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Armando Casillas, Jessica Granderson, Yimin Chen, John House, Guanjing Lin, Weiping Huang, Guhan Velmurugan, and Marco Pritoni

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ABSTRACT

Nearly 30% of commercial building energy use is wasted due to equipment faults and HVAC controls problems. The result is increased emissions, compromised comfort and productivity, and less reliable coordination of building power needs with a clean grid. The energy impact alone represents $17 billion in potential savings. Today's smart building software provides a robust solution to address these operational deficiencies. Energy management and information systems (EMIS) are saving up to 9% on average, with two-year paybacks. They are being incorporated into energy management processes, commissioning services, and utility programs. As effective as they are, two barriers prevent even deeper benefits; limited personnel to fix problems once they are identified, and the expense and time to manually implement changes in control systems.

In partnership with the research community, the EMIS industry is developing new capabilities to overcome these barriers. Moving beyond siloed products for either fault detection and diagnostics, or optimal control, these new capabilities empower users to not only automatically identify faults, but also to push corrective action, and control improvements to their buildings.

In this paper, several areas for enhancements are documented: 'one-time' correction of faults such as setpoints, schedules, and economizer lockouts; short-term active testing for automated proportional integral derivative (PID) loop tuning and functional testing; and continuous supervisory control for demand flexibility and year-round efficiency. Results are presented from a pair of partner implementations out of a dozen providers integrating these enhancements into their products, including field tests from across the country, and insights into operator acceptance and integration into operations and maintenance practices.

Introduction

Building energy consumption accounts for 70% of the annual electricity consumption in the US, and as a result is a major source of greenhouse gas emissions, with nearly one-third of emissions being attributed to buildings (Satchwell et al, 2021). Technologies that enable increased energy efficiency in buildings, including fault detection and diagnostics (FDD) play an important role in decarbonizing our building sector. Recent studies have shown that the adoption of FDD in commercial buildings had yielded a median energy savings of 9% and an ROI of less than 2 years for adopters, while the adoption of energy management and information system (EMIS) platforms, in general, has also seen increased adoption in recent years for an additional 3% median savings (Kramer et al, 2020). Although the current state of adoption is encouraging, there still exists a wide gap between actualized savings and potential, with certain studies estimating much larger savings for the resolution of faults, such as incorrect scheduling. (Li & O'Neill, 2019). This is primarily due to the much lower percentage of faults that get resolved with current fault resolution workflows that require a technician to fix the issue physically or programmatically.

Automated fault correction has been demonstrated in controlled environments (Katipamula et al., 2003) (Brambley & Katipamula, 2005; Fernandez et al., 2009a, 2009b; Brambley et al., 2011) and more recently tested in commercial EMIS products (Lin et al., 2020) (Pritoni et al., 2022a). Although some mechanical faults require manual intervention by a technician, a subset of these faults can be automatically corrected (e.g., incorrectly programmed schedules, suboptimal control setpoints) by manipulating the BAS parameters. In this new workflow, faults detected by an FDD algorithm can be programmatically resolved with user review and approval or auto-approval. The correction command is sent to the BAS to change the values of specific control variables. Realizing automated fault correction in commercial EMIS tools provide building managers with the ability to resolve faults as soon as they are identified, increase the savings realized through EMIS adoption, and ensure standardized corrections to common faults (Pritoni et al., 2022b).

The strategies that have been developed by LBNL have different data requirements based on their use case. Some of the corrective strategies run as a one-time correction, and thus only need to pull data once a day or periodically. With the same access to BAS points, EMIS can also implement other strategies, such as optimizing setpoint resets according to best-practice in line with ASHRAE Guideline 36. These applications require a steady stream of data at regular intervals. In the case of Guideline 36, the recommendation is pulling intervals of 2 minutes, although some partners have been exploring implementing algorithms with 15-minute data. The spectrum in Figure 1 illustrates the range of corrective strategies and the degree of data requirements. This study will detail our general framework for engaging with industry, and provide two examples of partner engagement and results from the field for the implemented corrective strategies.

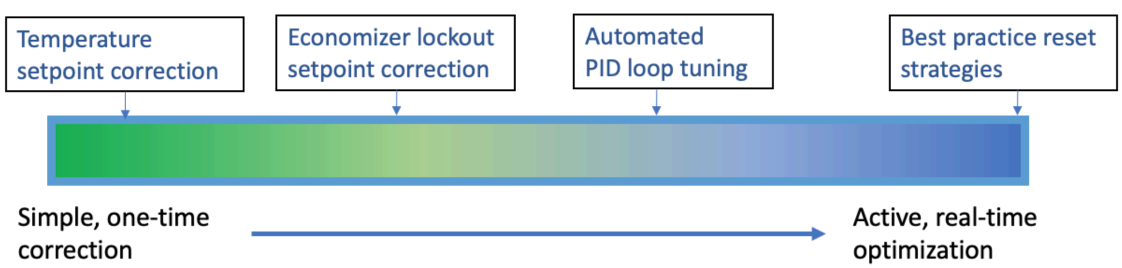

Figure 1. Spectrum of strategies offered in LBNL's growing library of corrective strategies

Methods

LBNL has published previous work detailing open specifications for corrective strategies (Lin et al., 2020). The open specifications serve as a guide for industry partners looking to implement these strategies. LBNL often engages actively with partners to help with their implementation. This usually involves demonstrating the fault detection at a site, confirming access to the appropriate BAS control points, and limited demonstration of the developed corrective capabilities.

When transferring specifications to partners, LBNL first meets with partners for an initial overview session and learns their development priorities and current FDD capabilities. LBNL then shares resources with the partner, providing guidance on implementation and staging of a test. The partner develops their corrective strategy from LBNL'S open specification, often adding proprietary features in fault detection, BAS integration, or control. In some cases, partners use existing EMIS software and may leverage LBNL's existing codebase. Finally, the partner designs and executes tests of the algorithm and collects building performance data based on LBNL guidance. Any data and findings from field partners can be used to publish further findings from the field, while also helping LBNL refine documentation of the open specification for future interested implementers. Figure 2 illustrates the complete process at a high level, showing the role of each party and illustrating how all partner data and findings are leveraged to further refine LBNL's resources.

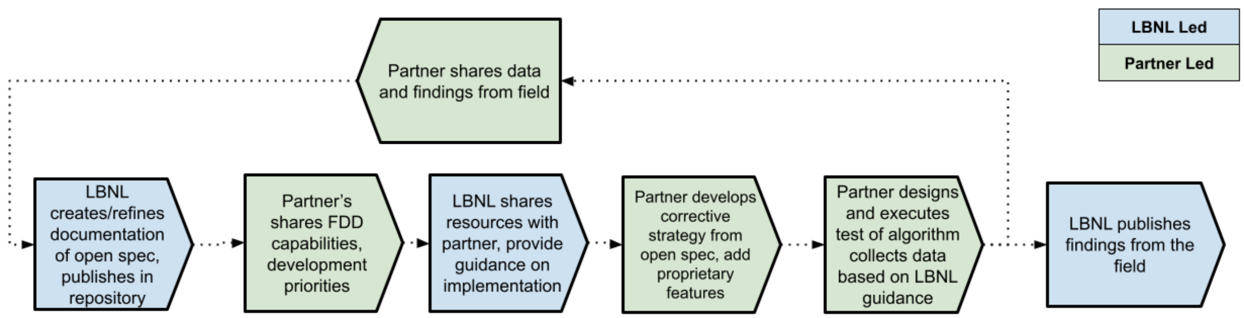

Figure 2. Partner engagement strategy for fault correction tech transfer

In this study, we summarize two instances of engagement with partners. Each case involves two separate strategies on opposite ends of the algorithm complexity spectrum shown in Figure 1. In both cases, one of LBNL's open specifications of corrective strategies was shared and integrated into a partner's existing suite of strategies. The first is an 875,000 sqft courthouse in Washington DC, in which a partner implemented both occupied and unoccupied zone setpoint correction through the SkySpark platform. The second case involves a 515,000 sqft office building in Toronto, Canada, in which a partner implemented Guideline 36 trim and respond logic for supply static pressure reset. In addition to presenting results of each implementation, we also characterize each case study's implementation and estimates of effort for each. Both sites are summarized in Table 1.

Table 1. Summary of case studies, building types and corrective strategies tested

Case Study	Site	Location	Strategy Tested	Size (sf)	BAS	FDD Software
1	Courthouse	Washington DC	Zone setpoint correction	875k	ALC	SkySpark
2	Office building	Toronto, Canada	Optimized G36 setpoint reset, rogue zone suppression	515k	Distech	Coppertree

Results

Case Study 1

The partner in case study 1 was interested in enforcing an institution-wide standard of occupied setpoints of 74F cooling, 70F heating, and unoccupied setpoints of 83F cooling and 55F heating (add in degree symbol). Multiple zones around the building are currently not adhering to this standard and thus leave much room for operational improvement. Zone temperature setpoint monitoring in fault detection and diagnosis (FDD) tools typically focuses on effective setpoints, which are the setpoints used in zone-level reheat and airflow controls, and which account for occupancy modes and occupant adjustments at the thermostat. These effective temperature setpoints and the related trending data will be integrated into and available in FDD tools for most standard FDD installations. Effective temperature setpoints can be used to detect scheduling issues and discrepancies with reference (or design) temperature setpoints, if those discrepancies are larger than the allowed occupant adjustments at the thermostat.

The strategy can be divided into two main parts, reading current values to detect setpoint misalignment, and writing back to the controller to correct a detected misalignment. These strategies were programmed within the SkySpark EMIS platform and transferred to the partner, who also leveraged SkySpark. Because of these commonalities, LBNL's codebase was easily transferred and implemented at the partner site. The first component involves detecting misalignment between the design setpoints and generalized inputs identified by the code we provided. These misalignments are displayed in an interface developed by LBNL in SkySpark. In this case, the effective setpoints are a function of occupancy mode, zone-level thermostatic adjustments, and the 4 generalized inputs: occupied, unoccupied, cooling, and heating. The EMIS manager was able to locate these generalized inputs as BACnet objects and integrate these into the misalignment detection interface. The same BACnet objects for the generalized inputs are natively writable and therefore are also used in the correction component. After an approval process in coordination with the site's operations and maintenance team, the EMIS manager was able to run a test to correct the setpoints of 6 zones. Half the zones had their occupied setpoints corrected and the remaining half had their unoccupied zone setpoints corrected. The screen capture displayed in Figure 3 shows the moment in which the occupied cooling and heating setpoints were changed from 76/72F to 74/70F. The setpoints were then returned to their original values per building staff's preference post test. Because of this, savings for this strategy were not quantifiable.

Given this partner's use of SkySpark, their process of integration was supported with LBNL's existing reference codebase for SkySpark functions. Additionally, the partner team had a zone controller programmed through Eikon from Automated Logic Control, which leveraged a previously internally developed translation from LBNL for setpoint correction. The total time to integrate these two strategies was estimated at 7 person-hours.

Figure 3: Trend output of setpoint correction in ALC in the courthouse field testing site

Case Study 2:

Case study 2 involved a partner that leveraged their supervisory controls infrastructure to implement ASHRAE Guideline 36 static pressure reset and rogue zone suppression strategies in a 515,236 sqft office building. In this case, the main component in the technology transfer was LBNL's open specification. The open specification for optimized reset strategies was previously put into practice on LBNL campus and involved implementing zone requests and trim and respond as specified in Guideline 36 as well as a rogue zone suppression sequence. Rogue zones are defined as zones with existing comfort or control issues that result in a high number of requests that drive the trim and respond sequence to operate under less-than-optimal conditions. The methods to identify rogue zones are well documented in the guideline while internally, LBNL has developed a list of existing fault rules that would flag a zone as rogue. The specification calls for a separate function that filters zones flagged as rogue and suppresses the requests from these zones. The result is an ability to detect problematic zones while also running a more efficient trim and respond sequence.

Figure 4 illustrates these strategies in effect at the test site. First, the implementation of zone requests allowed a trim and respond sequence, allowing the static pressure reset and fan speed reductions. Figure 4 shows a modulating static pressure setpoint in September (right) compared to the constant setpoint seen in March, before the deployment of the strategy (left, grayed-out section). The change to static pressure reset results in savings of 15%-30% in fan energy varying by season.

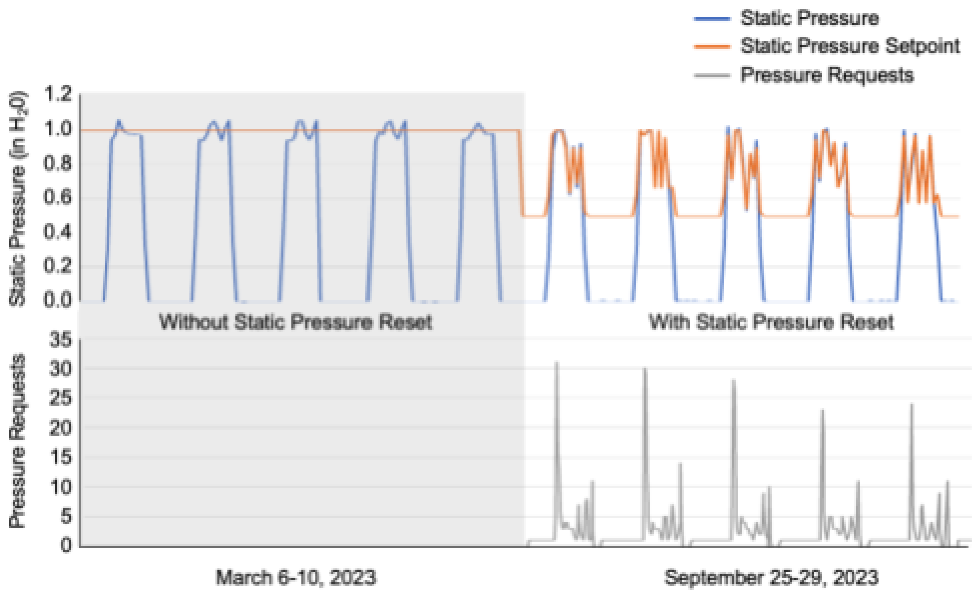

Figure 4: Static pressure control before and after deployment of static pressure reset. Setpoint reductions occur when two or fewer zones are issuing pressure requests.

To date, the partner's software in case study 2 has been used to deliver ASHRAE Guideline 36 algorithms for static pressure reset and rogue zone suppression and has plans to extend its use to plant-level reset strategies such as chilled and heating water differential pressure reset and chilled water temperature reset. This partner estimates that implementing this algorithm starting from the specification would typically take 16 to 32 person-hours depending on its complexity. The time needed for implementation is reduced by their ability to leverage their internal semantic models, which enables their algorithms to be "tag-driven" and streamlined.

Discussion

The two examples provided here are an apt representation of how LBNL's open specifications of corrective strategies are transferred to the industry and implemented through EMIS platforms. This type of control deployment provides a scalable way to add best-practice functionality without costly BAS re-programming or the struggles involved with the lack of processing and memory resources on the BAS themselves. This can be particularly attractive for portfolio energy managers, who are often responsible for maintaining a collection of BAS of different vintages from diverse manufacturers - all of which can be optimized quickly and cost-effectively with this new technology. Thus far, partners have delivered these capabilities alongside several building automation systems, including Delta Controls, Siemens, Distech Controls, and Automated Logic, demonstrating an important dimension of scalability. So far this technology has been transferred to a total of 42 buildings with more than 10 EMIS partners.

The two case studies presented here involved partners that either leveraged existing software capabilities and semantic modeling for streamlined configuration, or existing codebase from LBNL. This resulted in both partners spending 7-32 person hours, under a week of work, to implement these strategies into their respective software environments. Despite the accelerated success of both cases presented, some partners have encountered more elongated processes. Oftentimes, this class of partner is starting from scratch, taking LBNL's open specification, building out FDD capabilities, establishing write capabilities, and in absence of a development environment, need to seek permission from existing customers to perform limited tests to verify the strategies function as expected. This development path is more illuminating to our research efforts, as it is indicative of the process EMIS software companies need to undergo to shift their core capabilities from pure FDD, to enabling fault free optimal control in buildings.

The list of EMIS-induced control strategies will continue to grow, as LBNL currently is developing automated commissioning and demand flexibility strategies. The scalability of these corrective strategies will be further enhanced as we integrate semantic interoperability approaches, allowing solutions to automatically integrate exposed points and decrease the amount of time required to deploy these solutions. Furthermore, as LBNL's partner list grows, we will undoubtedly be approached by OEM's looking to provide cloud-based solutions that offer corrective strategies to existing customers. It will be important for us to continue to engage with building controls industry leaders to characterize the implications of this new approach. In order to ensure EMIS-based solutions have a path to scalability in the long term, future work for the LBNL team includes engaging with industry to develop minimum requirements for BACnet point exposure and semantic information.

Although the technical challenges our partners face is an important aspect of further developing and scaling EMIS-based controls solutions, there is a user acceptance component that is central to the success of this technology. During the tech transfer process for Case Study 1 for example, it was apparent that each stakeholder had differing views of the implications of EMIS-induced supervisory control. While the EMIS managers, tasked with implementing institutional standards across their managed building portfolio, welcomed these changes, the site operators, who were tasked with maintaining a functioning facility were apprehensive about external control. The ensuing conversations involved questions around BAS change logs and whether the EMIS control was recorded, and the level of priority these changes had. Our code base and documentation were well suited to reassure site staff. We also targeted zones that were not occupied at the time of testing to reduce the risk of unexpected effects of the EMIS correction. It is measures like these that are required to ensure that a building management staff, who traditionally interacts with a BAS to execute control, is comfortable with transitioning to resolving issues and continuously optimizing building performance through an EMIS tool. That is why, in addition to the implementation guide for facilities owners and managers available to interested parties (LBNL, 2023), further work LBNL is interested in involves developing resources specific to other key stakeholders, including EMIS providers so that they are more aware of best practices for building automation standard protocol, BACnet, as well as building operators and technicians so that they are more prepared to coexist with these new supervisory control capabilities.

Conclusion

The technical and user acceptance challenges presented here are crucial to document as we make the transition to EMIS-based supervisory control. In the face of a changing landscape in commercial building control and workforce, the buildings industry is primed for a new era of supervisory control through leaner software solutions, which allow building owners and operators to (1) leverage existing BAS infrastructure without the vendor lock-in issues from years past (2) while providing a new generation of facilities management professionals with tools that are more user-oriented and open-source. The work presented here provides two examples among many where LBNL has found success engaging with industry and further pushing the industry to realize the potential benefits these EMIS products can provide. The work LBNL is undertaking is key to facilitating this transition, not only providing comparable solutions compared to BAS control, but raising the bar of performance by combining controls with analytics, fault detection and optimization of energy consumption and demand flexibility.

Acknowledgements

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