Plugging Holes: Uncovering Critical Resource Gaps Needed for Commissioning to Thrive

Aleisha Khan, Portland Energy Conservation, Inc.
Martha Brook, California Energy Commission
Tudi Haasl and Hannah Friedman, Portland Energy Conservation, Inc.
David E. Claridge, Texas A&M University, Texas Engineering Experiment Station
Philip Haves, Lawrence Berkeley National Laboratory
Malcolm Verdict, Texas A&M University, Texas Engineering Experiment Station

ABSTRACT

The potential impact of commissioning is compelling – according to the U.S. Department of Energy's 1998 National Strategy for Building Commissioning, $50 million can be saved annually if commissioning occurs in just one percent of existing large commercial buildings (over 25,000 square feet) and seven percent of new construction. But do service providers have what they need to implement the large scope of commissioning now being encouraged across the U.S.? "Building Commissioning: Innovation to Practice," an ongoing multi-state collaborative program co-funded by a U.S. Department of Energy STAC grant, is standardizing and streamlining commissioning approaches through new tools and technology in an effort to provide this support.

The "Building Commissioning: Innovation to Practice," program has effectively addressed the high demand for training and tools that streamline commissioning – but the need existing in the commissioning field today has by no means been met. For example, experienced commissioning providers piloting the Program's functional testing resource confirmed the value of the content, but requested revisions to access it in different ways and suggested expanded content. Commissioning providers filled the Program's retrocommissioning training sessions that provided four-days of advanced hands-on training, while suggesting subjects for additional workshops. The Program is developing and piloting tools to automate some of the data-intensive aspects of the commissioning process – but there is more to do before these can be commonly used by commissioning providers.

While utility financial incentives and State mandates provide increased motivation to building owners, the activities of the "Building Commissioning: Innovation to Practice" program highlight the large need for training and effective resources for commissioning providers. It is likely that only a concerted effort in both of these areas will result in the successful and broad uptake of commissioning.

Introduction: Commissioning Momentum across the U.S.

The benefits of building commissioning are becoming increasingly well known, thanks to national, regional, and local programs. These programs, anxious to realize the energy savings potential of commissioning, now are spearheading the adoption of commissioning practices on a grand scale. However, in the face of these large savings goals, is enough being done to build the commissioning infrastructure so that the goals can be achieved?

There is a great deal of potential for commissioning, as seen by a 1998 study estimating that less than five percent of all commercial new construction – and less than 0.03 percent of existing buildings – are commissioned each year (PECI, 1998). While this number has increased over time, substantial opportunities remain. Widely-accepted benefits of commissioning include energy savings, peak load reduction, productivity and comfort gains, first cost reductions, and energy security benefits associated with commissioning. There are also related benefits to the environment linked to climate change and indoor air quality, and economic benefits arising from job creation and retention within the building industry. The U.S. Department of Energy's (U.S. DOE) National Strategy for Building Commissioning found that if just one percent of existing commercial buildings greater than 25,000 square feet were commissioned, along with seven percent of new construction for the same size, there would be the potential for more than $50 million in annual energy savings and economic benefits (PECI, 1998). A 2004 review of cost-benefit methodologies for commissioning and retrocommissioning found the energy benefits for new construction commissioning ranged from $0.05 to $0.64/sq ft, and the energy benefits of existing building commissioning ranged from $0.11 to $0.26/sq ft. (Mills, 2004).

Examples of Commissioning Interest at the National and State-Levels

To capture these opportunities, efforts at the national and state levels have recently increased to promote and/or mandate building commissioning. The U.S. Green Building Council (USGBC) is one of the most high profile of these efforts. USGBC recommends commissioning to the new commercial market through its LEED-NC® (Leadership in Energy and Environmental Design – New commercial construction and major renovation projects) standards – where commissioning of energy-related systems, lighting, and hot water systems is required as a prerequisite for LEED® certification. "Building commissioning is an important prerequisite of the USGBC's LEED® Green Building Rating System™ because it helps identify ways to maximize energy efficiency and thereby minimize environmental needs" (Fedrizzi, 2005). For additional specific commissioning activities, the buildings earn one point towards an energy credit (USGBC, 2005). The impact of the USGBC program is enormous – according to the USGBC website, there are currently at least 358 LEED® certified buildings in the United States.

California. In California, Governor Schwarzenegger signed *Executive Order S-20-04* regarding Green Buildings on December 14, 2004. The Executive Order sets a goal of reducing energy use in state-owned buildings by 20 percent by 2015 and encourages the private commercial sector to set the same goal. One significant objective is for all new State buildings to be LEED® certified, which, as mentioned above, includes commissioning requirements. The California Department of General Services (DGS) is currently modifying their new building design and construction processes to include building commissioning.

DGS, along with other state agencies, is also attempting to retrocommission a significant number of existing state buildings to meet the Executive Order's 20 percent energy savings goal by 2015. This is consistent with the California Energy Commission's recommendations for retrocommissioning in the energy efficiency policy report, *Options for Energy Efficiency in Existing Buildings* (State of California, 2005).

All of California's major electric and gas utilities have implemented retrocommissioning in recent years through their energy efficiency programs. California also has a design assistance program managed by the investor-owned utilities, called *Savings By Design*

(www.savingsbydesign.com), which promotes new building commissioning on the *Energy Design Resources* web site (www.energydesignresources.com). The Collaborative for High Performance Schools (CHPS) similarly promotes commissioning in the new construction of schools in California (www.chps.net). The program markets directly to school districts and designers – promoting energy-efficient buildings with non-energy benefits, including health and comfort, which provide a productive learning environment. Commissioning is a key part of the CHPS best practices and standards.

New York. In 2001, New York's Executive Order No. 111 for "Green and Clean State Buildings and Vehicles" required state agencies to meet the ENERGY STAR® building rating where possible. These agencies are also required to achieve a 35 percent reduction in energy consumption in all buildings owned, leased, or operated by the state by 2010 (based on 1990 consumption levels). Section II. A of the executive order recommends practices for existing buildings which include "inspecting/re-commissioning or re-tuning heating, air conditioning and ventilation equipment."

Washington. The state energy code in Washington is built on ASHRAE 90.1 but expanded to include additional requirements for mechanical systems commissioning and also require commissioning for lighting controls. For simple HVAC systems, the code stipulates minimum requirements to include a commissioning plan, systems testing and balancing, controls functional performance testing, a preliminary commissioning report, post-construction documentation, and a final commissioning report. Equipment functional testing is additionally required for all other mechanical systems (Kunkle, 2005).

Vermont. In Title 16 Section 3448(e) of the State of Vermont, the State Board of Education is required to adopt a set of rules regarding buildings and sites that are eligible for state aid. These rules state the following: "Project specifications for all new construction, additions, or renovations shall include a building commissioning plan. At a minimum, the building commissioning plan shall identify a process for verifying the performance of the new or modified HVAC system(s) in accordance with approved project specifications" (State of Vermont, 2005).

Massachusetts. In 2000, Massachusetts incorporated approval and acceptance requirements into the energy conservation section of its building code. Construction documents are required to include a variety of commissioning-like components such as design intent, the sequence of operations and system interaction, testing requirements and passing criteria, and required submittal of record drawings and control documents (Kunkle, 2005). Business customers in National Grid's service territory also have commissioning services available through the utility for their new construction and major retrofit projects (www.nationalgridus.com).

Market Response

While it is clear that building commissioning is increasingly required across the country is the commissioning market keeping pace? Do the expertise, level of training, and a sufficient suite of tools and resources for commissioning exist to fill the need created by these mandates? This is highly unlikely given the rapid increase in demand for services and the continued

evolution of the commissioning process. Is the market simply failing to comply with these requirements or is commissioning not implemented effectively? A 2005 study, funded by the U.S. DOE, looked into the effects of the building commissioning code in the city of Seattle and Washington State. It found that, in many cases, local commissioning service provider knowledge of how to meet such requirements is not present and codes are not enforced. Through interviews with building officials, utilities, commissioning agents, and industry groups, the study found that a lack of understanding of the provisions, across parties, has led to little if any change in practice (Kunkle, 2005). However, helping to train and expand the infrastructure of commissioning providers and improve the delivery efficiency of experienced providers will support code and other state requirements while improving the cost-effectiveness of commissioning for greater market impact.

STAC: Building Commissioning: Innovation to Practice

It is critical that the commissioning market continue to grow as an industry and keep up with state and national expectations. In 2004, six states and three additional collaborators[1] came together to propose a program to the U.S. Department of Energy under a funding source called STAC (State Technologies Advancement Collaborative). The objectives of this effort were to develop and introduce the market application of innovative, yet practical, functional performance testing, diagnostic tools, and training for commissioning providers and building operators. This was to occur in the states partnering together and represented in this program – California, New York, Texas, Oregon, Washington, Idaho, Montana, Nebraska, and Iowa. The collaboration represents states that have been active in developing commissioning infrastructure and practices for over a decade. These regions also have the most experience relative to the rest of the country in opening the market for commissioning and have a track record of sustained commitment to commissioning research, development, and program implementation.

The STAC program set out to streamline commissioning practices by addressing two widely recognized barriers to the adoption of commissioning, 1) the need for tools and technologies that standardize and simplify commissioning approaches and reduce implementation costs, and 2) the uncertainty about cost savings and other benefits from commissioning. The broad national collaboration of the partners made possible the participation of commissioning providers from different market regions to pilot, test, and provide critical evaluation of the tools and trainings developed in the program – enabling more effective and applicable resources to be put into the industry. This program structure also allowed for wide distribution of the tools and trainings, which in turn will build commissioning infrastructure and increase uptake in local and regional markets, as well as affect the national commissioning industry. The Program also focuses on the development of new commissioning projects and leverages existing projects, state and federal funds, and local resources to help accomplish its goals.

This Program incorporates several specific resource development activities. Each of the Program's six elements takes place in at least two of the participating states. The feedback obtained from initial deployments is used to improve the commissioning products, obtain

[1] The state partners are the California Energy Commission, New York Energy Research & Development Authority, Texas A&M University, University of Nebraska-Lincoln, Oregon Department of Energy, and the Iowa Energy Center. Additional collaborators are the Northwest Energy Efficiency Alliance, Portland Energy Conservation, Inc. and Lawrence Berkeley National Laboratory.

improved information about the benefits and costs of adopting these commissioning products and services, and expand the market awareness of the benefits of commissioning.

Functional Testing Guide

- Functional Testing Guidance Documents
- Advanced hands-on trainings for new and existing building commissioning
- Functional Testing Checklist Tool
- Functional Testing Data Analysis Tool
- Advanced Building Commissioning Analysis Tool (ABCAT)

Functional testing. While functional testing is a basic and essential element of the commissioning process, there is a significant difference between developing these tests and understanding how and when they are performed – especially if an unexpected result should occur. The STAC program has three activities directly related to the *Functional Testing Guide* – a resource library of information on how to perform functional tests (generally and specific to system types), including common problems and cautions when performing tests. The Guide is filled with example test forms, categorized by system, from all publicly available sources. This resource library makes it easier for commissioning providers to write high-quality tests that will uncover system deficiencies that could plague a building for its lifetime.

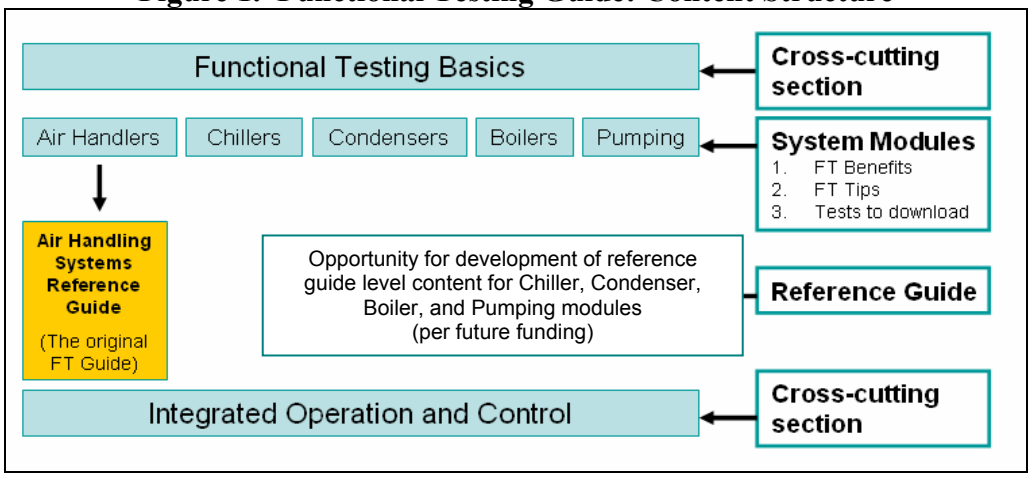
Functional Testing Guide background. The development of the Functional Testing Guide for Air Handling Systems (FT Guide) was first supported by the U.S. DOE's Office of Building Technologies and the California Energy Commission with the first version completed and disseminated widely by 2003. The intent was to improve building operation by providing designers, commissioning providers, and building operators and managers with detailed guidance on the commissioning of air handling units in commercial buildings with built-up HVAC systems. The concept was based on another resource – Pacific Gas & Electric's Commissioning Test Protocol Library (CTPL). The CTPL database of tests provided non-copyrighted functional tests to users and catalogued and evaluated an extensive set of tests in the market. The guide was developed to complement the CTPL by delivering information on developing and executing these tests.

A year after its release, a second U.S. DOE project interviewed users of the guide and resulted in the addition of content for systems other than air handling, specifically chillers, condensers, boilers, pumping, and integrated operation (figure 1). While the information in these modules was not developed to the level of detail found in that for air handling systems, they provide essential information and lay the groundwork for future development. The FT Guide was written to impart a practical understanding of the fundamentals, while sharing technically-sound field tips from commissioning experts for performing functional tests and identifying the root cause of problems uncovered by the tests. This is a bottom-up approach to training (as opposed to the "top down" coverage of the steps in the commissioning process), focused on developing the technical abilities of new commissioning providers and enhancing the skills of experienced providers.

FT Guide STAC pilot. The first step for the FT Guide element of this Program looked at what was needed to increase the use of this resource. An on-line training was provided to a group of fourteen paid commissioning providers from California, Oregon, Washington, Iowa, and New

York who were asked to integrate the guide into their current practices and provide feedback. The input facilitated from these participants covered how the guide was used, what the users thought about the accessibility of tests and general navigation, and the rigor of the technical content.

Figure 1. Functional Testing Guide: Content Structure



Source: Portland Energy Conservation, Inc. 2005

Overall, the pilot feedback expressed that the FT Guide contains a lot of valuable content that is not available anywhere else, but it is difficult to piece apart and use for reference. The information was found to be effective by participants who represented both new and experienced commissioning providers, although they reported using it in different ways. Examples of using the guide include: troubleshooting in the field, modifying or developing functional tests, and as a training resource. Experienced commissioning providers repeatedly demonstrated the need to skip over the background/basic information in the guide, while the less experienced providers expressed the value of these sections. These responses highlight the opportunity to continue development of the FT Guide on a path where it will remain a resource for different uses and levels of experience and, in some way, also facilitate such a varied application. The responses also demonstrated the need for this type of resource even for the most experienced providers.

Guide revisions. Navigation and format stood out in the pilot as the critical issues for allowing different levels of users to find the FT Guide valuable and functional. Responses were split regarding whether an HTML or Word format would be most useful; however, this division seemed to be tied to the participants' desire to download and modify tests for their own use. Aside from addressing the varied audience for the guide, there were critical problems with the format of the resource that often prevented its use across the board. The original FT Guide was a large number of Microsoft Word documents containing embedded Word hyperlinks that utilized macros. In addition, it was necessary to download all the guide documents into a common directory prior to use. The project dealt with several pilot users who needed technical assistance in downloading the guide and getting it to function with their personal computer systems. Because of the extent and magnitude of these technical problems, it became obvious that these same technical issues would occur for other potential users – likely preventing their ability to access the guide.

The expanded content, under development, received favorable reactions in the STAC pilot, and additional planned Program tasks were to focus on developing specific aspects of the guide (test guidance and checklists) which providers requested. Therefore, this initial effort honed in on a permanent fix for the navigation difficulties encountered by users. By converting the FT Guide into an on-line HTML format, the issue of accessing information by users with different needs was addressed.

The existing Word documents, and the new modules, were converted into HTML and placed on-line at www.peci.org/ftguide. Test documents remained in Word for easy downloading and modification. This effort involved extensive work to fix linkages within the guide and to the CTPL, improve presentation and formatting, and create a new navigation system. This work continued throughout the remaining elements of the STAC project to integrate all of the tools into a seamless resource.

New tests. During the initial FT Guide pilot, commissioning providers mentioned the need for "standards of quality" and "industry-expected standards" when it comes to functional testing. Participants were asked to prioritize a list of functional tests that could be added to the guide and fill gaps found in the CTPL. The CTPL has only four main sources of publicly available functional tests. There are about 25 air handler tests, in all, and they do not cover many of the procedures described in the FT Guide. The test list shared in the pilot was expanded to cover functional tests for all of the system modules now included. When PECI evaluated general input from the pilot on the value of adding functional tests they found that the majority of providers write their own tests and prefer their own formats. When using a resource such as the FT Guide, commissioning providers told us that they are looking for guidance on what makes an effective functional test.

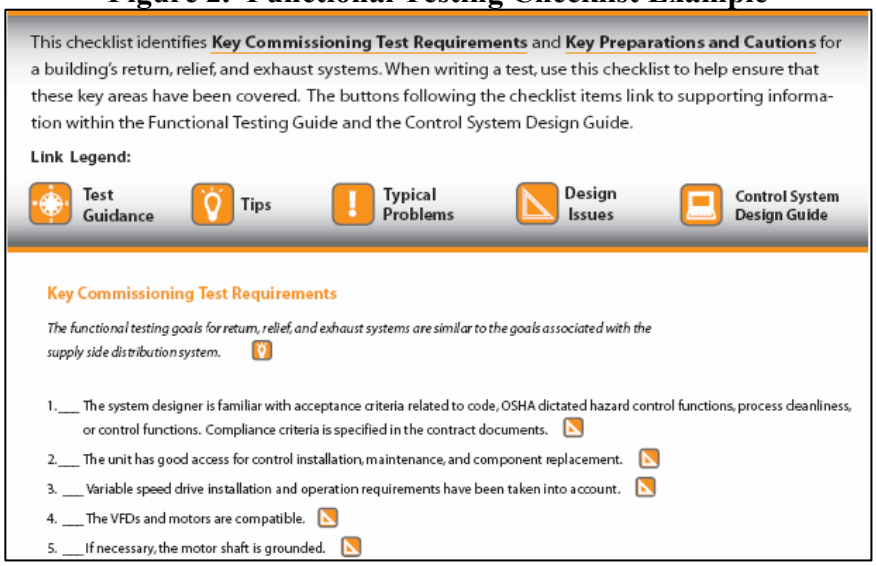
Using this pilot feedback, PECI moved forward to write testing guidance for fourteen of the prioritized tests. The new testing guidance documents were then piloted with the group of commissioning providers by asking them to write functional tests, and run them in building projects, using the guidance documents. The general consensus from the pilot participants was that the testing guidance was a useful way to improve their tests or build new ones. They provided constructive feedback on how thorough these documents were and on how well they streamlined the writing process. This beneficial feedback was analyzed and used for revisions.

FT Checklist Tool. The final piece of the FT Guide in the STAC program was the development of a Functional Testing Checklist Tool. The intent behind the tool was to enable users to determine which functional tests were needed for the particular systems of a specific project. They would then be able to generate a checklist of those tests which would link into tests contained in the FT Guide. The conversion to an on-line document, with content restructuring and a revamped navigation system, made part of these objectives unnecessary. What remained was the need for checklists that provided a quick method for verifying that a test contained the critical components.

The FT Checklist Tool was developed as a resource accessible from the main web page of the FT Guide. The checklists cover 17 different system/component functional tests, i.e. air handling unit (economizer and mixed air, preheat, cooling, reheat, warm-up, fans and drives, distribution, terminal equipment, return relief exhaust), chillers, condensers, boilers, cooling towers, variable air volume and constant volume pumping, and integrated operation and control. Each item on a checklist has a link into the FT Guide (figure 2) – directing the user to

background information on why specific elements of a test are important and providing additional information needed for testing. In this way, the checklists are both a quick way to evaluate a test, as well as a portal into the FT Guide for specific testing information. As with the other Program elements, the checklists will be piloted with the group of paid commissioning providers and feedback will be used to make revisions.

Figure 2. Functional Testing Checklist Example



Source: Portland Energy Conservation, Inc. 2006

Advanced Training

Under the Program's objective of delivering effective resources to commissioning providers, the advanced training, partially complete at the writing of this paper, has demonstrated compelling support for a need in the marketplace. PECI developed a four-day advanced hands-on retrocommissioning workshop. It was delivered twice in New York – in New York City and in Albany. Both trainings were limited to 15 attendees to create an effective learning environment, especially during hands-on activities, but in both instances responses were beyond capacity. These trainings were tailored to the specific facilities where they took place and required building staff time and access to equipment for the instructor and workshop attendees. The vital significant support from building owners exceeded expectations in both cases.

The training provided a brief overview of the retrocommissioning process for existing buildings and presented technical methods for identifying retrocommissioning opportunities (including historical operating information, drawings and specifications, visible indicators, utility consumption, data logging and trending, system flow diagrams, and targeted testing). The training also included instruction on selling retrocommissioning, scoping techniques, HVAC fundamentals, and how the FT Guide and the CTPL can be useful in streamlining testing. Hands-on activities covered such tasks as a building walk-through and performing a functional test.

Feedback from workshop attendees, who spent four full days immersed in the training, and from owners, who opened their facilities to the trainings, point to a continued support in the market for training. Participants at the New York Mercantile Exchange (NYMEX) facility in Manhattan and at the Dormitory Authority for the State of New York (DASNY) building in

Albany were given exit surveys to provide the Program with input. Additionally, two attendees in Albany were paid by the Program to provide in-depth review of the course material and participate in a telephone interview about the workshop. In all cases, there was very positive feedback on the course (material, presentation, activities) but also the request for additional topics, activities, and tools. Facility owners were engaged by the New York State Energy Research & Development Authority (NYSERDA) and, while perhaps apprehensive at first to open their facilities to a group of engineers to explore, became strongly committed to the process. Owners were incredibly dedicated and provided their facilities free-of-charge, assigned building staff to participate in a two-day pre-workshop scoping of the building with the instructor, and sent staff to attend the training. They came away with a new appreciation for the potential for retrocommissioning and proceeded to work with NYSERDA to continue these efforts.

PECI is also developing and delivering a one-day, interactive training for new buildings that teaches commissioning service providers how the FT Guide can be useful in streamlining their functional testing process. The workshop will lead the audience through the FT Guide's features and work with participants to develop a functional test for a particular part of the HVAC system at the workshop facility. The new building commissioning training workshops will be offered during summer 2006 in California, Iowa, Oregon, Washington, and Idaho.

Semi-Automated Tools

Diagnostic tools have an important role and significant potential in commissioning. Their ability to perform short-term and continuous diagnostics needed for commissioning contributes to streamlining the process. "A key value in using [diagnostic] tools lies in reducing the data management and analysis time necessary to obtain valuable information from EMCS data, thus enabling operators, managers, and engineers to efficiently assess building performance (Friedman, 2001)."

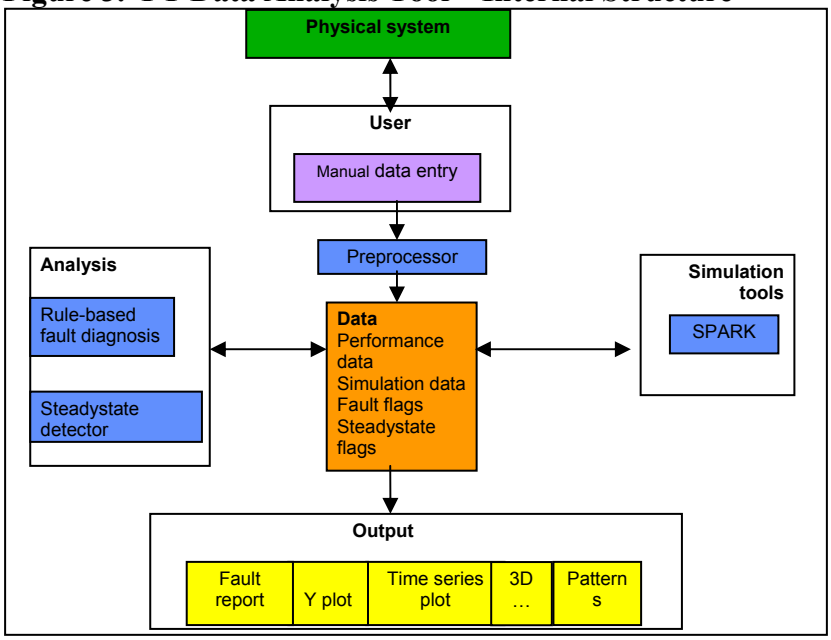
FT Data Analysis Tool. To identify building system failures and their probable causes, Lawrence Berkeley National Laboratories (LBNL) developed the Functional Test Data Analysis Tool. This tool uses a library of data analysis routines to analyze test data and assess performance. Typically, in this type of analysis, a baseline model of correct operation is first configured and calibrated against design information and manufacturers' data. This reference model is used to predict performance that would be expected in the absence of faults (figure 3). A comparator is used to determine the significance of any differences between the predicted and measured performance and, additionally, the level of confidence that a fault has been detected.

Activities for the FT Data Analysis Tool have included development of a convenient user interface to facilitate manual entry of test measurements – a graphical display shows the measured performance versus the expected performance, highlighting significant differences that led to the unit failure. The objective is to provide a useful tool to commissioning providers conducting functional tests in either new building commissioning or retrocommissioning environments, as well as to building owners and operators that conduct routine tests periodically to check their HVAC system performance.

The tool was beta-tested in January 2006 at the Iowa Energy Center's test facility. Staff experienced in the development and testing of fault detection and diagnostic tools provided feedback on the tool for an initial round of revisions. The Iowa Energy Center's Energy

Resource Station, which contains multiple commercial energy management and control systems, as well as three complete air handling systems, was used to test the tool. In the next step, test providers in California and New York will pilot the tool in actual building applications during the last half of 2006 and into early 2007.

Figure 3. FT Data Analysis Tool – Internal Structure



Source: Lawrence Berkeley National Laboratory

ABCAT. Building from initial work funded by the CEC's PIER Program, Texas A&M's Engineering Experiment Station (TEES) and the University of Nebraska (UNL) developed a prototype version of an Automated Building Commissioning Analysis Tool (ABCAT) for the STAC program. The objective of the ABCAT is to become a cost-effective, user-friendly tool for online detection and diagnostics of building performance and to provide a method to project the economic benefits from correcting degradation of the building systems.

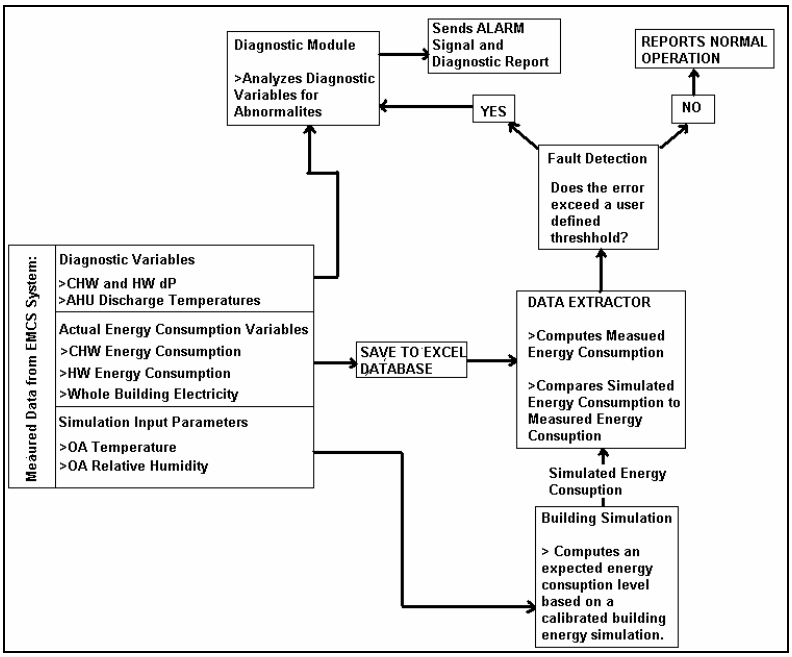
The ABCAT analyzes measured whole building consumption data and a limited set of data from the energy management system. When complete, it will be able to detect percentage and cost changes in whole building energy use, air handling-level comfort problems, and provide the building operator with a limited set of fault diagnostics (figure 4). The tool is installed after commissioning, when the building is assumed to be operating at an optimal level.

Hourly heating and cooling data is collected by the tool from the building automation system or separate meters and used for fault detection. The ABCAT is designed to detect excessive cooling and heating consumption. It will also detect excessive motor consumption, if VFD consumption data is available, and comfort problems at the air handling unit level. The user can determine the trigger levels for the faults and the tool will identify potential causes of failure when a fault does occur.

The pilot portion of the ABCAT program element involves testing in three distinct building types and takes place in Texas, Nebraska, and New York. The tool was initially piloted in a building on the Texas A&M campus – which was used to continue early development of the tool, and in a building on the University of Nebraska, Lincoln campus. The next pilot phase was

begun in early 2006. The prototype version of ABCAT will be installed in two New York sites – an Albany facility run by DASNY and in Buffalo on the Hauptman-Woodward Medical Research Institute campus. Commissioning providers will be trained to test the tool in order to provide timely feedback to the program. Necessary modifications during and after the commissioning process will take place based on this input.

Figure 4. Initial ABCAT Fault Detection Sequence of Operation



Source: Texas Engineering Experiment Station

Conclusion and Next Steps

The STAC program set out to develop and deliver to the commissioning market effective tools and resources for streamlining the commissioning process. It demonstrates support and need in the industry for such activities aimed at building up the commissioning infrastructure but what are the next steps? Will the market respond to the incentives and mandates across the country before it is ready and implement commissioning ineffectively - taking short-cuts that lower the benefits of projects and miss the goals of these programs? If there is a demand created for commissioning services, an influx of "commissioning providers" into the industry is a natural result as the industry heats up. But the fact is that not all of these commissioning providers are qualified for the projects they undertake.

Commissioning is necessarily an experience-based process. Training needs to be provided in an ongoing way to help people acquire the necessary skills to provide quality commissioning; resources can assist providers in developing quality functional tests. Diagnostic tools are increasing in their importance, especially as the focus of commissioning turns towards persistence and as more facility operators are tasked with maintaining the benefits post-commissioning. But diagnostic tools have been slow to come on the market. A focus on development, installation, training, and education around diagnostic tools is needed as the industry grows. Only through activities targeted at improving the *quality* of commissioning, in

addition to those that increase the *quantity* through raising demand, will the commissioning industry will be able to deliver the benefits sought after by the national and state governments.

Acknowledgements

Program Management Team: *California Energy Commission*: Martha Brook, *New York Energy Research & Development Authority*: Kim Lenihan, *Texas A&M University*: David E. Claridge/Malcolm Verdict, *Oregon Department of Energy*: Andrzej Pekalski, *University of Nebraska-Lincoln*: Mingsheng Liu, *Northwest Energy Efficiency Alliance*: John Jennings, *Iowa Energy Center*: John House/Curt Klaassen, *Portland Energy Conservation, Inc*: Tudi Haasl/Aleisha Khan, *Lawrence Berkeley National Laboratory*: Phil Haves/Peng Xu.

FT Guide, Testing Guidance, FT Checklist Tool – *PECI*: Tudi Haasl, Hannah Friedman, Larry Luskay, Bill Koran, Dave Sellers, Aleisha Khan, Kristin Heinemeier, Marci Shuman, Stephanie Callimanis; *LBNL*: Judy Lai; *Summit Engineering, LLC*: Karl Stum

Advanced Trainings – *PECI*: Dave Sellers, Larry Luskay

FT Data Analysis Tool – *LBNL*: Phil Haves, Peng Xu

ABCAT – *Energy Systems Laboratory at TX A&M University*: David Claridge, Malcolm Verdict, Frank Painter, Jonathan Curtin, Nabil Bensouda; *UNL*: Mingsheng Liu, Gang Wang

References

Fedrizzi, Rick. February 1, 2005. *Commissioning Excellence*, Greener Facilities Newsletter. Available online: www.Buildings.com.

Friedman, H. and M.A. Piette. 2001. *Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems*. LBNL Report 48629.

Kunkle, Rick. 2005. *Assessment of the Building Commissioning Code Provisions in the Seattle and Washington State Energy Codes*, WA State University Extension Energy Program.

———. 2005. *LEED-NC, Green Building Rating System for New Construction & Major Renovations, Version 2.2*. Available online: www.usgbc.com. U.S. Green Building Council.

Mills, E., H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl, and M.A. Piette. 2004. *The Cost-Effectiveness of Commercial Buildings Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States*, LBNL-56637.

PECI. 1988. *National Strategy for Building Commissioning*, U.S. Department of Energy.

———. 2005. *Options for Energy Efficiency for Existing Buildings*, State of California.

———. 2005. *(Series 600) School Buildings and Sites – Building Projects Eligible for State Aid. Statutory Authority: 16 V.S.A. Chapter 1 2 3, Rule 6143.3*., State of Vermont.