Crossing the Great Divide: Training Building Operators for Digital Monitoring and Control

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ABSTRACT

New York State funded commercial retro-commissioning and multifamily weatherization activities strongly suggest the need of building operators for greater sophistication with digital monitoring and control concepts, equipment, and procedures. A logical model is shown connecting building performance and operator capabilities in terms of persistence of savings, control tuning, skills with data acquisition, trending and visualization, and acceptance of demand-response functions. Training solutions are suggested as a necessary enhancement to programs and program design for market transformation. Two example programs are described: the Training Center of the Local 94 International Union of Operating Engineers and the Multifamily Energy Management Training Center of the Association for Energy Affordability. In both cases steps are being taken through a new Building Performance Lab at the City University of New York, to build upon existing training to create new curriculum specifically bridging between physical equipment operations and digital representations of the same operations.

Introduction

The "digital divide" is a term generally used to describe the gap between the computer-using population of the developed world and those without computer and internet access in the developing world. In this paper we will consider a version closer to home, one that confronts the working technical class that operates our buildings.

Practical people – mechanics, maintenance workers, tradesmen – live in a world of sights, sounds, smells and sensations associated with the complex machinery of our built-environment, some of which comes from instrumentation but much of which directly reflects equipment operations. These sensory impressions can be quite well defined, highly indicative and finely discriminating. They are a classic case of what has been described as "experiential knowledge" that characterizes expert knowledge in a domain that requires actions (Norman 1993). Re-engineering of building operations that reduces mechanics' regular field exposure risks losing touch with equipment conditions.

Digitalization has penetrated practical work at varying paces in different industries and trades. Machinists routinely program numerically controlled (NC) tools in factories. As drivers we still listen to the symptomatic sounds of our cars, but mechanics must investigate engine problems via computer. Perhaps our buildings lag behind the automotive industry (Capehart 2005) but more and more components integrate electronic chips even if still often remaining as local, equipment-embedded controllers, not tied to a central Building Automation System (BAS). Fire and life-safety systems for large buildings have automated networking to outside emergency responders. Building operators are accustomed to these devices and the chief engineer's office of almost all large commercial buildings today sports a master computer station.

The digital divide here is not about the presence of digital components but rather about information utilization. For our building operators, by and large, digitally captured data has not assumed the status of sensory data. Analog gauge readings are recorded on log sheets for periodic scanning and human memory is applied from day to day in processing and comparing observations. Operators know how to talk to each other about what they see, hear and smell in their buildings. The digital record can be at least equally rich and telling but it is not yet processed and utilized to the same degree by our buildings' human operators. This is the divide we suggest needs crossing.

Market Transformation

The need to cross this divide is created by increasing demands for building performance, which can be defined narrowly in the sense of energy but also expands to a much broader set of concerns. Environmental ideology, energy prices, and even security concerns are all aligned as "push factors." While perhaps not quite at a tipping point, green concepts have been making an impact and gradually transforming market demands upon new buildings. Designs for high performance place new demands on operating personnel. With an increasing adoption of high-performance, green elements for LEED certification, the issue facing the market is shifting to whether building operators are properly prepared to understand and operate buildings as intended.

As the market transforms, the advanced systems (a) by design may not carry all the building's loads, (b) may not yet be perceived as fully reliable and (c) can't be allowed to take a "black eye" from failure. So they are backed-up by conventional systems that will automatically maintain building services. Thus, if something goes wrong with the power output from a photovoltaic array or almost equally quiet fuel cell, grid electricity will make up the difference *without any visible impact on building services*. Conventional monitoring that relies on sensory experience, analog observation, and feedback from the served environment (ie- complaints) -- is not sufficient.

This is equally true for many of the energy system retrofits and upgrades favored by energy efficiency programs. Real estate industry surveys consistently show that thermal discomfort is the predominant complaint in office buildings. Operation to minimize tenant complaint has been the norm and a central criteria for performance. But increasingly our high performance systems operate invisibly, that is without the normal kinds of sensory feedback that indicate performance problems. The following list provides a sampling of advanced sub-systems or components whose failure or by-pass does not result in any diminution of building services:

- Variable Speed Drives
- Daylight Dimming
- Economizers
- Outside air controls
- Optimized start-up & shut-down
- Equipment capacity controls
- Heat Recovery
- On-site electrical generation
- BAS functions in manual by-pass

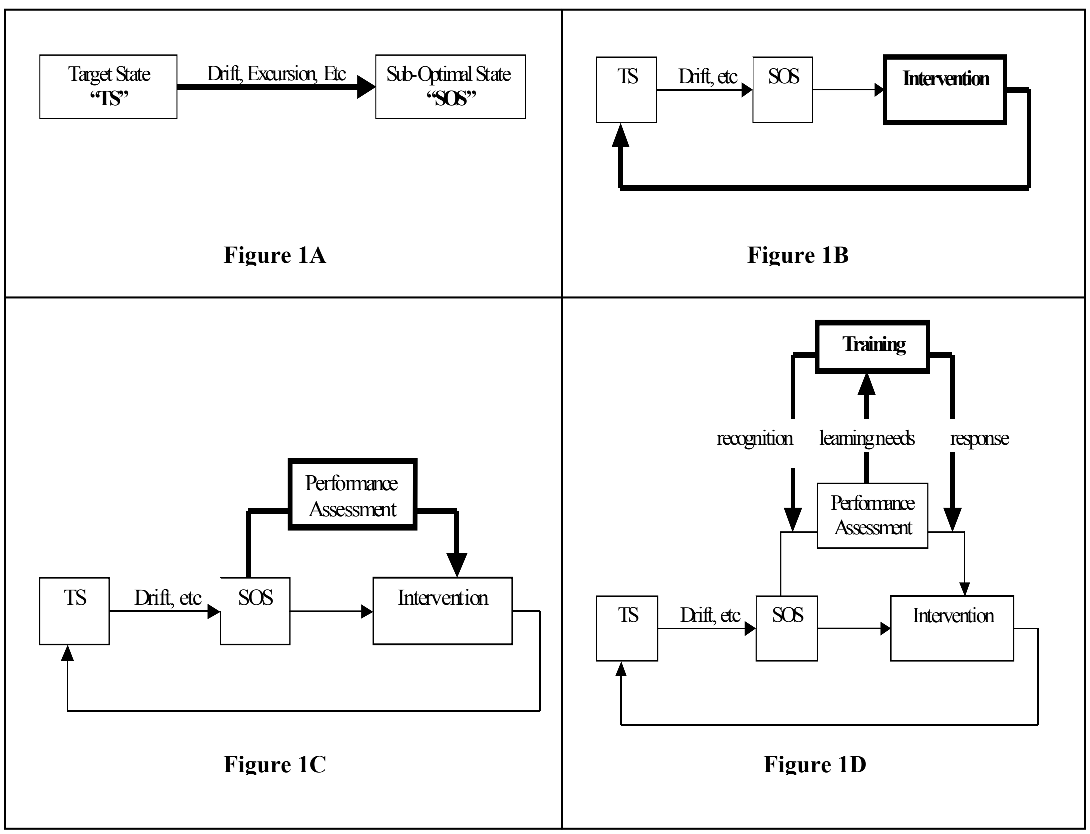
Realization that under-performance is chronic and can easily pass unobserved without specialized monitoring techniques and that, therefore, systems often can dramatically improve performance with just operational improvement, has led to development of existing building commissioning programs. In so far as these programs have adopted an engineering model of "identifying and correcting deficiencies" they fall short on a necessary aspect of market transformation: getting operating staff to incorporate monitoring and verification (M&V) approaches to building performance into their normal and standard practice. A logic model of building performance and program designs can help clarify the need to address on-going operational practices.

"Seeing" Building Performance, a Logic Model

System performance deteriorates for a variety of reasons. We know that sensors and controls drift out of calibration for physical reasons as well as for behavioral ones, as they are reset or over-ridden. Valve or damper actuators fail. Belts loosen. Leaks occur. Schedules change. We can think of these all as causes of "performance drift or excursion" from a target state to a sub-optimal state. See Figure 1A. The sub-optimal state or "SOS" can be a "cry for help", if only there are ears educated to hear it.

Maintaining performance (in related contexts also called "persistence of benefits") can be seen to have a central behavioral dimension, as added in Figure 1B. Variance from intended or best practice operation or a degradation of performance is recognized through a testing or monitoring activity and a corrective response is initiated.

Figure 1. Logic Model Schematics for Building Performance



Performance, then, depends on some form of regular maintenance awareness and intervention, human, automated or some combination of both. Without such recognition, the sub-optimal state can exist for the long-term and can eventually come to be seen as normal and correct. Performance depends on how quickly recognition and interventions occur to address the development of sub-optimal conditions. The speed and effectiveness of such recognition and response are subject to training. This logical model shows the fundamental importance of a continuing feedback loop between building and building operator for maintaining high performance.

Program design for performance assessment. Design of state and utility retro-commissioning programs to date emphasizes the identification and correction of operating "deficiencies," based on engineering observation and varied forms of analysis, usually by outside consultants. These are quantified as improvement projects and treated much as capital improvement recommendations under the older, familiar model of energy audits. Engineering focus is mobilized, problems found, and solutions implemented. Engineering observation and findings are embodied in a report, generically described as the "Performance Assessment" in Figure IC. The engineering review sits on top of the normal maintenance practices, seeks to identify sub-optimal operating conditions and facilitate corrective responses. The model of such program design ignores the repetitive nature of this loop. *The SOS-Intervention linkage cannot for the long term depend on an outside Performance Assessment; this step must be internalized by building operators*.

Adding the training dimension. Figure 1D shows the addition of a training level to the Logic Model to support skills development and process internalization. The Performance Assessment is now structured to identify not only system response needs but also operator learning needs that should be addressed by training, including both key optimization issues for the specific building and also monitoring and diagnostic principles and methods. This step is critical if the Performance Assessment capability is to be successfully transferred from outside engineering consultants to internal building operators. Proper training will enable operators to both recognize "SOS" conditions more readily and to respond more efficiently and effectively.

With this new element in the Performance Assessment, it becomes significant that there is no formal procedure for identifying operating staff training needs or specifying instructional activities that should occur as part of the commissioning agent's on-site work or in off-site settings. The formal evaluation of learning needs is a discipline outside of engineering. It is relatively easy to say that a learning needs assessment and learning design should become part of retro-commissioning programs. It is much more difficult to expect that the retro-commissioning agents, typically consulting engineers, will either readily accept or have the ability to meet such a requirement. Some engineers enjoy working and communicating with operators; given the time and the direction, they can be expected to be reasonably good trainers. This, no doubt, has been occurring relatively informally in the field in successful projects. Consistent program performance on a large scale cannot rely on such undefined procedures. The development of appropriate learning-needs assessment tools is the focus of further work.

Some Background on BAS Utilization and Digitalization in the Workplace

That building operator training is needed is also supported by findings about the operation of building control and automation systems. Studies of the effectiveness of BAS utilization find a large degree of underperformance. Two panels of experts asked to categorize performance problems considered "human factors" problems, including operator "interference" and (lack of operator) "awareness" as a set of factors in system underperformance. (National Building Controls Information Center, 2002, 2003).

Concepts of "advanced" building monitoring based on data acquired through the BAS have been suggested and developed, up through demonstration projects, including considerations of commercialization, key functionalities and comparisons of commercially available products (Piette, et.al., Yee, et.al., Haves, et.al.). In demonstration projects, highly motivated operators have grasped and utilized the new functionalities, gaining valuable insight into plant operations. Commercial products are increasingly available (Santos) and, to some extent functions are being incorporated by major BAS vendors. but their adoption and utilization remains at an early stage.

Emphasis on monitoring emerges from study of the connection between building performance and monitoring techniques, especially under the rubric of "Continuous Commissioning." Work was done initially to assess the performance of retrofits under public programs in Texas. Findings strongly suggest and document significantly improved savings and persistence from energy-use monitoring and feedback that incorporates operators. Moreover, when operators see their building systems functions more clearly and performance in more detailed terms, they seem to become more comfortable with system optimization changes (Haberl et.al.).

Advanced building monitoring functions are intimately bound up with the deeper utilization of digitally acquired data. A large literature on this topic is available from the cognitive sciences, in particular those researchers who examine the impacts and use of computer technologies in the workplace, providing many relevant examples relevant to the process considered in this paper (Brown 2000, Watson 1993).

Training via Building Performance Lab, City University of New York (CUNY BPL)

Training for energy efficient building operations has long been available in the marketplace, typically supported by public sector program funding of not-for-profit effort.[1] Community colleges have begun to explore updating the traditional HVAC technician training (Crabtree et.al., ATEEC). Nevertheless, at least in New York City, major institutional uptake has been lacking.

Unique among NYC's institutions of higher education, CUNY has a specifically articulated mission of serving the city's populations, industries and stakeholders. Recognition of its own need for improved building performance parallels this need for the city's key real estate industry and the workforce that serves it. With support from NYSERDA, CUNY is adopting the

[1]The Northeast Energy Efficiency Partnership (NEEP) has adopted a certification curriculum developed by the Northwest Energy Efficiency Council. The Building Owners and Managers Association (BOMA) has recently released an energy-efficiency program nationally. The inter-state STAC process as well as NYSERDA's retro-commissioning pilot have funded training sessions, drawing on Portland Energy Conservation Inc (PECI). The NYSERDA-supported Building Performance Institute has created certifications for energy efficiency workers in the residential sector.

model of the Energy Systems Lab at Texas A&M, through which a combination of performance monitoring, system optimization and practical engineering training will be applied, enhancing the skills available in the city's workforce of building operators.

The CUNY BPL will work through curricular and continuing education offerings and internships. A series of focus conducted with segments of the buildings industry to identify perceived needs found practically-based segments (operators, union labor) expressing a need for better grounding in fundamentals, while more highly educated segments (architects and consulting engineers) indicated a need for people with more field experience. The BPL provides an opportunity to meet both sets of needs through its focus on hands-on applications of analytic tools in real-building situations.

The BPL has also identified two sectoral training programs with which to collaborate. The Association for Energy Affordability (AEA) trains operators and energy efficiency workers in multifamily housing. Local 94 of the International Union of Operating Engineers provides staffing for the major commercial office buildings in Manhattan. Both have existing lab facilities used in on-going programs. CUNY support will help both of these labs develop training curricula to support adoption and use of next-generation digital controls, emphasizing building performance monitoring.

Connecting digital to physical: the AEA boiler lab. AEA has been providing technical assistance to community-based weatherization agencies in New York City for fifteen years through Low-Income Weatherization Assistance, a federally funded program with a history going back to the first oil crises, 1973-77 and the country's first National Energy Plan, under President Jimmy Carter. In urban areas like NYC, the program has an important focus in multifamily housing, with central plant equipment for heating and hot water.

The service delivery mechanism sets the target audience for training services:

- Community-based agency staff, responsible for initial assessments, owner negotiation, and installation oversight;
- Contractors bidding for work who needed to be familiarized with the requirements and expectations of the program.
- Building managers, superintendents, and maintenance staff, who must understand intended operation of new equipment and how it relates to performance.

The tasks, needs and level of technical development in these positions establish the kinds of training objectives:

Weatherization and Community-based Energy Program Staff

- Improve diagnosis of existing boiler operations by better understanding of operating sequences, control settings, adjustments
- Testing and commissioning of installed work
- Creating on-going working relationships with building managers and superintendents as part of a community energy services vision

Contractor and Service Personnel

- Practice set-up procedures for optimized combustion and equipment cycling so that improved results can be more easily and readily achieved in the field;

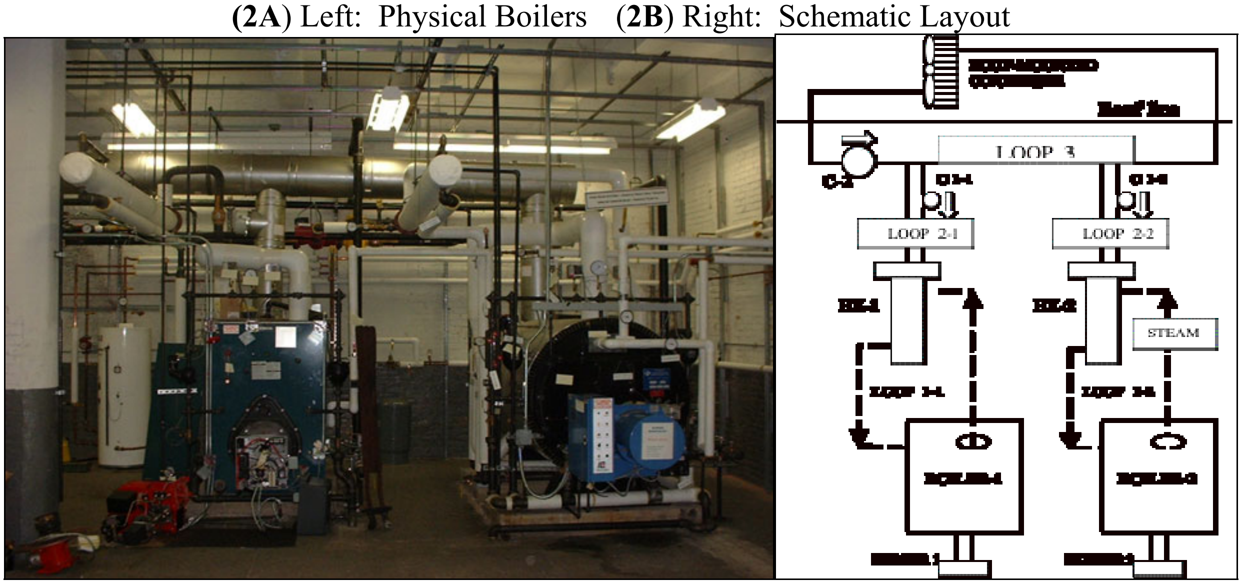
- Understand and be better able to implement new generations of controls and capabilities for advanced functions, such as optimized set-back/set-up, reset ratios, firing-rate and lead-lag sequences, oxygen trim, variable speed fan control

Building Managers and Superintendents

- Understand and recognize various operating patterns and their relationship to building energy performance
- Improve maintenance of efficiency adjustments through better recognition, information, and communication with service firms and mechanics.
- Realize how new sensor technology and GUI-web interfacing can provide data for monitoring building conditions and tracking gradual improvement efforts.

The boiler lab addition. Weatherization agency training is a long-standing activity at AEA and has recently expanded to Building Operator training (for managers, superintendents and staff) under NYSERDA support. Whereas hands-on aspects of training previously relied on access to operating boiler rooms, the Lab facility, Figure 2, greatly improves logistics and, at least as importantly, enables a more systematic approach to hands-on exercises.

Figure 2. Boiler Lab at AEA's Bronx Energy Management Training Center
(**2A**) Left: Physical Boilers (**2B**) Right: Schematic Layout



Source: Association for Energy Affordability

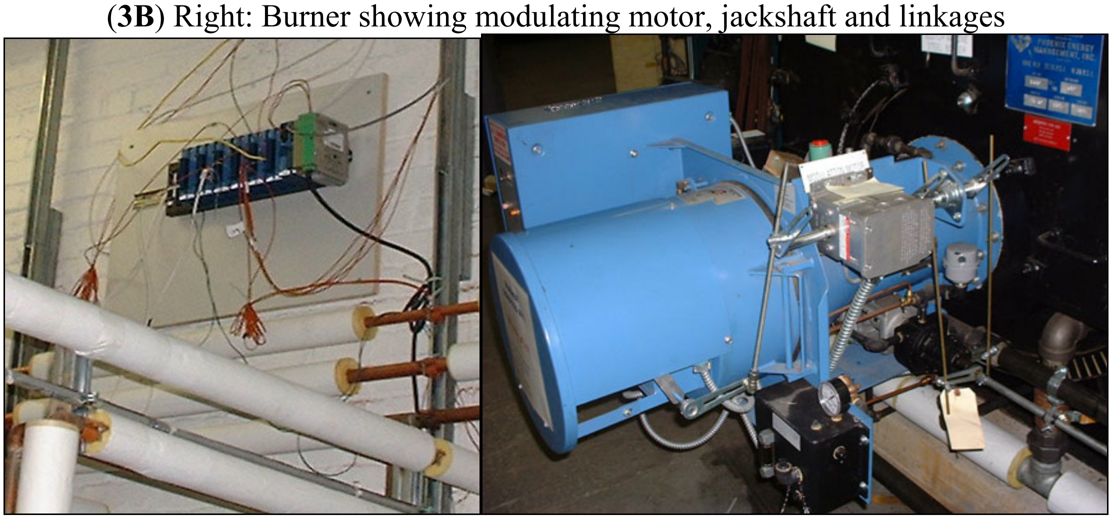
Lab exercises, Table 1, range from fundamental to relatively complex, with exercises 6-10 benefiting from digital instrumentation to show performance records.

Table 1. Boiler Lab Exercises

1	Normal boiler start-up and burner firing sequence
2	Opening boilers for inspection, cleaning, leak identification, and re-closing with proper gasketing
3	Low-water cut-off blow-down and switch testing, full boiler blow-down, monitoring of make-up water additions
4	Flame failure safety shutdown, response, and troubleshooting
5	Identification of surging and priming and corrective steps such as water level adjustment, firing rate adjustment, and skimming blow-down
6	Domestic hot water production and mixing valve control at various boiler temperatures and load conditions
7	Combustion efficiency testing and adjustment at various firing rates
8	Pressure control settings and burner firing rate modulation
9	Boiler lead-lag control and cycling in relation to varying load conditions
10	Outdoor temperature reset sequences and adjustments for steam and hot water

The boilers are overlaid with a LabView data acquisition system, Figure 3A. Various pressure, temperature, on/off, and flow points are integrated. The layout of the lab facilitates a training mode interactive between the physical and the digital. A room immediately off the main lab space , originally planned for storage and benchwork is being set up as the "remote data lab." Students can observe a physical sequence of operations on the boilers and then readily review its digital traces. Or teams can work in both rooms simultaneously, communicating changes and seeing how to "tweak" operations in both directions, digital-to-physical and physical-to-digital. Development of the user-interface associated with lesson-planning is the subject of other work (Huang).

Figure 3. AEA Boiler Lab, Details
(**3A**) Left: LabView Data Acquisition point
(**3B**) Right: Burner showing modulating motor, jackshaft and linkages



Source: Association for Energy Affordability

Across the full range of boiler room functions in this size range, the penetration of digital controls is still largely limited to embedded chips with code-based message interface. More advanced digital systems are only beginning to be deployed. Thus operators have very limited experience in looking at large amounts of digital data and connecting it to physical equipment operating patterns. It's at this level that AEA will focus it's digital systems training development work with CUNY.

The first area of expertise to be developed into digital-based curriculum is boiler capacity control, via burner firing-rate modulation, a common mechanism for which is shown in Figure 3B, and multiple boiler lead-lad control. Often found sub-optimized in the field, digital data tracks are able to graphically demonstrate load-matching dynamics under various conditions. A set of varying load conditions and operating pattern results under different firing-rate control modes is shown in Table 2. Varying the heat rejection loop's temperature and/or flow enables simulation of load conditions.

Table 2. Firing Modes, Load Conditions And Observations

Burner firing mode	Load Condition	Observations
On/Off	Fixed	Cycling pattern, timing
Modulating	Fixed	less cycling, overshoot and anticipation
On/Off	Varying	Increased cycling as load reduces
Modulating	Varying	more modulation action as load reduces

When combined with metered fuel and hydronic flows, students will be able to see the energy use impacts of different operating modes under different load conditions. Students will construct energy balances that will be cognitively connected to the experience of setting up the physical boiler operating patterns.

The latest models of commercial controls for this market are now beginning to place digitally acquired data onto websites, where data visualization tools can be applied to accumulated data. Wireless communications is reducing the cost of obtaining apartment temperatures and early adopters are finding that reducing overheating can endow significant economic benefits. Market demand for operators who know how to use digital systems to optimize system function and economics will not be far behind.

Introducing advanced tools: international union of operating engineers, local 94 training center. The situation with the Operating Engineers union is different from that of apartment building operators. This union staffs engineering operations for most of the city's major office buildings, almost all of which have BAS in place. Thus most of these building operators have direct experience with integrated digital systems, hierarchical architectures with local control panels, and graphical displays (GUI) at central control consoles. This population already has developed a cognitive connection between physical equipment and digital representations.

Although a rigorous work-study of these engineers and their BAS remains to be done, general observations suggest that these operating engineers will typically:

- know how to check the status of major components – air-handlers, chillers – via the BAS console;
- have access to real-time "snap-shot" views of operating conditions and also to (limited) historical logs maintained by the BAS.

Use of the latter (BAS logs) is similar to the way logbook entries of gauge readings have traditionally been used – relatively short-term scanning of variables for status and significant excursions from normal operations.

Such limited use of available historical data suggests the frontier of current practice for this class of operating engineers. From a combination of what (older) systems offer and what skills operators have (or lack), digitally available data is generally under-utilized, with theory-practice gaps along the following dimensions:

- Use of multivariate data review and data visualization tools
- Trending and baseline comparisons of energy use as telltale for performance excursions.
- Diagnostic data analysis to suggest functional areas of under-performance
- Documentation for understanding of interactive component and building responses
- Application of AI expert systems for automation or semi-automation of building system optimizations.

We might characterize current management of building systems as highly intuitive at the level of Chief Operating Engineers, with rules-of-thumb rooted in successful past practice governing decisions about how to match equipment operations to conditions. Operating decisions are made with judiciously wide safety margins for maintenance of comfort, with avoidance of complaint as an over-riding performance metric. As a result, for example, confidence in demand response actions is low.

The build-out of the BAS lab at the Local 94 Training Center is just entering its planning stage, which will be undertaken through a collaborative process with senior union members, building owners, and BAS vendors. The opportunity for technology transfer is enormous. The exploration of new tools and techniques can be developed through a well-defined "community of practice."

The Local 94 Training Center is supported by the local real estate industry with a set of training courses that are mandatory for new hires into the workforce. Among various hands-on training set-ups, their facility includes a lab for DDC components, following up on basic training in pneumatic controls and electric relaying. Courses are cross-coordinated with certifications through the Building Owners and Managers Association (BOMA) and BOMA's Building Owners and Managers Institute (BOMI). Advanced, non-mandatory course work is considered key to job advancement in multiple steps reaching to the level of Chief Operating Engineer ("Chief").

The emerging plan for the BPL-supported build-out of an "advanced BAS Lab" at Local 94 is to create a telecommunicated data hub equipped with a large assortment of data analysis, visualization, and diagnostic tools that will be able to work across the range of BMS platforms. A variety of communications design and access issues need to be resolved but the goal is to have capability for data-dumping from a building BAS and/or read-only remote access to the BAS. The initial target training audience will be Chiefs and aspiring Chiefs, who can arrange management approval for secured data access.

To use the lab facility Chiefs and senior engineers, possibly along with service engineers from BAS vendors, will meet in a seminar format in which tools can be learned through application to building data, exploring various system configurations and functions. CUNY academic credit towards a Bachelors degree is anticipated. Learning and technology transfer objectives are several-fold:

- Familiarize target audience (Chiefs) with range of tools, data visualization, and diagnostic methods and case study examples of how tools have been applied;
- Provide exercise in defining building optimization problems and data needs for their solution;
- Identify data accessible through site-specific BAS, data necessary for addressing specified building issues, possible data acquisition gaps and solutions;
- Begin transfer of specific (public domain) monitoring and diagnostic techniques from lab to buildings and/or support exploration of BMS features and/or commercially available tools;
- Enhance understanding of opportunities and needs for existing BMS upgrading in participant facilities;
- Gain feedback to tool developers from highly experienced building operators;
- Gain understanding of monitoring and optimization procedures that can usefully be instituted as part of normal practice for Chiefs and their staffs.

Conclusion: Training For Market Transformation

Application of information technology to building operations has led to development of advanced tools for building performance monitoring and diagnostics. A missing link in their market adoption has been the training that would encourage and support acceptance and utilization by building operators. Our common sense, along with research, experience and a logic model, tells us that training of building operators is an essential element of Market Transformation towards new high-performance practices. The real question is what kind of training and how best to structure its delivery. This paper has argued, we hope convincingly, that committed educational partners can create mechanisms to reach key segments with hands-on activities that will open new vistas of digital information utilization that, in turn, will translate into enhanced building performance.

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