OPERATIONAL EFFECTIVENESS IN USE OF BAS

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ABSTRACT

The effectiveness of BAS in controlling building systems is seen to reside in conjoint man-machine function. In an emerging industry paradigm, data is extracted from the BAS and used for analytics that inform enhanced operations. This processing may include a "mash-up" with data from other sources, such as energy meters. KPI metrics and Building Re-Tuning, an on-going commissioning process, are suggested as important ways to guide operators in training and subsequent understanding and use of data intensive tools. Short case studies of work in progress on two CUNY campuses are provided.

INTRODUCTION

Building Automation Systems (BAS) should, in theory, automate building control functions and run building systems optimally. In practice, this is far from the case. The reasons for this are poorly understood and not to be found in the literature despite some useful early investigations.[1] Bad sensors, calibration, failed actuators, poorly tuned loops, ill-informed human intervention all play a role. Regardless of cause, our largest, most complex buildings are run by a combination of machine (BAS) and human operator. Whether this is a good thing or bad can be – and has been – debated.[2] One has to wonder whether there is something in the kind of decision-making involved in building operations (as perhaps with other technical systems) that is beyond the ability of current automation practice and still requires a combined man-machine system in which the human operator brings certain capabilities.

As technologist Donald Norman writes, "whenever a task is only partially automated, it is essential that each party, human and machine, know what the other is doing and what is intended."[3] Human-machine interface and the study of error is a recognized field of study, developed especially for critical processes with high degrees of danger in failure. Supervisory control, mode recognition, and situational awareness are key concepts that require informational practices.[4] Our BAS systems, despite bright, detailed GUI system schematics with real-time measured data values, were not designed to facilitate such informational practices; for example, time-series context available through trend-logs is hidden away, making it an under-utilized resource. We do not have an established industry baseline of how operators use BAS nor what best practices might be. An ASHRAE research project is surveying operators to investigate desirable "dashboard" interfaces for operations.[5] The expansion of BAS to incorporate additional informational functionalities has been recognized for some time but is still in the process of entering the market and active utilization.[6]

In the emerging application of Fault Detection and Diagnostics (FDD) to building systems, we see a machine-based process of supervisory control. But even at this machine-to-machine-logic level, applications are being developed as external information engines for which data is extracted from the BAS. Many commercially available offerings deliver their outputs, perhaps ironically, to human operators. A few cutting-edge products and others at research and prototype stages, feed optimization instructions directly into BAS or IP-enabled

distributed controllers. Yet even these systems make provision to inform operators of control modes and intended operation; failing to do so increases the likelihood of manual by-passes. Even with machine-based supervisory control and optimization, human operators will continue to have responsibility for the foreseeable future; their participation in roll-out of next generation systems should be anticipated and planned.

The challenge, it seems, is to have a conjoint system that operates consistently, blending the skills of humans and machines, taking advantage of each to optimize building system performance. Since a conjoint man-machine system has not been an articulated intent of BAS system design, it should come as little surprise that it does not work smoothly in practice. Our goal in this paper is to suggest how practice can consciously move towards effective conjoint operation.

A TWO-SIDED EMERGING PARADIGM

There are two sides to the emerging informational paradigm in building automation: a rapidly developing machine-side, driven by market competition over next-generation products and services, and a more slowly developing human side, where market drivers and the excitement over new toys are much less in play. We review the machine elements first and then the human.

Machine Elements

Special Purpose Information Tools have seen rapid development through multiple platforms currently competing in the marketplace, developed to a certain extent within the BAS but more often external to it. These platforms follow a broadly similar form in their distinct implementations: data extraction, data transfer, data storage, analytics, feedback to the site. Figure 1 shows these elements schematically.

There are presently a handful of commercial offerings in the US using measured building data to optimize building/system energy performance. Johnson Controls recently released its PanOptix platform. Technology start-ups SCIEnergy, SkyFoundry, Energy IQ, Optimum Energy, and Clockworks offer "Software as a Service" (SaaS) products that take building data to cloud-based data storage where proprietary analytics are applied. FirstFuel and Retroficiency take a related approach

in which interval meter and satellite-based architectural data are combined into a model to produce a preliminary energy audit.
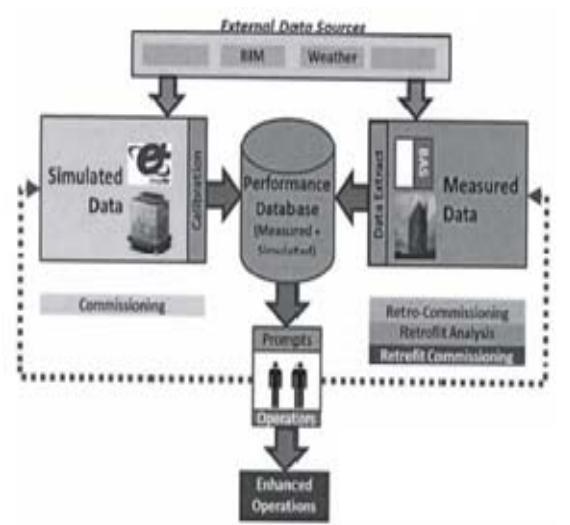

Figure 1 Typical Schematic Information Flows
source: CUNY BPL, LBNL, Sustainable IQ

BAS Data. The most common ways that BAS data are accessed is from trend logs. Trend logs are set up and data exported, typically in csv format, to a database external to the BAS. The first step may be an on-site cache, a server co-located with the BAS CPU. This can relieve data storage constraints at the CPU and provide data storage in the event of communication or remote problems. The remote location may be a distant server or, increasingly common, a cloud-based solution.

Data is acquired at 15 or 30 minute intervals. Collection can vary from several hundred to several thousand points. Obviously, constructing a comprehensive data warehouse from the outset would be desirable but may be constrained by communication capacities. This may be the case especially with older installations. Strategies for data caching and off-peak transmission may be required. Strategies may also be applied to reduce the scope of data points collected, identifying distinct areas of concern that are monitored for a period of time and focus then shifted to other areas.

A major hurdle in working with BAS data is the variability of points across systems and sites and, even more so, the variability of naming conventions. This semantic issue must be addressed when

extracting data and structuring the data base. Although industry inter-operability standards (BACNet, ModBus, LonWorks) and translational platforms (Tridium, Haystack) address semantics, the problem is still rife, especially – but not solely -- when dealing with older systems. Industry acceptance of shared schema would be highly desirable; building from existing IFC for Building Information Modeling (BIM) has been suggested.

Date Transfer. Taking data reports from trend logs is the most common method. Experiments are in progress with more direct methods.[7] Without common structures and point naming this step continues to be painstaking on a site-by-site basis. Set-up for transfer to one destination may not work for transfer to another, differently structured, destination.

Data Warehouse. The most common underlying structure for data warehousing is still the industry standard SQL database. To the best of our knowledge, each service provider develops its own unique database. So whatever progress has been made in inter-operability at the BAS level, in the present model data is now once again isolated by the specific database structure. This is an industry issue yet to be addressed, although it was anticipated in a foundational document, "A Specifications Guide for Performance Monitoring Systems"[8], which required an SQL-compliant database, along with other performance features but stopped short of prescriptive structure requirements. The Specifications Guide also puts forward a naming convention for the standardization of point descriptions.

Analytics. While database structures may vary perversely, it is at the analytics level that creativity in application should legitimately thrive. This is where competitors can demonstrate their superior concepts and implementations. All of the firms with offerings referenced above have their own approach to analytics.

Within the analytics framework there are many methods used. Rule-based approaches are the most common. Rules are most often statement of engineering intent. Rules can also be developed from data, using inverse, statistical methods, although this approach by itself has difficulty in establishing "correct" operation. Simulation models have a still-developing role to play in the evaluation of energy

performance data vis-à-vis system operation – experiments in using EnergyPlus in a real-time control environment have shown difficulties.[9] In so far as real-time control is to be directed by analytics, processing speed is a major issue to be addressed.

For discussion of the reporting-out of the results from the analytics engine, see the discussion of "Feedback", below. The Analytics will "mash-up" BAS data with data from other sources: weather, dynamic energy prices, and meter data. There has been rapid advance in Energy Information Platforms that handle meter data and their integration with BAS data promises to be a major near-term development.

EIS Data. Energy Information Systems (EIS) to capture energy use data are becoming increasingly common. Originally capturing monthly whole-building utility data and used for measurement and verification of energy performance projects, EIS platforms are adding interval data capabilities, direct capture of data from meters ad sub-meters, and built-in automatic analytics.[10] It is also increasingly common for BAS to directly obtain meter data.

Granderson provides case studies for the effective use of various EIS by energy managers.[11] While BAS data provides granular data with multiple physical dimensions at the system and sub-system levels, EIS provides a single view focused through an energy performance lens. At present these are primarily stand-alone tools, still separate from the FDD-oriented applications built-up with BAS-extracted data. But their usefulness suggests that they will soon become much better integrated.

The diagnostic drill-down process from energy performance deviations to building system operation remains as yet somewhat unclear. The literature on on-going commissioning (continuous commissioning©) offers perspective on moving from energy performance to system-level diagnostics. Interval data promise to offer new methods. Availability of large amounts of granular energy-use data raises the possibility of using inverse models for daily energy signatures rather than or as complement to forward simulation models. This data also presents opportunities for facilitating simulation model construction and calibration.[12]

Feedback. Feedback theoretically can occur as instructions and adjustments to the BAS: the external program sees error from the data (detection), identifies its cause (diagnosis), and initiates

corrective action. Direct machine-to-machine feedback is most advanced in the area of Demand Response, where initiation of a special mode activates prioritized load-shedding to meet a pre-determined kw level. The major controls manufacturers have prototypes for machine-to-machine oversight and implementation of specialized modes developed under ARRA funding but yet to be released as commercial product offerings.[13] Some commercial offerings, such as Optimum Energy, appear to make direct optimization adjustments from their remote analytics. This kind of black-box function may be the dream of many technologists.

However, most products currently in the market provide feedback by lists of alarms and recommendations that are presented to the operator. KGS Buildings' Clockworks product provides recommendations with varying information to match the concerns of different positions in the target audience. Even such contextualized messaging probably falls short of effectively engaging the human operators; more robust and engaging, although harder to master, are data visualizations that show the history of multiple parameters and system components and are almost always part of advanced supervisory systems.[14]

The Human side: Operator-in-the-Loop

With prospects for widely deployed machine-to-machine operation in at least the medium-term future, human operators will continue to have a significant role "on the shop floor" with the ability to adjust and override automatic controls. Even where external tools do directly adjust the BAS, the operator must be made aware of the operating mode and its intended sequences of operation.

What constitutes a well-informed operator? Long "to do" lists of deficiencies are equivalent to alarms set with too low a tolerance. In such cases, as is known from field experience, the alarm function will be turned off. Our experience of operators is that they are a stubborn group that believes they know what others do not, about building infrastructure in general and especially about their specific site. It is not at all certain that providing lists of operating deficiencies will consistently affect operator practices and behaviors. Operators are mechanically oriented and want to understand what is going on in their systems and what is the basis for a certain sequence; if they do not, they are likely to over-ride it.

Training. Thus we have repeated studies showing the importance of training for maintaining the benefits of commissioning and retro-commissioning.[15] Our extensive, multi-year classroom experience with operators indicates an eagerness to learn and an enthusiasm for improvement in practices when the full basis for them is understood.

Beyond "Snapshot" Data. Operators typically get only partial information about the performance of systems. They rarely get energy use information. Moreover, the information they commonly access on the BAS is instantaneous "snapshot" views. Each operator determines his or her own way to look at the myriad of data available across multiple screens. In working with operators, certain commonalities are found, such as the quick review of zone return temperatures to check that comfort conditions are being met. Such heuristics are important clues about how operators use data. They are not "data hounds" and data must be structured for them.
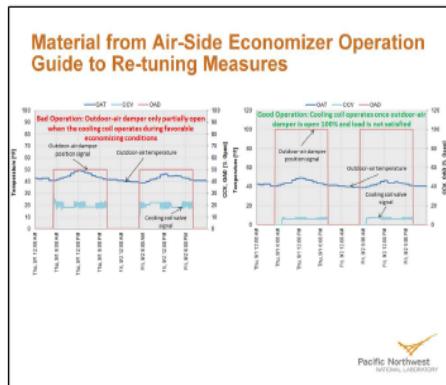
Key Performance Indicators. Data configured for performance monitoring can make a big difference in operator behavior and system performance results.[16] Such configuration includes highlighted posting of Key Performance Indicators (KPI) that are easy to remember and track. Mashing up energy use with system output into a ratio – such as KW per ton for chilled water – can be most effective. It is a version of posting motivational slogans in the team locker room. These metrics can be tracked over time. Team leadership can use the metrics to shift focus over time, such as heating in winter, cooling in summer, or shift through different levels of systems over time.

Drill-down. Once attention is focused on the big picture of performance, we have seen that operators become motivated to "tinker" – to look for optimizing adjustments in components.[17] So also useful is architecting the information display for drill down into specific components with their own metrics so that operators can come to understand the value of data for informing their practices.

Building Re-Tuning (BRT). The Building Re-Tuning protocol, developed and supported by the Pacific Northwest National Lab, provides a way of showing operators the data-derived detail of their equipment's operation BAS data is set up in trend logs and exported into structured spreadsheets that automatically plot data visualization graphs. The

Excel-based Energy Charting and Measurement (ECAM) tool is used for this purpose. A sample time-series graph is shown in Figure 2 taken from the BRT training resources. ECAM-based plots emphasize time-series representations but also include scatter plots and other graphical formats.

BRT uses major building systems and their intended energy efficient operating modes as the structure for observations, providing a systematic approach to equipment scheduling, zone conditions, air-system, pumping and central plant operations.
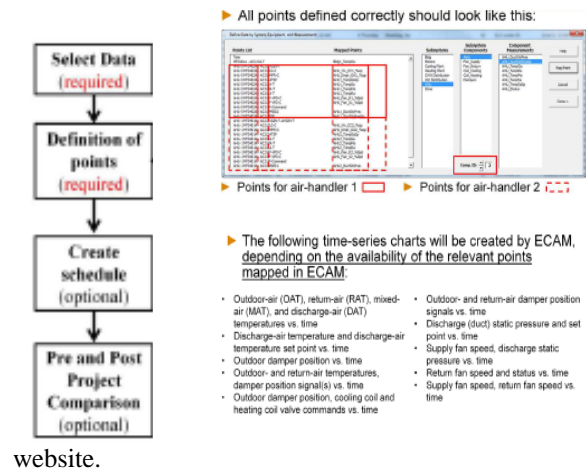

Note: As the user can see, an example of bad operation results when the outside-air damper (OAD) is partially open and the cooling-coil-valve (CCV) signal is also sending chilled water through the coil. If this occurs during conditions that are favorable for economizing (i.e., OAT<55), then the OAD should open up fully before the cooling coil opens up. The chart on the right shows an example of good operation, when the OAD is open 100% before the cooling-coil-valve is opened up.

Figure 2 Sample BRT-ECAM Data Visualization
courtesy: PNL

BRT Training. The PNL team and their DOE sponsors quickly understood that to widely deploy the BRT process required training of the operators who would have to implement the practices. As previously noted, operators are not usually well versed in use of data and interpretation of graphs that lie at the heart of BRT. Training needs have been addressed by on-site trainings with local hosts, by development of web resources and by development of a network of regional trainers. The web resources provide a rich tool for instruction in the graphical monitoring of key building system operations. The curriculum that CUNY BPL will offer to NYC operators will have an initial five-week structure with class time emphasizing use of trend logs and interpretation of graphical data representations of system functions while weekly homework assignments will move operator-students to set-up on their own systems.

BRT Data Set-up and Student Interns. The set-up of data for extraction and transfer is detailed and demanding. It requires knowledge and patience with data formatting. Figure 3 shows examples of the data set-up instructions from PNL's BRT resources

website.

Figure 3   ECAM Data Set-Up
courtesy: PNL

National experience with operators undertaking this step has been mixed.[18] Under our DOE-NIST contract for BRT Training as a Center for Building Operations Excellence, our model is to provide student interns to support operators in this step. Students gain valuable exposure to building systems and operators get a task done for which they and their staff are probably ill-equipped.

CASE STUDIES OF WORK IN PROGRESS

Sustainability interest at the City University of New York (CUNY) has led, over the past several years to students examining campus operations in various respects. Supported by a mix of administration and academic programs, some of this student engagement has been channeled into work around campus energy efficiency and BAS. Students have begun identifying need and building tools in collaboration with facilities engineering staff. We report on two of these cases here.

City College of NY. CCNY has a central plant that provides hot water and chilled water to campus buildings. The central plant and buildings have different BAS, many of the buildings' systems legacy and unsupported. An ALC BAS controls chillers and campus loop pumps while the boiler plant has built-up PLC controls, not integrated with the ALC. The

chief operating engineer has been at the plant for over twenty years.

A senior design student team tasked itself with seeing how they might contribute to central plant optimization. After study to understand the system, they elected to investigate the variable-speed campus loop pumping. The team focused on creating a useful metric within the BAS trend-log context.

Data were collected and plotted for BTU delivery and motor power. The metric of MBTU per KW indicated the pumping system efficiency, in particular whether speed was varying at light loads. The VFD percentage was independently plotted. Finding that pump speed only varied downwards with load to a point, the team learned that the pump speed control was based on the dynamic minimum requirement of any of several buildings on the loop, rather than on loop pressure itself. This led to suggestion to investigate the actual pressure requirements at various buildings on the loop. This is a more detailed experimental investigation that we hope a next round of students will pursue.

This project did not focus on BRT so much as on the cognitive approach of developing a key metric. To establish the value of their metric, students developed an initial quantification of the costs of over-pumping. The chief engineer, quite understandably with several fires to fight, has not thus far been motivated to use the metric, since any over-pumping that might exist is not threatening operations. Students from the team continue to work on the project, collecting chilled water and chiller plant data to examine for possible tuning.

Data was readily extracted from the ALC trend logs for use in ECAM and in spreadsheets built by the students. Pumping functions are not well covered in BRT ECAM so plotting was programmed using Python. Only later, when the project was continued into the summer, has data been transferred to a formally structured and maintained remote database, which was developed in connection with the John Jay project.

John Jay College of Justice. John Jay has just had a 300,000 square foot campus addition, with a Siemens Apogee BAS. Commissioning continues through construction close-out even as the building is fully occupied for full academic use. Our client here is the facility manager (Chief Administrative Superintendent), one step above the chief operating

engineer. This individual, SW, comes from an IT background, making him particularly attuned to the BAS as both an operational tool and a source of data.

There were a myriad of system functions about which the operations team was uncertain. We used BRT as an approach to provide structure and focus to the investigation. This approach has also had the benefit of yielding useful interim findings as we have gone along, working through building systems and individual pieces of equipment.

For this project, with the addition of resources from Dr. Ted Brown, professor of Computer Science at the CUNY Graduate Center and Director of the CUNY Institute for Software Design & Development (CISDD), we have added a point-mapping process for naming and for tracing locations back to building zones coordinated to plans, an external database developed in SQL, and formal processes for maintaining record of available data and for creating queries.

The structure of the system at this point is shown in Figure 4, showing John Jay and CCNY data both brought to a common database. The system is only partially automated and students still must manually initiate file transfers from John Jay and, from CCNY, download reports for thumb-drive transport and manual upload to the database.
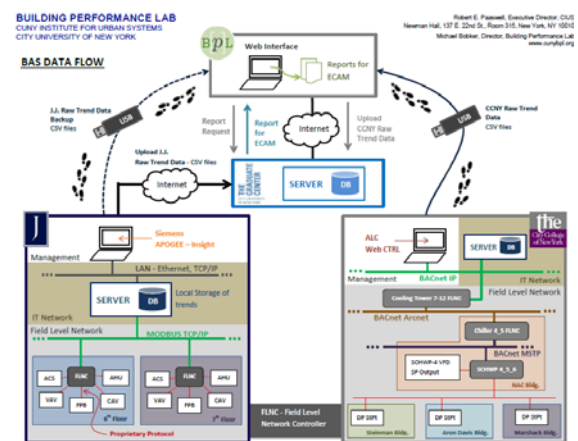

Figure 4   Data Transfer for the current CUNY BPL-CISDD Database

Dr. Brown's team has also begun experimenting with and developing data processes in "R". R is a free software environment for statistical computing and graphics. R has been used thus far primarily for data visualization trials but its integrated statistical

capabilities enables direct identification of statistical deviations in performance. The parallel machine-based statistical identification of faults with visualization for operators seems to be part of the way forward.

CONCLUSION

BAS have traditionally been the territory of control engineers and technicians writing sequences of operation into code and usually leaving them hidden from operators. Market developments emphasizing building-energy performance are now driving a data-intensive approach that is shifting control logic outside of the BAS.

There is a fortuitous and unexpected convergence between this trend and an emphasis on building operators. The new tools for performance monitoring, optimization and FDD actually open the way, through data visualization and strategic use of metrics, for enhanced operator understanding of their systems' performance and participation in controls-based performance improvement. Transparent data tools and training on them can make this happen.

The conjoint man-machine experience of "cruise control" in your car is possible for building operation. In this mode, the driver is not passive but the roles and responsibilities are clearly defined. We have not done this for buildings but it seems that we should be able to, especially as we "unpack" control algorithms from the black box of the BAS.

REFERENCES

[1] National Building Controls Information Program 2005 "NBCIP Roundtable Summary: What's Wrong with Building Controls? Part 2" Iowa Energy Center and NBCIP 2002 "Building Energy Use and Control Problems: Defining the Connection" Iowa Energy Center

[2] Brambley, Michael and Michael Bobker 2010 "How Much Automation: a debate" ASHRAE Seminar

[3] Norman, Donald, 2007 The Design of Future Things p3

[4] see, for example, the papers collected in Noyes, Jan and Mathew Bransby 2001 People in Control: Human Facotrs in Control Room Design Institution of Electrical Engineers

[5] Samouhos,S KGS Buildings work in progress, ASHRAE Research Project No. 1633 "Interfaces and Data for Advanced Building Management and Operation", unpublished

[6] Yee, Gaymond and Tom Webster 2004 "Review of Advanced Applications in Energy Management, Control and Information Systems" Trends in Energy Management-Part 4 FEMP LBNL53546

[7] Yan Lu, Siemens Corporate Research, personal communication, meeting of 8-9-123

[8] Gillespie, Kenneth, Phillip Haves, Robert Hitchcock Joseph Derringer and Kris Kinney 2007 "A Specifications Guide for Performance Monitoring Systems, version 1" Lawrence Berkeley National Lab

[9] Lu, Yan, Siemens Research Corporation, private communication, 2012

[10] Granderson, Jessica , Mary Ann Piette and Girish Ghatikar 2010 "Building Energy Information Systems: User Case Studies" Energy Efficiency open access at Springerlink.com

[11] Ibid.

[12] Claridge, David 2011 "Building Simulation for Practical Operational Optimization" in Jan Hensen and Roberto Lamberts Building Performance Simulation for Design and Operation Spoon Press

[13] Bailey, Trevor, Z.O'Neill, P.Haves, X.Pang 2012 "Automated Continuous Commissioning of Commercial Buildings" ESTCP Project EW-200929 Final Report, United Technologies Research Center and Lawrence Berkeley National Lab for

USDOE 2011; Lu, Yan 2012 "Advanced, Integrated Control for Building Operations to Achieve 40% Energy Saving" Final Report Siemens Corporate Research US DOE DE-EE0003843

[14] Yee, Gaymond and Webster op.cit.

[15] Friedman< Hannah, et.al. 2003 "Persistence of Benefits from New Building Commissioning" Proceedings of the National Conference on Building Commissioning; Mills, Evan et.al 2004 " The Cost Effectiveness of Commercial Buildings Commissioning: A Meta-Analysis of Existing Buildings and New Construction in the United States" LBNL publication no. 56637 . Bobker, Michael 2005 "Existing Building Commissioning: Market Transformation for Persistence of Savings--Recognizing and Formalizing the Role of Operator Training" Proceedings of the International Energy Program Evaluation Conference

[16] Bobker, Berninger and T. Angerame 2008 "Building Performance Data for Operators: What Can Work" ASHRAE Seminar

[17] Ibid.

[18] Katimapaula,Srinivas. Pacific Northwest National Lab, private communication 2012