Limited capabilities of existing building automation system hardware restricts the scope of most RCx projects. Incentive programs consider building automation system (BAS) hardware retrofits to be high-capital investments and do not allow them in typical RCx programs.

This paper describes work that the authors are leading to facilitate technical and market innovation in the BAS industry to unlock large savings in existing commercial buildings through deep retrofits of BAS hardware and software. California and New York research projects are demonstrating BAS retrofits leveraging the American Society of Heating, Refrigeration, and Air Conditioning Engineers' (ASHRAE) new Guideline 36 high performance sequences of operation to achieve greater than 20 percent whole building energy savings, while saving costs and reducing risk through streamlined processes and standardization across BAS manufacturer product lines and across implementation practices.

This paper describes market barriers that impede achieving deep savings from BAS retrofits in custom incentive and traditional RCx programs and presents a new *maximum potential BAS retrofit* model that addresses these barriers. The new model leverages the authors' efforts in market enablement through open standards, BAS industry partnerships, and tools for cost-effective scaling that includes tools for project screening, savings calculations, and measurement and verification (M&V). This approach is widely applicable and will be ready for at-scale implementation within two years.

Terminology

Building automation system: System used to control building HVAC and other building systems. Also known as a building management system, energy management system, or an energy management and control system.

Sequence of operation (SOO): English-language description of how building systems components are controlled by a BAS, usually incorporated into BAS specification documents.

Control logic: Implementation of SOO as programming within a BAS software platform, sometimes referred to as controls software or control application.

Normalized metered energy consumption (NMEC): An M&V approach that uses energy measured at the utility or sub-meter, normalized for variation in key associated parameters such as weather, production, occupancy, etc.

Retro-commissioning: The process of improving BAS SOO to improve energy efficiency and comfort.

Full BAS retrofit: A 'business as usual' retrofit of the BAS that includes replacing all controller hardware and updating SOO. This includes the front end, equipment controllers (including system- and zone-level), and some sensors, and it is distinguished from a *BAS Modernization*. Term is defined for the purposes of this paper.

BAS Modernization: A full BAS retrofit that uses control logic with high performance standardized SOO based on ASHRAE Guideline 36 (GDL36). Term is defined for the purposes of this paper.

IPMVP: International Performance M&V protocol developed by the Efficiency Valuation Organization, which presents common principles and terms that are widely accepted as basic to any good M&V process.

Introduction

Many existing buildings have sub-optimal HVAC controls, which result in wasted energy and occupant discomfort. Various building control issues lead to the waste of 10 to 30 percent of total energy consumption in existing commercial buildings (Pacific Northwest National Labratory 2020). Building owners typically address energy waste due to sub-optimal HVAC controls through RCx or through a full BAS retrofit. While both solutions save energy, they require lengthy, expensive, and highly customized processes that require specialized expertise, which limits their implementation. There are many challenges inherent in the HVAC controls industry that lead to inefficiencies and issues in getting a BAS properly installed and operating in buildings. These challenges can command an inordinate amount of time and effort from building controls stakeholders, and they make BAS implementations prone to errors during installation that often result in energy wasted, which often worsen throughout the life of the building.

While building owners can leverage incentive programs to perform RCx or a full BAS retrofit, the same cost and quality constraints limit these paths. RCx projects often involve quick payback controls measures that do not mesh with long program administrator review cycles. RCx implementation requires expertise, and it places a large burden on owners, designers, implementers, and program administrators in terms of data gathering, analysis, audits, recommendation reports, incentive application, and review processes to verify savings. RCx programs generally do not incentivize full BAS retrofit projects. Thus, full BAS hardware upgrades must use customized incentive programs. Custom programs present challenges for full BAS retrofits related to establishing energy savings baselines and review timelines that impact implementation schedules.

In 2018, ASHRAE published Guideline 36 – High Performance Sequences of Operation for HVAC Systems (GDL36), which provides standardized, optimized HVAC SOO for airside HVAC systems. This paper proposes a new approach leveraging GDL36, streamlining processes and reducing risk, to achieve maximum potential energy savings with a *BAS Modernization*, including both control hardware and software to address the challenges laid out in the paragraph above. In this paper, we:

- Summarize the development of ASHRAE Guideline 36.
- Summarize the current BAS retrofit industry workflow, challenges, and opportunities.
- Summarize how typical incentive programs treat BAS retrofits.

- Describe the technical and market innovation of GDL36 and how funding from the California Energy Commission (CEC) and New York State Energy Research and Development Authority (NYSERDA) is supporting market adoption.
- Propose that *BAS Modernizations* leveraging GDL36 can be cost-effective and achieve deeper savings for some existing buildings that would otherwise only undergo RCx.
- Propose a BAS Modernization Program (BMP), a new incentive program model focused on *BAS Modernization*.

ASHRAE Guideline 36 Standardized Advanced HVAC SOO: Technology & Opportunity

In 2008, ASHRAE initiated a research project to develop comprehensive optimized SOO for common air distribution and terminal subsystems (Hydeman et al. 2014). Following the completion of this work, ASHRAE formed a committee (Guideline Project Committee 36) to publish and maintain these SOO and future SOO for other systems. The committee consisted of designers, BAS manufacturers, commissioning providers, and other stakeholders. Starting with the related research project, the committee developed state-of-the-art SOO from real projects with demonstrated savings, based on committee consensus and broad industry support. The committee published these SOO in Guideline 36-2018 – High Performance Sequences of Operation for HVAC Systems (ASHRAE 2018), which are summarized in an ASHRAE Journal article (Taylor, Engineers Notebook: Making VAV Great Again 2018).

Some of the key SOO in GDL36 are dual maximum variable air volume (VAV) logic for terminal units and demand-based supply air temperature and duct static pressure resets. These SOO maximize system turn-down as load varies while trading-off between compressor energy, fan energy, and reheat energy to minimize the overall energy use. Though a building owner ideally implements all relevant sections of GDL36, it may be possible to realize a significant portion of the benefits through just these key SOO.

Another ASHRAE-initiated research project began in 2017, developing optimized SOO for chilled water and hot water plants (Taylor, Advanced Sequences of Operation for HVAC Systems - Phase II Central Plants and Hydronic Systems 2020). GDL36 is expected to be updated to include waterside SOO following the completion of this work, and it will continue to expand and improve on new and existing SOO as implementation becomes more widespread.

BAS Controls Industry Current Workflow, Challenges, and Opportunities

The HVAC controls industry consists of several primary stakeholders: BAS manufacturers, controls contractors (BAS dealers), design engineers, commissioning providers, and building operators. In this section, we describe each key stakeholder's role based on the current typical workflow, and we identify challenges and opportunities for improvement. Though there are both hardware and software components to BAS infrastructure, this discussion focuses on the software elements only.

Current BAS Industry Workflow

The HVAC control industry suffers from many equipment and user deficiencies. These deficiencies result in systems that have poor energy efficiency, do not meet design intent, and fall short of intended performance potential. In the first step of project delivery for a typical new construction or BAS retrofit, a building owner issues a request for proposals (RFP) with little detail regarding SOO. Based on this RFP, a controls designer (engineer or contractor) develops the HVAC system design and writes the SOO. In the next step, a controls contractor interprets the SOO and develops the control logic within the BAS programming interface. Next, a commissioning provider reviews and tests the control logic. Throughout the lifetime of the building, the building engineer operates the building to maintain occupant comfort. At each of these steps, the design, installation, testing, and operation of BAS software is a custom, unique effort for each building and system vendor.

We have summarized the existing industry process for BAS software installation in Figure 1 and identified specific areas that are *high risk*, indicated by warning symbols. We define high risk as steps that consume a lot of time and cost, are often customized for each building and thus prone to errors, and often result in energy wastage due in large part to these being manual processes.

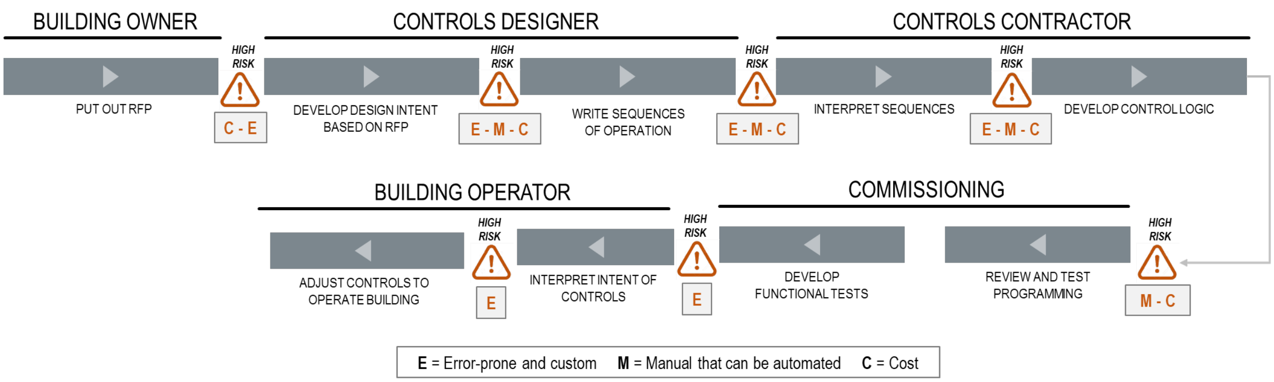

Figure 1. Business-as-Usual with high-risk steps indicated

The first high risk step is when the controls designer interprets the building owner's needs from an RFP and writes SOO in plain English. Most designers write high-level SOO that do not clearly define the control design intent, leaving the details to the controls contractor to define, which creates another high-risk step. Adding to that risk, contractors are commonly pressured to work quickly due to the competitive, price-driven industry, and the realities of being one of the last steps in the construction process before building occupancy (for a new construction case) or contract deliverable date (for a retrofit case). A commissioning provider develops and performs functional tests specific to the building controls, highlighting control logic programming errors for the contractor to fix, which could result in blame getting passed on from one party to another. Ultimately, after BAS project completion, the building operator is responsible for running the building to maintain occupant comfort.

Challenges with Varying Performance Outcomes

Partly as a result of the current industry workflow, BAS control logic installations are customized, ad-hoc, and frequently buggy, often leading to poor performance from the start, which only gets worse over time. Good SOO are complex, and it is unreasonable to expect the controls industry to cost-effectively implement this complexity one building at a time.

A study by the Pacific Northwest National Laboratory identified 14 HVAC controls measures they determined to be the most impactful in current energy codes. Field assessors scored the code compliance of these measures, resulting in an average score of less than 7 out of 10 across 24 buildings in seven states. (Rosenberg 2017). The results underscore that HVAC controls are complicated and that even meeting minimum code requirements prove to be a challenge to designers, controls contractors, and commissioning providers. Other studies have shown lost savings due to frequent errors in control logic programming (Ardehali 2003) and variations of more 60 percent in HVAC energy use due to choice control logic approach (Pang, et al. 2017).

An additional challenge with BAS control logic retrofits is savings persistence and assumptions for effective useful life. A study of 28 buildings in ComEd's RCx program concluded that around 60 percent of the energy savings remain three to six years after implementation (Gunasingh 2018). California has placed the effective useful life of RCx measures at three years, which limits programs ability to achieve cost effective energy savings programs (CPUC 2019).

Building operators are key to good building performance. It is common to find over time that operators have overridden automatic controls or changed setpoints from the design values in attempts to satisfy occupants. The use of and the need for overrides may be explained by a number of reasons: (1) real implementation issues due to *high-risk* steps in BAS delivery previously mentioned, incomplete BAS designs, designer error, or value engineering for contractors to be cost competitive, (2) lack of understanding of BAS design intent due to incomplete designs, poor training and communication, or lack of documentation, (3) lack of time to investigate root causes, (4) or past experience and operator preference for using manual overrides for older control systems rather than relying and trusting the automatic controls. Because operators are often able to maintain acceptable thermal comfort levels through these overrides, resulting energy performance degradation may go unnoticed unless operators proactively investigate trends and alarms.

Lack of Value Proposition Challenge and Partial Retrofit Challenge

While the expected lifetime of a BAS is 15 to 20 years according to ASHRAE (ASHRAE 2019), in practice, some existing BASs stay in place for 20 to 25 years and longer (ASHRAE 2020), with zone controllers often staying in place for longer than 25 years[1]. When BAS hardware upgrades occur, the scope is often limited to the central equipment controllers (air handlers, chillers, boilers, etc.), while older downstream zone controllers are left in place, including pneumatic zone controls, which are likely at least 25 years old.

Full BAS retrofits rarely occur because they are not highly valued, and there is perception among building owners, design engineers, and project developers that full BAS retrofits are not cost-effective based on energy savings. This perception is likely due to BAS industry workflow issues combined with varying performance outcomes, both described previously, that result in lost energy savings potential and highly varying energy savings outcomes. Therefore, full BAS retrofits usually only occur when existing controls systems reach the end of their useful life or when other need exists, such as making the building easier to manage.

The benefits of BAS retrofits are difficult to estimate upfront. Identifying measures and predicting savings through investigation is a costly effort that requires specialized expertise that varies across markets. There are few savings prediction tools due to energy modeling software's limited capability to model detailed control logic or control faults/errors, as well as the widely

[1] Observations of zone controller age is based on the authors' experience with hundreds of existing building audits.

varying capability of existing BAS hardware. Decision makers view payback calculations as highly risky. Lastly, although a BAS retrofit is likely to improve occupant comfort and reduce maintenance, this benefit is rarely quantified and almost never monetized.

These reasons tend to focus the industry on quick payback controls, software-only measures, such as occupancy scheduling, supply air temperature control, static pressure control, and outside air intake control. The limited capabilities of the existing BAS hardware often allow only rudimentary control of these variables, which limits the benefits and energy savings. There is a big gap in the current controls industry value proposition for full BAS retrofits.

Incentive Programs: Opportunities and Barriers with BAS Retrofits

Existing Incentive Program Opportunities for Full BAS Retrofits

Programs across the country offer incentives for HVAC controls upgrades with RCx programs and custom programs. Custom programs, as the name suggests, apply to customized measures that deemed channels cannot incentivize. Administrators typically limit RCx programs to control logic measures and require that full BAS retrofits involving significant hardware upgrades use custom programs. Program designs, including qualifications and incentives, vary slightly based on the utility, but they broadly offer incentives for any controls-related measures such as full BAS replacement, add-on controls capabilities, or RCx-type activities through their custom energy efficiency programs. These programs cover a broad spectrum of energy efficiency measures, and the programs estimate savings using custom engineering calculation tools. The Database of State Incentives for Renewable & Efficiency has additional information on the existing custom energy efficiency program offerings across the United States (DSIRE 2020).

We are aware of only one incentive program specifically designed for full BAS retrofits. The program, offered by Puget Sound Energy, offers incentives to implement a major HVAC controls upgrade, and it requires adding or modifying at least three significant energy savings SOO in addition to other upgrades such as new controllers (Puget Sound Energy 2020).

Existing Incentive Program Gaps and Barriers for Full BAS Retrofits and RCx

Utilities offer incentives for full BAS retrofits involving hardware through their custom program offerings. Custom programs cover a broad swath of energy efficiency measures, and administrators generalize program requirements to cover a diverse portfolio. This introduces unnecessary complexities into the incentive application process for full BAS retrofits. Following are barriers in program design that limits the opportunity to do a full BAS retrofit, based on the author’s 20 years of experience managing and reviewing custom programs.

a) For a full BAS retrofit, current program designs often treat these projects as end of life replacement and use existing building energy code (applicable state codes such as Title 24 or ASHRAE 90.1) to establish a program baseline. By only crediting energy savings achieved above the current code, and not above the existing building conditions, this dilutes the savings potential and incentives, which makes the projects financially unattractive to decision makers.
b) The programs currently use a calculated approach to estimate energy savings. The existing building simulation tools have limitations to accurately estimating energy savings for full BAS retrofits, and modeling assumptions related to building operation

tend to lean on the conservative side. Additionally, the calibration requirements for simulations on buildings, in which changes have occurred over time, present another challenge to this calculation approach.

c) The process by which program administrators perform technical review of projects is time intensive and requires significant commitment from the customer and the designer. This impacts project implementation schedules and disincentivizes the customer to leverage the programs.

RCx is typically a cost-effective solution to improve the performance of HVAC systems. However, the following are barriers in the current program design that makes it challenging to effectively implement RCx projects, based on the authors' long experience managing and reviewing RCx programs:

a) Typically, RCx involves implementation of improved control logic to improve system operation. The legacy controls infrastructure in the buildings limits the implementation of sophisticated control logic. Equipment replacements can trigger a different baseline such as California's Title-24 or ASHRAE Standard 90.1, which changes the financial components for the customer's decision makers.
b) Assumptions regarding persistence of energy savings from RCx measures has been a major issue impacting cost effectiveness of the programs.
c) Historically, utilities funded the cost of RCx investigation studies and were the main market driver for RCx projects. However, due to program cost effectiveness issues relating to persistence, recently, some programs have shifted the cost of investigation studies to the customer. This change has impacted customers' financial payback from RCx projects.
d) There have been efforts, especially in California, to develop simplified calculation tools for a limited set of typical RCx measures. The use of these tools have waxed and waned based on the current disposition of the California Public Utilities Commission, allowing or disallowing them to estimate savings. Even with basic calculation tools available, more sophisticated RCx measures require detailed Excel-based calculation tools or whole building simulation tools such as eQuest or OpenStudio, adding additional cost and complexity to the program without additional savings accuracy.
e) The overall review process can be burdensome to the project cycle. As stated earlier, an RCx study is targeting low-cost, quick payback measures. A three to nine-month span from identification to approval and implementation is not uncommon, which often exceeds the measures' simple payback. Convincing building owners after identification to delay making changes until the program administrators' notice to proceed presents a challenge for programs that have invested in the technical engineering study.
f) Majority of the legacy controls in buildings lack or have limited trending capabilities. Adding specific points is an additional cost borne by the customer either by adding communication points or labor setting up the trends. These impact the ability to accurately assess the baseline and functionality of the measures. External data logging adds program cost, is not comprehensive, and may be less accurate. The lack of good baseline data results in inaccurate estimate of savings potential.

BAS Modernization Approach: Leveraging ASHRAE Guideline 36

We propose a revolutionary new approach that bridges the gap between traditional RCx and custom programs to maximize potential energy savings with a *BAS Modernization*, including both hardware and software, leveraging GDL36. Many buildings suitable for RCx can achieve deeper savings through this *BAS Modernization* approach, while gaining additional non-energy benefits. This approach leverages standardized high-performance SOO from GDL36 to save energy, reduce transaction costs and risks, and improve occupant comfort. The replacement of central and zone HVAC equipment controllers with new BAS hardware capable of performing GDL36 also future proofs a building with modern controls infrastructure—compared to the common practice where only the front-end BAS is upgraded, leaving zone controllers with limited functionality including the extreme example where zone controller are still pneumatic.

GDL36 enables development of tools and processes that pave the way for market adoption and new program models. Current NYSERDA- and CEC-funded projects are actively facilitating technical and market innovation to support market adoption of GDL36, discussed in the next two sections.

Technical Innovation: Optimized, Standardized SOO

Today, GDL36 has optimized SOO for common, large commercial building HVAC systems, including VAV reheat and dual-duct systems, that save energy and improve occupant comfort over current industry practice. They are robust, produce less nuisance alarming, and require less facilities management intervention compared to current industry practice. They are documented, comprehensive, and vetted.

Where GDL36 is implemented, a facilities manager will see improved thermal comfort due to reduced zone overcooling. ASHRAE research showed that controls logic retrofits that incorporate Guideline 36 zone SOO reduced pre-existing summertime cold complaints by half (Paliaga 2019) (E. H. Arens 2015). The GDL36 SOO are robust, cover all operating conditions, and alleviate the need for operators to use overrides, making them easier to manage than current industry practice.

Modernizing BAS hardware to programmable BACnet controllers future proofs the system with a flexible and open platform that also enables other smart building software and systems, such as lighting controls, fault detection and diagnosis (FDD), energy management and information systems (EMIS), and internet of things solutions that leverage the BAS platform.

There is an opportunity to standardize and optimize the technical aspects of building controls beyond just SOO. These could be a part of GDL36 or an accompanying standard, and it could include hardware requirements, have a way to track revision control, include user interface requirements, and other features that would make this standardization more comprehensive.

Market Innovation: Streamlined Industry Workflow

We believe that today GDL36 can greatly improve current industry practice. When a building owner puts out an RFP, they can specify the use of GDL36. The risk involved in interpreting SOO from the designer is mitigated, because GDL36 has been studied and vetted by committee, so it is much clearer and less ambiguous. The level of effort decreases at all steps across the industry.

The promise of GDL36 is that the standardization of SOO will allow manufacturers to program and centrally test the control logic and then distribute to installers, thereby reducing cost and risk of errors inherent in the current practice. Designers can specify GDL36 rather than write their own SOO. Installers can draw from a library of GDL36 control logic rather than program their own logic. GDL36 can minimize functional testing, as the logic will be pre-tested at the factory. Likewise, uniformity will improve understanding of the control system design intent throughout the industry, including facility operators in particular, which will help ensure that the systems are operated effectively as designed.

The NYSERDA and CEC funded efforts are engaged with most of the large BAS manufacturers to support development of application libraries, and nine manufacturers have started the process. The NYSERDA project is supporting the development of a library that will be implemented at demonstration sites directly by the BAS manufacturer, with minimal programming effort by the BAS dealer. An aspirational intent for implementation is for BAS manufactures to pre-load the GDL36 control logic on the controllers before shipping, so that the BAS programming is effectively close to complete after hardware install. The NYSERDA project is investigating a *plug and play* approach to GDL36 delivery to small/medium commercial buildings, where GLD36 application libraries are configured with a drag-and-drop interface that is much easier to use than a typical BAS programming interface. This approach would enable cost effective *BAS Modernization* at many small and medium sizes business.

The CEC project is supporting the development of model specification language, application guides, and a retrofit project screening tool to streamline the process of controls system specification and BAS retrofit project delivery. The CEC project is also supporting the development of a GDL36 Performance Validation Method and Testbed, a GDL36 Energy Savings Calculator, and an FDD Specification Guide for GDL36, as described in a companion paper in these proceedings (Pritoni 2020).

In this process, there will be more automated workflows and significantly reduced risk. Therefore, beyond saving energy with optimized SOO, we will see substantial process improvements from incorporating GDL36.

Figure 2 shows the value proposition of GDL36 for various stakeholders. Facilities management, building owners, design engineers, controls contractors, controls manufacturers, and commissioning providers will secure cost savings, increased revenue, and improved occupant comfort. The building owner will see lower design and construction costs and improved thermal comfort, leading to fewer occupant complaints. Overall, design engineers, controls contractors, and commissioning providers will put in less effort to design, implement, and test systems, and they will see an increase in customer satisfaction. As a result, controls contractors and commissioning providers can expect an increase in market demand, which can have significant economic benefits such as new jobs. Despite the added value for stakeholders, there are likely to be adoption challenges from disruption to current business practices as stakeholders adapt to new workflows.

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

Figure 2. Industry Benefits to Leveraging GDL36

Cost and Savings Potential

The first costs and energy savings potential with *BAS Modernization* may vary considerably based on several important factors. Nevertheless, there are a few key data points that indicate significant, cost-effective, energy saving opportunities. When tied together with end-of-service life replacements, the incremental cost of the energy efficiency project may be reduced to nearly zero. In addition to the improved SOO, control retrofits provide a synergistic opportunity to address deferred maintenance and other measures that may deliver additional energy savings. A large study of hundreds of buildings found RCx resulted in 16 percent whole-building energy savings in existing buildings (Mills 2011).

An end-of-life replacement for an obsolete BAS in a large office building in California that utilized SOO similar to GDL36 resulted in measured savings of 15 percent of whole-building electricity and over 50 percent natural gas, with an overall simple payback of seven years (Taylor Engineering 2020). The authors are currently conducting a CEC research project where they have implemented BAS retrofits with GDL36 SOO in four buildings and GDL36 with existing BAS hardware in three buildings in California. NYSERDA is funding a similar demonstration in four buildings in New York State. The first completed *BAS Modernization* site shows savings of 22 percent of whole-building electricity, 40 percent of chilled water use, and 61 percent of heating hot water use, with an estimated simple payback of eight years. We anticipate that results from the additional sites will further corroborate the significant energy savings, while also showing a diversity of results that will help industry better understand the range in potential outcomes and the contributing factors. Two other existing building demonstrations implemented a portion of the zone SOO from GDL36 using the existing modern BAS and found HVAC savings of 10 – 30 percent (Kaam 2018) (E. H. Arens 2015). Simulation studies of similar control strategies show significant energy savings potential compared to conventional practice, which corroborate the scale of the field measured energy savings mentioned above (Wetter 2018) (Pang, et al. 2017).

The first costs of the two *BAS Modernization* field studies are within the range of costs that we have seen in the California market of $2.50 and $8 per square foot. Each of these early installations were implemented according to the status quo market delivery mechanism (control logic manually programmed and tested for each job). Transaction costs and contractor risk will reduce as industry migrates toward standardization around GDL36 with the logic pre-programmed and pre-tested by the manufacturers at the factory.

Outcomes of GDL36 and research and demonstration efforts are an established payback, reduced headache factor and risk, and a streamlined process. We envision this will all lead to a significant proportion of buildings seeing value in a *BAS Modernization*, rather than traditional RCx. This is an opportunity for the controls market, which has already shown its support for GDL36 standardization, and for incentive program design.

A New Incentive Program Model for *BAS Modernization*

Incentive Program Overview

The authors propose a new program model based on the market assessment described above—the BMP. The program bridges the gap between traditional RCx programs and custom incentive programs, while leveraging GDL36 to achieve maximum potential energy savings with a *BAS Modernization*, including upgraded control system hardware down to the zone level. The BMP builds on the opportunity provided by GLD36 and tools and resources being developed with CEC and NYSERDA funding, previously described in this paper. The table below shows a summary of the new program idea compared to today's business-as-usual approach:

Table 1. BMP Program Process Compared to Traditional RCx Programs

Program phase	Business as usual RCx program	BAS Modernization Program
Consumer acquisition (marketing)	• Multiple entry points into program	• Multiple entry points into program • Pre-approved control industry trade allies supported
Screening (segmentation)	• Customized initial evaluation, with results dependent on RCx provider's energy efficiency measure expertise	• Standardized initial evaluation tool that provides consistent results
Investigation	• Labor intensive evaluation • Customized calculations • Identified measures and savings estimates dependent on skill and experience of RCx provider	• Streamlined process • Standardized calculations tool that provides consistent results
Implementation	• Focused on SOO optimization familiar to RCx Provider with minimal hardware retrofits • Customized SOO • Labor intensive to implement and commission • Error prone	• Standardized preapproved industry accepted SOO • Hardware and control logic upgrade • Conducive to standardized commissioning and functional testing
Verification	• Targeted process that mirrors the custom investigation	• Streamlined process • Conducive to standardized verification procedure
Savings	• Trend data based calculations • Often IPMVP option A adherent	• NMEC • IPMVP option C adherent

To succeed in scaling up, BMP should include new BAS delivery approaches, tools, and processes to address previously described challenges and barriers. These tools could include a screening tool, a preliminary savings calculator, and best practices guide. The BMP administrator(s) should iterate these tools over time to identify, recruit, and commit successful

GDL36 retrofit projects. On the process side, BMP should leverage a trade ally model that works with existing BAS vendors and installers to acquire participants and implement the *BAS Modernization.* BMP can work with vendors to pre-program GDL36 SOO into preapproved control logic function blocks or with manufacturers to ship BAS controller hardware with pre-loaded GLD36 control logic to save time and money.

The authors propose a pay for performance (P4P) model for BMP, where incentives paid are based on actual energy savings measured through NMEC protocols. BMP project savings are large enough to enable accurate whole building NMEC, significantly reducing M&V effort through less metering and analysis. P4P also reduces the accuracy requirements for predicting savings during initial investigation and accommodates varying outcomes with an outcome-based incentive structure. The P4P approach requires the use of standardized calculations to estimate initial savings and then requires the building owner/operator or designated contractor to measure and verify the facility's energy consumption and savings over a period of a year or more. Incentives to program participants should be milestone-based, with the final true up portion of the incentive based on results of the NMEC approach.

Customer Acquisition

Participants traditionally gain entry into incentive programs through multiple points of access: account representatives, program providers, other parallel programs, and directly through the program administrations. BMP should also leverage existing control vendors and dealers as trade allies to recruit and implement the BMP measures, which engages the existing industry rather than side stepping it. Preference should be given to vendors using preapproved factory developed function blocks or pre-loaded control logic on controllers based on GDL36. GDL36 standardization and library development by vendors and dealers will enable the program administrator to pre-approve trade allies based on a review of their GDL36 control logic and function blocks. New vendors should be added as trade allies through a continuous enrollment process, after full vetting of their control logic library.

Screening: Segmentation

BMP should have a streamlined screening process to be used by engineers, building operators, and project developers. These users can collect their own screening data to avoid excessive program staff time conducting site audits. The goal of initial screening is to determine if a building is suitable for GDL36 and if a *BAS Modernization* is likely to be cost effective, with a minimal amount of data collection. Over time, the screening tool and standardized process should ensure consistent results across all users.

The screening process should define eligibility (building types, HVAC systems, existing control hardware, existing control logic, and minimum performance criteria), while also identifying existing building deficiencies. The three main steps of the screening process include:

- **Step 1:** Determine if the candidate building HVAC system is covered by GDL36.
- **Step 2:** Review a short list of building characteristics and existing BAS conditions that have the most impact on cost effectiveness (e.g. zone size, number of zones and air handling units, occupancy/load diversity, zone control type, zone minimum setpoints, and control logic for supply air temperature and static pressure setpoint control).

- **Step 3:** Evaluate feasibility using data from Step 2. The tool should include typical industry *BAS Modernization* costs and savings estimates using internal program benchmarks or the preliminary GDL36 savings calculator developed for the BMP.

BMP savings and incentives need to be combined with industry benchmark estimated project costs to determine if a project is a good candidate for the next step of the program. The screening tool currently in development as part of the research team's ongoing work includes cost estimates based on conditioned square footage. As part of program development, these rules-of-thumb should be refined to provide estimates based on normalized cost metrics, while also including adders for special features such as replacement of pneumatic zone controls.

As part of the screening, BMP should prioritize buildings with the highest energy savings and payback potential, which is largely influenced by the type of existing BAS hardware. The follow list of existing BAS hardware type is ranked in order of high to low opportunity:

- Pneumatic zone control (typically with newer BAS hardware for central equipment)
- Stand-alone electronic zones, or old zone controllers, that use a gateway to talk to central system (typically with newer BAS hardware for central equipment)
- Configurable (not programmable) zone controllers
- 10+ year old programmable zone controllers
- Newer programmable zone controllers may be a candidate, but a software-only upgrade (traditional RCx) is probably the best option.

NMEC Baseline

When program savings are calculated through a site specific NMEC approach (Granderson 2019), it is critical to establish an acceptable baseline before moving past the screening process. There are many NMEC tools and algorithms available, and the authors lean towards open source algorithms such as the time and temperature model used in the Lawrence Berkeley National Lab (LBNL) RM&V Reference Tool (LBNL 2020). Using the most recent 12 months of historical whole-building interval data, the BMP implementer should confirm acceptable modeling results match program defined "goodness of fit" requirements. Guidelines developed by LBNL (Granderson 2019) quantify goodness of fit, but the program requirements need to be versatile enough to capture a wide variety of buildings. We have found that buildings most in need of *BAS Modernization* can be those that have difficulty meeting goodness of fit requirements, since their systems do not respond consistently to typical independent variables.

With an NMEC approach, it is also important to define what constitutes non-routine events (NREs) at the onset of a project and identify procedures for NRE adjustments to NMEC calculations. NREs can be short term, long term, or permanent changes in building energy use that increase, decrease, or add variations to the load. Magnitude and duration of critical NRE parameters need be defined early in the process to maintain consistency and accountability.

Investigation and Incentive Payment Structure

A savings calculator can perform the heavy lifting of the BMP initial investigation, and a proof of concept tool is currently being developed with CEC support (Pritoni 2020). The tool will need further development and expanded capabilities to accommodate the demands of the program. Estimating RCx and custom BAS project savings is currently a manual and labor-intensive process. A standardized, robust, and well vetted *BAS Modernization* savings calculator will make it easier to determine whether the retrofit is likely to be cost-effective. The tool will be faster and require fewer inputs than existing customized processes, and it will be useful for quantifying initial discounted incentive values, with final incentive values dependent on actual measured energy savings.

The tool will have error bars due to the challenges associated with establishing accurate existing conditions in a large variety of building types, load profiles, and systems. Initially, the error bars may not be mathematically derivable, in which case the program should de-rate the savings predictions based on what is programmatically acceptable. As researchers and implementers collect data on the saving calculator's predictions verses actual savings, the error band of the model should be refined, leading to increased confidence in the estimates.

The estimated savings from the savings calculator can be discounted based on the error band determined during program setup, if the final savings are trued up in subsequent NMEC based incentive payments. The authors recommend an initial incentive payment at the completion of implementation and commissioning, followed by two phased NMEC payments, one several months later, and a final payment one year after completion. The total incentive value is adjusted (up or down) in the final payment, based on verified NMEC savings. This payment structure balances the desire to provide incentive payments as quickly as possible to customers who have likely financed the project and the need to safeguard rate payer funds with proof of actual savings. Phased NMEC incentive payments allow participants to tune the building and encourage persistence of savings. Training operators ensures that savings will persist well beyond the project's completion through effective interaction with the BAS control logic, rather than overriding automatic control.

Incentive rates and milestone payments need to be determined based on the realities of the program's location/market and economics. The program should provide additional incentives for *BAS Modernization* projects that add FDD or EMIS that help ensure savings persistence.

Implementation

BAS Modernization projects can benefit from a best practice guide for manufacturers, building owners, portfolio management companies, building operators, controls contractors, commissioning providers, and design engineering firms. The best practices guide should contain case studies showcasing successful implementations of GDL36, which detail the GDL36 design and implementation process, roles and responsibilities of stakeholders, challenges and lessons-learned, and performance results.

BMP implementors should also develop a building operator guide to teach operators, who may lack training, how to best operate a building. The operator guide should be specific to GDL36, which will help ensure savings persistence and maximize the incentive by prescriptively indicating how an operator should address occupant complaints and other issues that require interaction with the BAS.

Verification

After installation, a third-party commissioning provider or BMP staff should gather implementation cost data and validate that the site has implemented the controls retrofit according to GDL36. This validation will take less custom engineering review to analyze than current programs or RCx, since the specifications and control logic are standardized across all projects and have been pre-qualified as part of the trade ally process. Program verification can use a sampling approach to compare implemented control logic and function blocks against preapproved versions.

The standardization of GDL36 makes it so all projects should achieve the same implemented control logic, facilitating standardized commissioning, and functional test protocols. These pre-defined processes will reduce the verification time, effort, and cost compared to current practice. Note, ASHRAE will be adding functional test scripts to GDL36 in the future for all the SOO included in the guideline.

To assure savings are accumulating as expected, the program can monitor project savings every two to three months during a project's performance period and check for the occurrence of NREs. This savings persistence validation is a backstop to the functional testing and any implemented FDD because savings degradation will flag issues that might have not been caught during commissioning that can be fixed during the performance period. Any identified NREs need to be explored to determine their cause and remove their impacts from the final savings analysis. Based on our experience, participants are amicable to progress checks since they are a means to report energy savings successes to their management.

Conclusions

The *BAS Modernization* model presented in this paper outlines a new approach to maximizing energy savings from retrofitting BAS hardware and control logic by leveraging ASHRAE GDL36. The new model is being tested in current demonstration projects funded by the CEC and NYSERDA, with an eye towards market scalability. The new approach represents a potential breakthrough that, over time, will transform the HVAC BAS industry and promote better energy efficiency and occupant comfort by making BAS upgrades more cost effective for the customer, reducing the perceived risk of BAS upgrades, streamlining contractor interactions with standardized tools and SOOs, and optimizing the incentive program to meet the specific needs of the controls industry.

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