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### Authors

Hitchcock, Robert J

Piette, Mary Ann

Selkowitz, Stephen E

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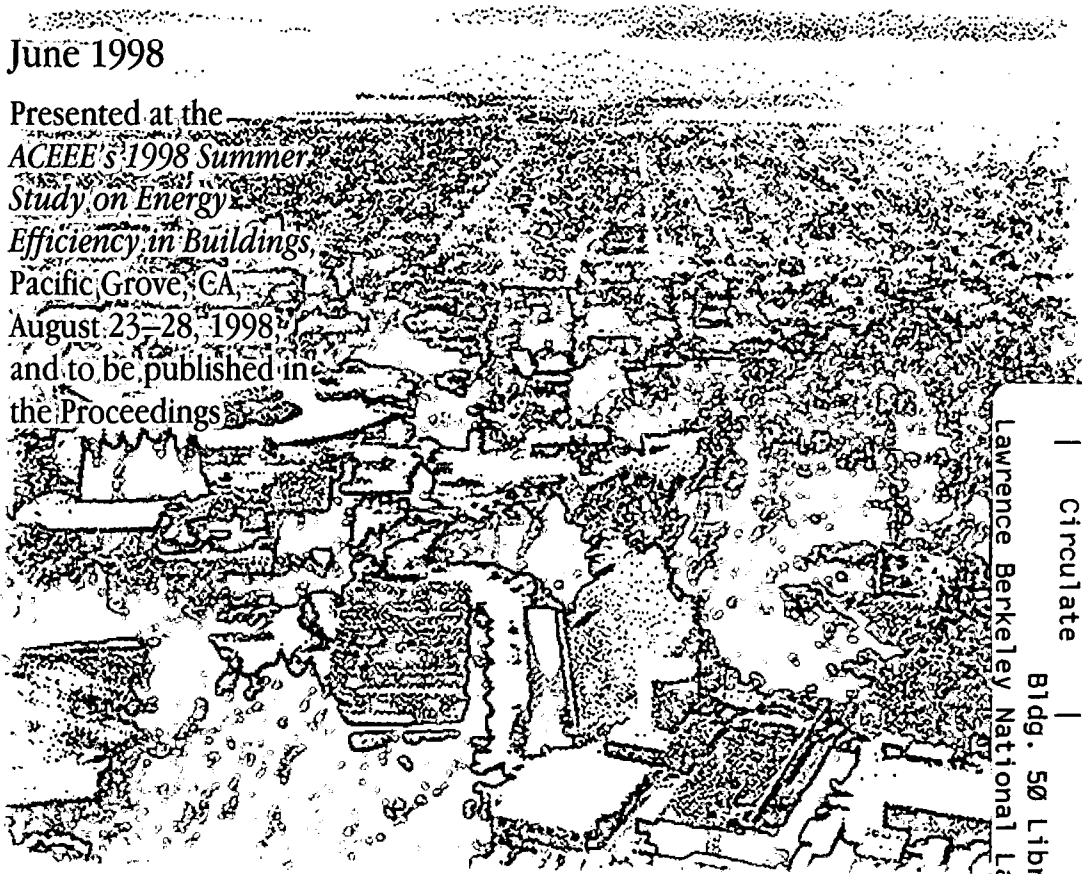
## Performance Metrics and Life-Cycle Information Management for Building Performance Assurance

Robert J. Hitchcock, Mary Ann Piette,  
and Stephen E. Selkowitz

**Environmental Energy  
Technologies Division**

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# **Performance Metrics and Life-Cycle Information Management for Building Performance Assurance**

Robert J. Hitchcock, Mary Ann Piette, Stephen E. Selkowitz

Building Technologies Department  
Environmental Energy Technologies Division  
Ernest Orlando Lawrence Berkeley National Laboratory  
University of California  
Berkeley, CA 94720

June 1998

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# **Performance Metrics and Life-Cycle Information Management for Building Performance Assurance**

Robert J. Hitchcock, Mary Ann Piette, Stephen E. Selkowitz  
Lawrence Berkeley National Laboratory, Berkeley, CA

## **Abstract**

Commercial buildings account for over \$85 billion per year in energy costs, which is far more energy than technically necessary. One of the primary reasons buildings do not perform as well as intended is that critical information is lost, through ineffective documentation and communication, leading to building systems that are often improperly installed and operated. A life-cycle perspective on the management of building information provides a framework for improving commercial building energy performance.

This paper describes a project to develop strategies and techniques to provide decision-makers with information needed to assure the desired building performance across the complete life cycle of a building project. A key element in this effort is the development of explicit performance metrics that quantitatively represent performance objectives of interest to various building stakeholders.

The paper begins with a discussion of key problems identified in current building industry practice, and ongoing work to address these problems. The paper then focuses on the concept of performance metrics and their use in improving building performance during design, commissioning, and on-going operations. The design of a Building Life-cycle Information SyStem (BLISS) is presented. BLISS is intended to provide an information infrastructure capable of integrating a variety of building information technologies that support performance assurance. The use of performance metrics in case study building projects is explored to illustrate current best practice. The application of integrated information technology for improving current practice is discussed.

## **Introduction**

Despite significant advances in building technology and the promulgation of tighter building codes, buildings consume one third of all energy in the U.S. at an annual cost of \$200 billion. Commercial buildings alone consume about 15% of all energy at a cost of over \$85 billion annually (EIA 1995). Perhaps half of this consumption is wasted, compared to what is cost-effectively achievable. Assuring achievable building performance should be a priority in an increasingly competitive world. This goal requires a careful examination of the complex processes by which buildings are created and specified, which includes several fragmented steps, such as design, construction, start-up and commissioning (if done at all), operations and control, maintenance, and retrofit. A life-cycle perspective on how information is managed in the building sector provides useful new insights and opportunities for achieving performance potentials.

Life-cycle information management systems are becoming widely adopted within many industries such as aircraft, industrial plant, and ship building, but are relatively slow to penetrate into the building's industry (PDES, Inc. 1998). The design and building of the Boeing 777 is one

successful example of the application of new integrated information technologies (Norris 1995). As building systems, controls, technologies, and operations become more complex and dynamic, successful projects rely on integrated decision-making in design, construction, commissioning, and operations, informed by appropriate and timely data. Specific benefits of improved information management include the following: consistency and reliability of available, up-to-date information; easier retrieval of information for multiple users at any level of complexity; avoidance of redundant data; and reliable tracking of data and decisions. These benefits can only be achieved if the information technologies are easy to use; provide direct benefits to the user; and are not cumbersome to install, use, and maintain.

### ***Research Objectives***

The ***Building Performance Assurance*** (BPA) project at Lawrence Berkeley National Laboratory (LBNL) was initiated to explore performance issues in today's buildings industry, and develop techniques to address these issues. Previous efforts have been discussed in various publications (BTP 1998; Hitchcock et al. 1997; Olken et al. 1996; Piette et al. 1997; Selkowitz 1996). Our basic approach is to examine information transfer and performance issues in a variety of contexts for both new and existing commercial buildings. Our overall goal is to provide decision-makers with the information and tools needed to cost-effectively assure the desired performance of buildings. The broader objectives of the project are: (1) to identify and evaluate specific shortfalls in current building practices that influence building performance in general, and energy performance in particular; (2) to develop strategies, techniques and practices to address these shortfalls including both short-term recommendations that can be easily integrated into today's design, commissioning, and operational practices, and longer-term approaches that utilize emerging information management technologies; and (3) to evaluate the costs and benefits of the developed approaches.

Part of the long-term strategy is to develop individual tools tailored to respond to the needs of project participants within a specific phase of the project life cycle. Each of these tools should also be standardized to allow interconnection through a common information infrastructure. The BPA project is developing the Building Life-cycle Information SyStem (BLISS) which is intended to provide a distributed computing environment for managing, archiving, and providing access to the wide variety of data that are generated across the complete life cycle of a building project.

The activities in the Building Performance Assurance project are oriented toward assuring *energy* performance although we use the term "performance" in a broad sense. An outstanding building that "performs well" should support high levels of energy efficiency, occupant comfort and productivity, and indoor air quality, with low operating and maintenance costs.

### **Building Industry Problems**

There are numerous aspects of the building industry that create problems for assuring the overall performance of buildings. These aspects include a large and fragmented industry, poor information management across the life cycle of a building, and a lack of feedback between design and operations phases of the building process.

## *Large, Fragmented, and Energy-Indifferent Industry*

Construction of residential and commercial buildings is one of the nation's largest manufacturing activities, contributing \$800 billion to the U.S. economy, or about 13 percent of the Gross Domestic Product, and creating nearly ten million jobs (IPMVP Committee 1997). There are hundreds of thousands of small companies involved in designing, constructing, and operating buildings. This fragmentation stands in sharp contrast to other major energy sectors such as transportation or industry, where a fewer number of large companies are responsible for the design and operations of aircraft, trucks, automobiles, steel plants, paper mills, and other such items. The fragmented nature of the buildings industry inhibits wide-scale innovation and is a major barrier in changing current practice to include greater levels of energy-efficiency. This fragmentation is one of the reasons integrated information technology is needed.

Another related problem is that designers are typically indifferent to the energy performance of buildings, or even in conflict with energy-efficiency goals. Architectural and engineering designers (A&Es) are rarely compensated for the extra effort required to evaluate alternative designs that save energy and money. Traditional fee structures can even penalize A&Es who pursue cooling load reduction strategies that result in equipment downsizing and a related reduction in fees.

Overcoming these hurdles requires a building owner who is sufficiently motivated to clearly specify and support energy-efficiency as a project objective, and decision makers who are well-informed enough to target and assure achievable energy performance levels in the constructed building.

## *Critical Information Poorly Managed or Lost*

There are numerous types of problems associated with the loss of critical information that is generated during building design, construction, and operations. Major assumptions made during the design stage are poorly recorded for later use. Operations and Maintenance (O&M) manuals are incomplete. The end product of information loss is that building owners and operators inherit incomplete information about building systems that results in sub-optimal or problematic operations, high energy use, and poor comfort and indoor environmental problems. A recent review of HVAC related liability claims, performed by a large insurance agency for architects and engineers, cited poor information transfer (e.g., regarding expected thermal loads and HVAC requirements) as a common factor (Thomson 1997).

## *No Feedback Between Design and Operations*

Building designers rarely participate in evaluating the performance of constructed building systems they design. This is one aspect of the general problem that there is little feedback between design and operations. This particular example means that the energy consequences of design decisions are not well understood, and design errors are often repeated in future buildings. A related problem is that commissioning is not common practice, so most buildings are operated without having been subjected to even simple performance verification tests. Such tests help ensure that systems are installed, calibrated, and controlled as intended. Building owners assume that the current process of design and construction results in a "working" building, but numerous studies have shown that nearly all buildings have problems that could be addressed by proper commissioning (Piette and Nordman 1996). Even "best practice" commissioning does not usually include energy performance tests, which may require evaluating systems as they are actually operated over time.

One reason that there is little feedback between design and operations is that there are few performance tracking systems in place to provide feedback. Energy management and control systems (EMCS) don't directly measure energy use. Monthly utility bills, while definitely useful for evaluating whole-building energy use, are too coarse for system and component analysis. Furthermore, building operators have trouble understanding the design intent of building systems they are responsible for because they lack concrete and complete information on the design intent concepts and assumptions.

Two final key reasons there is little to no feedback between design and operations are the lack of standard methods for performance verification, and the lack of a well defined set of standard performance metrics. Certainly the development of monitoring and verification (M&V) standards will, in part, serve the industry well in promoting uniformity for M&V concepts. However, M&V standards are currently used primarily with retrofits and performance contracts, rather than as part of ongoing building performance evaluation activities.

## **Emerging Solutions**

The problems discussed above are general in nature. There are a variety of efforts and trends emerging within the building industry to address these problems. In this section we review several of these efforts.

### *Commissioning*

Commissioning is a process to ensure that building systems and equipment meet design intent. Commissioning practices are not widespread, but are growing. A recent survey sponsored by the EPRI was distributed to 432 firms in the U.S. and Canada known to provide commissioning and diagnostics services (Benner and Dasher 1997). The industry is young; more than half (60%) of the respondents (122 firms) have been providing these services for less than five years.

The commissioning field has evolved because the current building design and construction process falls short in providing performance verification procedures. Ensuring overall system performance was the number one reason cited for commissioning in a study of 175 commissioning case studies (PECI 1997). Another reason commissioning is gaining in popularity is that some building owners are beginning to understand that building systems have become more complex and dynamic, with more sophisticated controls and variable frequency equipment. Instead of delivering simpler, energy efficient buildings, today's more complex technologies require greater levels of coordination by controls and testing to ensure proper, and hopefully optimal, operation.

There are a variety of commissioning guidelines used within the industry (ASHRAE 1989; PECI/USDOE 1997; SMACNA 1994). The detailed guides include literally hundreds of pages of extensive forms and checklists to assist in documenting design intent and recording results from pre-functional and functional tests. Nearly all commissioning tasks require managing detailed information such as equipment and system specifications for comparison with what was actually installed and how it operates. There are several outstanding questions regarding how to make commissioning more cost effective, including: the correct level of testing to ensure operational efficiency, documentation requirements for field tests, and providing the right information technology to assist in reducing



commissioning costs. These questions will need to be answered before commissioning becomes common practice.

### *Monitoring and Verification Standards*

The International Performance Measurement and Verification Protocol (IPMVP) is a document that discusses procedures to allow building owners, energy service companies (ESCOs), and financiers of energy efficiency projects to quantify energy conservation measure performance and energy savings (IPMVP 1997). The IPMVP establishes common terms and measurement techniques that are of growing interest to building owners and other stakeholders who want to track key performance metrics using continuous energy tracking and other information technology systems. The opportunity exists to use monitoring and verification (M&V) data for more than verifying energy conservation measure performance. For example, such data can be used to benchmark building performance for key end-uses against similar data from comparable buildings, or to identify operational performance problems by tracking changes in M&V reports. Unfortunately, most ESCO projects to-date use only the most simple M&V techniques, such as one-time power measurements before and after a retrofit. More sophisticated M&V schemes offer more valuable data that can be used for performance monitoring.

### *Open Control and Monitoring Technology*

There are also new and emerging control technologies that are revolutionizing building controls. One such technology is BACnet, a data communication protocol for Building Automation and Control Networks (ASHRAE, Standard 135-1995). BACnet building management systems (BMS) can communicate with each other. By contrast, most of today's BMS and EMCS utilize proprietary communications systems, requiring expensive gateways to connect them to other systems. A similarly promising new technology called Atrium is being developed at the Honeywell Technology Center (Honeywell 1998). Atrium allows BMS data to be archived in a standard database. These data are accessible through an Internet browser. Such a system offers the possibility of turning BMS and EMCS into performance monitoring and tracking tools. Atrium is being designed to link to any BACnet-compliant BMS.

### *Software Interoperability*

One important industry-based effort to improve the capture and transferability of building information is the International Alliance for Interoperability (IAI). The IAI is a worldwide non-profit alliance of the building industry including: architects, engineers, contractors, building owners and facility managers, building project manufacturers, software vendors, information providers, government agencies, research labs and universities. Its mission is to "integrate the AEC/FM (Architecture, Engineering, Construction and Facility Management) industry by specifying Industry Foundation Classes (IFC) as a universal language to improve the communication, productivity, delivery time, cost, and quality throughout the design, construction, operation and maintenance life cycle of buildings" (IAI 1997). The IFC is a standard data model specification designed to support direct sharing of data between software applications.

### **Performance Metrics and BLISS**

The Building Performance Assurance (BPA) project at LBNL addresses the building industry problems identified above by working to integrate a variety of emerging information technology solutions. A long-term goal of the BPA project is to provide building decision-makers with the

information and tools needed to cost-effectively assure the desired performance of buildings across the complete life cycle of a building project. We recognize that simply developing new information technology tools will not solve all of the identified problems. Yet, a significant barrier to improving building performance is the fact that building decision-makers do not clearly understand the interconnectedness of performance problems and cannot easily assess the quantitative consequences of them.

A key element required in achieving our goal is a method for explicitly documenting the building performance objectives that are of importance to stakeholders. This has led to the concept of *performance metrics*, which provide quantitative benchmarks useful in evaluating alternative design or retrofit solutions, commissioning the newly constructed building systems, and tracking and maintaining the actual performance of the occupied building over time.

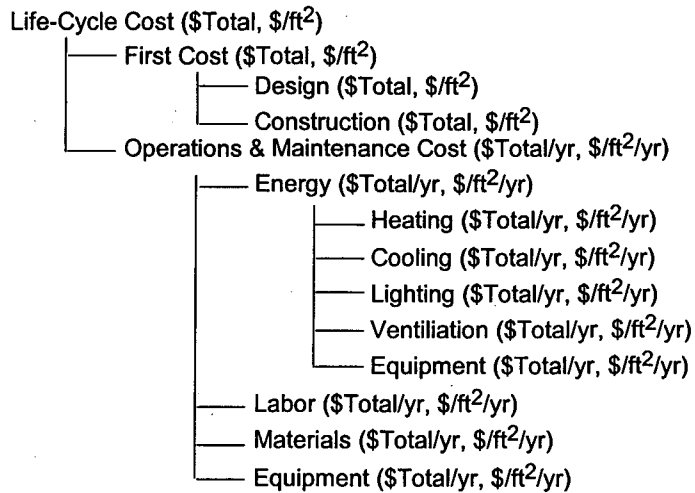
To effectively document performance metric data, and make these data accessible to multiple project participants across the building life cycle, we are developing the Building Life-cycle Information SyStem (BLISS). BLISS is intended to provide an information infrastructure capable of integrating a variety of building information technologies that support performance assurance. This section includes a definition of performance metrics, followed by a description of BLISS, and a scenario for the use of performance metrics across the life cycle.

### *Performance Metrics*

A building project begins with a consideration of the various performance objectives of interest to building stakeholders. While primary attention is generally given to space requirements and construction costs, a wide spectrum of objectives may be at least informally considered, including: life-cycle economics; energy-efficiency; environmental impact; occupant health, comfort and productivity; and building functionality, adaptability, durability, and sustainability. The process of identifying the objectives for a given building project is often referred to as programming, and is accomplished through discussions between building stakeholders such as the owner or developer, occupants, and planning experts. The outcome of programming is most commonly recorded in text that becomes part of design and construction documentation. This documentation may be frequently referenced during design, and occasionally referenced during construction, but then most often collects dust from that time forward.

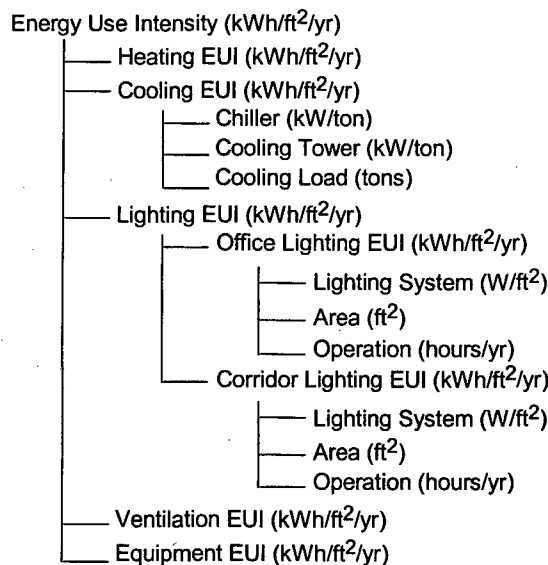
Performance metrics are designed to explicitly represent project objectives, using quantitative criteria, in a dynamic, structured format that provides value across the life cycle. One or more metrics may be defined for any given performance objective that building process participants (e.g., owners, designers, operators, occupants) wish to specify and track. A guiding principle in defining a performance metric is to identify a critical variable that measures, reflects, or influences a particular performance objective. To be useful across the building project life cycle, each metric must also be capable of being either predicted or measured at various stages of the project so that the achievement of each objective can be evaluated.

In most instances, a high-level performance objective will need to be delineated by multiple metrics that influence its overall satisfaction. This delineation can be organized hierarchically as illustrated in Figure 1 for life-cycle cost.



**Figure 1. Performance Metric Breakdown for Life-Cycle Cost.**

While life-cycle cost is a relatively straightforward performance objective to delineate, others, such as energy performance, may be more difficult. The hierarchy in Figure 2 shows one possible subset of performance metrics that could be used to specify, track, and maintain a desirable energy use intensity in a building. Note that each performance metric is not necessarily a simple arithmetic sum of its constituent metrics as was the case for life-cycle cost. The hierarchical organization logically groups metrics that are important to track because of their impact on their parent metric. For example, the hierarchy below indicates that one component of whole-building energy performance is the cooling system energy use intensity (EUI) which in turn is influenced by chiller and cooling tower efficiencies and building cooling load, among other possible elements. It is not sufficient to track only whole building energy use. Constituent metrics must also be tracked to support problem detection and performance assurance by the end user of these data. It is also important to note that energy use intensity is only one of the many performance objectives for a building, and must be considered in conjunction with objectives such as occupant health and comfort, and overall building functionality.



**Figure 2. Performance Metric Breakdown for Energy Use Intensity.**

Performance metrics come in a variety of forms for which there is presently little standardization. For example, chiller efficiency can be specified using a single value parameter (e.g., coefficient of performance (COP) or integrated part load value (IPLV)), multiple data points representing a two-dimensional part load curve for specific operating conditions or a three-dimensional part load surface across the full operating regime, or a mathematical curve or surface function. Moreover, the preferred method for documenting a performance metric may change over the life cycle of a project. Following the chiller efficiency example, pre-design planning might specify a desired chiller IPLV. Detailed design simulation might use a mathematical representation (e.g., a curve fit) of the performance of the selected chiller, based on manufacturer specifications. Commissioning and O&M measurements might subsequently collect multiple data points within the chiller's operating regime.

The specification of a performance metric should therefore be flexible enough to accommodate this variety of forms, yet be standardized to allow consistent interpretation. This requires a data definition for performance metrics that is capable of representing and capturing the various data types. It also requires that standards be developed that identify a key set of performance metrics of interest to building stakeholders, and that provide methods for comparing different data types (e.g., an IPLV and long-term time-series data) across the life cycle.

Our data definition of a performance metric includes the following attributes: name, specifier, date of specification, benchmark value and source, and assessment value(s) and source. The metric name is simply an identifier. The specifier and date of specification document the building process participant concerned with this aspect of building performance. The benchmark value documents the intended level of performance. The benchmark source archives the origin of the benchmark value (e.g., code, standard, simulation, manufacturer, EMCS). One or more assessment values record the performance of a building design or an operating building over time. The assessment source indicates the means by which a performance level has been assessed (e.g., simulation, measurement, estimation).

Sets of both benchmark and assessment values are archived for each performance metric over the life cycle of a building project. There may be an initial benchmark value established in pre-design planning, updated benchmark values and predicted assessment values determined during design, short term commissioning measurements, and long term monitored values. End users of this data would be able to compare these different values to evaluate building performance in a variety of ways.

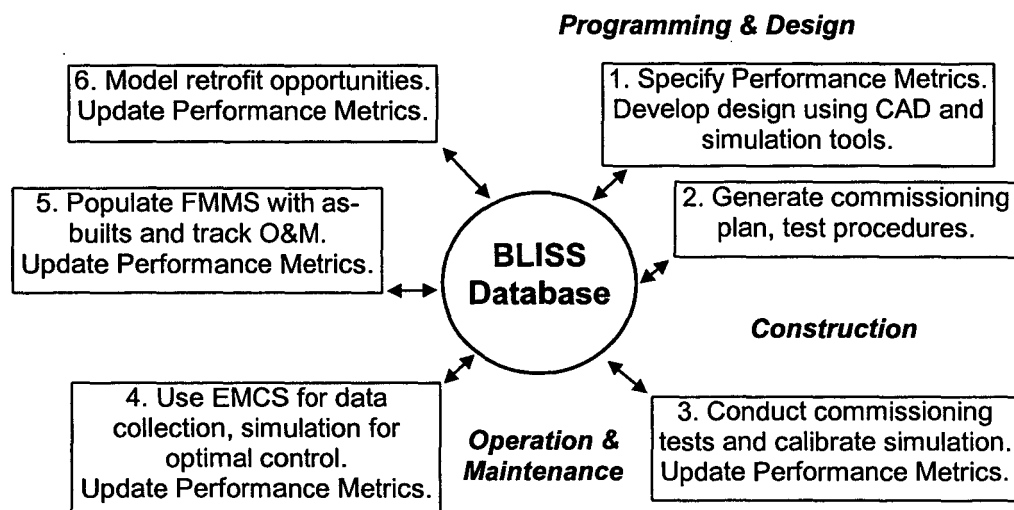
### *A Building Life-cycle Information SyStem (BLISS)*

One of the challenges in the development and use of tools to archive performance metrics is that the metrics cannot stand on their own. They are linked, for example, to design assumptions or operating conditions that generate the specified, predicted or measured performance that is to be evaluated against a benchmark. Thus, the concept in BLISS is to ensure that there is a model of the building that can be used to predict design performance through the use of simulation tools. When carried forward and updated during commissioning and O&M, this model captures as-built documentation. Using the design simulation in later phases of the building life cycle is one method to update performance metrics over the building life cycle. The revised versions of the model contain information that can be used to re-calibrate performance benchmarks for comparison with the occupied building performance.

There are numerous uses and potential benefits of explicit documentation of building performance metrics. For example, project planners could more clearly document the desired performance objectives during initial project planning. Multi-criteria evaluation of proposed solutions during design could be better supported, and the resulting decisions could be better documented for sharing amongst design team members. Multi-criteria assessment of design changes during construction and operations and maintenance (O&M) could be improved. A more comprehensive commissioning process could be cost-effectively supported by ready access to clearly specified performance benchmarks. O&M evaluation of the day-to-day performance of a building, and the early detection and diagnoses of maintenance problems, could be enhanced through performance benchmarking. Performance contracting and measurement and verification could be supported in a structured manner. Formal post-occupancy evaluation of the building could be more easily performed to provide feedback on the success or failure of design decisions, both for continuous performance tracking of the occupied building, and for the future design of similar buildings. Building performance labeling could also be supported.

BLISS is intended to provide a complete and coherent representation of both design intent and the basis of design. *Design intent* is captured in the hierarchical organization of performance metrics. The *basis of design* is captured in the data model that contains all details of the building such as walls, windows, spaces, HVAC and lighting equipment and modes of operation. This data model thus documents the design decisions that have been made in the attempt to achieve the stated performance objectives. During design, the data from this model can be used as input to various simulation tools to predict the performance of the current design for evaluation against the desired performance. When a specific design is approved, and documented as constructed, the output from these simulation tools become the benchmarks against which to evaluate the measured performance of the occupied building. Modifications to the building design due to construction changes, or to the building operation due to occupancy or use changes, must be consistently documented in the building data model. New simulation of the modified building can then provide updated benchmark values for the related performance metrics. In this manner consistent up-to-date documentation of both design intent and the basis of design is maintained throughout the life cycle of the building.

Figure 3 outlines a possible future scenario for the use of performance metrics and life-cycle information systems. The scenario begins in the programming phase (Step 1), where a set of performance metrics are specified by project stakeholders to represent the building performance objectives, and are archived in BLISS. Computer aided design (CAD) tools are used for the architectural design, and the CAD data are used as input to an energy simulation tool. Results from the energy simulations are compared with their corresponding performance metrics established during the programming stage. Both the CAD data and the simulation results, for the final design, are archived in BLISS. The energy implications of changes that occur as the building is constructed can be evaluated using simulation, and the details of each change documented in BLISS. In Step 2, a detailed commissioning plan and test procedures are generated from the CAD building description archived in BLISS. The simulation results will serve as updated benchmark data sets for use in commissioning. As installation of each building system is completed the commissioning tests are conducted to determine if the design intent was met (Step 3). Also at this stage, in-situ test results are used to re-calibrate simulation models and update the appropriate performance metrics.



**Figure 3.** Use of Performance Metrics through the Building Life Cycle.

In Step 4, an enhanced EMCS is used to continuously monitor the building and provide diagnostics using real-time simulation that checks actual operation with intended and optimal performance benchmarks. These data are also used in a Facility Maintenance Management System (FMMS) in Step 5, which dispatches and tracks maintenance actions. One benefit of such integrated information systems is that the energy impact of O&M actions can be readily assessed. For example, when the chillers are cleaned, the efficiency is improved and the new energy performance readily measured. O&M can therefore be optimized. The system is also linked to a retrofit simulation tool that allows the facility manager to explore the energy savings from possible major or minor system changes (Step 6). Each step involves the generation of metrics which are archived and accessed in a common database format. The facility manager has a clear record of the design, as-built, and as-operated equipment, along with the total energy and economic performance of the building.

Clearly, the realization of this scenario will require considerable further development of the emerging solutions discussed above. We are currently focusing our attention on BLISS and performance metric tracking. The foundation of BLISS is a standard data model that is capable of managing and archiving all critical life-cycle information. We are developing a BLISS prototype based on the IAI Industry Foundation Classes (IFC) Release 1.50 data model enhanced with our data definition for building performance metric. We have also developed a performance metric tracking tool, which we call Metracker, that provides a user interface for the specification and tracking of performance metrics. This is accomplished through a data browser that displays the organization and details of a BLISS archive, and graphical visualization of performance metric data comparing intended and actual performance across the building life cycle.

### **Case Studies**

To obtain some practical insights into how the BLISS concepts could be applied in practice we have conducted three case studies to examine how performance metrics are used in actual design, commissioning, and operations practices. The three sites were: (1) Southern California Gas Company's Energy Resource Center (ERC), (2) Naval Hospital, Camp Pendleton, Chiller Replacement, and (3) Naval Demonstration Building, Point Hueneme. We were looking to see if tasks, that we feel are critical for improved performance metric tracking, were performed at each site. The

following tasks were considered: identification of specific performance metrics of concern, establishing appropriate pre-design planning objectives for these metrics, methods for predicting and evaluating the performance of design alternatives with respect to the specified metrics, commissioning testing procedures using the specified metrics, documentation of commissioning results, and procedures for tracking building performance following occupancy.

While each of the case studies made some use of performance metrics, they also exhibited inconsistent use of this information, and its generally poor transfer between design, commissioning, and operations phases of a project. A brief look at one of the case studies will illustrate some of our concerns. Similar results were found at the other two sites.

The Energy Resource Center (ERC) is a 45,000 ft<sup>2</sup> conference and education center created by the Southern California Gas Company to help energy decision makers learn about energy-efficiency and environmentally-sound technologies. The building is one of the U.S. Environmental Protection Agency's 25 Energy Star Showcase buildings. Our study involved evaluating the documentation used and prepared by the commissioning agent, along with related papers about the building. Mathaudhu (1997) stated the original objectives for the mechanical system design as follows:

- Reduce source energy consumption by 30% more than mandated by California State Energy Efficiency standards (Title 24) and ASHRAE Standard 90.1 and Standard 100 Series.
- Design the mechanical system with minimum use of refrigerant.
- Design higher indoor air quality for maximum comfort of building occupants.
- Optimize performance of both the existing and new mechanical systems.

While the first of these objectives is somewhat quantitative, it does not provide a definitive baseline since Title 24 and Standard 90.1 are not identical. Furthermore, the commissioning agent subsequently specified the energy target as a 45% saving over Title 24 (Schexnayder 1997). This illustrates the potential for inconsistent specification of intended performance using traditional paper based methods for project documentation. The remaining objectives give only general guidance without providing any clear quantitative measures for evaluating their achievement.

Two DOE-2 simulations of the building were developed for use in evaluating the objective of reduced energy consumption, and for assessing the impact of changes in building occupancy. The first was developed during renovation design, the second was developed as part of a post-occupancy evaluation. The input to DOE-2 constitutes a very detailed and specific documentation of the building design. The output from DOE-2 embodies a detailed specification of intended building performance. A simulation model like this can provide a method for predicting and evaluating the performance of design alternatives with respect to the specified metrics, and an energy baseline useful in commissioning some aspects of the building. However, the model must be accurately maintained throughout design and construction to support these uses, and a skilled simulation user is required to extract the relevant data.

Lastly, enhancements were made to the EMCS both for use in commissioning as well as for long-term performance tracking. However, the monthly reports that are generated by this system only show current energy consumption without specific reference to the original design performance targets

as comparison values. Furthermore, the data provided by the system has been underutilized in evaluating building performance over time.

The use of BLISS and the Metracker tool would have been useful on this project in several ways, as described above for the scenario presented in Figure 3. The primary benefits derived from these tools would be a common repository for building information, and a standardized structure for capturing and tracking building performance across the project life cycle.

## **Conclusions and Future Work**

This paper has reviewed building performance problems related to information transfer and the use of prototypical and emerging industry practices and information technology to address these problems. The development of a Building Life-Cycle Information SyStem, compliant with the emerging IFC from the IAI, is seen as a key to successful linkage of information across various phases of the building life cycle. A number of private and public entities have expressed interest in this open systems approach, along with the explicit definition of critical performance metrics. We are exploring methods to promote the further development of similar tools and open systems to move the activity forward.

Our case studies have shown that it is useful to identify key performance metrics to be tracked from design through operations. Enhancing an EMCS with the addition of extra monitoring points has been shown to be useful in commissioning. Unfortunately, energy tracking systems put into place are often under utilized during ongoing operations. This is partly because there are not standard methods for synthesizing long-term time-series data into standard metrics for simple comparisons. While there are many project sites and research projects that have developed methods to examine these long-term performance data (Mingsheng 1997; Sebald and Piette 1998), there are few standard formats and methods for detailed continuous performance tracking systems. We hope to address this gap as we continue development and field testing of BLISS and Metracker. During field testing in particular, we intend to study issues of the costs and benefits of new information management methods, and the institutional barriers to their utilization.

BLISS and Metracker are still in early prototype stages. They are intended as functional tools that can be applied in actual building projects to demonstrate their use, provide a testbed for feedback and further development, and explore the costs and benefits of life-cycle information systems and tools. The continuing effort required to achieve BLISS should not be underestimated. This effort will involve not only tool development, but also effective interaction with the building industry to refine the concepts, prove the added value of such a system, and help evolve new business models that will encourage industry adoption of integrating information management technologies.

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ONE CYCLOTRON ROAD | BERKELEY, CALIFORNIA 94720**