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## **Interoperable, Life-cycle Tools for Assuring Building Performance: An Overview of a Commercial Building Initiative**

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## **Overview**

A key impediment to improving the energy efficiency and reducing the environmental impact of buildings is the complexity and cost of managing information over the life cycle of a building. A surprisingly large fraction of the total cost of buildings is embodied in the decision making and information management process due to the structure of the building industry, the numerous people and companies involved in the process, the current nature of the building acquisition process, and the long time periods over which buildings operate once design and construction are completed. We suggest that new interoperable software tools could greatly facilitate and rationalize this complex process, thereby reducing time and cost, and greatly improving the habitability and environmental impact of these buildings. We describe a series of projects in which we are building and testing several prototype toolkits as part of a building life-cycle information system that will allow interoperable software tools to function more effectively throughout the design, construction, commissioning, and operations phases.

## **Background**

Virtually every decision made over the life cycle of a building has performance and environmental consequences of both a short and long term nature. The creation of a sustainable building requires that thought and care goes into a wide range of performance issues and impacts on a local, regional, national and even global scale. Many consequences of creating a building are immediate and “visible,” but some are more subtle or complex in the way they manifest themselves to designers and owners. Although the occupants, or society at large, may ultimately experience these effects, these groups typically have almost no direct input to the building planning, design, and construction process and often not much more once the building is occupied. Building design

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and operation is a business in which time and money are important. When the consequences of a decision are “invisible,” little extra effort or resources will be spent on fine-tuning or optimizing that decision.

A central challenge to the task of creating more sustainable buildings is thus to be able to bring all the information needed to assess the consequences of numerous decisions to the attention of the appropriate decision makers in a timely, cost effective, and practical way. This is a challenge that begins when the client first considers constructing or renovating a building to meet a need, and continues over the entire life cycle of the building. As a prerequisite, it requires that people choose to create a sustainable design, and there are numerous cultural and educational obstacles to overcome in this regard. But assuming this can be done, if we are to have the required impact on a national scale, it must become easier, less risky, and more “practical” to design and create a sustainable living and working environment. This will require innovation and advances in both design process and in building technology. As we approach the beginning of the 21st century, computers and the software infrastructure that supports their operation will almost certainly play a rapidly growing and critical enabling role in meeting these challenges.

Researchers at Lawrence Berkeley National Laboratory (LBNL) have been addressing many of the interrelated issues of sustainable design over the last 20 years, in partnership with industry, government, and professional societies. Since the U.S. Department of Energy has been our primary client, energy use and energy-related impacts have been the focus of our work. Because energy use (extraction, conversion, transmission, and end use) is thought to be the single largest human activity with direct environmental impacts, much of our past and ongoing work has immediate relevance to the challenge of creating sustainable buildings. Over the last three years we have refocused efforts on the challenge of improving the design and operation of commercial buildings.

Despite significant advances in building technology and the promulgation of tighter building codes, commercial buildings consume about 15% of all energy used in the U.S. at a cost of \$85 billion annually, half of which is wasted compared to what is achievable, with associated adverse environmental impacts. Assuring total building performance (which includes health, comfort, and productivity in addition to operating expense such as energy costs) is a priority in an increasingly competitive world. Achieving this goal requires a careful examination of the process by which buildings are designed, built, and operated. A life-cycle perspective on how information is managed in the building sector provides useful new insights and opportunities for achieving performance potentials.

To address these challenges we have launched the “Building Performance Assurance” project. Much of the initial proof-of-concept exploratory effort has been funded by internal research and development funds at LBNL. Members of the Energy and Environment Division teamed with colleagues in the Information and Computer Sciences Division to pursue this initiative. The immediate goal of the project was to initiate the development and standardization of an interoperable set of tools that enhance building performance by facilitating information transfer throughout the building life cycle. These tools are individually optimized to respond to the specific needs of each phase of the building’s life, but are linked by a shared information infrastructure, the Building Life-Cycle Information Systems (BLISS). Our overall project strategy was to develop

workable, cost-effective prototype solutions to assuring building performance as a springboard for creating building industry interest in these concepts and then developing future private sector partnerships to implement a more complete vision for interoperable tools.

Our initial effort has focused on the conceptual development of BLISS and the development of a series of prototype tools: a tool for capturing Design Intent, a Chiller Commissioning tool kit to assist in the process of verifying and documenting installed chiller performance, and a Performance Evaluation and Tracking Tool, which incorporates a chiller emulator and data visualization module. In this exploratory project we focused our efforts on chiller system performance, beginning in the design phase and extending through commissioning and operations. We are also using other tools already under development, such as the Building Design Advisor. In addition, we are linking this project to related CIEE-supported activities in Building Diagnostics, and to another DOE-supported initiative to manage and operate multiple buildings remotely over the internet. In order to ground the proof-of-concept in reality, all of the software models under development have been driven by measured data from Soda Hall, a newly occupied building on the U.C. Berkeley campus. As part of this project we have added additional instrumentation to the existing building energy management system and have tapped into these data streams (approx. one gigabyte per month) as needed by our software tools. In addition to the tool development efforts, we have created a computer-based mockup and videotape that demonstrates key elements of our entire BLISS vision and have held a series of meetings with utilities, manufacturers, building owners, and government agencies, all with prospective interests in the successful completion of this effort.

## **Tool Development Projects**

A brief overview of each of these efforts is given below. More information can be obtained from the references and by contacting the authors.

***Building Life-Cycle Information Systems, BLISS.*** The goal of this effort is to create a software infrastructure that can be used for information sharing across disciplines and can be used to link interoperable software tools throughout the building life cycle. The project has three major elements: (1) to specify the distributed software architecture, (2) to build a life-cycle database, and (3) to develop a mechanism to capture and update “design intent” throughout the life cycle (see below). The distributed systems architecture describes how various building software components communicate and the database schema specifies the structure and semantics of the database. An initial version of this software will be built as an extension of the Building Design Advisor data model (see below). In order to be sure that our work is truly interoperable with industry efforts to create a standardized building model, we will make this software consistent with the evolving software specification from the International Alliance for Interoperability (IAI).

***International Alliance for Interoperability, IAI.*** Only a small fraction of buildings are designed using computer-based energy simulation tools, such as DOE-2, in part because of the time and effort needed to enter descriptive and performance data. Much of this needed information already exists in other building design tools (e.g., CAD tools contain the required geometric data) but it is not readily accessible since there is no agreed upon procedure for sharing such information

between tools. In the building industry, the goal of “interoperability” means concurrent access to project/building information and information sharing: a single building model that is shared by all participants in a building’s design, construction, and use. When interoperability supplants the current piecemeal sequential data exchange, information will no longer be lost in the life-cycle process. An interoperable building model would assure data compatibility across applications and platforms. Software users will benefit from enhanced communication among disciplines and across project teams, reduction of inconsistencies from decisions made by different disciplines, and direct links of CAD data to non-CAD applications. The industry will see major cost savings through more efficient information management, tracking of project/building decision-making, and the ability to add to previously made decisions. The benefits of an interoperable future are clear—the challenge is how to get there.

In the fall of 1994 LBNL joined eleven private sector companies, each a major force in the building industry, and formed an alliance whose goal was to bring interoperability to architecture, engineering, construction, and facilities management. A ten-month intense development effort culminated in the creation of a demonstration of the potential benefits of software interoperability at the AEC Systems Show in Atlanta in June, 1995. LBNL participated in the demonstration with the Building Design Advisor (BDA), DOE-2, and RADIANCE, which were simulated in use in a fully interoperable building design environment. After the demonstration, the private alliance of twelve companies was reorganized as the non-profit International Alliance for Interoperability (IAI), which now has 70 U.S. members and 200 additional international members in new chapters in Europe and Asia.

IAI’s main task is to define, publish, and promote Industry Foundation Classes (IFCs). IFCs comprise a library of commonly defined software “objects” that depict building components, features, and events, and which can be shared by diverse applications throughout a project’s/building’s life cycle. All IFCs are to be defined by the IAI and are open; i.e., not owned by any vendor. They will be implemented incrementally, and would continually evolve to meet industry needs. IAI has recently published version 1.0 of IFCs, which contains the reference object model definition, IFC conformance criteria, IFC implementation guidelines, and specifications for model exchange requirements. Twenty-five companies have already committed to developing software that will be IFC compliant. Prototypes will be demonstrated in the fall of 1996 with initial products available in 1997. If IAI can successfully accomplish its goals and become a de facto new industry standard, it opens the possibility that all environmental and energy-related tools will be able to communicate and share information with each other, as well as with the CAD, cost estimation, and facilities management software that is at the heart of the building industry. This has the potential to significantly enhance the impact of energy and environmental tools on building design and operations.

### Goal of Industry Foundation Classes (IFC)

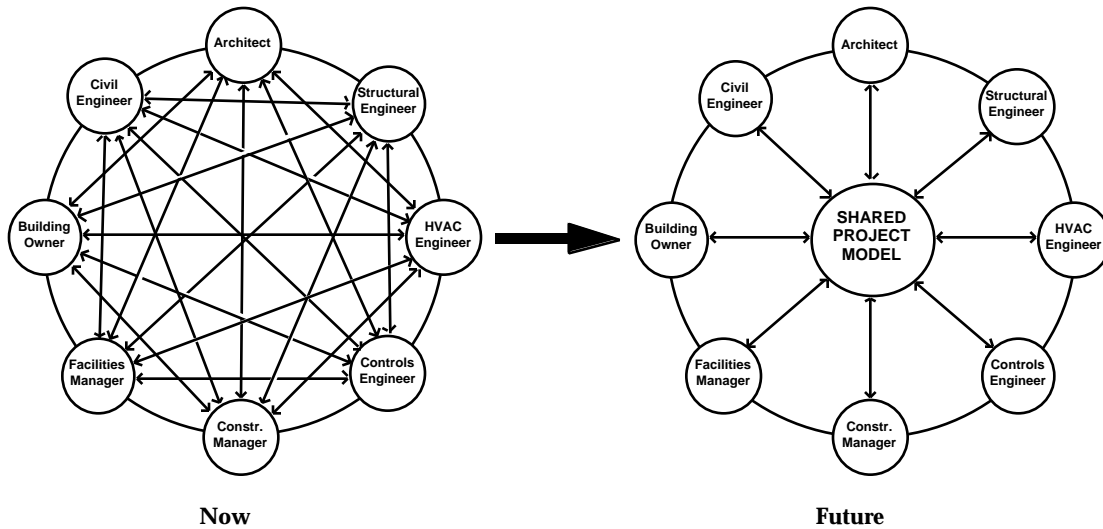


Figure 1. Industry Foundation Classes (IFC) will allow the building profession to share a single project model, thus facilitating the use of interoperable tools.

### IFC Vendor Implementation

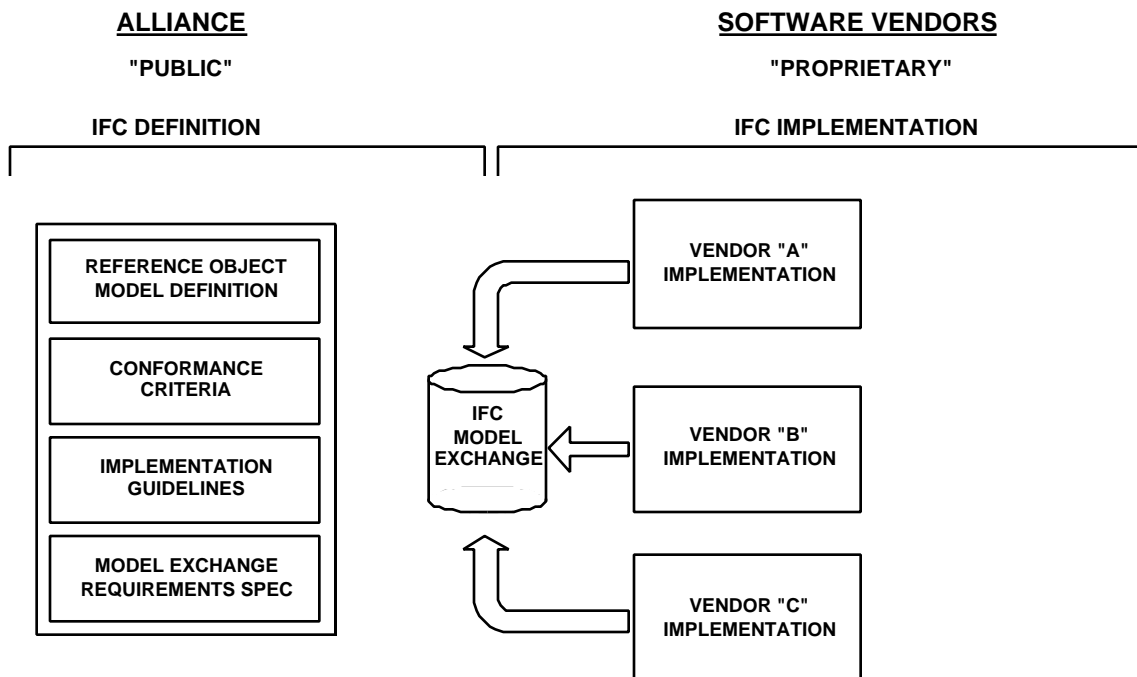


Figure 2. The framework for IFC is being developed by the IAI as a “public” activity. Individual software vendors will then implement IFC in their proprietary software.

***Design Intent Tool.*** The design, construction, and operation of a building is a complex undertaking that spans many disciplines over long time durations. Although virtually every element of the building life cycle has become more complex over time, the building information management methods used to support and integrate the wide variety of project participants and their activities have not kept pace. In current practice, the bulk of building design-related information is still documented and communicated in the traditional forms of paper-based specifications and graphical drawings with text annotations. Much valuable information, in particular the intent behind the myriad design decisions made by all project participants, is altered or lost due to inadequate documentation and poor information management. We have been examining the issue of documenting design intent from a life-cycle perspective so that this information can be made accessible to all project participants throughout the life cycle to better assure that a building achieves the functional and operational needs of its owners and occupants. We have developed a formal methodology for identifying and documenting the required building-related information. We then developed a prototype of an early vision of a software tool for documenting design intent (1).

This software tool will assist in documenting design intent as expressed in a set of performance objectives that are initially generated during the early phases of design, but then revised and altered in both planned and unplanned ways over the building life cycle. The performance objectives can take the quantitative form of a performance metric with target values or the qualitative form of a text-based descriptive statement. The rationale behind the initial decisions and later alterations, which is typically lost, will be archived by the software for later retrieval as needed.

The prototype software assists in explicitly identifying and documenting the performance goals (explicit global objectives, EGOs). An individual EGO may take the quantitative form of a performance metric with its target value or the simple qualitative form of a text-based descriptive statement. We also specify Context Parameters which define the operating environment within which the building has been designed to achieve the stated explicit global objectives; e.g., the design day cooling load used to size an HVAC system chiller. A series of Design Rationale Records document the basis for design decisions in which building components, systems, and operation procedures are synthesized to achieve identified objectives under stated operating contexts. A single Building Design Version is thus comprised of a complete set of objectives, context parameters, design records, and other supporting information. The initial Building Design Version then changes over time to reflect life-cycle variations of a building, which can include alternative design solutions, the as-specified design that is sent out for construction bidding, the as-built building, the post-commissioned building, and the building at various stages in its ongoing operation. In the coming year this early prototype is currently being tested using real building data sources. Such a tool may prove to be useful in documenting and tracking compliance with various commercial building rating systems.

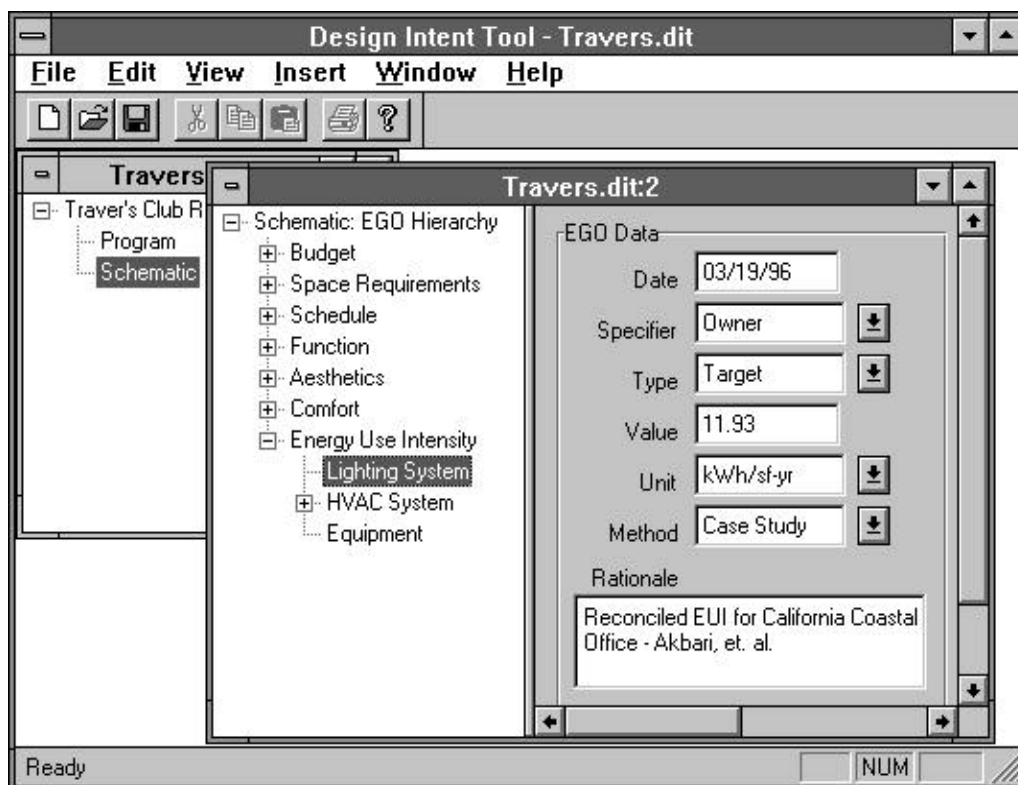


Figure 3. Screen image of Design Intent Tool objectives hierarchy with data shown for energy use of lighting system.

***The Building Design Advisor (BDA)*** is a computer program that allows designers to quickly and effectively use multiple analysis and visualization tools and integrate their output to support informed multicriterion decision-making. The development of BDA started in FY94 with funding from the Pacific Gas & Electric and Southern California Edison through the California Institute for Energy Efficiency, as well as the U.S. Department of Energy. The objective of the BDA development effort is to promote energy efficiency and environmental awareness in the design of new buildings, particularly in the schematic design phase, by providing means for decision-makers to analyze and evaluate the potential performance of their designs. Unless energy and environmental benefits can be accurately predicted, along with other non-energy performance aspects—such as comfort, esthetics, and economics—most building designers will not risk the implementation of new energy-efficiency strategies and technologies in their designs.

The currently available tools for accurate prediction of energy and environmental performance are very hard to use because they require preparation of complicated text files to describe the building and its context and provide output in the form of numerical tables that are hard to review and understand. Moreover, such tools use building modeling representations that are incompatible with each other and thus require multiple, specialized descriptions of the building and its context. As a result, such programs are generally used only by experienced consultants for large projects that can justify and support the high associated costs. Our initial goal is to move these decision-making



capabilities to the architect's office early in the design process and to make its use cost-effective as viewed by designers.

To facilitate the integrated use of multiple analysis tools—such as DOE-2 for energy simulation, and RADIANCE for lighting analyses and photo-realistic rendering—BDA uses a real-world, object-oriented representation of the building and its context, mapped onto the specialized representations of the analytical models linked to it. In this way, BDA shields building designers from the modeling complexities of the individual analysis and visualization tools, allowing them to concentrate on design decisions. BDA allows the user to quickly specify the basic geometric attributes of spaces, windows, doors, etc. through a CAD-like Schematic Graphic Editor while it automatically assigns default values from a Prototypical Values Database to all non-geometric parameters required for energy and other analyses. The default values are assigned based on location, building type, and space type and can be reviewed and changed at any time using BDA's Browser. Using the Browser, the user can select any number of input and output (computed) parameters for display in BDA's Desktop for decision-making.

In addition to the Prototypical Values Database, BDA is linked to a multimedia Case Studies Database that allows building designers to compare their designs to existing buildings and create an appropriate, realistic context to set performance goals and evaluate performance. The Case Studies Database serves as an electronic magazine and supports the use of images, sound, and video for enhanced coverage of building performance. This database is being developed as a world wide web-based application to encourage sharing of building design and performance data.

The major development effort to create a working prototype of BDA began in 1995 and a beta version was released in 1996. The release of version 1.0 will occur in early 1997. We have also started with initial development of new modules to extend the functionality of the tool to environmental issues, cost issues, and expect to make BDA compliant with IAI's IFC object specifications. We are also exploring the use of BDA as an educational tool, and examining how the internet might be used to support BDA development, distribution, and training (2).

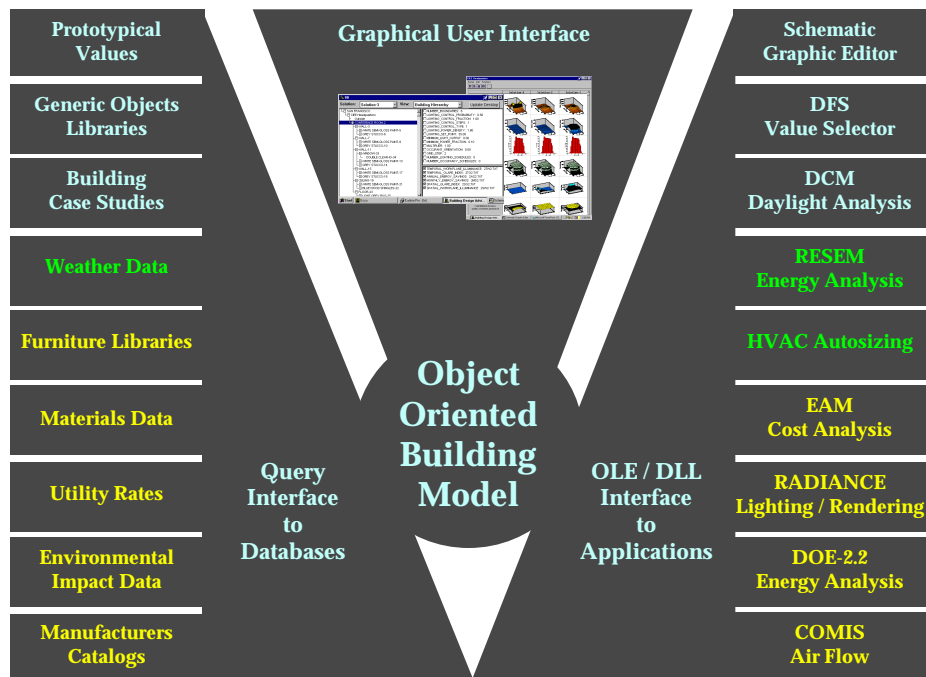


Figure 4. Schematic diagram showing the Building Design Advisor software environment.

**Computerized Chiller Commissioning Tools.** The focus in this project is to explore the general structure of commissioning tasks and their implementation, plus the development and testing of commissioning procedures for one specific component, chillers, in a new, well-instrumented building. Our prototype commissioning tool kit includes test procedures as well as software to assist in the commissioning of chillers. The software contains a component library and test plans, and it archives results from the commissioning tests.

Commissioning is a set of processes to ensure that building components and systems are installed and operated in an optimal fashion to meet or exceed design intent. Most buildings are not commissioned in a structured manner, resulting in significant problems such as defeated energy-efficiency strategies, incomplete control sequences, and poor documentation on as-operated conditions. While recent LBNL analysis of the benefits of commissioning has shown it is often cost-effective on energy savings alone, efforts to reduce costs are needed to encourage more widespread use of commissioning processes and techniques (3).

Computer-based information technology is one approach to address the loss of information that occurs as a building moves from design to operations. We have developed a prototype chiller commissioning tool to assist in the development, customization, execution, and archiving of commissioning plans. Our initial efforts have focused on chiller commissioning, since chillers are the largest single energy-using component in buildings with central plants. The first step in applying the software is to describe the characteristics of the chiller components, such as chiller size, type, design efficiency, flow rates, and operating temperatures. The software contains a

general description of chiller commissioning activities and a module to record specific test plan methods, customized for a particular building. Laptop computers can be used to track changes to test plans and collect data during plan execution. Test results are recorded and outstanding issues and deficiencies are tracked to ensure that the chiller is fully functional.

The procedures were tested on a 109,000 sq. ft. building on the U.C. campus. At the conclusion of the commissioning process we obtained an updated performance model of the as-built performance of the chiller system in this building, a model which is then used as the starting point to track building performance in the operations phase, using the performance tracking tool described below.

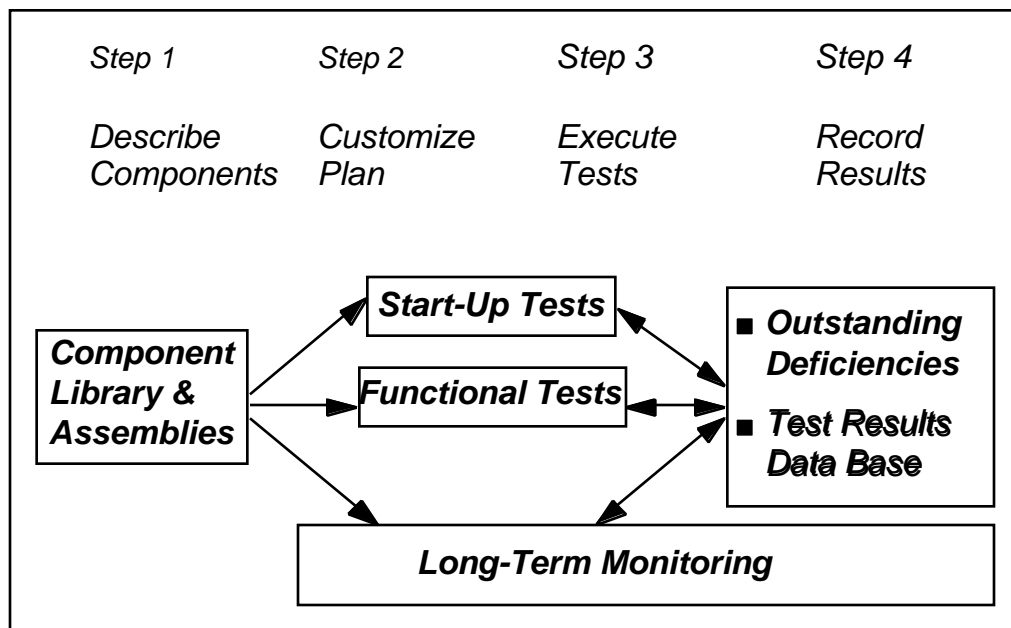


Figure 5. The four steps of commissioning and the use of a computer-based chiller commissioning tool.

**Building Performance Evaluation and Tracking Tool, PETT.** The focus of this project is the development and testing of performance tracking tools, again focusing on cooling plants. The bulk of the effort was in the development and calibration of a component-based SPARK HVAC simulation model of our case study building to evaluate chiller performance. This model in turn will be the starting point for a controls optimization and retrofit tool.

Measured HVAC time-series data are descriptive of the performance, but only under the strict boundary conditions that the building was exposed to during the monitoring (such as weather conditions during monitoring, the control strategies that were applied, etc.). When one wants to estimate performance under other possible conditions, measured time-series data of the past is of limited use. However, a dynamic model of the HVAC systems calibrated to monitored data can facilitate such estimations.

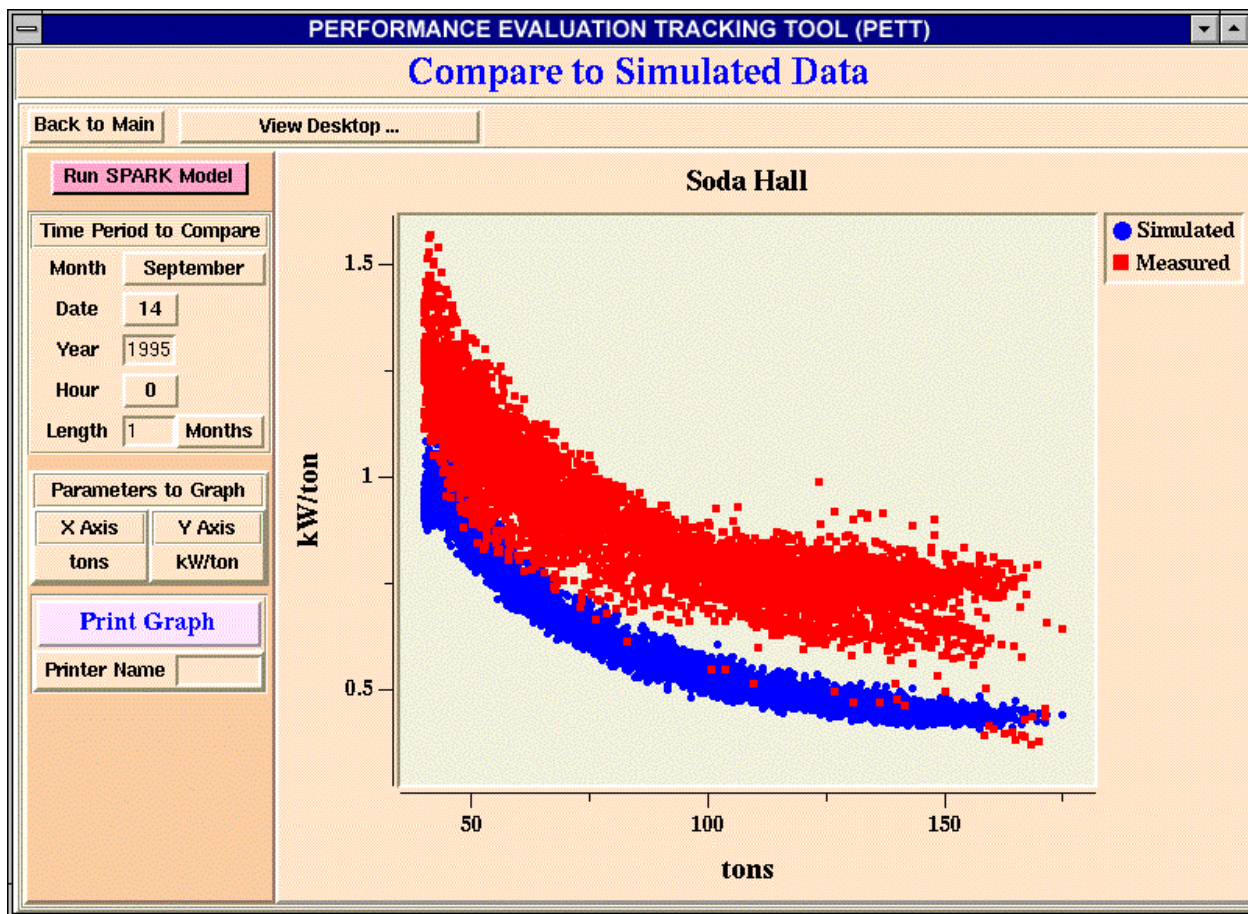


Figure 6. Measured and simulated data for the chillers of a case-study building.

A major objective during this phase of the project was to develop a prototype emulation tool using a dynamic model of the chiller system to track system performance in a testbed building and optimize chiller operations as required. We used the Simulation Problem Analysis Research Kernel (SPARK) to build our emulation model. SPARK is an object-based differential and algebraic equation solver that is well suited for detailed modeling of HVAC systems.

In our methodology, during the *design phase*, the HVAC model is built using the design documents and manufacturer-supplied data on equipment performance. At this stage, it is possible to emulate several design options (such as different equipment sizes, efficiencies, etc.), compare the energy performance of these different options, and feed information back to the design process.

During the *commissioning phase*, the SPARK model built using the design data is calibrated to represent the dynamic behavior of the system as it actually performs. After the acceptance of the building, time-series data on the HVAC variables are used to revise the SPARK model parameters. At this point, the emulation results and the real data from the building should be very close.

Using the *performance tracking* options, data from the building can be compared to benchmark data from other similar buildings, to historic data from the same building during other time periods,

or most significantly to the emulated data using the SPARK HVAC model. Deviations of the building data from the simulated data may indicate problems in the HVAC system. At this stage, this project is not attempting to pinpoint and diagnose the source of such problems. Other related research projects at LBNL are addressing these diagnostics opportunities.

The calibrated emulation model can be used for *control strategy analysis* to facilitate changes to the control logic that is actually used in the building. The environmental conditions and the building loads are maintained at the reported levels, but simulated changes are made on the control choices, such as temperature set points or equipment status. The emulator then predicts the expected building performance which can be compared to actual performance or to other control alternatives. Although at this stage, these control strategy analysis options serve as a “what-if” type of analysis facility, capabilities here can be expanded to include optimization. In such an application, the tool would return an optimal set of choices for all of the control options.

## **Summary**

A series of projects are underway to provide a new set of tools that should make it far easier to create energy efficient, cost effective, sustainable commercial buildings. A set of interoperable tools addresses key decision-making issues in design, commissioning and operations. The development of a Building Life-Cycle Information System, compliant with the emerging IAI specifications for describing buildings, is seen as key to successful linkage of a series of interoperable tools that are needed if sustainable buildings are to become the norm, rather than the exception. The initial tool development has been carried out in parallel with related tests and energy measurements in a near-by building, to validate the initial process and tools.

A number of private and public entities have expressed interest in this open systems approach. We are developing partnerships to cost-share further development of these tool kits. We are interested in learning more about related efforts and exploring how such efforts might be integrated with this project.

## **Acknowledgement**

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A video of the software mockup is available. E-mail us for a complete publications list and for information on the BPA web site which will soon be publically accessible.

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