ijfm International Journal of Facility Management
Vol.2, No.1 – May 2011

Research Methodology for Building Automation Performance Index

Shariar Makarechi, Ph.D.
yar@spsu.edu
Assistant Professor, Construction Management, Southern Polytechnic State University, Marietta, GA 30060-2896
&
Roozbeh Kangari, Ph.D.
roozbeh.kangari@coa.gatech.edu
Professor, Building Construction, Georgia Institute of Technology, Atlanta, GA 30332-0680

ABSTRACT: Automation is intended to improve overall building performance. Building Automation Systems (BAS) are attractive to facility managers and popular due to their promise of increased operational effectiveness. BAS can be optimized, and a well-designed and well-implemented BAS is expected to increase a building's overall appeal and value as a result of improvement to its performance. In order to improve the level of automation in buildings, a measurement tool in the form of a performance index is needed. The goal of this paper is to describe a research methodology for quantifying a typical building's level of automation-performance for developing an Automation Performance Index (API). A framework and roadmap with ten tasks to accomplish the research goals are described. The research methodology describes an integrated approach for using the results of literature search and input from expert survey in the field of building automation. It presents a framework for identifying and classifying the key parameters.

KEYWORDS: Automation, building, framework, index, methodology, performance, research, system.

INTRODUCTION

The goal of this paper is to describe a research methodology and its associated challenges for developing a building Automation Performance Index (API) model.

Buildings like their occupants need to stay efficient and healthy. They need to be examined and tested to ensure all of their vital signs are within acceptable healthy ranges. Just as a physician usually orders lab tests to evaluate a patient's condition before prescribing remedies for improvements, a facility manager who cares for a building needs to assess its vital systems and the level of their performances, and then take effective steps for improvements. One of the greatest parts of the building anatomy is its brain which centrally controls the functions of its systems. Facility managers can benefit from tools that measure performance of building's central automation systems which are the monitoring, controls and command systems otherwise known as Building Automation System (BAS).

Improvement to the performance of a building may be accomplished by reducing the energy consumption of its environmental comfort systems. Any attempt at making such improvements in performance should pay close attention to its automatic controls and monitoring systems otherwise known as BAS. A customized BAS properly implemented is expected to improve both building comfort levels and its overall performance which translates into energy efficiency. There are many options for customization of building automation. The next step was a set of questions that a reader may have, but not yet discussed. For example, how does one measure the performance of each customized BAS in order to compare and select the optimum measures?

Current energy codes and industry standards of environmental system operational practices, such as those provided by ASHRAE 90.1 (ASHRAE 2001), Energy-Star (Energy-Star 2005) and Leadership in Energy and Environmental Design (US Green Building Council 2002) are designed to provide generic prescriptions that may be tailored into proper dosage of steps for improvement of each project's energy performance profile. A practical prescription may be in the form of maximum energy use budgets (DOE/EIA 2005).

In case of this research, pre-determined healthy ranges of such environmental systems' performances will form a target performance range after systems are improved. System improvements are initiated in order to reach the target performance range. After implementation of the system improvements, their performances are measured and compared with the target range and corrections are made as required, to reach and stay on the target range. These sets of targets for building systems are sometimes prescribed by building codes as minimum acceptable performance standards.

Although building codes may set the minimum acceptable performance standards, such performances are usually not the best performances that should be expected. In fact any minimum performance requirements prescribed by a client or a code body automatically becomes the maximum level of performance that the contractors would aim for achieving. As a result, what was intended to be a minimum acceptable practice becomes the highest-possible performance. In final assessment, many buildings may fulfill the prescribed code requirements without delivering the possible optimal performances. This could be addressed by a performance-based in lieu of prescribed-based approach to building construction. The advantages of performance-based approach have been addressed by Kashiwagi (Kashiwagi 2005). He provides case studies and examples that clearly show how specified minimum standards in a competitive bidding environment automatically set those (minimum) levels as the maximum goals for the construction delivery systems. A performance-based approach, on the other hand, will remain focused on satisfying the client's best interests without limiting the level of effort required to achieve it. Kashiwagi demonstrates that improvement of building performance requires creativity and determination to sometimes push against all apparent constraints. He explains that, to promote creativity, one should avoid limits naturally imposed by prescribing the details of the process. Once developed, a tool like API can be used to measure BAS performance against set goals without dictating the details of how BAS should be configured. Questions such as how much automation is the right level for a given facility, may be answered with the help of this tool.

PROS AND CONS OF BUILDING AUTOMATION

The installed cost of a commercial grade Building Automation System in 1980 was approximately $500 per direct digital control (DDC) point. In 2010, this cost is less than $20 per DDC point and it has been predicted that the point will be dropping to insignificant levels (Sinclair 2005). On the other hand, the total cost of operation and maintenance of building systems, including the direct and indirect costs of building systems' environmental impacts, is increasing, and so is the desire to reduce these costs.

The study showed that regulating agencies and construction code authorities are increasingly enforcing stricter energy efficiencies and environmental policies. These drivers, coupled with the availability of low-cost controls and communication systems and access to real-time information via the Internet, all together have created a very fertile ground for building industries to move towards an integrated and global approach for operational optimization. This simply means there are both incentives and rewards for growing use of BAS, not to mention the demand of the tenants and the clients for the added features BAS can offer.

The variety of ever-increasing facility management features and options available through the evolving BAS technologies facilitate building administration and provide opportunities for more efficient and flexible operations. This prompts the owners and developers to implement increasing levels of automation in modern building construction. Continental Automated Buildings Association (CABA 2002) has documented many successful cases and provided educational and informational seminars (Zimmer 2005) and many research papers have been published in this area for designers, contractors and facility managers. The evolution of BAS is shown in Figure 1.

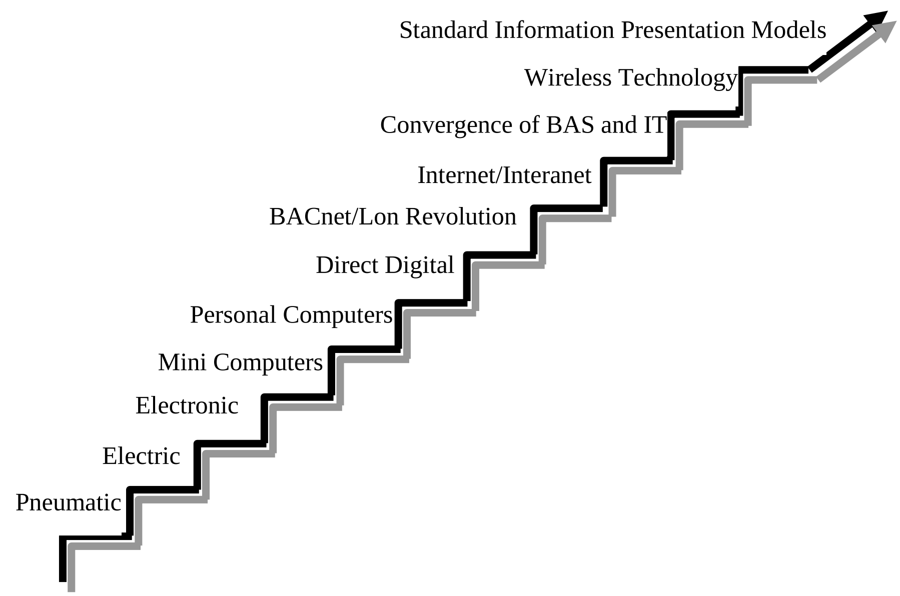

Figure 1. Evolution of Building Automation and Control Systems (Zimmer 2005)

Features, flexibility and added efficiency offered by more technologically advanced BAS are complemented with the economical rewards for this industry, both for the consumers and service providers. This serves as additional motivation for implementing more sophisticated automation in building construction. It is predicted that the BAS business will grow steadily into the $30 billion range by 2009 (ARC 2005). Therefore is important to research the relationship between the performance of increased BAS and the level of its use, and whether such growth in building automation has predictable improved performance levels. Also, the result of such research can help in deciding on the limits of BAS use.

POTENTIAL GROWTH

Depending on one's perspective, a building's performance may be measured by its operating cost, energy use, or its net income. BAS may be designed to govern building systems according to a calendar-based and time-related sequence of operation. In commercial buildings, the BAS is either formed separately as an overriding controller, or by integration of several independent operating systems. The governed systems in this study include: heating, ventilation, air conditioning, lighting, security, life-safety, plumbing, irrigation, fenestration, circulation, communication, transportation and janitorial systems. This list is not exhaustive and can be expanded depending on the building type and its services. For example, nurse call systems in healthcare buildings, room entertainment systems in hospitality buildings, hazardous waste containment systems in industrial buildings, and surveillance systems in institutional buildings can be added to the list.

Studies have shown significant improvements to government buildings' performance levels through proper applications of building automation (GSA 2005). Some government studies, such as the National Institute of Standards and Technology's report on the high cost of inadequate interoperability (Michael P. Gallaher 2004), promote more integration of building systems and increased levels of building automation.

However, research (Zhi-Gang Wei 1998) also indicates too much automation may actually be detrimental to a system's performance: "In fact, too much automation results in poor operator performance caused by too-low workload, loss of skill, and loss of awareness of the system status. This raises a series of questions: How much automation should be used? What affects human use of automation? How does an increase in level of automation affect system performance and operational safety? Many such questions assume the existence of some quantitative measures for the degree of automation. To our knowledge, no such measure has been developed" (Zhi-Gang Wei 1998).

Experimental studies of general automation with a simple lab-based set-up to define and test a proposed linear model has been performed (Zhi-Gang Wei 1998) to predict the optimum "Degree of Automation" (DofA) from human performance aspects. The researchers acknowledge that further studies for more complex systems, such as buildings environmental control systems, are required. The DofA research concluded that some manual intervention by human operators should be kept in the loop for improved results of an automated system which is the role of facility mangers for building automation systems.

Building energy standards, such as ASHRAE 90.1 (ASHRAE 2001), guidelines, such as Energy Star (Energy-Star 2005), or programs, such as LEED certification (US Green Building Council 2002), were found out to be helpful in promoting efficient and sustainable design and practices in construction. Building codes and standards predominantly use prescriptive approaches. To verify the effectiveness of any prescriptive tools on a building, a measure of its performance was ultimately needed.

Many projects built to meet codes have failed to provide the intended performance. If a performance-based approach in lieu of a prescriptive approach is followed, innovation and ingenuity is encouraged (Kashiwagi 2005). This can be illustrated by the simple example of the process of purchasing a car. If the automobile is being considered for someone else, a description of the needs and requirements of the user will lead to a purchase that minimizes the cost yet delivers the quantitative and qualitative aspects of the intended user. However, if the car is being purchased for one's own use, a more long-term view of the cost benefit and performance quality will be assessed, and higher cost and more risk of toying with the latest technology may be justified. This research contributes to BAS performance improvement by providing a scale to index the level of automation labeled Automation Performance Index (API).

Outside of detailed numerical simulations, practical scientific methods for evaluating building automation systems' performance are very scarce (Makarechi 2005). When simulation modeling tools, such as Energy Plus (Crawley, Winkelmann et al. 2002), Power DOE (Hirsch 1998) or eQuest (DOE 2005) are utilized to assess a building's energy or operating cost performance, BAS is simply treated as a set of options chosen from a list. The research found that these tools are not designed to evaluate the performance effects of the degree of automation prescribed. Automation is assumed to be at its optimum level whenever that option is selected to be available. Another misconception is in the parallel between the building's intelligence verses its performance. A presentation sponsored by the Continental Automated Buildings Association (CABA) notes: "Intelligent Building is a building which has the inherent ability, through the design of its infrastructure and systems, to respond to the changing needs of its tenants/occupants and building owner/investor group quickly, safely and cost effectively" (Katz 2005).

According to this definition, any improvement in building automation would be an improvement to its intelligence. Is it possible that after a certain point, an increase in the amount of automation (intelligence) may not necessarily offer any improvement to its performance? In 2005, CABA initiated development of a web-based utility to measure the building's level of intelligence, coined as the Building Intelligence Quotient (BIQ) (CABA 2005). The idea is to promote more building intelligence. Once BIQ is developed, tested and validated, it may become a complementary tool to API. However, the focus of API is performance level and not the intelligence level of a building.

PROBLEM STATEMENT

The world is facing an energy crisis and buildings are major energy consumers. Implementation of Building Automation Systems are expected to facilitate more effective and efficient building operations. Effective in terms of providing more comfortable and productive environments, and efficient in energy use and cost of building operations as shown in Figure 2. The question is how much building automation is needed and how to measure it. Macwan, Wei et al. (Zhi-Gang Wei 1998) have stated that too much automation results in poor operator performance, and Michelle Addington, professor of the Architecture Program at Harvard University's Graduate School of Design, has likewise expressed concern that "the technology is coming in before we have the sophistication to know how best to deploy it" (Bowen 2005). On the other hand, implementation of technology and networking in some commercial projects have been shown to reduce the cost of building cooling system operation down to 50% level of the conventional optimized systems, as reported in I-Homes and Buildings magazine (Hartman 2006).

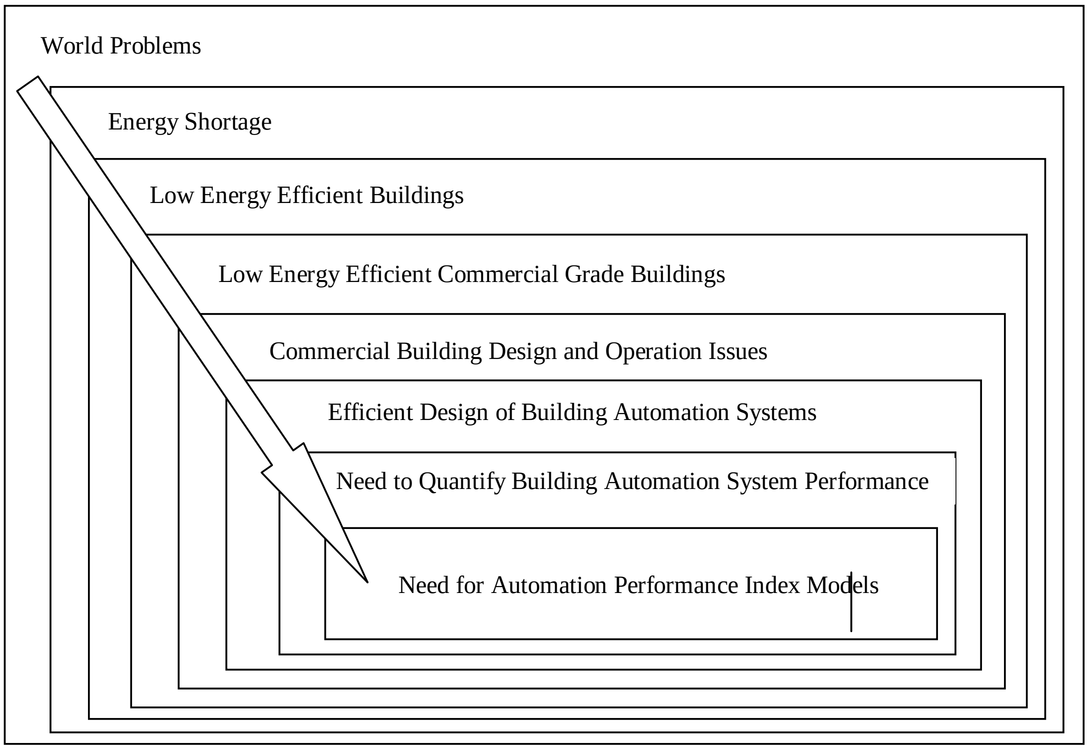

Figure 2. The Big Picture: Automation Performance Index
within the Context of the Built Environment

BAS can take many forms. It can be as simple as a time-clock that operates a device, or as complex as integration and coordination of the scheduling, operation, monitoring and metering of all building systems and technologies. Table 1 demonstrates a few of the possibilities for BAS. In this table, some of the aspects or alternatives that may be considered for 'Building', 'Automation' and 'System' are provided for the purpose of demonstrating the numerous combination possibilities that may be considered.

It was found that proper configuration of BAS can simplify the facility manager's job, in addition to taking advantage of the operational efficiencies associated with and expected from integration of different building systems that traditionally have been controlled separately. Facility managers, owners and tenants see the value in implementing technology that will increase performance and reduce costs. Commercial facility owners, in particular, are motivated to incorporate additional levels of BAS in order to increase the appeal of their buildings in the minds of the potential tenants.

Table 1. Examples of BAS Combination Possibilities (Selecting one parameter from each column will result in many combinations)

Building	**Automation**	**System**
General	Individual	HVAC
Specific	Integral/Open	Lighting
Type	Networked	Security
Location	Closed	Life Safety
Single	Web-Based	Plumbing
Multiple	Local	Irrigation
Existing	Remote	Fenestration
New	Digital/Electronic	Circulation
Conceptual	Pneumatic	Communications
Renovated	Electric	Compactors
Use	Commercial	Transportation
In/Out Side	Industrial	Vacuum

OBJECTIVE AND SCOPE OF RESEARCH

The objective of the research was to develop an Automation Performance Index (API) model for evaluating the extent of a building's automation-performance. The hypothesis was that a building's level of automation-performance is quantifiable.

The scope of the research was limited to commercial grade building automation systems. These systems are manufactured with tolerance and operating limits suitable for projects such as office, retail, academic, courthouse, and light-institutional buildings. Industrial grade controls usually require higher levels of accuracy, tolerance and performance (Franklin, Powell et al. 1990) and were not within the scope of this research.

ASSUMPTIONS

Every model has limitations. These limitations were described under the assumptions of the model. Assumptions allows a realistic view of the developed model. It also allows improvement of the model in future by relaxing some of the assumptions.

In this research, it was assumed that international building codes (International Code Council., Building Officials and Code Administrators International. et al. 2003) and other international-level facility design guidelines and standards, such as those published by the US Air Force, Army, Navy, design guides found listed in Whole Building Design Guide (NIBS 2006), GSA publication PQ100.1 (GSA 2005), as well as engineering guidelines of professional organizations such as (ASHRAE 2006), and (Netherlands Standardization Institute 1998) are valid references and research studies for defining the boundaries of the API model.

In order to allow a focus on BAS performance aspects, rather than design issues, and to simplify the quantification of the complex parameters, such as "user needs" and to provide a clear definition of terminologies used for model evaluation the following assumptions were recommended:

- Minimum level of satisfaction is assumed to be API = 1.
- All building equipment and controls are properly sized, commissioned and calibrated, and all devices and components are properly selected for their applications. Furthermore, all building systems and associated devices are assumed to meet the needs and limitations of the application for which they are used.
- Growth in user needs will prompt proportional expansion of building automation system, which means an increase in the number of control points.
- Building automation and building controls are treated synonymously.
- Terminology used by American engineering professionals and reference manuals such as (ASHRAE 2006) is valid and commonly accepted.

RESEARCH METHODOLOGY

Figure 3 shows the research methodology which has already been used successfully in similar work (Makarechi 2006). The proposed framework served not only as the research methodology, but an effective way of communication with the stakeholders (e.g., Facility managers). The research methodology map shown in this figure consists of a set of tasks blocks (shown by task numbers from 1 to 10), and a number of solid blocks representing "Decision Criteria" for each stage of this research (shown by letter 'a' to 'i'). It is important to notice that one of the contributions of the research was the description of these Decision Criteria which for simplicity called *Criteria*. At each of these solid blocks, the research has developed a set of Criteria (or standards and policies) for the selection or identification of variables and model development. These Criteria could be considered as filters or justifications for a decision are:

(a) Decision Criteria for Literature Research.
(b) Decision Criteria for Forming a Panel of Experts.
(c) Decision Criteria for Identifying Relevant Parameters from Literature Research.
(d) Decision Criteria for Identifying Relevant Parameters from the Expert Panel.
(e) Decision Criteria for Identifying the Most Significant Parameters.
(f) Decision Criteria for Identifying a Suitable Approach for the Model.
(g) Decision Criteria for Applying the Governing Building Codes.
(h) Decision Criteria for Defining the API Model.
(i) Decision Criteria for Testing and Validation Method.

In order to discuss the methodology, let's be mindful of the fact that building automation can provide controls for a variety of environmental, mechanical, and security systems, because each of these systems can separately or together form a BAS (Table 1). The approach for developing the API depicted in Figure 3 has purposefully stayed generic and does not get involved with any of the specific systems that may be controlled. In addition to the above listed Decision Criteria, ten tasks which are illustrated and referenced by numbers in Figure 3 show the research work task in the methodology. These tasks are fundamental steps in the API model development:

- Task #1: Establishing decision criteria for each step.
- Task #2: Conducting comprehensive literature research.
- Task #3: Forming the expert panel.
- Task #4: Designing the questionnaire for the panel.
- Task #5: Receiving the required approvals for research using human subject input.
- Task #6: Identifying, Organizing, Classifying and the major building automation parameters.
- Task #7: Selecting the significant parameters.
- Task #8: Identifying suitable approach for API modeling.

- Task #9: Developing the API model.
- Task #10: Testing and validating the model.

The following section briefly describes these decision criteria and research tasks.

Establishing Decision Criteria

The first step in the development of the model involved establishing Decision Criteria as shown in Figure 3.

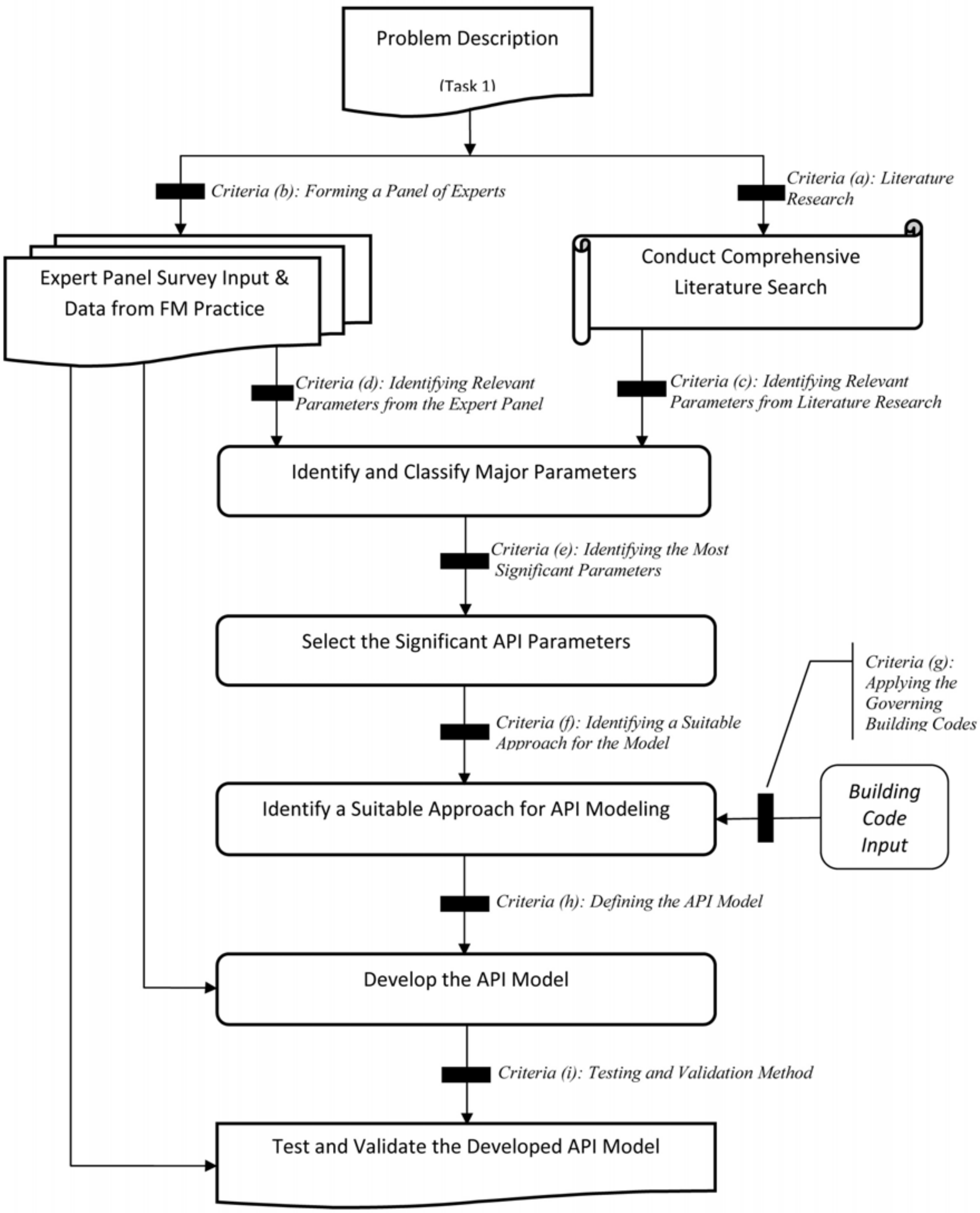

Figure 3. Research Methodology

The following provides a guideline for establishing each decision criteria for API model development.

Literature Research: A comprehensive literature search for Building Automation Performance, Automation Performance Evaluation, and other combinations were conducted. A matrix tabulating the results of these articles was developed. The matrix identified and classified the parameters (critical variables) that were cited with the highest frequency. Major categories for the parameters were established based on the literature search and expert knowledge as described in the following sections.

Forming a Panel of Experts: Seminars and conference proceedings related to building controls, HVAC industry, building performance and engineering societies were identified, selected and attended to select industry experts and professionals to solicit participation in the research. Those with extensive working experience, practical and theoretical knowledge of different aspects of building operation and its automation performance but did not have published work in this area were selected for the survey in this research based on the following two major guidelines: 1) Recent professional experience in one of the aspects of building systems operations and performance, and 2) Willingness to participate and provide expert knowledge to this research.

Identifying Relevant Parameters from Literature Research: This criteria was based on collecting a comprehensive list of relevant parameters which were frequently cited in the scholarly publications. Then, these parameters were classified into groups with similar characteristics, and key parameters influencing the performance of building automation systems were identified by tabulation for the matching citations.

Identifying Relevant Parameters from the Expert Panel: Based on the above two guidelines, a list of potential candidates for identifying relevant parameters influencing the performance of Building Automation Systems were identified. The expert panel members were asked to provide their knowledge based on their own experience at the field. Each panel member individually and without access to other members was asked to provide recommendations based on their professional practice regarding the most significant parameters that influence performance of BAS.

The initial list of the parameters obtained from the panel members, were tabulated and similar items were combined into the same categories identified in the literature search. Based on how frequent each parameter category was cited, the most significant ones were identified.

Identifying the Most Significant Parameters: Comparing the two lists of parameters and aspects with high frequency of citation, a final list of the key parameters with the highest number of recommendations and citing were produced.

Identifying a Suitable Approach for the Model: Various modeling techniques referenced in scholarly publications in similar areas were investigated and tabulated. The criteria for model selection was based on: type of data needed (numerical vs linguistic, probabilistic vs deterministic, and dynamic vs static), size of data from expert panel, ease of use, relationship or correlation among the model parameters, level of accuracy, versatility and practicality. An extensive investigation of various modeling techniques conducted by the authors titled: “Dynamic Decision Support Systems” (Makarechi 2004) were used, in which appropriate decision support models are identified based on the stage of a project, whether in the early planning or design, development, construction, operation and even in latter stages of re-commissioning. The general conclusion was that in earlier stages of a project when actual data is scarce, heuristic methods and, in the latter stages, numerical methods should be utilized.

Applying Building Codes and Guidelines: Governing building codes were utilized to define the model’s boundaries. This research has used the criteria established by large organizations, such as General Services Administration (GSA), Emory Healthcare Facilities, Georgia Tech Facility Design Criteria (Yellow Book), as its criteria for model development. The criteria in these codes and guidelines are applied as boundary conditions to determine the model’s constants.

Defining the Automation Performance Index: The criteria used for indexing is based on the assumption that API is a positive index defined between 1 and 5. API equal to 1 indicates a satisfactory automation performance, API values less than one are considered lower than satisfactory performance, and API values higher than one are considered improved performances. Technical completeness is in terms of the representation of entities and attributes, relationships, unique identifiers, sub-types and super-types, and constraints between relationships were considered in this research.

Testing and Validation of API: The testing criteria shall be based on the validation of model by those buildings which are not included in original set used for model development. Therefore, additional information about existing buildings with known automation performance will be obtained to validate and test if the model's prediction would match with the actual experience of the facility mangers.

Establishing Research Tasks

This research work was divided into ten major tasks, allowing extensive investigation of each research part, and integration of them to accomplish the goal of this research. These research *Tasks* should not be confused from *Decision Criteria* described in the previous section. Although, some of the titles are similar, however, a research task is defined as a research work for a specific part of the whole research study such as conducting *Literature Search*, when criteria is defined as a set of standards and policies for selection of parameters and modeling techniques. It acts as a filter that justifies a decision such as *Criteria for Literature Search*. The major tasks were:

Conducting Comprehensive Literature Research: The research extensively utilized engineering and building automation journals and Internet resources, as well as a comprehensive literature search of related subjects. This task should exhaust search of referee journals, trade publications, conference proceedings, and any other related publications. Additionally, seminars such as those organized by the International Council of Research and Innovation in Building and Construction (CIB 2005), Building Futures Council (BFC 2005), and High Performance Buildings 2006 (ACG 2006), and review of these and other conference proceedings, were conducted. Literature research, as well as information obtained from experts in building automation, formed the basis for identifying key parameters relevant to BAS performance. As described by Chung (Chung 2004), "Domain Experts" are considered invaluable sources in practical research. Since they provide experience-based information from actual field-specific practice, their advice requires little qualification or validation. The most-significant parameters were identified using the input from the practicing facility managers through a number of communications and meetings using a Delphi method of reaching consensus (Linstone and Turoff 2002). This effort, combined with information obtained through literature research, was used to screen the most-significant parameters for defining the API model. The model was further refined by application of the industry standards and guidelines (NIBS 2006) before testing and validation.

Forming the Expert Panel: To establish a basic understanding for the state of the industry and also to meet experts in the subject, information from following relevant seminars were used: Converging Building Systems Technologies (BuilConn 2004), Performance Based Procurement (Kashiwagi 2005), Building Futures Council (BFC 2005), International Council of Research and Innovation in Building and Construction (CIB 2005), W92 Construction Procurement Systems Symposium, and High Performance Buildings (ACG 2006). From the above seminars, and also from the list of building automation professional contacts, qualified experts in assisting with the research were identified. The preliminary research was done in two stages. Stage one was completed as an independent study titled: "A Step towards Development of Building Automation System Performance Indicators" (Makarechi 2005), in which a smaller group of 13 experts provided input. Stage two was completed as a part of the PhD thesis, in which a larger number of resources and experts were consulted to identify and rank the significant parameters for developing a few models for API.

Designing the Questionnaire for the Panel: A questionnaire was designed and developed to capture the expert knowledge from expert panel's input. The questions were designed to be relevant to this research, short and precise without leading the experts in any direction. A total of three questions were sent by e-mail. A sample of the questioner is shown in Figure 4. The first question was intended to get an overall view for the current trends in the BAS industry. The response to this question did not affect the process of forming the API model, but helped in validating it. Questions 2 and 3 were the key questions for the model.

Receiving the Required Approval for Research Using Human Subjects: Human-based research requires special review and approval from the Institutional Review Board (IRB 2005). The protocol of this research was submitted and approved (IRB H05151), and the required training to obtain research certification was completed.

Organizing, Classifying and Identifying the Major Building Automation Parameters: Information from literature and online research, and feedback from the expert panel was tabulated and organized separately into similar categories for the parameters cited, and the most significant parameters were chosen. Parameters cited most often were given more priority in the selection process.

Selecting the Significant Parameters: Parameters were selected based on the frequencies of their citations in literature search and expert opinions from survey. Some of the parameters were not directly scalable. In order to define scalable parameters for the model, logical correlations between the parameters that identified by this research and other quantifiable parameters were established.

Identifying Suitable Approach for API Modeling: Heuristic and numerical models shall be considered for scaling significant parameters. Numerical analysis using value engineering techniques (Sadri 2004), (GSA 2004), Utility Theory (Bell, Raiffa et al. 1988), and Fuzzy Logic (Zadeh 1994) modeling techniques have been utilized in this type of research.

Developing the API Model: API is defined as an index representing the expected performance levels of BAS. This index, in general form, is the weighted average of the normalized significant automation performance parameters. Models chosen for API were further refined by building design guidelines (NIBS 2006), such as GSA P-100 (GSA 2005). A quantitative model to evaluate the performance of BAS helped to assess the existing state of system in comparison with its desirable mode. Any inferior deviations were then addressed. Structuring a decision-support system to routinely monitor and reduce deviations from set objectives which improved the system performance (Makarechi 2004).

Testing and Validating the Models: Verification shall be done to ensure that the model is dfined correctly, the algorithms have been implemented properly, and the model does not contain errors or oversights. No computational model will ever be fully verified, guaranteeing error-free implementation. A high degree of statistical certainty is all that can be realized for any model as more cases are tested. A set of sensitivity analysis shall be conducted for observing the range of API and validation of its estimates and trends predicted by the numerical model.

SUMMARY

The research methodology presented in this paper demonstrates how a model for quantifying a building's performance index can be developed using the significant parameters identified by this approach. The accuracy of the API predictions can be established using data available but not used in developing the model and set aside for the validation of the model. API model developed by this methodology will provide useful feedback to professionals during the design and construction process for improved decisions towards optimization of building automation performance and to facility managers when they need to compare performance of alternative building automation systems.

The research demonstrates that improvement requires monitoring and measurement, which is made possible by having a model, such as API. As the construction industry moves towards more intelligent buildings with integrated automation systems, further discussion regarding the significant parameters for improving the building automation performance tailored for specific clients are encouraged by this research. The benefits of enhanced building intelligence, versus the challenges of a sophisticated system operation can be captured in further modeling efforts and analysis of API.

REREFENCES

ACG, A. C. G. (2006). High Performance Buildings. High Performance Buildings 2006, MGM Grand, Las Vegas, Nevada, AABC.

ARC, A. G. (2005). "Building Automation System Worldwide market." Vision Experience Retrieved Sept 28, 2005, from http://www.arcweb.com/txtlstvw.aspx?LstID=12b87554-99b6-45ac-a879-79853650c407.

ASHRAE (2001). Addendum "e" to ANSI/ASHRAE/IESNA Standard 90.1-2001, ASHRAE.

ASHRAE (2006). Aerican Society of Heating and Refrigeration Engineers.

Makarechi, S. (2004). Building Automation Systems at the Crossroads. Consulting Specifying Engineer: 4.

Makarechi, S. (2004). Dynamic Decision Support System for Optimized Project Delivery. 2005 CIB W92, Las Vegas, CIB.

Makarechi, S. (2005). A Step Towards Development of Performance Indicators for Building Automation Systems. Georgia Tech: 38.

Bell, D. E., H. Raiffa, et al. (1988). Decision making : descriptive, normative, and prescriptive interactions. Cambridge ; New York, Cambridge University Press.

BFC. (2005). "Building Futures Council." Retrieved August 2, 2005, from http://www.thebfc.com/.

Bowen, T. S. (2005). "Overly Smart Buildings." Technology Research News.

BuilConn (2004). Converging Building Systems Technologies. BuilSpec Educational Seminar 2004, Atlanta, GA, BuilConn.

CABA (2002). Building Control Network Protocols. Information Series. I. I. B. P. T. Force and T. L. T. Solutions. Ottawa, Continental Automated Buildings Association: 16.

CABA (2002). Technology Roadmap for Intelligent Buildings. Ottawa, Continental Automated Buildings Association .

CABA (2005). RFP for Integrated & Intelligent Building Ranking Tool. RFP. T. F. 1, Continental Automated Buildings Association: 15.

Chung, C. A. (2004). Simulation modeling handbook : a practical approach. Boca Raton, CRC Press.

CIB (2005). International Council of Research and Innovation in Building and Construction. CIB, Worldwide, CIB.

Crawley, D., F. Winkelmann, et al. (2002). Energy Plus: A New-Generation Building Energy Simulation Program, U.S. Department of Energy and Lawrence Berkeley National Lab and U.S. Army Engineer Research and Development Center and University of Illinois: 6.

DOE. (2005). "Department of Energy." Retrieved 11/21, 2005, from http://www.energy.gov/engine/content.do.

DOE/EIA (2005). Annual Energy Outlook with projections to 2025. Annual Energy Outlook. P. D. Holtberg. Washington DC, Energy Information Administration: 248.

Energy-Star (2005). Guidelines for Energy Management, EPA: 36.

Franklin, G. F., J. D. Powell, et al. (1990). Digital control of dynamic systems. Reading, Mass., Addison-Wesley.

GSA. (2004). "Value Engineering Work Book." Retrieved February 2, 2006, from http://www.gsa.gov/Portal/gsa/ep/contentView.do?contentType=GSA_OVERVIEW&contentId=8155&noc=T.

GSA (2005). Facilities Standards for Public Building Services. G. S. Administration, GSA: 365.

GSA (2005). General Services/Energy & Building Automation. Annual Performance Measurement Report. GSA. Washington DC, GSA: 4.

GSA (2006). FY 2005 Fedeal Real Property Report. Washington DC, GSA office of Governmentwide Policy: 16.

Hartman, T. (2006). "What Is the Role of Advanced Technologies in Green Building Design?" i Homes and Buildings 3(1): 17-19.

Hirsch, J. J. (1998). "DOE2.Com." Retrieved October 4, 2006, from http://www.doe2.com/.

International Code Council., Building Officials and Code Administrators International., et al. (2003). International building code. Falls Church, Va., The Council: v.

IRB. (2005). "Institutional Review Board Guidelines." Retrieved October 12, 2006, from http://www.compliance.gatech.edu/IRB/.

Kashiwagi, D. (2005). Best Value Procurement. PBSRG, ASU, Tempe Arizona, Performance Based Studies Research Group.

Katz, D. (2005). Venture Capital Forum. A website to rankBuilding Intelligence CABA. Anaheim, CA, CABA.

Linstone, H. A. and M. Turoff (2002). The Delphi Method, Techniques and Applications. New Jersey, Portland State University and New Jersey Institute of Technology.

Michael P. Gallaher, A. C. O. C., John L. Dettabarn, Linda T. Gilday (2004). Cost Analysis of Inadequate Interoperability in the U.S Capital Facilities Industry. U. S. D. o. Commerce, NIST: 210.

Netherlands Standardization Institute, N. (1998). "Energy Performance of Non-Residential Buildings." Translated Version. Retrieved September 14, 2005, from http://www.climaticdesign.nl/english/project/nen2916.htm.

NIBS, N. I. o. B. S. (2006). Construction Criteria Base, Whole Building Design Guide.

Sadri, S. (2004). Value Management for Integrated Construction Services. Atlanta, Georgia Institute of Technology: 68.

Sinclair, K. (2005). "Get With the Grid." Engineered Systems 22(11): 1.

US Green Building Council, G. (2002). LEED Green Building Rating System, USGBC: 75.

Zadeh, L. (1994). What is Fuzzy Logic. Azerbaijan International. B. Blair. Berkeley, UC Berkeley.

Zhi-Gang Wei, A. P. M., Peter A. Wieringa (1998). "A Quantitative Measure for Degree of Automation and Its Relation to System Performance and Mental Load." Human Factors 40.

Zimmer, R. (2005). Facility Management Forecast 2010. CABA. Pine Mountain, Continental Automated Buildings Association.

Zimmer, R. (2005). North America - Slow and Cautious With NextGen Projects. CABA. Anaheim, Continental Automated Buildings Association.

Building Automation System Market is estimated to reach USD 100 Billion by 2022, Building Automation System Market expected to grow with 13% of CAGR by 2022 | Building Automation System Industry.Â The building automation system is a crucial requirement in any infrastructure. It is essential for monitoring, security, mechanical, humidity, fire and lightning control systems. The building automation system is useful for autonomous building.Â The company specializes in process-driven methodologies that helped us create multidimensional approaches, thoughtful strategies, and a broad business perspective. Its team translates complex information into comprehensive and comprehensible deliverables. - Tony Wood, Chief Data Officer. Building information modeling (BIM) is a collaborative work methodology that seeks to connect people, processes, and digital models in building and infrastructure projects, thereby allowing fluidity in the transfer of information and communication [1]. Thus, with a digital graphic representation of the physical characteristics and functionality of the project, it is sought to manage the phases of design, construction, and administration throughout the.Â The MacLeamy time-effort distribution curve in Figure 1 shows how capacity to influence costs and changes of a project is greater at the design stage and decreases significantly as the project enters the operation phase (curve 1). At the same time, the cost of making This performance gap determines a problem of credibility in the building industry and, more in general, in sustainability oriented practices. Therefore, design and operation practices should evolve in order to be able to cope with performance uncertainty determined, for example, by evolution of climate conditions, variability of behavioural patterns and performance degradation of technological components.