BUILDING PERFORMANCE LAB
CUNY INSTITUTE FOR URBAN SYSTEMS
CITY UNIVERSITY OF NEW YORK

BP Lab White Paper

Enabling Advanced Building Automation in Existing Buildings

The Role of a Building Automation System Assessment Tool (BASAT)

Prepared by

Stephen Samouhos, PhD   Michael Bobker M.Sc., CEM   CUNY Institute for Urban Systems

Christopher Petrone, Carol Brito Masters Program in Urban Sustainability, City College of NY

Christopher Garvin,AIA   Travis Knopf, M.S.,   Cook+Fox / Terrapin Bright Green Consulting

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Anthony Abate, Project Manager

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0. INTRODUCTION : PURPOSE OF THIS WHITE PAPER

Commercial building owners and operators have many opportunities for improving building performance through the technologies available in modern building automation systems (BAS) and, increasingly, many third-party BAS applications. Despite the growing set of useful advanced BAS features, market experience suggests that owners and operators are slow to adopt these new features into their buildings. Cost is obviously one barrier.[1] But many of the potential improvements are relatively low cost additions that can be made to existing hardware or software infrastructure. Or may even be operational routines that are already present but not utilized![2] Consequently, we believe that an important barrier is Owner Uncertainty in decision-making about a complex and changing technology.

There is uncertainty about what technology options to choose. There is uncertainty about how much new infrastructure is required. There is uncertainty about whose recommendations to trust. And there is uncertainty about how much of whatever is new will actually be used by operators.

The purpose of this white paper is to suggest how an evaluation tool could help the market overcome these uncertainty barriers. A BAS assessment tool would provide the basis for a standardized approach to evaluating existing building infrastructure relative to desired BAS features. For example, the tool may include a checklist to confirm such things as appropriate sensors for monitoring of specific systems, integration of utility meters, programmability for complex algorithms, interoperability, capacity for data transfers and new visualization tools (dashboards). What points and capabilities are present? What points and capabilities are needed for specific building functions? What is necessary to add them?

Many benefits could be realized from this tool: the industry would gain a common, shared vocabulary for talking about and evaluating BAS infrastructure; owners would be able to compare buildings across their portfolios and have a consistent basis for drafting improvement plans and issuing "good housekeeping seals"; consultants would have a standard template and industry-accepted guidance upon which to base their evaluation and advice; and vendors would gain an explicit industry benchmark

[1] Brambley et.al., 2005 “Advanced Sensors and Controls for Building Applications: Market Assessment and Potential R&D Pathays” Pacific Northwest National Lab, PNNL-15149, pp2.6, 2.32

[2] The role of operator knowledge is considered in Brambley, op.cit. 2.5 and TIAX 2005 “Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential” US Dept of Energy.

which both they and their customers can agree upon. For operators, the industry would gain a clear, consistent framework from which training on ***generic*** BAS functions can be conducted.[3]

We consider the issues in the following sections:

1. **Technical Context**
2. **The Commercial Real Estate Context of BAS**
3. **The Social Organization of BAS: Stakeholders**
4. **A Technical Framework for BAS Improvements**
5. **Building System Examples of the BAS Assessment Tool (BASAT)**
6. **BASAT in Overcoming Socio-Technical Barriers to BAS Improvement**
7. **Conclusion: Development Next Steps**

We conclude the paper with an outline of the tool's functionality and design, which we hope will elicit constructive feedback from the BAS community to refine our conceptual design of the assessment tool.

1. TECHNICAL CONTEXT

There is a robust body of procedural tools for energy and functional assessment in buildings, including the following notable energy audit and commissioning guidelines:

- ASHRAE Procedures for Commercial Building Energy Audits
- Building Commissioning Guidelines by the California Commissioning Collaborative
- Procedural Standards For Retro-Commissioning Of Existing Buildings, published by the National Environmental Balancing Bureau (NEBB)
- Model Commissioning Plans & Guide Specifications, and Functional Testing Guides, published by PECI

This literature, however, focuses on energy or functional testing for buildings and building assessments, not on assessing BAS features and components. Some of this literature points to dependence upon BAS, especially for data, but does not evaluate BAS capabilities.[4]

Traditionally energy audits and commissioning studies are conducted manually through a series of standard processes. One recent innovation has been the addition, by individual service providers, of Demand Response opportunity integrating with energy efficiency.[5] Most recently companies have

[3] Vendor training in specific system programming is already well established in the market and will remain a key feature.
[4] PECI A Building Owner's Guide to Existing Building Commissioning and Pacific Northwest National Lab's Building Re-tuning protocol.
[5] See product offerings by EnerNoc as a leading example of this approach

attempted to automate some of those processes within software tools. Such tools for energy audits and commissioning tend to focus on expediting the documentation processes for those services, accelerating the collection of pictures, text, and field readings and their assembly into a final report.[6] Other new companies have focused on remote audits using analytics derived from downloaded interval data and satellite imaging.[7]

The importance of standardized rating and ranking for industry evaluation of building performance has been established by EnergyStar's benchmarking process. Along these lines, researchers at the Hong Kong Polytechnic University have proposed a rating system for Intelligent Buildings.[8] Their proposed system looks at both automated building functionalities and degrees of integration, as assessed via survey. Beyond this there is limited attention in the academic literature to assessment of existing automation systems; the weight of discussion about building controls seems placed on advanced topics such as agent-based and neural network approaches.[9]

While not addressed by academic researchers, there is a small stream of on-going attention to BAS up-grading in the professional building management literature. This literature consists of columns and feature stories, often headlined on the cover page, providing "how-to" tips for a successful project; some coverage is provided of organizations that have taken a systematic approach to the BAS in their property portfolios.[10] A review of the BACnet International Journal from 2010 did not find any articles addressing field testing or evaluation of existing systems for up-grade.

Discussions with technology experts, including leading sales executives from global BAS vendors suggests that the industry as a whole does not possess any BAS-specific assessment tools that can be applied to identify missing or improvable BAS features.[11] Overall, the proliferation of new and existing BAS features is primarily driven by business relationships between vendors and clients, where trust, not standards or processes, leads to technology adoption. Some of these discussions, however, also

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[6] See for example the recently released KWHours product
[7] See websites of recent market entrants First Fuel and Retrofficiency
[8] Wang, JKW, et.al. "Intelligent Buildings Research: A Review" Automation In Construction volume 14 (2005)
[9] see for example, Dounis, AI, Caraiscos, C, "Advanced control systems engineering for energy and comfort management in a building environment-A review" Renewable & Sustainable Energy Reviews Volume: 13 Issue: 6-7 Pages: 1246-1261
[10] "Steps to Success with Controls Upgrades" Building Operating Management January 2012; "New Capabilities Boost AS/EMS Performance" Building Operating Management October 2011; "Smart Meters and Energy IQ" Buildings January 2011. Also see Paul Ehrlich's monthly column on Building Automation in Engineered Systems.
[11] These discussions were conducted informally by the principal authors throughout the course of the White Paper development. Since discussions were informal and not for attribution, individuals are not named here; more specific information is available as a separate document, available upon request.

reveal that vendors perceive that they could benefit from a tool like BASAT, by standardizing their internal sales process for qualifying prospects and driving adoption of new technology[12].

In the same vein as energy auditing tools, Demand Response assessment tools also focus on building energy questions and notably the simulation of DR potential for a building, not an assessment of infrastructure needed to implement DR[13]. In fact, other research work focused on DR has explicitly discussed the need for tools to help owners and managers understand and evaluate their internal BAS infrastructure for DR applications[14]. Discussions with industry experts suggests that the solutions sales process once again drives DR assessment tools to focus on the verification of DR potential rather than infrastructure capability. Sales processes within the BAS industry focus first on establishing the value of infrastructure improvement, and then on the challenges associated with implementing that improvement. This follows naturally from the perspective of qualifying worthy sales opportunities before investing time in developing a complete solution for the customer. The proposed BASAT assessment tool could simplify DR infrastructure assessment such that it could be integrated with the analysis of a building's DR potential.

Summary: *Literature review and expert testimony lead to our conclusion that traditional energy audit, system commissioning and DR assessment processes would be complemented and strengthened by BASAT.*

2. THE COMMERCIAL REAL ESTATE CONTEXT OF BAS

Sophisticated BAS are found in primarily in large commercial properties; BAS are estimated present in about 10% of the 4,700,000 commercial buildings nationally, with likelihood of having a BAS increasing with building size.[15] In NYC the concentration of larger properties is higher than nationally. NYC identified 22,000 buildings of 50,000 square feet and larger, two-thirds of which are apartment buildings.[16] Smaller commercial and apartment buildings have less sophisticated control systems, which may be good candidates for upgrading to "BAS-lite" systems that are being designed to achieve many of the functionalities of full-fledged BAS.[17]

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[12] Private conversations with Chip Simek, Sales Account Executive with Schneider Electric, Boston
[13] See for example, the "Demand Response Quick Assessment Tool" published by EERE and originally created by LBNL
[14] Kiliccote, S, Piette, MA , Ghatikar, G, "Smart Buildings and Demand Response", Physics of Sustainable Energy II: AIP Conference Proceedings Volume: 1401, 2011
[15] Brambley op.cit. 2.7
[16] NYC PlaNYC2030
[17] Brambley op.cit. 2.8

Building automation systems (BAS) scale to meet the size and complexity of the building that they serve. Historically this has been in a challenge in large buildings since BAS began to evolve in the 1960's with a layering of central monitoring and control over non-digital, pneumatic and higher voltage monitoring and control devices. Since then, BAS vendors have reduced the costs and complexity of installing and operating a BAS by transitioning to fully digital and electronic control, command and monitoring systems. The latest generation of BAS has become even more useful by adopting web-based functionalities, inter-operability standards, and sophisticated graphic interfaces. However, while the potential exists for BAS to integrate the major systems in the building,[18] incorporating lighting, fire/life safety, vertical transportation, access and security, they remain largely focused on their traditional primary function to maintain HVAC comfort conditions for building occupants.

HVAC Configurations in NYC Class A and B Buildings. Urban commercial properties are divided into classifications that generally reflect the overall quality and associated rent, with designations of Class A and Class B[19]. In NYC Class A and Class B buildings may be broadly characterized as having two types of HVAC system configurations respectively: highly centralized and hybrid-distributed systems. "A" buildings typically have centralized systems (left image in figure 1) that rely on a central heating and cooling plant distributing steam or hot water and chilled water to air-handlers and perimeter systems (such as induction units and fan-coils). HVAC utilities that maintain space comfort conditions are part of base building operations and are provided as part of the lease; only terminal elements reside in tenant spaces. In contrast, Class B buildings are more variable, with systems (right image in figure 1) that may produce heating and cooling utilities in various combinations at a central plant AND through local or zone-based devices. For example, a common "B" building configuration has a boiler along with packaged terminal air-conditions (PTAC) or packaged air-handlers that provide cooling near the point of use. In this case, the cooling equipment may be owned and operated by the tenant. Tenant air-handling equipment might also include gas-fired or electric heating to supplement perimeter steam, supplied by the building. There is a great variety of equipment and of the level of service it receives.

[18] This perspective of "Convergence" has been a major theme of CABA, the Continental Automated Building Association, http://www.caba.org

[19] The *Building Owners and Managers Association* (BOMA) defines Class A and B buildings as:
Class A: *Most prestigious buildings competing for premier office users with rents above average for the area. Buildings have high quality standard finishes, state of the art systems, exceptional accessibility and a definite market presence.*
Class B: *Buildings competing for a wide range of users with rents in the average range for the area. Building finishes are fair to good for the area. Building finishes are fair to good for the area and systems are adequate, but the building does not compete with Class A at the same price.*

It is common to find varying design approaches, sometimes within the same building, depending on a building's retrofit and tenant history. For example, while most NYC Class A buildings rely on a central plant with hydronic distribution, some newer "A" buildings pass utilities to tenants by providing

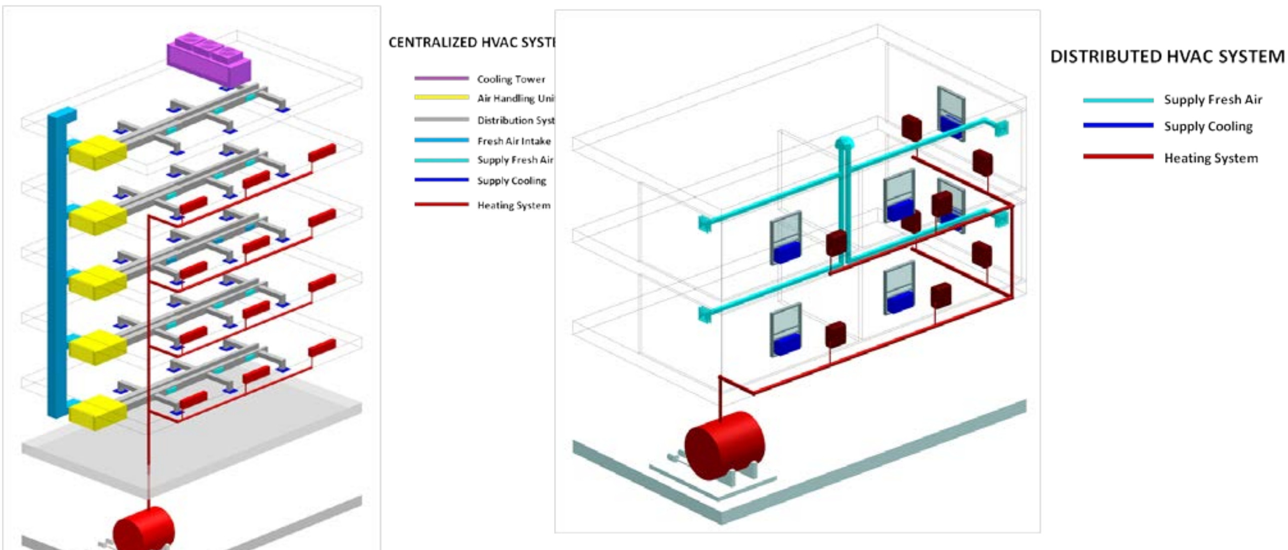

Figure 1 Centralized (left) and hybrid-distributed (right) HVAC systems.

water-source heat pumps with a base-building low-temperature boiler/cooling tower loop. Class B buildings tend to be older, often of pre-war vintage and hence typically utilized distributed cooling equipment that was easier to retrofit into the building. Installations were often done incrementally as part of tenant fit-outs. The Empire State Building is an interesting case of a 1930's building long classified as a "B" that has recently undergone tenant-space changes to re-position it as an "A." BAS deployments face challenges in integrating multiple system components in highly variable HVAC configurations.

"A" buildings are the main target for control vendors and would seem to offer the prime market for controls retro-commissioning and up-grades. They constitute a large but nevertheless limited market; in NYC constituting several hundred million square feet but concentrated in only several hundred buildings. In "B" buildings, with their tenant-controlled HVAC equipment, there would seem to be much less opportunity for BAS and, in fact, this is reflected in the current market where "B" buildings have limited or no integrated BAS.

We, believe, however, that there may be an emerging sub-market for BAS where "B" buildings would like to move up-market to become or approach "A". This up-scaling requires improvement in building services but, unless the building is going to be fully vacated, changes will have to be made incrementally, as tenants choose to renew leases or leave. New lease-ups are beginning to feature what are being called "Green" provisions, under which owner and tenant undertake new obligations to one another towards the mutual goal of a sustainable high-performance building[20]. In this context, a BAS provision can set a standard such that all new tenant equipment needs to be compatible with a central building system. With this in place, the owner incrementally gains access to better information, with which he can improve the level of building service, providing advisement to tenants about their systems or even assuming direct service. What is especially attractive here is that the BAS becomes part of the owner's core strategy for the property and a key part of the justification for higher rents.

NYC Sustainability Policy. The City of New York has taken leadership in building sustainability with a series of new local laws, grouped under the rubric of "Greener Greater Buildings" that apply to all buildings 50,000 square feet and larger. Within this set, Local Law 87, makes an energy audit and retro-commissioning mandatory on a ten-year cycle.[21] These new requirements, coupled with rising energy rates, have made BAS installation, operation and maintenance a potentially attractive business focus for many entities. The role of BAS in facilitating the retro-commissioning process has been often recognized.[22]

A Significant Industry Segement. Beyond the boundaries of New York City, recent publications by BCC Research in 2010 announced that "*Investment in Energy Management Systems (EMS) for commercial buildings will total $67.6 billion during the period from 2010 to 2020…Improving energy efficiency in commercial buildings via advanced diagnostics, applications that monitor and adjust energy usage based on usage patterns, and overall automation are all products and solutions that are seeing sustained growth across a broad range of building types and uses.*" As a consequence of the potential for dramatic growth opportunity there is a need for infrastructure assessment standards for qualifying BAS improvement opportunities that are accessible and useful to all market stakeholders. Such standards would promote transparency across the industry and ultimately make customers more comfortable with investing in infrastructure improvement projects.

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[20] www.nyc.gov "MAYOR BLOOMBERG ANNOUNCES FIRST EVER LEASE FOR COMMERCIAL OFFICE SPACE THAT CONTAINS GROUNDBREAKING LANGUAGE THAT INCENTIVIZES ENERGY EFFICIENCY"

[21] For an overview of the new legislation, see http://www.nyc.gov/html/planyc2030/html/about/ggbp.shtml

[22] Many RCx guidelines start with requiring the availability of a BAS. See for example PECI 2007 A Retro-Commissioning Guide for Building Owners. http://www.peci.org/sites/default/files/documents/epaguide.pdf

3. THE SOCIAL ORGANIZATION OF BAS

The utilization of BAS is powerfully determined by the interests, knowledge, and skills of organizations and individuals. The original and over-riding concern with comfort conditions, for example, allowed energy meters to remain unconnected to BAS until very recently, ironically even when called “Energy Management Systems.” Modern BAS do often now integrate energy meters but typically only for the purpose of networked data collection and greater ease of meter billing; there is still little use of energy data within “Energy Management Systems”. Major vendors have long held a “lock-in” business model for keeping customers on their platforms while selling after-market services such as programming and system maintenance. Poor documentation and training has made building operators quite likely to by-pass and over-ride poorly understood BAS functions. As a more performance-driven model of building operations emerges, use of the BAS will be a critical element but will be handicapped by human factors such as operator training and education about the more complex system features and interactions.

Stakeholders and their Perspectives on BAS. We have segmented the market actors around BAS into four distinct Stakeholder groups, each with specific perspectives on BAS and potential uses for an assessment tool. We add state and federal government as a fifth kind of stakeholder.

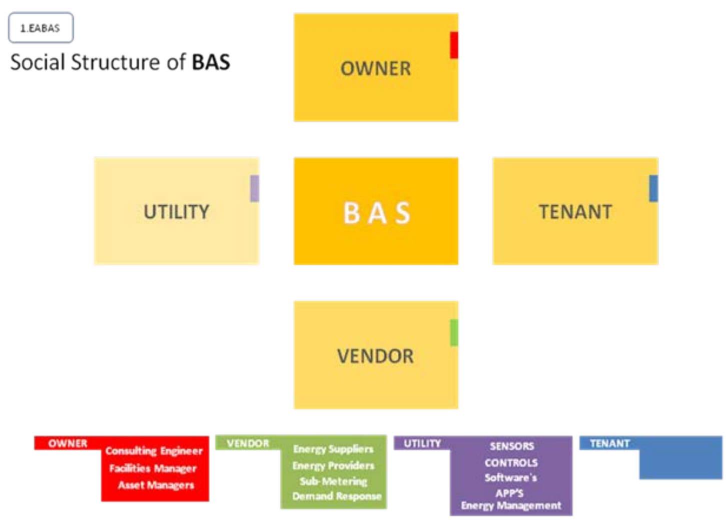


Figure 2 Stakeholders in BAS utilization and

(A) Owners: organizations that either own, represent or advise the ownership of a building; the BAS focus here is relative to the selection and utilization of BAS features .

- **Asset/Property Managers:** personnel responsible for the financial operation of a building and who may serve as advisors to owners and tenants
- **Facility Managers and Operating Engineers:** personnel who operate the building and use the BAS on a day-to-day basis.
- **Engineering Consultants:** providers of technical expertise to whom Owners turn for system recommendations

Engineering companies and consultants could use a standard BAS infrastructure assessment tool to offer portfolio wide BAS assessments that are metered by a common benchmark. Much like the impact of Energy Star rating on the broader aspect of building energy efficiency, a standard for BAS infrastructure assessment allows a large population of people to participate in and interpret the results of investigation. This in turn gives credence to participating in such an assessment since the results can be more meaningful than an isolated and one-of-a-kind investigation, as most retro-commissioning projects are perceived. From a business perspective, a standard BAS assessment tool allows engineering companies and consultants to streamline their offerings, focusing the education of their employees to meet a standard, and ultimately making such assessments less costly.

At the same time, asset managers and facility operators could use the new standard tool to validate the activities of their engineers and consultants, and also show their employers that a regulated action was taken to investigate improvement opportunities for their building.

(B) Vendors: this stakeholder group includes all members of the industry that deliver BAS solutions that can be specified or purchased by ownership stakeholders. Primary focus on BAS functionalities for the client and the business propositions involved in delivering useful solutions.

- **Equipment manufacturers:** stakeholders that manufacture, sell and install components for a BAS - sensors actuators, processors and programming services -- who may be integrated with suppliers of HVAC and other building system equipment
- **System integrators:** companies who sell and install BAS and provide integration services for unifying building automation onto a single platform
- **Third-party software providers:** a new breed of vendors in the BAS world, these stakeholders offer software solutions that leverage a BAS platform to deliver new, software-based, services and products in buildings.
- **Performance Service Providers:** offers energy performance contracts that utilize software for monitoring, measurement and verification. Some of the major BAS manufacturers were early – and remain - participants in this kind of offering.

Vendor stakeholders can use a standard BAS assessment tool to streamline their offerings according to the assessment tool, and also contribute product information to be included in the tool itself for educating the customer about new BAS features. The tool could essentially serve as a vendor-neutral platform for educating customers about new and successful BAS features, while helping BAS vendors focus their offerings to meet the results of the standard BAS assessment. Both of these functions serve to reduce the cost of best-in-class features through cost-competitive market demand, while accelerating proliferation of the best BAS ideas.

(C) Utilities: utility stakeholders issue, contract, deliver, meter or help manage utilities for a building. Primary focus on BAS role in interfacing buildings to the grid for load management.

- **Utilities:** distribute electricity, gas and district steam. They control metering and meter data, and are increasingly interested in BAS as a potential interface point for load management, demand response and evolving “SmartGrid” programs.

- **Energy Service Companies (ESCOs):** companies that engage customers through commodity sales, power-purchase agreements and other energy services could leverage the BAS assessment tool as a complement to energy auditing activities in order to rapidly identify building load profiles for commodity purchasing, contract management, and potential improvements for financing through energy savings contracts (see "Performance Service Providers" above).
- **Sub-metering companies:** can integrate sub-metering with BAS for various functions, including automated billing, record keeping and additional data driven services like utility theft detection, and mining energy efficiency opportunities

(D) Tenants: tenant stakeholders are related to the operation of BAS primarily through BAS role in comfort and workplace conditions and, in some cases, utility cost control. In some cases, larger tenants may have their own BAS that may, in turn, interface with the base building's system.

- Class A tenants place a premium on leasing spaces that support the most advanced sustainable and energy efficiency technology, and to that end the BAS evaluation toolkit may be used by those tenants to validate the suitability of a candidate space lease.
- In Class B properties, metering and leasing often place energy costs on tenants, giving rise to 'split incentives' where the owner has little motivation to improve BAS functionality for energy efficiency since the tenant shoulders all of the utility costs. However, recent "Green Lease" approaches to bridging the split incentive require shared information, much of which may usefully come from an appropriately configured BAS.

(E) State and federal funding agencies. Federal and state funding agencies may be seen as an additional stakeholder by virtue of delivering incentives to promote energy efficiency and, in this connection, the adoption of new or improved BAS features. The transparency of a standard evaluation toolkit can help utilities accurately gauge where incentives need to be deployed in order to spur customer investment in the most useful BAS features.

4. A TECHNICAL FRAMEWORK FOR BAS IMPROVEMENT ASSESSMENT

We began by thinking that we would survey the building systems subject to automation, assess what capabilities are in place, and from there identify potential areas of improvement. This led us to an overview listing that might be useful for structuring a building survey.

BUILDING SYSTEMS	**FUNCTIONS**
• HVAC	• Utility metering/sub-metering
• Fire and life safety	• Alarms and notifications
• Security and building access	• Demand response and load management
• Ventilation (Indoor Air Quality)	• Data acquisition and storage
• Envelope monitoring and control	• Data analytics and visualization
• Lighting systems	• System inter-operability
• Power Distribution (quality monitoring)	• Occupant complaint/satisfaction systems
• Plumbing Systems (eg - leak detection)	• Maintenance Management (CMMS)
• Data Centers and communications	

We expect that this listing will provide the basis for developing an overview portion of a survey tool. It did not, however, provide us with necessary analytical discrimination about how systems might be improved.

BAS are built from a common set of basic components including sensors, controllers, workstations, actuators, communication buses and human operators. They have become increasingly built-up and layered in their functionalities, such that conceptual levels must be discriminated. This is well represented by Figure 3. A hierarchy of devices and operations suggests distinct levels at which improvements may be pursued.

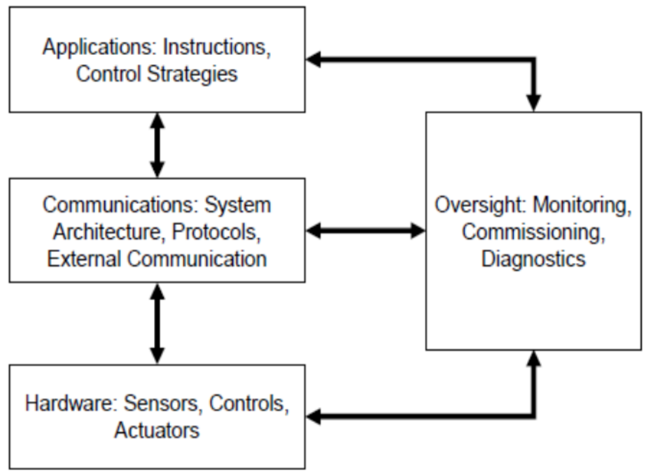


Figure 3 A Conceptual Framework for BAS Source: Brambley et al. 2005

Also in this figure, the concept of "oversight monitoring, commissioning, diagnostics" is introduced as standing outside of the baseline control process. BAS were not originally designed for this monitoring function and it introduces a new dimension of data communication and management. Gillespie et.al explored the requirements for varying levels of monitoring, albeit with reference to new BAS systems.[23]

How such requirements might be handled by existing systems is a critical but difficult question. We have repeatedly found in field experience, operators -- and even sometimes vendors -- to be uncertain about the ability of a system to handle trend-log data collection without compromising its ability to process higher priority control functions. This is a key question that the industry needs to be able to answer with a testing protocol for communications bandwidth and local data storage capacities for periodic data retrieval.

A BAS Stack. The hierarchy of devices, communication, and instructions as an integrated BAS suggests the IT concept of "the stack", through which data inputs are passed, converted, used and returned as outputs. A similar use of the stack concept to articulate the structure of BAS has recently been put forward by the Johnson Controls Institute for Building Efficiency.[24] Our stack differs in including a specific user "operational" level, recognizing the current status of the industry, in which the

[23] Gillespie, K. et.al. 2007 A Specification Guide for Performance Monitoring Systems LBNL http://cbs.lbl.gov/performance-monitoring/specifications/pdf/PM%20Spec%20Guide%20Version%201_2007-03-23.pdf

[24] Nix, Olivia "Building Information Technology and Management: Issue Brief" December 2011 http://www.institutebe.com/InstituteBE/media/Library/Resources/Smart%20Grid_Smart%20Building/Issue_Brief---Building_Info_Tech_and_Mgmnt.pdf

operating engineer plays an active role in determining control functions. We segment the BAS, including its human and machine components into the following BAS stack:

STACK LEVEL	
Reporting	Analytics processing, communication and display for managers, service providers, other users of building information
Data Management	Data capture, storage, and processing at centralized points across the building network
Operational	User interface with instantaneous data displayed, system documentation, and access points for user input
Control	networked controllers communicate at the building level, executing coordinated, programmed actions
Field	Field devices exchange inputs and outputs and execute actions in simple, local control loops

Figure 4 BAS "Stack"

At the bottom of the BAS stack are the field level devices that include sensors, actuators, and field level controllers; these are the devices that locally move, sense, and manage the conditions in a building. Above the field level devices is the control layer comprised of building-level controllers and their programming, network routers and other data gateways; these devices enable network level operation of the BAS across an entire building. Beyond control, the operation level of the BAS stack includes human operators and their training, system documentation, and software interfaces for using the BAS. The software available at this layer includes interfaces for programming the BAS, responding to its alarms, and monitoring its performance. Continuing upwards in the BAS stack is a data management layer that enables capture, storage and processing of data. It is at this level that capacity resides (or would be added) to enable information-based functions beyond the control data, which utilizes instantaneous and volatile data and instructions. The last layer of the stack provides informational functions for management oversight, external vendors and service providers, and building users (tenants, etc. New BAS software technologies aim to capture the attention of management personnel through high-level reports on environmental stewardship and energy efficiency.

BAS Improvement. Advanced BAS features may impact and alter any of the stack components. This leads to a categorization of types of improvement:

A) **Equipment-based:** 'smart' devices (sensors, actuators, with on-board diagnostics) or just additional sensors and actuators in various locations to create much richer data environments and control opportunities.

B) **Intelligence-based:** algorithms and analytics that help automate or improve energy conservation and building performance optimization; for example, these could include control strategies for load profile management and demand response, or analytics for fault detection and diagnostics.

C) **Processing-based:** system features that enhance BAS data storage, computation, communication and interoperability; for example these could include BACnet gateways, Ethernet communications and cloud storage of data

D) **Interface-based:** human-machine interfaces that improve the use of the BAS or people's satisfaction with its operation; for example this includes new software interfaces, dashboards and kiosks.

E) **Design-based:** technologies and methods that streamline BAS design and implementation for a building; for example these include the use of BIM or simply better operations manuals.

To understand the range of improvement opportunities, we can plot these improvement categories against the levels of the BAS stack, leading to the 5 x 5 cell table.

			Improvement Process				
			A	B	C	D	E
			EQUIPMENT-based	INTELLIGENCE-based	PROCESSING-based	INTERFACE-based	DESIGN-based
BAS Stack	5	REPORTING Level				*dashboards, messaging*	
	4	INFO MGT Level	*storage capacity. data extraction*		*analytics, external data*	*visualization*	*BIM*
	3	OPERATIONAL Level	*mobile interface*	*fault detection & diagnostics*		*documentation, sequences*	
	2	CONTROL Level	*data exchange*	*predictive control*	*com-based integrations*		*inter-operability*
	1	FIELD Level	*added sensors, wireless, smart components*	*self-diagnostics, self-calibration*			*plug-and-playcomponents*

This table proves useful in identifying and defining improvements. We can simply implement better control routines, as in Cell 2B. But some control routines may need external data – weather, prices—and therefore depend on external information access (4C), which raises IT issues of security and fire-walls. Cell 4A underlies many other improvements as the necessary data platform for moving from control to data-based analytics and FDD. The resources available in cells 2A and 2C constrain how much information can be transferred over existing control wiring. *Equipment* and *Processing* capabilities might be evaluated on the *Reporting layer* by looking at the data storage and computational resources of the server that underlies management dashboards.

New capabilities cannot be realized without the underlying data infrastructure. Test methods, not readily available in the market, are required for evaluation of such resources. This is a major issue for existing systems. Business models are based on it. Manufacturers can use it as a leverage point for the sale of new systems or substantial up-grades.[25] A newer kind of "third party" vendor is promoting a model that ports data out of the system for housing on a separate site (or in the cloud), analytical processing, and return of relevant inputs. There is presently no clear guidance on which pathway to follow. While we are beginning to have guides that aid engineers in testing the control response of mechanical systems,[26] we do not have such procedural guides for BAS evaluation.

The 5 x 5 approach proved too abstract, especially in the absence of resource evaluation tools, to serve as the basis of a field assessment tool. Instead we turned to a more building-system based approach. We asked, what specific system features would be attractive and could we evaluate how they would be implemented by controls. In taking this more concrete approach, we realized that the BAS evaluation should be intended to help owners, operators and vendors assess a BAS for the deployment of specific, useful BAS features.

The evaluation process should address not only "advanced" implementations, typically of system up-grading or new controls sales but also what we might call standard or "classic" BAS control functions. Features from both of those categories deserve inclusion in the evaluation toolkit, since there are many buildings that lack even ostensible 'classic' BAS features or where they have become non-functional and need to be retro-commissioned.

In other cases we realized that the BAS evaluation turned on the ability of the BAS to integrate multiple systems or impose universal constraints to optimize whole building performance. Automated Demand Response (ADR) is a good example of a BAS feature that ultimately imposes the constraint of minimized electric demand on the global optimization of control in the building. Demand-Controlled Ventilation (DCV) is another example of a feature that imposes the constraint of minimum outdoor air ventilation across the building.

Toolkit Evaluation of BAS features. As we looked at samples of building system features that could be enabled, the evaluation procedure developed into a list of triage questions, much like a troubleshooting guide, to help the evaluator determine if the existing BAS can support a specific feature; conversely, the evaluation toolkit is also intended to help evaluators determine what BAS improvements

[25] Tiax, op.cit. indicates that 75% of new system sales are in existing buildings, which presumably includes new systems that replace pre-existing ones.

[26] PECI's functional testing guide can be found here http://www.peci.org/ftguide/ . It is one of the most extensive resources to-date emerging from the needs of the relatively new commissioning industry.

are needed in order to realize a certain feature. We realized that the toolkit could be based on a library of features cast in the same format and with a consistent set of basic toolkit evaluation questions such as:

- Does the BAS have the sensors and actuators needed to enable the BAS feature?
- Does the controller have the processing capability to consume the sensor data, execute the algorithm, and effect control, in a reasonable amount of time?
- Does the BAS have a corresponding graphic that enables operators to understand what the feature is doing to the building?
- Does the BAS communication network support collecting the necessary data for the feature, internal and external of the building?
- Does the BAS handle external signals in a secure manner?
- Is the BAS designed to make the best of the BAS feature?

While this approach actually emerged out of examining various building feature optimizations by controls, we reverse the order and in the following section provide examples of this procedure. The experienced reader may wish to scan quickly through this section.

5. BUILDING SYSTEM EXAMPLES OF THE BAS ASSESSMENT TOOL (BASAT)

BAS features from lighting systems, HVAC controls, demand response and data analytics were chosen for further discussion in order to illustrate the possible structure of a BAS evaluation toolkit. We chose these features for discussion because of their popularity in the marketplace and their mix of ‘advanced’ and ‘classic’ features. Each feature is discussed and reviewed according to BAS evaluation criteria mentioned above.

Lighting Controls

Lighting controls are a broad topic with many features that can deliver significant building energy savings. For example, there are passive and active control strategies that can be used to add more day-light to a space or dim electric lighting in un-occupied rooms or stair-wells. While many of these applications might be considered ‘classic’ BAS features, there are more ‘advanced’ features that can be captured by integrating lighting controls with other BAS components.

Occupancy Lighting Control [27] [28] Occupancy lighting controls are used to modulate electric lighting based on sensed occupancy of a space. These systems are typically stand-alone installations where local sensors are used to directly control nearby lighting fixtures. There are well-known energy and maintenance benefits to utilizing occupancy lighting control, and in many states there are regulations requiring their use in office buildings. Less well known and utilized within commercial office buildings, however, is network integration of occupancy lighting controls with HVAC systems. If local occupancy sensors can be used to turn lights on and off, then they could also modulate space heating, cooling and ventilation, resulting in even greater energy efficiency from an existing set of sensors.

The BAS feature that we wish to evaluate in this case is the integration of occupancy lighting controls with the HVAC control; this would be considered an ‘advanced’ BAS feature, even though it is built on classic BAS components. The motivation for this advanced feature is to accomplish two energy efficiency strategies (lighting and HVAC occupancy control) from a single set of sensors (lighting occupancy controls) that are, in many cases, required to be installed by law. Following from our evaluation criteria described above, the tool kit may prompt the following investigative quations about the building’s automation system in order to qualify it for the advanced BAS feature:

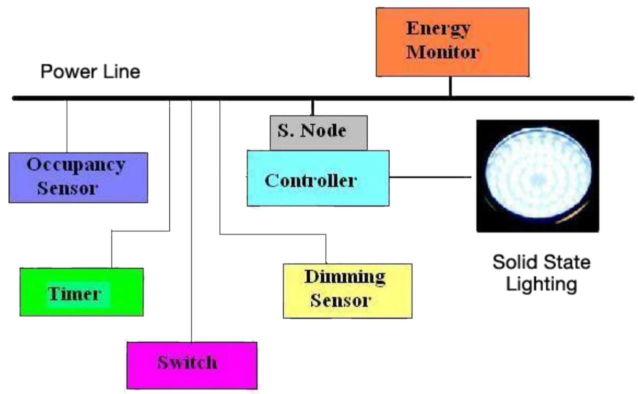
- Does the BAS control the local HVAC terminal units?
- Does the BAS provide some occupancy override control for those terminal units?
- Do the local occupancy sensors have an external output for connection to a BAS?
- Can the BAS accept input from the occupancy sensors in order to control the terminal units?

These questions follow from evaluation criteria on equipment, design, and intelligence of the existing BAS. The questions are intended to be answered in a waterfall fashion, where a ‘yes; to the first questions leads to the next one, and a ‘no’ to any question leads to a suggestion for improving the BAS.

[27] Colak, N., J. Jennings, F. Rubinstein. “Occupancy and Time-Based Lighting Controls in Open Offices.” *Lawrence Berkeley National Laboratory*. Illuminating Engineering Society of North America annual conference. (2001) 2-28. Non-print.
[28] Leephakpreeda, Thananchai. “Adaptive Occupancy-based Lighting Control via Grey Prediction.” *Building and Environment*. Vol. 40 Issue 7 (2005) 881-86. Non-print.

If the answer is 'yes' to all of the questions, then the evaluation toolkit will indicate that the 'advanced' BAS feature is possible with the existing infrastructure.

Day-lighting Controls [29] [30] While less popular than occupancy based lighting controls, active day-lighting systems have been implemented in a number of class A office buildings in New York City. The concept may be considered to be an 'advanced' BAS feature, integrating actuated blind systems with light level sensors, however the underlying technology is still comprised of classic BAS components. Daylighting control systems serve the dual purpose of reducing electric light usage and managing comfort conditions. By modulating the insolation of a space, the daylighting system can affect the use of electricity for lighting as well as the energy used for heating and cooling. For example, on a cold, sunny day, a well-integrated day-lighting system may open blinds to displace electric lighting with sunshine, and reduce active heating through natural radiation loads.



Components and sensors in an integrated lighting controller
Source: Wise Grid Solutions. <http://wisegridsolutions.com>

The success of the strategy is dependent on sufficient integration between the fenestration actuators and sensors, the electric lighting system and HVAC controls. The evaluation toolkit may guide an evaluator to explore this advanced BAS feature with the following set of inquiries:

- Does the BAS exhibit control over the local HVAC terminal units?
- Is there sufficient room to mount actuated blind systems for the space?
- Are there local space temperatures sensors connected to the BAS?
- Are there light-level sensors in the space, and are they connected to the BAS?
- Can the BAS be programmed to control the fenestration actuators, relative to light-levels and space temperature measurements?

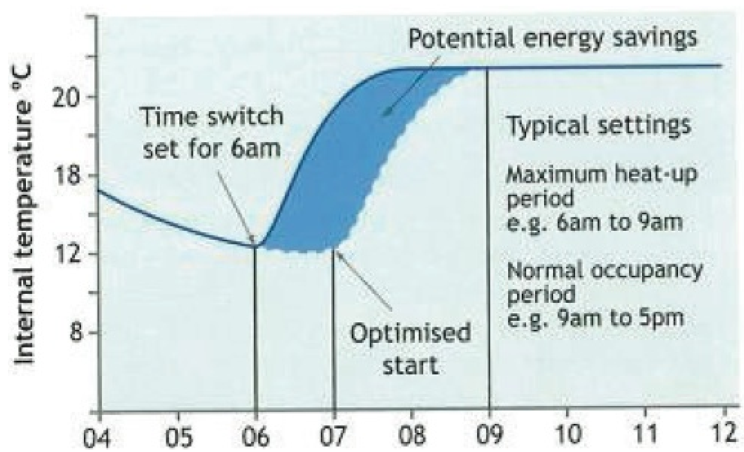
[29] DiBartolomeo, D.L., E.S. Lee, S.E. Selkowitz. "Thermal and Daylighting Performance of an Automated Venetian Blind and Lighting System in a Full-Scale Private Office." *Energy and Buildings*. Vol. 29 Issue 1 (1998) 47-63. Non-print.
[30] Guillemin, A., N. Morel. "An Innovative Lighting Controller Integrated in a Self-Adaptive Building Control System." *Energy and Buildings*. Vol. 33 Issue 5 (2001) 477-87. Non-print.

Once again, these questions can help an evaluator triage the ability of the BAS to support an active fenestration system. Examining the **intelligence**, **equipment**, and **processing** capabilities of the BAS, we can determine if the BAS is capable of supporting this advanced building feature.

HVAC Control

By far the greatest application of a BAS today is for HVAC control. Many 'classic' BAS features exist for this application, and more 'advanced' contemporary features focus on system integration challenges and fine-grained dynamic response of the building. The features enumerated below represent some of the most popular current topics in the BAS HVAC control marketplace.

Optimal Start/Stop [31] [32] Optimal Start/Stop is a 'classic' concept for HVAC control that has received renewed attention as a more 'advanced' feature due to its improved algorithmic implementation in BAS. The basic concept of the feature is to start and stop an HVAC system at times during the day that minimize energy usage without affecting comfort conditions. For example, the algorithm might determine that 7:30 am, instead of 6 am, is an appropriate time to start heating a building to meet the start of a work day with comfortable space conditions. Likewise, the algorithm may determine that 3 pm is the optimal time to shut down an HVAC system, allowing it to 'coast' through the end of the workday without using energy or causing occupant discomfort.



This description of the feature follows from its 'classic' implementation, but contemporary start/stop algorithms can include considerations for minimizing electric demand (crossing over with another BAS topic, demand response), weather forecasts, and many other factors. Even the implementation of basic start/stop algorithms using building space temperature measurements has evolved with stronger BAS microprocessors to use more sophisticated and accurate analytical models. The feature is important regardless of being 'classic' or 'advanced' because it is typically

[31] Maldeis, N., J. Murphy. "Using Time-Of-Day Scheduling to Save Energy." *ASHRAE Journal*. Vol. 51 Issue 5 (2009) 42-48. Non-print.
[32] Salsbury, Timothy I., "A Survey of Control Technologies in the Building Automation Industry." *Controls Research Department: Johnson Controls, Inc*. (2005) 1-9. Non-print.

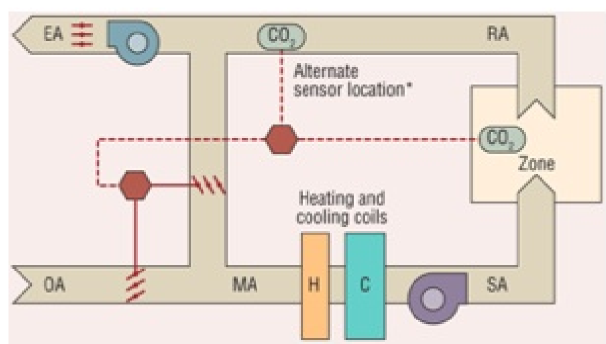
considered 'low-hanging' fruit for energy efficiency and we consistently find buildings where it is not implemented.

The evaluation toolkit may provide the following questions in order to evaluate this BAS feature in a specific building:

- Are there space temperature measurements points monitored or used for control by the BAS?
- Does the BAS control the terminal and central units that serve the space?
- Does the BAS support a 'canned' start-stop feature?
- Does the BAS have an input for the building's electric demand?
- Does the BAS have an outdoor air temperature sensor?
- If the BAS does not have a 'canned' start/stop algorithm, does it have sufficient memory and processing power to support that independent coding?

These evaluation questions can help an investigator identify additional components that need to be installed in order to support the optimal start/stop feature on the BAS.

Demand-Controlled Ventilation (DCV) [33] [34] DCV is an 'advanced' BAS feature that reduces the amount of fresh air brought into a building based upon the dynamic occupancy of a space. ASHRAE standards in ventilation dictate minimum fresh air ventilation levels based upon space occupancy in order to maintain carbon dioxide concentrations below a set-point, usually in the range of 800 – 1,000 PPM. Certain laboratory and other research spaces that are at risk for poor or even toxic indoor air quality must maintain higher outdoor air ventilation rates; these are typically computed based on threshold concentrations of substances found in the space air. Several newer companies, the leader among them being AirCuity, are implementing air-sampling-and-analysis systems that will supplement or replace simple CO2 sensors and provide more robust reporting on indoor air quality.



Fresh air ventilation incurs a high energy cost due to both the ventilation power expenditure and the tempering of that air to comfort conditions. DCV is recognized as an alternative to standard

[33] Apte, Michael G., "A Review of Demand Control Ventilation." *Lawrence Berkeley National Laboratory*. (2006) 2-6. Non-print.
[34] Stipe, Marty. "Demand-Controlled Ventilation: A Design Guide." *Northwest Energy Efficiency Alliance*. (2003) 1-12. Non-print.

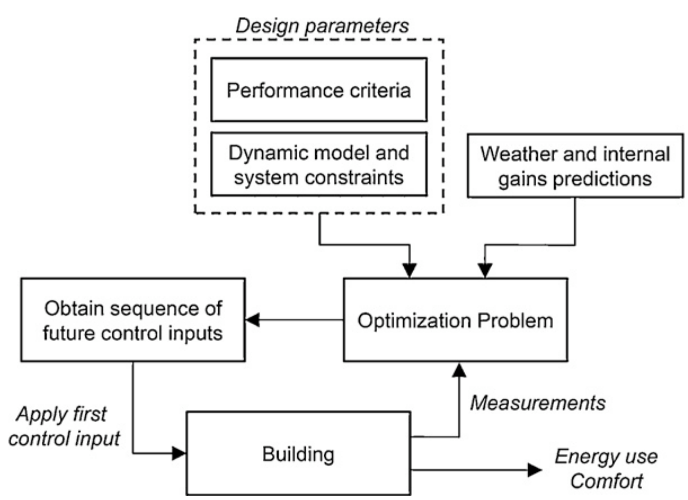
minimum ventilation requirements. Ventilation is increased or decreased by damper control and variable frequency fan drives such that the minimum quantity of fresh air is always introduced to the building without sacricing indoor air quality.

In this case, the BAS evaluation toolkit may offer the following guidance for investigating the capability of a BAS to support DCV:

- Does the BAS control the fans and dampers associated with space ventilation?
- Do the ventilation fans operate at constant speed or are they modulating?
- Are there any carbon dioxide sensors installed either at the zone level or in the retunr plenum?
- Is there sufficienct memory on the controller for adding a DCV program?
- Is there an alert system on the BAS to notify operators when the DCV algorithm alters ventilation rates?
- Are there air flow stations on the central air handlers or on the terminal units?

This initial set of questions helps the investigator immediately identify what infrastructure improvements might be necessary in order to deploy this advanced BAS feature. As the investigator asks and answers the questions, the toolkit can suggest additional questions or provide feedback on next steps.

Model Predictive Control [35] [36] Model Predictive Control is a broad, advanced set of BAS features that allows a building to operate based on forecasts of future events and conditions. This is a very powerful and new feature for BASs since it enables a building to optimize it's response to both current and future conditions. The predictive control algorithms are typically stated in the form of an optimization problem: "what choices now maximize a performance indicator in the



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[35] Gwerder, M., D. Gyalistras, C. Jones, B Lehmann, M. Morari, A. Parisio, F. Oldewurtel. "Use of Model Predictive Control and Weather Forecasts for Energy Efficient Building Climate Control." *Energy and Buildings*. Article in Press. Accepted date: September 2011. 1-13. Non-print.

[36] Kolokotsa, D., C. Lazos, A. Pouliezos, G. Stavrakakis. "Predictive Control Techniques for Energy and Indoor Environmental Quality Management in Buildings." *Building and Environment*. Vol. 44 Issue 9 (2009). 1850-63. Non-print.

future, given current conditions and their future forecasts?" For example, predictive controls can plan chiller operations over a 24 hour period such that comfort conditions are always met in a building at a minimum of peak electricity usage. Physically this might translate to planning a schedule for turning the chillers on an off in such fashion that the building's thermal inertia coupled with weather and occupancy conditions yields a comfortable space with very small peak electric demand.

There are many exogenous inputs that predictive control systems can leverage, including weather forecasts, time-of-use utility pricing and occupancy events and schedules. Likewise, there are many different technical approaches to implementing predictive control algorithms, and they can be optimized to meet a variety of objective goals.

While the analytical methods and sensory inputs for a predictive control system can vary based on its objective goal, there is still a consistent set of required evaluation parameters for deploying MPC:

- Does the BAS have a connection to the Internet?
- Can the BAS receive a feed of forecast data, typically in the form of an Internet document (XML, HTML, RSS feed)?
- Does the BAS control the central plant equipment?
- Does the BAS have space condition monitoring sensors?
- Can the BAS receive commands via an inter-operable standard like BACnet or MODbus?

MPC is a particularly unique and 'advanced' BAS feature due to its need for forecast data, most of which is only available over the Internet. While many control systems have adopted web-based functionality for viewing and commanding the BAS, very few have built in support to intake a feed of forecast data from the web. Consequently, MPC is typically offered by 3rd party vendors who can integrate an additional piece of hardware with the BAS. This reflection of the industry is included in the toolkit question concerning interoperability between the control system and other hardware via BACnet or MODbus.

Demand Response

Demand Response (DR) is a 'classic' BAS topic that has received tremendous attention in the last 5 years due to its relative ease of implementation compared to the value produced per customer. Most business models for deploying DR services are based upon paying DR constituents for reducing their electric loads at certain times. It provides the building with a contracted revenue reward for being available to reduce its electric demand for relatively short periods when called upon by utilities or grid operators, usually no more than several times a year.

At a fundamental level, DR is simply a set of features designed to reduce peak electricity usage on the grid, most often by turning off loads (and/or turning on back-up generators) within buildings. Traditional DR is considered "manual" or "slow-acting" non-automated activity in response to day-ahead or even 2-hour notice of a DR event. Sophisticated DR features may co-exist and leverage other BAS features like model predictive control or even day-lighting control to yield more "fast acting" automated response to DR opportunities. Overall, any feature that can reduce significant electric demand for a building, through peak load management or utility price response, may fall into the DR category.

Semi-Automated Demand Response [37] [38] Many of the businesses that entered the DR market in the last decade provided their services through manual processes; they would call their DR constituents to have them shut down loads, and operators would respond by manually turning their equipment off. Technology has caught up with that practice to yield semi-automated DR programs whereby building operators can shed loads through programs on their BAS, rather than manually. Moreover, BAS have evolved to provide operators with specific DR dashboards to help operators take the fullest advantage of DR events and carefully track the response of their building to equipment shut down, duty-cycling, or derating.

Implementation of semi-automated DR requires a number of BAS components, most notable of which is sub-metering on all DR-driven loads. The following set of initial evaluation questions may be included in the BAS evaluation toolkit for a semi-automated DR feature:

- Are the primary loads of the building electrically sub-metered through the BAS?
- Are those same loads controlled by the BAS, either for enabling/disabling, or derating?
- Are there space condition monitoring points on the BAS?
- Are there load-specific monitoring points on the BAS?
- Does the BAS support a global DR command for automating the response to a DR event?
- Does the BAS have a graphic interface for viewing equipment loads that may participate in DR?
- Does the BAS have a graphic interface to the building's instantaneous peak electric demand?

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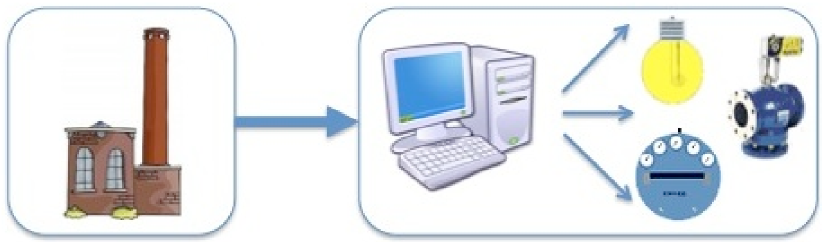
[37] Chevva, K.R., S. Fernands, N. Thakur, R. Walawalkar. "Evolution and Current Status of Demand Response in Electricity Markets: Insights from JPM and NYISO." *Energy*, Vol. 35 Issue 4 (2010) 1552-60. Non-print.
[38] Ghatikar, G., S. Kiliccote, M.A. Piette, "Design and Implementation of an Open, Interoperable Automated Demand Response Infrastructure." *Lawrence Berkeley National Laboratory*. (2008) 2-6. Non-print.

- Can the BAS receive an exogenous input for utility pricing signals?

These fundamental evaluation questions help identify the most immediate requirements for integrating semi-automated DR in the BAS. The last question is also useful for allowing the building operator to independently respond to utility price signals rather than enrolling in a DR aggregator contract.

Automated Demand Response [39] [40] Automated demand response (ADR) is the next evolution of 'advanced' BAS features related to DR. In this case, the BAS is enabled to directly receive an electronic signal from the DR provider and respond automatically with a pre-programmed load shedding plan. Alternatively, it also allows the BAS to receive pricing signals directly from the utility company and automatically alter system control in order to minimize



energy costs. Many of the components required for semi-automated DR are also required in this feature, with the added complexity of automating the response of the BAS to exogenous inputs. While ADR appears to offer the convenience of faster response times and reduced risk of human error, it also introduces other security and technology concerns; for example, what happens if there is a rogue ADR signal to the BAS, or if the BAS erroneously executes the DR plan without an ADR signal?

These issues raise additional questions for the BAS evaluation of ADR:

- Does the BAS support encrypted exogenous inputs from the Internet (i.e. HTTPS messages)?
- Does the BAS have alarms and notifications set for equipment that may respond to ADR signals?
- Can the BAS integrate ADR signals with other BAS features like model predictive control or optimal start and stop?

Data Analytics & Visualization

As BAS become more complex and automated to do more for operators, the need will grow for BAS features that help operators better manage their BAS through advanced visualization, reporting and analysis on building performance. These features are not necessarily 'advanced', since BAS graphics and interfaces have always existed, but their methods of implementation and ease-of-use have evolved

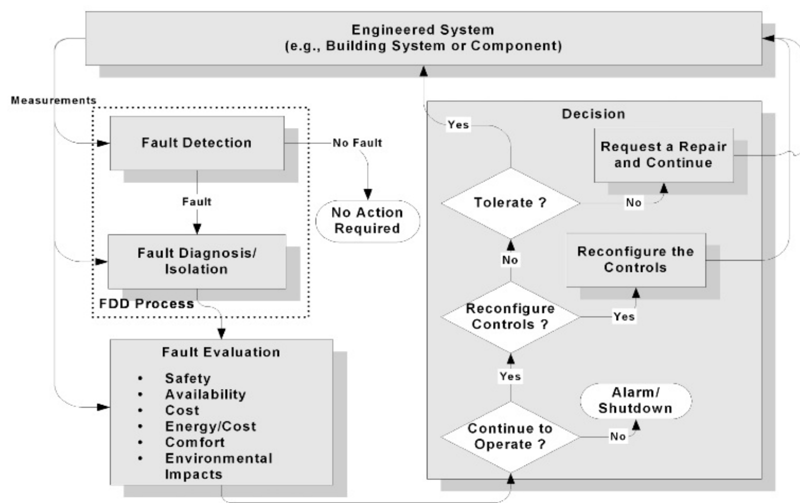
[39] Albadi, M.H., E.F. El-Saadany. "A Summary of Demand Response in Electricity Markets." *Electric Power Systems Research*. Vol. 78 Issue 11 (2008) 1989-96. Non-print.

[40] Chevva, K.R., S. Fernands, N. Thakur, R. Walawalkar. "Evolution and Current Status of Demand Response in Electricity Markets: Insights from JPM and NYISO." *Energy*, Vol. 35 Issue 4 (2010) 1552-60. Non-print.

even faster and to a greater extent than the BAS features considered previously. These types of BAS features impose greater requirements for processing, network communication and data storage capabilities, as well as more effort to design and implement system graphics and interfaces. \

Automated Fault Detection Diagnostics [41] [42] Automated fault detection and diagnostics (AFDD) is an advanced BAS feature that helps operators leverage BAS data to automatically detect and diagnose BAS misbehavior and malfunctions. This is a key feature to enabling the success of other advanced BAS features because AFDD helps ensure that the BAS is operating properly. Without AFDD, operators are left on their own to manage the BAS, which is possible but becomes increasingly difficult as the BAS is expected to do more on its own.

AFDD consumes BAS sensor, actuator and programming data within different analytical models that generate fault signals whenever discrepancies are found in the data. Alarms and notifications are the very simplest form of fault detection, but those features are only applicable to instantaneous operation of the BAS, and even then they typically apply to single variables rather than whole systems of data. In contrast, AFDD does not provide instantaneous alerts for any variables that exceed alarm thresholds, however, AFDD can detect and diagnose equipment malfunctions and improper programming.



AFDD rule tree for consuming data and diagnosing system

Evaluation questions for AFDD deployment on a BAS must consider a variety of factors, ranging from BAS sensor deployments communication network capabilities:

- What sensors exist on the BAS for the different types of systems in the building?
- Is the communication network sufficient for scalable data collection from the BAS sensors?
- Can the BAS store control system data over long periods of time, measured at arbitrary intervals?

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[41] Brambley, M.R., Katipamula, S., "Methods for Fault Detection, Diagnostics, and Prognostics for Building Systems – A Review, Part I." *HVAC&R*. Vol. 11 Issue 1 (2005) 1-20. Non-print.
[42] Pakanen, Jouko E., T. Sundquist. Automation-assisted Fault Detection of an Air-Handling Unit; Implementing the Method in a Real Building." *Energy and Buildings*. Vol. 35 Issue 2 (2003). 193-02. Non-print.

- Is the BAS data easily retrieved from the data warehouse in standard formats (i.e. XLS, CSV)?
- Does the analytics server possess the computational power to analyze all of the BAS data?
- Are the operators trained to review BAS trend data or AFDD results?

6. BASAT IN OVERCOMING SOCIO-TECHNICAL BARRIERS TO BAS IMPROVEMENT

The BAS evaluation toolkit is intended to help the market overcome barriers to the adoption of advanced BAS features by increasing the transparency surrounding infrastructure changes necessary to support those features. Even with such transparency there are other technical and market limitations, especially human factors having to do with knowledge and decision-making.

Knowledge Barriers. The BAS evaluation toolkit includes questions pertaining to topics like BAS network communication bandwidth, controller processing capabilities, data storage capacity and system interoperability. These technical questions about the installed system are central to evaluating whether a building's existing infrastructure can support a wide variety of desirable BAS features. However, they may also be difficult to answer in practice. Through our own experience with using BAS networks for extensive building data acquisition, we have found that few BAS vendors actually have the ability to test a priori whether an existing network can support scalable data collection. Likewise, IT-oriented inquiries into BAS server data storage capacity or system interoperability may be outside the knowledge domain of typical BAS vendors at the local level.

In practice, it appears that the technical research and development into advanced BAS features has outstripped the technical capabilities of typical BAS installers and control system engineers. Based on that experience it seems that BAS vendors themselves are undergoing a shift in their talent base where installers and engineers need more IT background. The result of this knowledge gap is that BAS vendors themselves may be reluctant to promote advanced BAS features that they do not feel comfortable installing or maintaining. This points to the need for increasing the education of BAS installers and vendors to include IT knowledge in order for advanced BAS features to fully take hold in the market. Beyond even IT knowledge, BAS vendors will most likely need increased education into the advanced algorithms and physics that underlie maturing BAS features like ADR, MPC, and AFDD. The last feature in particular will require BAS vendors to learn more about how to write programs for interpreting and using data to detect and diagnose BAS malfunctions. Complementary to the education of BAS vendors who must install and sell advanced BAS features is the further education and training of building operators who will have to use those advanced features on a day to day basis.

An industry standardized platform, such as might be built out from BASAT, in pointing to broadly accepted functionalities and the associated system capabilities would powerfully enable such appropriate training and education.

The Marble Lobby: Getting Beyond First Costs. Social norms, split incentives, and market constraints dissuade many building owners from exploring what could be worthwhile investments. A major inhibiting factor of BAS upgrades is first cost.[43] Building owners may not invest in upgrades to their building systems even if they are projected to have a healthy return on investment. While the first cost of upgrades is certain, the benefits often are not. Energy efficiency estimates may be overly optimistic; more data collection may require additional training for operators; the system may not work properly because of improper installation or operation; major construction may disrupt the tenants, and so on. At the outset of this paper, we pointed to Owner Uncertainty as a main barrier.

Risk-averse landlords are likely to say that if a BAS is not broke, don't fix it. The market currently values tenant comfort much more than energy efficiency. This is in part due to split incentives; most leases give landlords no incentive to perform energy efficiency upgrades because the tenant is ultimately paying the energy bill. Unless the tenant is particularly green-minded, occupant comfort and responsiveness to complaints drive Class A management, not efficiency.

When this is combined with a building management team that is understaffed or undertrained, there will likely be even less interest in adding bells and whistles to an already-functioning BAS. If building engineers are involved in the design of the BAS from the start, they may be strong advocates for a system that provides them with lots of data and control tools. This is an ideal situation, but a rare one. More likely, building engineers used to working with first generation BAS may conclude (often correctly) that these systems are unreliable, poorly programmed, prone to malfunction, and unable to accommodate new technology. Older or poorly operating BAS's can be a distraction to the building engineer's primary job: responding to tenant complaints. Efficiency and durability of building systems are usually not a part of the engineer's compensation, promotion schedule, or job security. Overcoming these cultural limitations may be as important as resolving the technical limitations that confront the optimization of building management systems in New York City.

A standardized expectation of intelligent building functions, as can emerge from BASAT, would go a long way towards making BAS more like the "marble lobby" that is de rigeur without regard to

[43] TIAX op.cit. and Brambley op.cit. both cite BOMA annual survey data.

first cost.[44] *If being able to know and to demonstrate that your building is "smart" is a baseline feature for a property, BAS upgrades will be freed from the uncertainty constraint.*

Emergent solutions to increasing advanced BAS feature proliferation. Technology innovations have overcome some of the cultural resistance to advanced BAS features. However, cultural change does not happen quickly in the buildings industry, and educating decision makers about the capabilities of modern BAS is still important. Open protocol communications like BACnet can make system integration much more effective than before. Modern wireless sensors can track data on occupancy, air quality, and temperature cost-effectively, without any significant construction or wiring. New methods of compiling and displaying data, like on user-friendly dashboards, can require minimal additional training to interpret. By collecting and analyzing data more effectively, BAS can provide detailed information to building engineers, and a more general report to asset managers, allowing for simpler oversight of building operations. *Credibly educating building managers about these opportunities could yield significant gains in building operations. That role could in part be filled by the BAS evaluation tool this paper envisions.*

6. CONCLUSION: DEVELOPMENT NEXT STEPS

Through this white paper we have outlined the industry value and basic features of a BAS assessment toolkit (BASAT) to help promote the adoption of advanced BAS features in commercial office buildings. The toolkit is intended to build transparency amongst stakeholders around the infrastructure improvements necessary to implement advanced BAS features and to facilitate and accelerate the evaluation of existing BAS infrastructure within buildings.

(a) Market Introduction.

The process we are proposing has similarities with well accepted building market practices such as energy auditing and, increasingly, commissioning, with its functional testing protocols and multiple formats (retro-, continuous, and others). Literature review and expert testimony lead to our conclusion that traditional energy audit, system commissioning and DR assessment processes would be complimented and strengthened by BASAT. The BASAT provides unique services unmet by any of those existing building assessment approaches, including:

- Targeted, rapid assessment of BAS infrastructure for specific BAS applications
- High-level, vendor neutral evaluation of applicable BAS features
- Common vocabulary and investigation procedure for evaluating different BAS components

[44] J.K.Wong, et.al. "Intelligent Buildings Research: A Review" <u>Automation in Construction</u> v.14 (2005) reviews intelligent building characteristics from this perspective in the Asian commercial property market

- A guided investigation tool that is targeted for use by less experienced energy professionals
- Method for collecting, storing and sharing BAS infrastructure evaluations

These needs diverge from existing evaluation programs in so far as they do not:

- Assess the broad topic of whole building energy efficiency
- Require functional testing of existing equipment
- Require utility or other BAS data for analysis

(b) Promotion of BASAT to Industry.

The tool, if properly used at scale can help spur the market for advanced BAS features by providing:

- Market data on the real capabilities of existing BAS infrastructure, relative to emerging features
- Feedback from ownership stakeholders on their most desirable advanced BAS features
- Transparent information to ownership stakeholders who are considering infrastructure improvements and advanced BAS features.
- Training data for educating BAS vendors and operators on how to evaluate their infrastructure, and what additional education they should pursue to use advanced BAS features

(c) Establish Education and Training Role

The BASAT's potential benefits from establishing industry training and education has been emphasized. Foremost amongst those benefits may be accelerating the education of ownership stakeholders about advanced BAS features and useful infrastructure improvements. At the same time, the input data to the evaluation toolkit may be collected and used by various vendor and utility stakeholders to improve their knowledge of the market. For example, the toolkit data may help utilities better understand what infrastructure improvements actually need further utility subsidies in order to accelerate adoption of the best BAS features. Likewise, BAS vendors can gain a greater insight into the true state of existing BAS infrastructure, and the evolving desires of the marketplace, allowing them to focus more on products in greatest demand.

Within ownership stakeholder groups, the output of the evaluation toolkit could help asset managers and facility operators justify investment in infrastructure improvements, and create budgets to accommodate more beneficial, advanced BAS features in the future. Owner's representatives and engineering consultants can also benefit from the toolkit by adopting it a standard training element for their employees. Finally, legislative stakeholders can also benefit from the toolkit as it can provide a standard metric for assessing compliance with new energy laws, and measuring the change in the market that is generated by those laws.

(d) Develop Prototype with Demonstration Functionality

The BAS evaluation toolkit proposed here can eventually entertain a large scope of advanced BAS capabilities, however, to continue the development of the tool we must focus on a more manageable subset of features. *Pending feedback on this white paper from the expert community, we will focus our development of the toolkit towards BAS evaluations for automated fault detection and diagnostic (AFDD) applications.*

This feature selection is motivated by current market needs for tools and technology that ensure the success of energy efficiency investments. AFDD is unique amongst the set of advanced BAS features because it is intended as a 'watch dog' feature to ensure the successful operation of the BAS and controlled systems. Given the aggressive market today for minimizing energy usage and meeting local compliance, we believe that an initial focus on AFDD will generate a testable prototype tool that will be in high demand. *AFDD also relates to Owner core concerns for comfort and reliability; if faults can be discovered early, comfort complaints or equipment breakdowns may be avoided.* Moreover, the infrastructure assessment appears to be straightforward, matching existing systems with BAS sensors and fault detection algorithms to generate stakeholder reports on what sensors should be added in a building such that additional diagnostics can be performed by the BAS.

(e) Develop and Test Prototypical Procedure.

The BASAT will include a spreadsheet tool that guides the evaluator through the actual assessment process. The targeted user of the toolkit is any member of the ownership, vendor or utility stakeholder groups with at least a basic energy professional background. The target user may have a CEM or even a BCA designation, and some literacy in BAS products and features. The assessment procedure includes:

- A site walk-through to document the types of systems in the building, and the extent of the BAS deployment on those systems
- Ownership stakeholder interview to assess their interest and experience with:
  - Improving BAS communications, processing and interface infrastructure
  - Additional sensor deployments for monitoring applications
  - Advanced BAS features that might be beneficial to the building
- Access to the BAS workstation in order to document:

- What sensors are deployed on the systems within building
- Graphic interfaces used by operators to interact with the BAS
- Trending, data storage and collection capabilities of the BAS
- Interoperability of the BAS with non-proprietary communication standards
- Network diagram of controllers, workstations and other interfaces
- Where possible, sequences of operation for major systems

The spreadsheet tool is envisioned to guide the investigator through each step of the procedure, providing a structured set of questions that helps the investigator collect as much useful information as possible about the existing BAS infrastructure. We envision that the toolkit will be organized for assessing one system at a time, providing the investigator with a set of triage questions and eventual 'expert suggestions' on BAS features that might be applicable to the building. These suggestions are expected to include a description of the value that the BAS feature might bring to the building, as well as a summary of infrastructure improvements that might be necessary in order to deploy that feature. The final output of the toolkit is expected to be a summary of all of these results, which may be printed and given to the ownership stakeholder.

(f) Expert Consultation

The project's immediate next step is to convene a discussion with industry experts, based on the concepts developed in this White Paper and in the accompanying Preliminary Product Design. We hope that readers will make the time to join us. Date options and invitation to follow separately.