Addressing the Operator as a Driver of Building Performance

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ABSTRACT

A handful of programs emerging in the United States attempt to address operational improvements in buildings and the need for building operators to attain a more sophisticated level of knowledge, understanding and practice. Program results are considered at two levels. The first is change in the industry's expectations of operating engineers. These new expectations are seen as the basis of skills sets and learning objectives. The second level is based on training evaluation, conducted through pre/post surveys in 2009, that assesses participating operators' perceptions of their job functions and specific skills. Preliminary findings suggest that properly structured training can contribute to changes in operator functions as required by the industry but that further specification of training instruments is still necessary.

Introduction

Operations is becoming recognized as key in the energy and indoor environmental performance of buildings. Recent studies starkly raise the issue of under-performance (Turner 2008, Gifford, 2008). Advanced designs employ increasingly complex systems, the proper functioning of which requires effective supervisory control, an important role for human operators. On-going Commissioning results demonstrate the potential for major gains by such supervisory diagnosis and intervention. Yet while we specify systems in great detail, what operators need to know remains under-defined. This paper is written based on the primary author's experience in developing and delivering continuing education for building operators in New York City. The author also participated in the development of the ASHRAE Operations and Performance Management Professional (OPMP) certification and certification test and, as a thirty year veteran of energy services delivery in New York City buildings, is an active participant in various on-going industry transformation processes. This experience informs and provides much of the basis of the views developed in this paper.

We observed in earlier work that the consulting engineering profession is ill-equipped to establish proper training programs for building operating staffs as they lack background in the discipline of training design (Bobker 2005). Training design is based on formal procedures based on Needs Assessment, development of end-state vision and roadmaps, and the definition of specific Concept/Skill Sets. A recent evaluation of the Retro-commissioning program in southern California found weakness in operator training to be a significant area of program under-performance from the customers' perspective (Peters and Scholl 2009). The work presented here should be considered as a contribution towards better understanding of how to define and develop appropriate Training for Operators of commercial-institutional buildings.

Industry Trends

Trends in the buildings and property management industry drive expectations of what building operators and operating engineers should be able to do. The trend towards incorporating Sustainability, as defined along multiple dimensions, can be seen in trade magazines such as Buildings, Building Operating Management, the ASHRAE Journal, and others. A formal content-analysis is yet to be done but the overall trend is clear. Aspects of this trend impact directly upon expectations for Operator knowledge and skills. We discuss three such trends below:

- Measured performance
- New technologies
- From Component to Systems Thinking

Measured Performance

Demand for actual measured performance is increasingly called for as necessary to confirm the achievement of design intent and the persistence of performance over time (Hinge). Performance most commonly refers to energy but is appropriately extended to other building services and qualities: water, air, illumination, and acoustics (ASHRAE 2009). Measurement and monitoring will typically draw information on an on-going basis from the Building Automation System (BAS), with increasing attention to the importance of usable display, such as in currently popular "dashboards." (Bobker 2008). In so far as measured performance is implemented, it affects how building operations are perceived and evaluated and what is expected from building operators.

The Measured and Monitored Performance paradigm is reflected in procedural methods under various rubrics, for example on-going commissioning, continuous commissioning©, retro-commissioning, tune-and-adjust, building re-tuning. These all may be considered forms of enhanced building operations. They may also be understood as a form of supervisory control applied at the building level, in which human operators use advanced methods to watch over building operations that are carried out largely on an automated basis.

New Technologies

The property industry is constantly trying out and adapting new technologies and this is only accelerating with pressures and incentives to save energy and reduce carbon footprints. Technologies applied for energy conservation range from basic, such as application of pipe insulation and weatherstripping, to complex, such as cogeneration and photovoltaics. Given this fundamental industry process, what do operators need to know? In some cases – such as simple, inexpensive technologies – they may be the decision-makers, but in general they will not be.

Our most advanced technology sets have been found to under-perform (NBI, Gifford). Causes of this are currently being debated and may be various. Operations is considered part of the mix. Of course the Operators may not know about the variance (shortfall) in performance or even that they could be considered responsible for it.

Component vs Systems Thinking

The industry is defining and seeking a higher level of O&M management that incorporates responsibility for overall building performance. Traditional training programs teach technicians how to maintain and repair equipment – boilers, pumps, fans, valves etc. This kind of knowledge and skill is generally well implemented in the industry, through work experience, on-the-job training, manufacturer seminars, and some level of formal training programs by professional training organizations.[1] Such component-based training is a critical baseline for O&M work. Some component-based training has layered energy conservation onto equipment fundamentals. But this kind of training stops short of what might best be described as "systems-thinking", necessary to recognize and diagnose performance outcomes rooted in complex control strategies and system interactions. Recognition and diagnosis require quantitative and interpretative data skills that incorporate and go beyond equipment level testing.

Outside consultants are often used when *more* sophisticated analysis is called for. Machine intelligence is applied through Fault Detection and Diagnosis (FDD). To what extent will this trend affect in-house building operators and engineers?

Industry Programs Addressing Building Operations

Associated with industry attention on sustainability, especially for existing buildings, programs have emerged that recognize O&M as significant for performance. Four programs are considered as representing distinct but inter-related approaches[2] with details in Table 1:

- The Building Energy Efficiency Program and the 7-Point Challenge of the Building Owner and Manager Association (BOMA-BEEP)
- LEED Existing Buildings Operation & Maintenance Rating System of the United States Green Building Council (USGBC LEED-EBOM)
- The Building Operator Certification program of the Northwest Energy Efficiency Council (NEEC BOC)
- The Operations Performance and Management Professional of the Amercian Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE OPMP)

BOMA BEEP and the 7-Point Challenge and USGBC LEED-EBOM address owners and managers to initiate change processes from the top. They show a common emphasis on transforming operational practices with new objectives. LEED EBOM, through its pre-requisites for owner requirements and existing performance, emphasizes documentation of existing operations and then awards points for measured, documented improvements beyond these baselines. There are no specific training requirements. BOMA provides what might best be considered orientation and then seeks organizational commitments to certain specific

[1] For example, the National Association for Technical Excellence (NATE) provides a variety of training.
[2] Focus of this paper is limited to the commercial and institutional buildings, primarily in-house staff. Focus on the residential sector would require consideration of the work of the Building Performance Institute (BPI). Also not considered here are various union training programs. The International Union of Operating Engineers makes available to its members courses of study leading to Energy Conservation Specialist and Indoor Air Quality Specialist titles.

change goals that are based on measurable performance. It should be noted that the BEEP and Challenge programs are related but separate and are not marketed as an integrated package.

While these programs address upper management, they do provide implications for what is expected of building operators and engineers. As we are still early in the transformational process, much of the groundwork – inventories, building process documentation, audits -- is done with consultants. This is common, for example, with Retro-Commissioning and the EnergyStar benchmarking that are pre-requisites for LEED-EBOM. As industry practices are transformed, the expectation is that On-going Commissioning practices will become a part of mainstream, enhanced, building operations, with in-house processes cost-effectively replacing consulting services (Bobker 2005).

Table 1 Comparison of Commercial Building Operations Certification Programs

	BOMA BEEP & 7-STEP CHALLENGE	**USGBC LEED EBOM**	**NEEC BOC**	**ASHRAE OPMP**
FORMAT	Webinar series, organizational commitment	Multi-dimensional documentation process	Class & practical training.	examination
TARGET AUDIENCE	Owners, Property Managers	Owners	Building Engineering staff	Advanced Building Operating Engineers
AMOUNT OF TRAINING	Six 2-hour webinar programs.	None required.	60 hours of classroom plus practical projects	None required. Education and experience qualifications to sit for exam.
OUTCOMES, EXPECT-ATIONS	Awareness and organizational commitment	Building Label	Individual certification	Individual certification
REFERENCE MATERIALS	Slides and recording	LEED EBOM Reference Guide published by USGBC.	Slide-based handbooks as used in classroom sessions.	Body of Knowledge emphasizing ASHRAE Standards, Guidelines, Handbooks.
SKILLS	Awareness of energy program steps.	Specific practices that are pre-requisites or earn points. Broad coverage of sustainability dimensions.	Efficient equipment operations and energy data management, covering HVAC, electrical systems, and Indoor Air Quality.	O&M approaches, system knowledge with significant level of quantification skill required.

The second pair of programs, NEEC BOC and ASHRAE OPMP, directly addresses Operations' personnel and capabilities. NEEC-BOC provides classroom training that emphasizes energy management principles, actions, and measures and includes practical exercises conducted by students in their own buildings. One significant segment of BOC, Handbook 102-Energy Conservation Techniques, provides instruction in the collection, management and interpretation of energy data. This is an area that has not traditionally been part of the building engineer's focus; it thus provides a new skill set. ASHRAE, as the premier professional organization in the HVAC industry, provides market direction in creating a “body of knowledge” where none previously existed. This provides the basis for training that could be provided by others, but ASHRAE itself offers no direct training for its certification, following ANSI guidelines.

The concept of (new) skill sets is critical to enabling Operations staff to play a productive role in the transformation of building operations towards sustainability. Skills sets are distinct from, for example, specific knowledge about specific technologies. We will return to this distinction in considering what to evaluate.

We might hope and expect that from these several industry programs we would find a clear statement of the skills thought to be necessary for work within the transformed, enhanced building operations paradigm. Logically, these skills would provide the Learning Objectives for training. However, such articulation is not to be readily found in the literature of any of the programs, leaving a distinct gap between the industry’s objectives and its training.

Skill Sets and Learning Objectives

Given the need for defining skills sets and learning objectives (SS-LOs), we offer an initial effort, drawn from BOC training as provided by the City University of New York (CUNY) in the hope that its consideration and discussion can sharpen the understanding of curricular needs. We identify sets of skills in the following areas:

1. Documentation of existing systems
2. On-going measurement and interpretation of performance
3. Team-based improvement processes.

Skills in Documentation of Existing Systems

- Be able to describe and record characteristics of building mechanical and electrical systems and technology - hvac, plumbing, electrical distribution, motors, lighting and controls
- comprehend system configurations, draw simple schematics, and observe and interpret operating conditions
- Read, observe, confirm/disconfirm specific control sequences of operation and control results in relation to specified requirements
- Understand the energy-use impacts of systems and their operation

Skills in the On-Going Measurement and Interpretation of Performance

- Understand energy data sources, data management and interpretation. Perform basic functions with energy data, including compilation of energy use histories, calculation of indices, use of software tools, spreadsheets, diagnostics
- Be able to use units and concepts of building science for calculating performance of ventilation, heating and cooling, pumps and fans, illumination

- Be able to take appropriate measurements of operating equipment and indoor environmental conditions, utilizing portable instruments, data-loggers and building automation systems.

Skills in Team-Based Improvement Processes

- Understand and explain to others the purpose and goals of energy/carbon reduction and other improvement processes
- Identify and characterize specific energy-saving and building-greening project opportunities
- Participate effectively in structured approaches to building performance improvement and greening,
- Awareness and application of basic concepts for systematic maintenance and maintenance management

This is a rather abbreviated preliminary list of skills sets and learning objectives but it maps well onto the industry's goals. It should be noted that little is said about specific technologies. This is intentional, to emphasize that there are skills sets that are common to the operational performance monitoring of all manner of specific technologies. For example, measuring the energy consumption of a motor on a variable speed drive has much in common with measuring the varying output of a photovoltaic system.

Curriculum and Pedagogy

SSLOs inform curriculum development and target outcomes. We also identify pedagogical principles that can inform training class practice. We discuss several key areas for SS-LOs, including:

- Basic science concepts
- Calculations and use of basic formulae
- Practical projects
- Using Schematics to capture system relationships

Actual course content will of course cover specific technologies and operations, which will be at least in part based on the kinds of systems and equipment in use by the target audience. It is important to be able to line up lessons with the specific systems with which operators work. For example, for a target audience with a high predominance of rooftop units, curriculum should incorporate emphasis on economizer cycle function and how to monitor it. We emphasize the importance of Learning-by-Doing. While the "learning-by-doing" principle is effective in itself, what is to be learned needs to be carefully considered in light of industry objectives, behavioral goals, and SSLO based on these considerations.

- **Basic science concepts.** Provide an important organizing principle that helps students gain fundamental understanding rather than simply memorizing equipment-related checklists. Change-of-state, for example, unifies many HVAC processes – steam generation and distribution, latent heat transfer and the pyschrometric chart, and the vapor-compression cycle. Volume, air, and water flows are also inter-connected with basic thermal quantification.

- **Calculations and use of basic formulae.** Is an important activity that helps advance Operators from the intuitive understanding of flow processes that they often possess. The importance of design projects is well recognized in community college HVAC programs but has not generally been extended to continuing education courses for those already working in the field. CUNY's BOC offering includes a module on HVAC calculation and another on energy audit calculations. Another BOC module requires use of a spreadsheet to calculate an Energy Use Index (BTU/square foot) using bills from their own facility. Use of a spreadsheet, often not part of the Operator's skill set, turns out to among the most satisfying learning elements.

- **Practical projects**. While lecture is an efficient way to transfer large quantities of information, students take away best what they have worked on. The BOC curriculum requires a series of practical projects to be done in by each student in their home facility. These might be seen as preparatory for actual change projects as required under the BOMA Challenge and LEED EBOM. We have incorporated preparation of LEED EBOM pre-requisite documents, such as Owner Building Requirements and Control Sequences of Operation, into BOC Practical Project assignments.

- **Using schematics to capture system relationships.** Being able to show the essential elements of and relationships within systems is brought to bear through Practical Projects based on the development of mechanical and electrical schematics. Requiring students to be able to both read and develop schematics both develops a useful skill and helps in facility documentation.

Evaluation

Once properly established, the SSLO also lay the groundwork for evaluating training's impacts and effectiveness. It is important to measure the right things, which makes it all the more important to align SSLO with industry needs and goals. At present we do not yet have such a Needs Assessment.

Pre-/Post-Surveys

We also do not have a proper set of baseline conditions from which we are measuring. Baseline conditions can be established as a characterization of building operations staff along dimensions aligned with industry expectations and SSLO. We report here on initial effort along these lines.

Two surveys have been employed at the beginning and end of a BOC-qualifying sequence of study. They seek to establish Operating Engineers perceptions of their functions and self-evaluation of certain skill levels. The first survey questionnaire is shown as Table 2, with the survey questions followed by the average and median responses before and after training. Responses to questions were by marking a 1-5 scale. The second questionnaire and response sets are shown as Table 3. This second survey is more detailed about specific skills and technology knowledge. The second questionnaire has an additional data column, labeled “Retro-Pre”. When administering the post-survey, respondents were asked to retrospectively rate what they now thought of as their “pre” level of ability along with rating of their post-training ability. Both questionnaires are administered at the same time, as a two-sided sheet. For the post-training survey, it is administered along with course evaluation surveys provided by the university.

For both surveys, responses are shown from two separate cohorts of students. Both cohorts consist primarily of building operating engineers[3] who completed 90 hours of classroom training incorporating BOC Level 1 qualification. The “DCAS” class (n = 24) was offered through the NYC Training Center under a contract with the NYC Department of Citywide Administrative Services. The “L94” class (n = 27) was offered through the International Union of Operating Engineers (IUOE) Local 94 Training Center. This cohort came heavily from a single owner/manager, Vornado Realty Trust. Vornado, like most of the employers who hire through Local 94, operates a portfolio of major “class-A” commercial properties, including Penn Plaza. Subsequent classes have been offered in both settings with the same questionnaires administered and results will be added to the data set.

Table 2 Survey A with Average and Median Pre and Post Responses

	SURVEY QUESTIONS		DCAS		IUOE Local 94	
			PRE	POST	PRE	POST
1	I know my facility’s energy performance	average median	2.29 2	3.50 3.5	2.70 3	3.37 4
2	I know how my facility’s energy performance rates in comparison to other similar facilities	average median	1.92 2	2.84	2.15 2	3.00 3
3	I know the energy characteristics and performance of systems and equipment in my facility	average median	2.63 2.5	3.55 3	3.04 3	3.65 4
4	I can explain how energy performance in my facility relates to global issues of climate change risk	average median	2.63 2.5	3.68 4	2.08 2	3.22 3
5	I have a clear set of metrics to gauge the performance of my facility	average median	1.71 1	3.60 4	1.81 1	3.15 3
6	I understand the LEED rating system and how it works.	average median	1.91 2	4.20 4	2.07 2	3.59 4
7	Satisfying occupant comfort complaints is a major part of my work	average median	3.96 4	4.00 4	4.41 5	4.27 5
8	Satisfying occupant comfort complaints generally requires that I use more energy	average median	3.33 3	2.90 3	2.69 3	2.67 3
9	I know how to measure energy efficiency in my facility	average median	2.21 2	3.90 4	2.70 3	3.74 4
10	I regularly see the energy bills for my facility	average median	2.29 1.5	2.65 2.5	2.15 1	3.00 3
11	I know what data I need to monitor the performance of my equipment and facility	average median	2.75 2.5	4.15 4	2.60 3	4.07 4
12	I regularly download and trend BAS historical data for major equipment such as chillers, cooling tower, air-handlers.	average median	1.29 1	1.65 1	2.44 2	2.85 2
OVERALL AVERAGE OF RESPONSES		average median	2.41 2	3.39 4	2.57 3	3.38 4

[3] The DCAS cohort includes a wider range of facility types and skill levels, including some more administrative personnel

Table 3 Survey B with Average/Median Pre, "Retrospective-Pre", and Post Responses

	SURVEY QUE3STIONS		DCAS			IUOE Local 94		
			Pre	Retro- Pre	**Post**	**Pre**	Retro-Pre	**Post**
1	Understanding of energy units and performance indices	average median	2.20 2	1.70 1.5	3.30	1.90 2	2.00 2	3.28 3
2	Ability to work with energy data and reports	average median	2.30 2	1.60 1	3.32	1.80 1	2.00 2	3.36 3
3	Ability to work with system and building data to understand energy use	average median	2.40 2	1.60 1	3.32	2.10 2	2.22 2	3.48 4
4	Ability to address complaints with deeper understanding	average median	2.90 3	2.50 3	3.26	2.80 3	2.90 3	3.64 3
5	Familiarity with the purpose, conduct, and outcomes of energy audits	average median	2.00 2	1.40 1	3.25	2.30 2	1.80 2	3.12 3
6	Familiarity with the purpose, conduct, and outcomes of retro-commissioning	average median	1.80 2	1.40 1	3.00	2.00 2	1.80 2	3.04 3
7	Ability to monitor equipment operations specifically for energy performance	average median	2.50 3	1.70 2	3.10	2.10 2	2.20 2	3.48 3
8	**Understanding of specific system improvements and likelihood of identifying and recommending them:**							
8.1	Chiller plant control	average median	3.04 3	2.10 2	3.00 3	2.73 3	3.04 3	3.72 4
8.2	Economizer cycle	average median	2.74 3	2.21 2	3.11 3	2.68 3	3.12 3	3.63 4
8.3	AHU and ventilation optimization	average median	2.80 3	2.20 2	3.11 3	2.70 3	3.04 3	3.71 4
8.4	Boiler plant control	average median	1.73 1	2.35 2	2.9 35	2.68 3	2.00 2	2.76 3
8.5	Steam traps	average median	3.09 3	2.47 2	3.37 3	2.64 3	2.96 3	3.56 4
8.6	Heating/cooling distribution balance	average median	2.88 3	2.25 2	3.30 3	2.69 3	2.83 3	3.54 4
8.7	Heat recovery	average median	2.42 3	1.89 2	3.32 3	2.48 2	2.52 2	3.46 4
8.8	Lighting levels and quality	average median	2.43 3	1.70 2	3.30 3	2.38 2	2.12 2	3.24 3
8.9	Lamp efficiency and life	average median	2.33 2	1.75 2	3.40 3	2.27 2	2.20 2	3.25 3
8.10	Lighting controls	average median	2.42 3	1.75 2	3.30 3	2.41 2	2.28 2	3.21 3
8.11	Motor efficiency	average median	2.79 3	1.60 1	2.90 3	2.46 2	2.58 3	3.52 4
8.12	Pump or fan speed control	average median	2.91 3	2.05 2	2.85 3	2.59 2.5	2.79 3	3.52 4
8.13	Cogeneration	average median	1.87 2	1.55 1	2.80 3	1.68 1.5	2.08 2	2.96 3
8.14	BAS and/or other control settings	average median	2.44 2	1.85 2	2.90 3	2.14 2	2.81 3	3.42 3.5
8.15	Equipment schedules & settings	average median	2.96 3	2.10 2	3.35 3.5	2.74 3	3.00 3	3.56 4
9	Comfort level with discussing energy conservation programs and procedures	average median	2.38 2	1.60 2	3.30 3	2.10 2	2.48 2	3.25 3
10	Comfort level with the LEED EBOM system and process	average median	1.48 1	1.40 1	3.00 3	1.43 1	1.60 1	3.13 3
OVERALL AVERAGE OF RESPONSES		average median	2.50 3	1.90 2	3.15 3	2.30 2	2.40 2	3.37 3

Discussion of Survey Results

Several baseline observations can be made across this preliminary data:

- Responses from the separate cohorts are quite consistent. There is a significant discrepancy on use of BAS data (Q12) since a much smaller percentage of municipal building operators (DCAS and other city agencies) have BAS. For the IOUE group, BAS data use is slightly negative and does not improve, giving an important indication of needed improvement in the training.
- While consistent improvement is shown on most questions, post-responses in the 3+ range leave significant room for further improvement. Operators are not fully confident upon completion of the training.
- Response to comfort complaints is seen as a major part of the job (Q7). This confirms general industry perception. In both cohorts it scores with the highest positive pre-score. The training shows virtually no impact in changing this perception
- The two cohorts diverged in their perception of whether more energy must be used to satisfy comfort complaints. The IUOE cohort had a slightly negative association on this count originally which training did not improve, while the DCAS cohort shifted from its initial positive association to a slightly negative one.
- The strongest improvement comes in reported understanding of the LEED system (Q6). This is an interesting finding that supports the general perception that LEED has been so effective in the market because it provides an easy hook for many separate things.
- Understanding of how to gauge and monitor (energy?) performance (Q5 and Q11) show the next strongest improvements to high positive associations from originally negative ones. This can be taken as a significant success for the training, showing progress on a key message of the training and an industry goal.

This initial work with surveys suggests that operator perceptions can be usefully captured and matched to industry goals. This kind of feedback can also show areas where the training is more or less effective in achieving the desired changes in how operators see their work.

The Logical Model

Evaluation studies employ logic models to show connected and intervening variables in a change process. This is an important concept and technique for complex market transformations. In aggregate, changes in operator behavior will contribute significantly to energy savings and the persistence of savings. But individual actions by operators may be so small as to be lost in the noise of whole-building energy use (ASHRAE Guideline 14). Operator actions may also share responsibility for energy savings with actions by others. For example, when an operator corrects a faulty adjustment on a new piece of equipmenr, how should this savings be credited?

Because regulators want "program evaluation for cost-effectiveness", they want to know about short-term energy impacts. This is an erroneously over-simplified model that exerts pressure to try to justify programs on this basis. The BOC training has attempted several such efforts While numbers have been produced, they are subject to methodological challenge, as they are developed largely by calculation and stipulation rather than measurement (Opinion Dynamics 2009). Moreover, these numbers probably sell training short; they do not reflect the significance of improved operations in implementing and maintaining savings across a range of technologies and projects.

Conclusion

Building operations and operators are seen to be part of a cultural shift that is occurring in the property management industry. Understanding this shift enables the specification of new skill sets that are necessary and learning objectives to develop those skills. A training model developed on this basis can be effectively matched with an evaluation scheme that is based on and reflects this market transformation.

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