A Flight Simulator for Buildings: New Interactive Tools to Train the Incumbent Workers and Next-Generation Facilities Engineers

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ABSTRACT

The increased importance and growing complexity of building automation systems (BAS) has created a severe workforce skills gap, exacerbated by limited hands-on training opportunities for new and incumbent building engineers. Methods for developing essential building controls and fault detection skills, which rely on on-the-job experience, are unreliable and largely absent. At the same time, bench test training setups have limitations in their ability to effectively train new building engineers and technicians because they are not connected to real buildings, preventing them from experiencing realistic building responses and data.

To provide a scalable controls training environment for instructors and students, we have developed and piloted a hands-on, simulation-based BAS training platform that can be used in classrooms and remote learning settings. Through the introduction of interactive simulations, which work like a “flight simulator”, into the instructional strategy, students can experiment with both conventional and advanced control strategies in a realistic environment. This hands-on, risk-free approach allows incumbent workers and students to develop familiarity with BAS tools and methods, practical troubleshooting skills, and a deeper understanding of building system dynamics without impacting real operations.

Our pilot test with incumbent building engineers and facility managers shows that simulation-based instruction enables effective, scalable online training for building controls, overcoming many limitations of traditional methods. We present best practices for implementation and outline a vision for further development of digital training platforms that can be applied by educators to teach building controls.

Introduction

Building Automation as a Foundation of High-Performance Buildings

Building automation systems (BAS) serve as the operational backbone of modern commercial and institutional buildings. Through the BAS, facility operators manage schedules, alarms, trend logs, setpoints, and supervisory control strategies that govern how HVAC systems respond to changing conditions such as weather, occupancy patterns, and internal loads. Despite these capabilities, a large share of buildings continue to experience control related issues that affect system performance (Crowe et al. 2023), often resulting in occupant discomfort and unnecessary energy use. As a result, effective use of BAS tools is critical for maintaining reliable operation, occupant comfort, and achieving energy-efficient and time-aware performance over the lifetime of a building.

At the same time, building control systems have become increasingly complex. Modern HVAC systems consist of multiple interacting components including cooling/heating equipment and water loops, air handling units, terminal devices, sensors, actuators, and supervisory controllers that operate according to control sequences embedded within the BAS. The dynamic interactions among these components can be difficult to interpret, and issues such as overridden setpoints, incorrect schedules, or poorly tuned control loops can propagate through the system and create persistent operational problems. In practice, many building performance issues arise from such controls related problems, which often appear through alarms or unexpected system responses (Crowe et al. 2023). As a result, the ability of building engineers and operators to effectively navigate BAS interfaces, interpret control sequences, and troubleshoot system behavior is key determinant of building performance. Skilled operators can identify abnormal conditions, resolve control conflicts, and maintain efficient system operation, while insufficient controls literacy often leads to persistent operational inefficiencies or reliance on external vendors to diagnose issues at a significant cost. Developing BAS competency within the building operations workforce is essential for reliable operations, effective technology integration, and enabling increasing connectivity between buildings, onsite energy resources, and the grid.

Training Gaps in Building Automation and Controls

Despite the central role of BAS in maintaining reliable building operation and energy performance, workforce training pathways for building automation and controls remain fragmented. Much of the learning in practice still occurs informally through on-the-job experience, where operators respond to immediate operational issues rather than systematically developing diagnostic skills. Real building systems are typically overly complex for the purpose of training staff who are new to BAS and control troubleshooting.

Participants in the pilot presented in this paper further identified practical barriers that limit workforce development, including staffing shortages, vendor lock-in, alarm overload, and limited access to hands-on training (discussed further in 'Pilot Outcome and Participant Feedback' section).

Traditional training methods used in vocational schools such as bench systems are effective for teaching wiring, sensor inputs, and basic control theory but typically do not replicate the dynamic interactions between HVAC equipment, building loads, and control logic that occur in real buildings. Similarly, classroom instruction can introduce concepts such as Sequences of Operation (SOO) or Proportional-Integral-Derivative (PID) control but lacks repeated hands-on practice using BAS interfaces to troubleshoot operational issues or observe system responses over time.

The broader training landscape reflects similar gaps. Public-sector educational resources, such as the Building Operators: Grid and Occupant (BOGO) curriculum introduce BAS literacy and uses emulator-based tool (Building Operations Emulator) to demonstrate building performance responses to control adjustments (DOE, 2021). While valuable for conceptual learning, these tools do not replicate full BAS head-end environments with alarm dashboards, trend logs, or point-level control actions needed for operational troubleshooting. Private training providers also offer BAS-focused education like Smart Buildings Academy (n.d.). However, they are primarily delivered as self-paced online courses at a significant cost and do not typically incorporate realistic lab environments where participants can interact with a simulated building system and observe dynamic responses to control changes. Another category of training consists of BAS vendor-provided education programs, which often provide technically rigorous instruction and hands-on experience with proprietary platforms, such as the Siemens Buildings Academy (Siemens n.d.) and Schneider Electric Ecoxpert Certifications (Schneider Electric n.d.). However, they are inherently vendor-specific, expensive, and typically focus on configuring and maintaining a particular manufacturer's system rather than developing vendor-neutral troubleshooting skills applicable across heterogeneous buildings.

Collectively, these programs contribute important pieces of the building controls education ecosystem but do not consistently provide scenario-based hands-on training environments where operators can practice diagnosing faults, interpreting alarms and trend data, and verifying performance improvements. This gap highlights the need for training approaches that combine realistic system behavior with hands-on interaction using BAS tools in a safe and repeatable learning environment.

DOE Workforce Training Project

The U.S. Department of Energy (DOE) recognized that a critical barrier to the adoption of advanced controls and grid-interactive technologies in the buildings sector is the wide gap between building automation and controls related skills in the existing workforce and targeted education for the pipeline workforce (Satchwell et al. 2021, 58). Therefore, DOE has been funding Lawrence Berkeley National Laboratory (LBNL) to develop BAS-focused workforce training in partnership with the Building Efficiency for a Sustainable Tomorrow (BEST) Center since 2023. The multi-year project started with creating a BASview3[1]-enabled BAS overlay to the controls and data acquisition systems of LBNL's FLEXLAB® facility to equip the testbed for workforce training purposes.

In 2024, LBNL and the BEST Center (hereinafter "LBNL-BEST") launched a training pilot leveraging the FLEXLAB testbed representative of small commercial buildings for hands-on training. The pilot consisted of three differentiated cohorts targeting incumbent building engineers, facility managers, and HVAC class instructors from community colleges and vocational programs. A similar range of topics from control basics, energy efficiency strategies, building system interactions, BAS troubleshooting fundamentals, to utility bills and demand flexibility were covered in all three cohorts, although the depth on each topic varied significantly as tailored to the different objectives, teaching format, and total instructional hours allocated for each cohort (see **Table 1**). Among the three cohorts, the *Building Engineers* cohort is the most extensive as far as topics covered and FLEXLAB-based lab exercises provided. The *College Instructors* cohort had similar rigor on lab exercises but less overview lectures due to the faculty's familiarity with these topics. The *Facilities Managers* cohort is lighter on hands-on practice and delivered remotely through web-based FLEXLAB access with the goal of creating the managers' awareness of BAS capabilities to support the use and investment of such technologies and training for their staff on these topics.

Considering that only several trainees that can be accommodated for troubleshooting activities at a time by a physical testbed with a single air handler, LBNL-BEST started to explore using virtual simulator to simultaneously support a greater number of trainees as a scale-up strategy. The Building Optimization Testing Framework (BOPTEST) tool was selected for this purpose considering its capabilities for creating detailed and realistic building HVAC operation scenarios based on Modelica[2] simulation (Blum et al. 2021). In addition to a web API, BOPTEST supports a BACnet interface feature that enables integration with existing BAS

[1] BASview3 is a stand-alone, embedded, web-based graphical interface for building automation and process automation systems. It can be accessed from any web browser — providing supervisory functionality to any BACnet/IP or Modbus TCP system. See https://www.ccontrols.com/pdf/ds/DS-BASVIEW3.pdf.

[2] https://modelica.org/language/

(Fierro et al. 2022). This combination of realistic modeling, web-based accessibility, and BAS integration positions BOPTEST as an optimal solution to be used as the basis for HVAC training and it was first piloted in a virtual training cohort for K-12 district facilities professionals in 2025 with success (see **Table 1**). More details of the pilot are found in 'Pilot Implementation and Observed Outcomes' section.

Table 1. Cohort Design in the LBNL-BEST Center 2024 and 2025 Pilots

	Building Engineers (2024)	**Facility Managers (2024)**	**College Instructors (2024)**	**K-12 Facility Professionals (2025)**
Format	Hybrid: remote + in-person (6-week)	Remote (4-week)	In-person (1-week)[1]	Remote (5-week)
Total Hours	64 hours	16 hours	38 hours[1]	25 hours
Lab Sessions	2 in-person lab sessions; 3 remote lab sessions	3 remote lab sessions	9 hours of lab sessions	4 remote lab sessions
Training Platform	FLEXLAB	FLEXLAB	FLEXLAB	BOPTEST simulator
Key Objective	Increased capability of using BAS for troubleshooting	Buy-in for staff training and technology adoption	Prepare faculty to include or enhance BAS training in their curriculum	Increased BAS fluency and basics for troubleshooting
Topical Focus	Control basics with plenty hands-on practices; energy cost awareness	Awareness of using BAS for troubleshooting, energy efficiency, grid interaction	Control basics with plenty hands-on practices; energy efficiency, grid interaction	BAS interface; control basics with hands-on exercises; efficiency awareness
Participants	18 completed (of 23 accepted). Primarily from CA due to ability to travel	21 completed (of 28 accepted). Nationwide; very diverse incl. K12 O&M staff	20 completed. Faculty from community colleges nationwide[1]	26 completed (of 31 accepted). School districts nationwide. Outreach via EHSP.

1- BEST Center provided subsidy for instruction time and travel cost for some out of state participants out of National Science Foundation's funds.

In 2025, LBNL-BEST also worked with two community colleges in New York and Texas to implement two enhanced courses – *Energy Literacy* and *BAS Fundamentals* – originally developed in 2024. These two colleges were selected from a mini-grant solicitation process managed and promoted by the BEST Center through its nationwide community college network. LBNL-BEST provided virtual and in-person technical assistance to the faculties at these colleges to review their existing curricula and syllabi to incorporate contents from the above two courses. BEST Center also trained them to assemble 12 sets of training board each with a BAS22 controller, inputs/outputs, and connected with software for BAS programming. These two colleges started teaching the updated courses with this content in spring of 2026.

Objectives

As introduced above, the constraint associated with physical testbed-based hands-on training motivated the development of a simulation-based, "flight simulator"–style BAS training approach that preserves realism and interactivity while enabling scalable, accessible workforce training. The remainder of this paper describes the concept and framework underpinning this approach, the workforce skill progression it supports, design and outcome of a first successful pilot, its programmatic implications, and future work. Key objectives of this paper include:

- Document a replicable realistic building simulation-based BAS training framework and system architecture, which has been validated through a successful pilot implementation in 2025.
- Explore a multi-level BAS skill development progressive structure, which guides the instructional use cases of this innovative training approach in alignment with the workforce needs.
- Project programmatic implications and discuss best practices to support broader deployment and long-term scale-up success.

Conceptual Framework: A "Flight Simulator" for Buildings

Much like how flight simulators allow pilots to practice emergency maneuvers and complex navigation in a controlled environment, the simulation training platform described in this paper provides a dynamic, high-fidelity digital twin where building operators can learn to manage building operations without risking equipment damage or occupant discomfort. **Figure 1** illustrates this conceptual framing and the analogy to flight simulator-based pilot training.

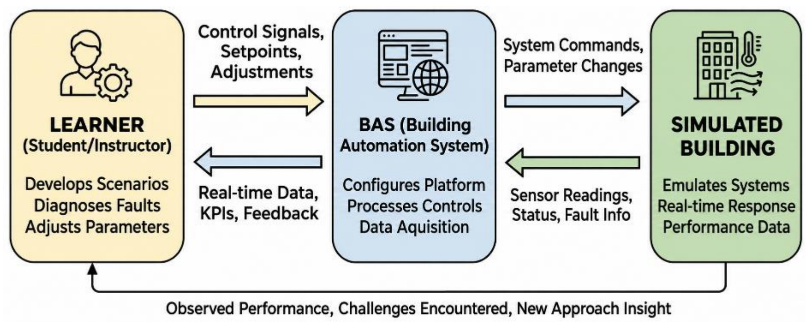

Figure 1: Conceptual Framework around "Flight Simulator"-based BAS Training

The teaching framework of the building flight simulator is built upon the pillars of experiential learning, deliberate practice, and safe failure. Rather than relying only on classroom learning, the platform centers the learner as an active participant in a cycle of concrete experience, reflective observation, and active experimentation. This experiential approach allows students to engage in the iterative process of troubleshooting, modifying controls, and observing the resulting effects on building systems. To enable deliberate practice, the flight simulator is designed to allow instructors to set up a wide variety of specific and reproducible scenarios, so that students can learn and practice specific skills. A critical innovation of this instructional model is safe failure. In a real building, the consequences of an incorrect control override or an unaware setpoint change can be significant and can lead to equipment damage, occupant discomfort, or unexpected energy cost. The simulator provides a sandbox environment where failure is not a liability but an educational tool.

The platform is designed to provide realistic system dynamics, direct interaction via industry-standard tools, and fault-rich scenarios to achieve these teaching goals. Unlike static bench trainers, which often lack the realistic simulation of building thermal dynamics and equipment behavior, the simulator leverages physics-based models to mimic the responses of HVAC systems. Furthermore, by enabling trainees to interact with the simulation through a standard BAS interface, the platform can help students develop fluency with the same tools that they will use in the field. Lastly, this environment allows instructors to set up diverse sets of faulted scenarios affecting both mechanical and controls systems, like stuck dampers, leaking valves, or untuned PID loops.

This approach occupies a distinct niche, providing advantages that physical bench systems and design-focused building energy modeling cannot offer. Conversely, design-phase focused building energy models don't typically allow real-time interaction, and may not have accurate simulation of the response dynamics of a building control system (Wetter, 2024). Some vendors utilize simulation tools for training on controls systems, but none address the scope of building controls challenges. Most major vendors have classroom programs for training and certification with their particular BAS. Students may be asked to develop and simulate control programs. However, the feedback loop of how the building would respond to these controls is missing. Honeywell offers an immersive field simulator, which includes how equipment would respond to operator interventions, but it is focused on heavy commercial infrastructure (Honeywell International Inc. n.d.).

Simulation-Based BAS Training Platform Architecture

The platform architecture is engineered to be modular, scalable, and vendor-agnostic, ensuring that it can be integrated into various educational and professional settings. The system consists of four primary, interconnected components as shown in **Figure 2**: the BAS user interface (vendor-agnostic), the BACnet/IP network interface, the BOPTEST simulation ecosystem, and a dedicated Scenario Manager. This multi-layered structure allows for a seamless flow of data where the simulation behaves like a physical building.

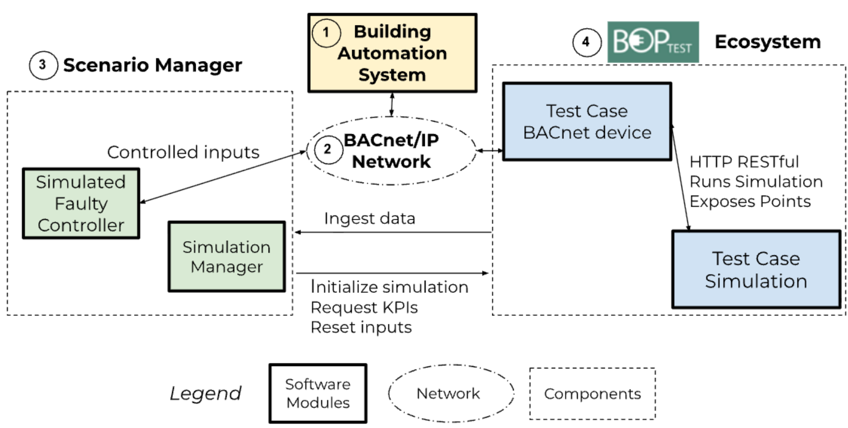

Figure 2: BOPTEST-based Training Platform Architecture (adapted from Paul et al. 2025)

The first component, the BAS interface, serves as the primary point of interaction for the learner. Because the platform utilizes the BACnet communication protocol standard, the industry's most prevalent language for building automation, it is compatible with nearly any commercial BAS head-end or data analytics software. For the purposes of this project, a Contemporary Controls BASview3 was used for a supervisory graphical interface.

Communication between the virtual building and the BAS is facilitated by a BACnet/IP network interface (BACnet Committee n.d.). This component acts as a translation layer, building a BACnet wrapper around the existing BOPTEST web API (IBPSA Project 1 n.d.). By creating a virtual BACnet device, this network interface allows all the data in the simulation to appear on the BAS interface as points of a physical controller on a local network. The wrapper translates data from the simulation, exposing it to the BAS, and implements commands written from BAS into the simulation inputs.

The underlying simulation environment is provided by BOPTEST, which includes multiple high-fidelity Modelica building models, called “test cases”. These test cases encompass the HVAC systems, the building envelope, embedded baseline controls, and other environmental factors such as weather, occupancy patterns, and internal heat gains. They allow simulation under specific weather conditions, such as peak heating or cooling scenarios. BOPTEST also provides standardized Key Performance Indicators (KPIs) that track energy consumption and thermal comfort. These metrics offer an objective baseline for evaluating controls performance. BOPTEST provides detailed documentation of each of the test cases and KPIs.

Finally, the Scenario Manager is where an instructor would set up the faults for students to address. First, it handles the setup of the BOPTEST test case, which includes the specific building, weather conditions, and the starting time for the simulation. The Scenario Manager also allows instructors to introduce specific mechanical or software faults, such as a stuck valve or an untuned PID controller. During instruction, the Manager allows the instructor to reset control inputs to their baseline states and request KPI reports, facilitating instructor and student review of the impact of diagnostic and corrective actions.

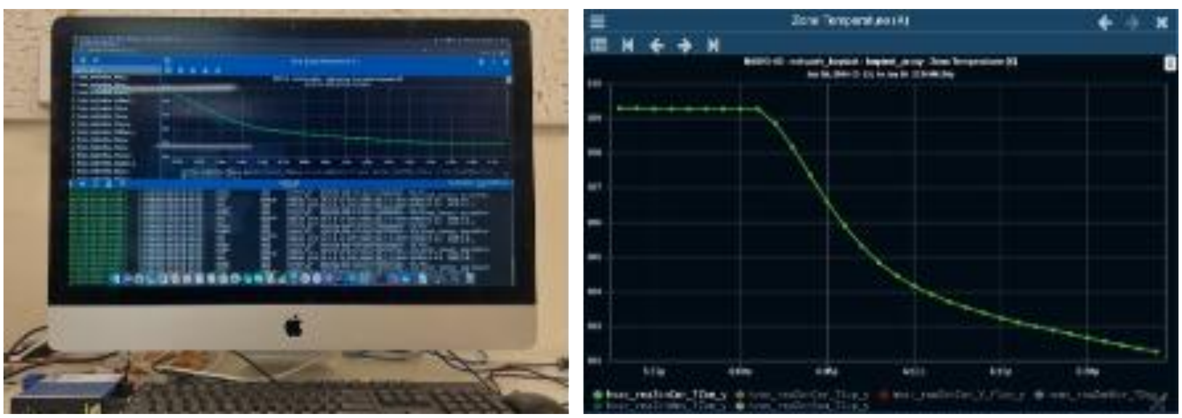

Figure 3: Image of case study. Left, BAS connected to a desktop running BOPTEST and BACnet network. The top window shows the BAS interface, the bottom window shows BOPTEST simulating a damper stuck fully open. Right, BAS trend showing the zone temperature rapidly cooling due to the stuck damper fault beginning at 6:00 pm.

Instructional Use Cases and Workforce Alignment

LBNL and BEST Center has been designing a workforce training curriculum using the recently developed BOPTEST simulation-based BAS training platform aligned with the progression of energy efficiency and grid-interactive building teaching objectives.

Instructional Use Cases Supporting Skill Progression

The skill progression around using BAS in building O&M can be divided into six levels as the following: 1. Operational fluency (interface-level competence), 2. Control logic literacy (understanding sequence of operations), 3. Diagnostic reasoning (identifying fault), 4. Energy performance awareness (identify and implement improvement strategies), 5. System level optimization (understand dynamic interactions across systems), and 6. Grid-interactive readiness. The training platform is suitable for supporting modular course design for building core competency at each level. Below we discuss example use cases of how using the platform can help students master the required key skills.

Level 1: Operational Fluency. The key skills taught at Level 1 include: navigating the BAS graphical user interface (GUI), list of points, and equipment hierarchies, understanding BACnet object types, configuring data trends and views, and managing schedules, overrides, and alarms. These skills enable O&M professionals to access operational information and understand system status, schedules, setpoints, and alarms. The BASview3 from Contemporary Controls is a supervisory graphical interface that is currently used in the training platform. It provides a realistic GUI that represents a similar underlying structure as multiple other BAS vendors' interface design and therefore well-support such training needs.

Level 2: Control Logic Literacy. The objective of the Level 2 learning is developing an ability to understand sequence of operations (SOOs) – i.e., reading and interpreting how the system is intended to operate. Required key skills include interpreting SOOs and control diagrams, understanding PI and PID loop fundamentals, identifying reset logics (supply air temperature, static pressure, etc.), understanding economizer operation and minimum ventilation needs, and distinguishing supervisory logic and local controller logic.

These knowledge and skills provide a solid understanding of what normal operations should look like and an ability to identify expected vs. unexpected behaviors based on cause-and-effect, which is essential for the next level of learning around diagnostics. An advantage of using the training platform vs a static BAS interface for these learning goals is that it allows the instructor to change parameters and let students observe the impact to enhance the learning of cause and effect. In addition, the platform allows the instructor to use simple examples from simulated prototype buildings to introduce and illustrate key concepts without any unnecessary complexity associated with real building systems.

Level 3: Diagnostic Reasoning. Level 3 focuses on restoring proper system operation and maintaining required services such as thermal comfort and ventilation. The skills that are required to bring a dysfunctional system back to work include structuring a troubleshooting workflow (symptom -> hypothesis -> test -> verify), recognizing common HVAC control faults and differentiating that from mechanical issues, using trend analysis to identify related issues at zone level and system level, and implementing and validating corrective actions.

Building upon the previous level of building control literacy skills, instructors can leverage the virtual simulation-based teaching platform as a safe "sandbox" for students to experiment with troubleshooting workflows by carrying out control modifications based on their hypothesis and learn from a trial-and-error process. Unlike teaching with real building systems, the platform provides a more friendly environment for instructors to develop troubleshooting exercises with progressively more difficulty levels. Instructors can insert targeted artificial faults that are purposely built for understanding common faults and certain types of system dynamics without tangling them with other problems. This is a significant advantage compared to using real building systems in teaching early troubleshooting skills because it can often be hard to isolate one issue from another due to the complex interactions across subsystems or multiple faults in real buildings (i.e., the "messiness" of real building systems).

Level 4: Energy Performance Awareness. Once the learner has mastered diagnosing and remedying functional issues, improving energy performance becomes the next level learning objective. Foundational skills needed for identifying, implementing, and validating common energy performance improvements include setting up energy performance KPIs tracking using trend data, understanding common energy wastes in HVAC systems such as simultaneous cooling and heating and over-ventilation due to economizer malfunctioning, and strategies for minimizing them, identifying energy saving opportunities, implementing and monitoring them, and balancing cost savings from energy efficiency gains with other objectives such as comfort and operational robustness. The training platform can support practices of improving energy performance in a similar way as it supports troubleshooting exercises mentioned in Level 3. The differences lie in problem discovery of inefficiencies vs failures and validating improved performance after improvement has been made as opposed to restoring basic functionalities.

Level 5: System Level Optimization. Building upon all previous levels of learning, students may be ready for the challenge of combined airside and waterside systems as often encountered in larger buildings and campuses. The learnings include understanding dynamic interactions across airside and waterside systems, tracing upstream and downstream impacts of a given fault or override, identifying control loop conflicts and evaluating stability across multiple loops, troubleshooting complex problems such as low delta-T syndrome and implementing sophisticated, highly efficient control strategies such as following ASHRAE Guideline 36. More hands-on practices on complex problems with sufficient time and room for experiments is of essence in developing the above skills. Real building systems that are suitable and accessible for training a group of students are generally hard to find. The training platform fills a critical gap not only providing a risk-free sandbox available to many students simultaneously but can also offer a variety of exercises to work on. It is also possible to have the students independently work on the exact same problems by creating multiple instances of the same simulation testcase and then let the students compare their solutions and outcomes.

Level 6: Resource Integration and Grid-interactive Readiness. Traditional BAS training has been primarily focused on HVAC systems although sometimes domestic water heating and lighting controls may be also tied into the BAS. Today, more building owners invest in onsite generation, stationary energy storage, and electric vehicle charging assets out of business, financial, and social responsibility objectives. Some also aim to leverage these assets to participate in local utility's demand response (DR) programs in addition to reducing building loads during DR events. It requires an even higher level of skills to maintain and troubleshoot the orchestrated controls of behind-the-meter (BTM) energy resources and building loads and automated response to utility grid signals. The controls fundamental knowledge, diagnostic reasoning skills, and system perspective taught in the previous levels provide a solid foundation to the learners in navigating this additional complexity. The current training platform is limited to the traditional building loads within the building envelope. However, the expandability to support Level 6 training needs will be explored in the future.

Workforce Alignment

This section outlines how simulation-based training can be tailored to meet the distinct needs of incumbent workers and pre-employment learners entering the building operations workforce.

Incumbent Worker Upskilling. For experienced building engineers and facility managers, the training should have more emphasis on contextualized learning that leads to addressing their skill gaps and immediate application of the training content at their jobs as well as strategic career growth. These learners often possess significant mechanical experience but limited if any formal controls training. Therefore, it may be useful to couple the simulation-based platform with knowledge gap targeted lectures, and to cover a wider range of common faults in various system types in hands-on troubleshooting exercises. Such training can help them strengthen BAS fluency and enable them to resolve more common problems in-house so as to reduce reliance on vendors, which can be costly. For organizations that focus more on energy cost savings and sophisticated energy management, the training should be tailored to help connect their daily operational decisions to measurable energy performance outcomes.

Logistically, another critical benefit of using the simulation-based training platform is that it allows the training to be delivered remote or hybrid formats, which accommodates incumbent workers who have traveling or scheduling constraints.

Pre-Employment and Community College Programs. For younger adults in higher education programs oriented towards trade careers, such as those offered by vocational schools and community colleges, it may be beneficial for training programs to offer a comprehensive foundational coverage (mechanical, electrical, controls, and basic IT/networking), broad application, industry-recognized credentials, and bridging any significant gaps for the targeted group of students.

For HVAC students, the platform provides exposure to modern BAS capabilities and troubleshooting workflows that are often absent from vocational curricula. By embedding platform enabled lab exercises into semester-long courses, instructors can systematically introduce control concepts alongside mechanical fundamentals. Students gain familiarity with industry-standard interfaces and troubleshooting processes before entering the workforce, narrowing the gap between classroom preparation and field expectations. Integration into HVAC programs in community colleges also supports stackable credentials. Introductory modules can be incorporated into HVAC fundamentals courses, while advanced modules support specialized certificates in building controls.

To support advanced career preparation beyond the traditional HVAC technician career path, topics of energy efficiency, system optimization, onsite energy resources, and grid interactivity, all of which rely on fundamental and intermediate BAS skills, should be incorporated as part of the comprehensive foundational coverage.

Pilot Implementation and Observed Outcomes

In spring 2025, LBNL and BEST Center developed a virtual training cohort targeting K-12 school district facilities professionals nationwide. The facilities department of school districts are often under resourced in managing a wide range of issues that come up in a large number of buildings across sites while staff are often under-equipped with control knowledge and skills. In collaboration with the DOE's Efficient and Heathy Schools Program, 31 registered participants were recruited from school districts geographically ranging from Florida to Alaska, representing both building-level operations staff and district-level management. Twenty-six of the registered participants completed the training. Examples of cohort participants' professional background include HVAC technicians, BAS operators, energy managers, energy specialists, facilities directors, and district sustainability managers.

Pilot Design and Curriculum Integration

The pilot was positioned as a fundamental course to teach facility professionals how to use BAS to achieve energy efficiency objectives, which involved teaching how to navigate the BAS interface, the most common efficiency strategies, and simple troubleshooting. It used the format of a five-week workshop series (25 hours total) with a five-hour workshop session on the Friday of each week tailored to facilities staff's work schedule considering time zone differences. The workshop series combined lecture-based instructions with hands-on exercises. The lecture-based portions of the curriculum used for this pilot was built upon those developed for the 2024 *Building Engineers* and *Facilities Managers* training cohorts. The lab-based, virtual hands-on exercises portions of the pilot curriculum was developed in early 2025 around the newly developed virtual training platform by integrating BASview3 with BOPTEST simulation to enable educational instructions around BAS fundamentals and energy efficiency for the first time. Therefore, this pilot was an important innovation in building controls workforce training.

The first workshop in the pilot was an extensive overview session which covered a wide range of topics including energy efficiency principles, electrical theory, building controls basics, mechanical system architecture, control system architecture, and an orientation around the BOPTEST simulation-based training platform. The following four workshops each consists of three hours of instructions and two hours of lab activities covering main topics as the following:

- Workshop 2: Sequence of operations and overrides including energy impact; lab activity involved identifying and removing overrides
- Workshop 3: Schedules, overrides on schedules and alarms; lab activity of optimizing schedules and configurating alarms
- Workshop 4: Reset schedules and impact of overrides; lab activity involved enabling reset schedules
- Workshop 5: Energy data collection, review, and KPIs; lab activity included trend data collection and pre- and post- energy consumption comparison

Targeted Skills and Lab Exercises

This first-of-its-kind pilot addressed learning objectives across Level 1 through 4 of the skill progression outlined in the sections above. Given the limited instructional hours (25 hours), the use cases in the pilot were mostly focusing on Level 1 skills while the coverage on Level 2 to 4 was of limited depth. Below are two examples of lab exercise used in the pilot that were designed to build initial competency around troubleshooting reasoning and understanding energy performance consequences.

The BOPTEST test case chosen for the pilot was a simulation model of a prototype, single-floor small office building located in Chicago weather with a five-zone variable air volume (VAV) HVAC system. In one troubleshooting lab exercise, the participants were presented with a pre-configured fault triggering an active zone temperature alarm in the virtual multi-zone VAV building. They were tasked with identifying the underlying fault using only the tools typically available in a BAS interface: floor plan graphics, alarm logs, operating modes, setpoints, and historical trend data. Participants examined temperature and airflow trends, reviewed schedule interactions, and assessed control behavior in real time. Through guided analysis and discussions, they determined that the alarm was not caused by equipment failure but rather by a manual override of setpoint that disrupted the intended sequence of operation. This exercise helped the participants build alarm triage skills, reinforce understanding of schedules and overrides, and strengthen the ability to distinguish root causes from symptoms.

Another example of lab exercises was aimed at closing a learning loop by linking an implemented operational change (i.e., resolving an alarm) to the evidence of consequential energy performance improvement. After correcting the override, participants accessed the BAS interface to download historical trend data—specifically total building power log—over defined time periods. The emphasis was on learning how to locate, export, and preserve relevant operational data from a BAS head-end. By retrieving and reviewing trend data before and after the intervention, they were able to observe changes in building energy consumption. This exercise achieved the goal of connecting alarm-based troubleshooting to measurable system energy performance improvement, and therefore, reinforced the relationship between control actions and energy outcomes.

Pilot Outcome and Participant Feedback

At the beginning of the training, the instructor and facilitators also encouraged pilot participants to share their experience in using BAS and troubleshooting. The cohort represented a diverse range of technical backgrounds and system experience. Common challenges reported across school districts included staffing shortages, vendor lock-in, alarm overload, and limited access to meaningful hands-on training. Many participants described operating in a reactive "firefighting" mode, with insufficient time or training to conduct structured troubleshooting.

One of the key objectives of the pilot was to help participants build operational fluency around navigating the BAS user interface by understanding a commonly used structure in BAS GUI design. Participants' learning outcomes were collected using post-pilot feedback forms consisting of questions regarding knowledge gains and successes and future improvements suggestions for the BOPTEST simulation. Based on the feedback, the new virtual training platform was viewed as a valuable and accessible learning tool by the participants. They highlighted the clean interface and user-friendly design of the BASview3 environment and appreciated that the platform created an "even playing field" regardless of which BAS vendor they use at work because it is somewhat representative of the interface design used by multiple major BAS vendors. Pilot participants demonstrated noticeable growth in navigating the BAS interface over the course of the training sessions through multiple lab exercises.

The simulator environment also reduced hesitation around troubleshooting activities for the participants, as in real buildings, operators and technicians may be reluctant to change setpoints or disable overrides due to concerns about occupant complaints or unintended system impacts. With the virtual platform, participants were able to remove overrides or adjust control parameters and immediately observe the resulted system response through updated trends and alarms without impacting a real occupied space. Such a risk-free training environment encouraged more experimenting with structured diagnostic workflows, moving from symptom observation to hypothesis formation, testing, and verification. Facilitators observed that participants became more systematic in approaching alarm evaluation and more deliberate in distinguishing between control-related issues and potential mechanical faults, which allows them to step away from defaulting to vendor intervention.

Participant feedback supported these observations and consistently emphasized three themes: realism, safety, and transferability. The simulated dynamic building response to troubleshooting actions was realistic enough to be engaging, and the absence of operational risk while building confidence was repeatedly cited as a major benefit. Participants described the ability to “try things out” without fear of disrupting occupants or impacting real assets as a rare opportunity in their daily jobs and existing training programs. Several also highlighted the value of practicing alarm triage and override management within a controlled environment, which are common challenges in their districts. One senior participant remarked that such training would have been invaluable earlier in their career, reflecting a broader sentiment from the cohort that workforce training on building controls has historically lacked hands-on learning opportunities.

Facilitators also solicited constructive feedback and suggestions for future improvements. Participants’ ideas included requests for additional alarm scenarios and more guided assignments for beginners. They also expressed interest in adding features such as an undo or reset function and a history log of user actions in the platform. These suggestions underscore the importance of iterative development of the simulation-based training platform and the need to balance realism with instructional scaffolding.

Programmatic Implications and Best Practices

Using BASview3 and BOPTEST simulation-enabled platform for BAS interface and control troubleshooting training is an innovative and compelling approach to building controls workforce development because it:

1) Provides learners with access to a risk-free environment to practice control techniques and strategies without impacting real building systems and occupants;
2) Enables learners to create alternative control strategies and isolated interventions, and to compare upstream and downstream impact to gain a deep understanding of component interactions and system dynamics;
3) Offers a suitable environment for instructors to customize targeted hands-on exercises in modular forms appropriate for the students’ learning level and goals;
4) Enables remote and hybrid teaching format which can reach a much larger base of potential learners considering their time and resource constraints;
5) Bares much lower incremental cost for adoption and scaling once the platform, test cases, faults, and exercises have been created.

Programmatic Implications

The implications of this work extend beyond individual classroom instruction to utilities, labor organizations, and workforce development boards concerned with supporting building performance. Reliable building services and persistent energy savings from efficient control strategies both depend on building operator’s competency. Even well-designed high-performance sequences will not uphold if facility staff lack the skills to understand its intent, diagnose faults, interpret data, and validate system behavior. By building structured BAS competency—from operational fluency through system-level optimization—the simulation-based platform directly supports efficient alarm management, durable retro-commissioning savings, and effective day-to-day operational decision-making.

The platform also carries potential in modernizing traditional trade training models by enabling repeatable, scenario-based practice that is difficult to achieve in occupied buildings. Because it can be deployed remotely and replicated with relatively low incremental cost once developed, it expands access to consistent, hands-on controls training without requiring dedicated physical assets. Embedding structured simulation exercises within workforce programs helps institutionalize BAS literacy as a core competency rather than an informal, experience-based skill acquired only through years in the field.

Instructor Role and Facilitation Best Practices

As discussed in the background section, the workforce gap in building controls skills is pervasive and the need for such training with effective hands-on learning features is immediate and nationwide. Therefore, LBNL and BEST Center have been focusing on a “train the trainers” model in developing the training platform and designing the surrounding course materials. As discussed in Pilot section, this new teaching approach is suitable for both incumbent workers in the building O&M industry and the future workforce in vocational schools and community colleges. Therefore, the instructor bares an important role in aligning the teaching modules to the educational objectives at hand and tailoring the classroom exercises to meet where the students are.

From a pedagogical standpoint, the instructor shifts from lecturer to facilitator. Consistent with the structured workflow used in the pilot above, the instructor plays a central role in selecting appropriate test cases, configuring exercise scenarios, and guiding workflow and reflective discussions. During classroom exercises, learners should drive the investigation while instructors can guide them by prompting analytical reasoning questions (e.g., “How does this change affect upstream system parameters?”). In reflecting an exercise, instructors can use KPIs to anchor discussion around energy cost, comfort, and system stability trade-offs.

Best Practices for Adoption and Scaling

Successful adoption requires intentional curriculum integration and instructor preparation. The platform should be embedded within a structured, competency-based learning sequence. Instructors will benefit from modular scenario templates, mapped learning objectives, recommended troubleshooting workflows, and reflection prompts linked to energy and comfort outcomes. A “train-the-trainer” approach will equip instructors with technical capabilities and help them shift from giving lecture-based instruction to facilitating analytical reasoning and validation. To support broader uptake, programs should develop and maintain a shared library of progressively complex fault scenarios, standardized KPIs, and implementation guides tailored to incumbent workers vs. pre-employment students, along with clear IT setup guidance. Over time, communities of practice among instructors can accelerate scenario development, enhance curriculum design robustness, and keep training aligned with evolving workforce market demand and industry standards.

Conclusions and Future Work

This paper presents the development, implementation, and outcomes of a simulation-based "flight simulator" approach to building automation and controls workforce training. By integrating the BOPTEST physics-based simulation environment with a commercial BAS supervisory interface (BASview3), LBNL and the BEST Center have demonstrated a scalable, risk-free training platform that provides realistic, interactive learning experiences without impacting real building systems or occupants. The pilot conducted in spring 2025 with K-12 school district facilities professionals nationwide validated the platform's ability to deliver hands-on BAS training in a fully virtual format. Participants demonstrated noticeable growth in navigating BAS interfaces, interpreting alarms and trend data, and connecting control actions to energy outcomes. Participant feedback consistently emphasized three themes: realism, safety, and transferability—all of which are difficult to achieve with conventional training approaches.

The results confirm that simulation-based instruction addresses longstanding gaps in building controls education, enabling repeatable, scenario-based practice and progressive skill development while remaining deployable remotely at low incremental cost. These characteristics position it as a compelling complement—or in some contexts, an alternative—to physical bench trainers for developing BAS competency at scale. The platform was also well-received across a diverse range of technical backgrounds, affirming its suitability for both incumbent workers and early-career trainees across multiple workforce pathways.

Several directions for future work are planned. The simulation test case library will be expanded to include additional HVAC system types and fault scenarios of increasing complexity, supporting skill development through Level 5 (system-level optimization) and eventually Level 6 (grid-interactive readiness), including behind-the-meter energy resources and demand response. On the instructional side, future work will focus on building out a shared library of progressively complex fault scenarios, standardized KPIs, and instructor facilitation guides, as well as formalizing a "train-the-trainer" pathway to support broader adoption by community colleges, vocational programs, and workforce development organizations nationwide. Platform usability improvements—including user action history logs and exercise reset functions as requested by pilot participants—will also be incorporated in future iterations.

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Generative AI tools used: ChatGPT, Gemini

Purpose: AI assistance was used to perform light editing for clarity and coherence, support copy editing prior to final review, and conduct preliminary landscape exploration of available BAS-related training programs to inform Introduction section. Additionally, generative AI was used to visualize the conceptual framework of the 'Flight Simulator' (Figure 1).

Extent: Drafting brief descriptive text segments and project summaries; preliminary identification and synthesis of BAS-related training programs for contextual background; generating diagrams to visualize author-developed materials; informing use cases; light editing and copy editing for clarity and readability.

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