

HPCBS

High Performance Commercial Building Systems

A New Guide for Commissioning Air Handling Systems: Using a Model Functional Test

Element 5
Project 2.1
Task 1a2

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Presented at the ACEEE 2002 Summer Study on Energy Efficiency in Buildings, August 18-23, 2002, Asilomar Conference Center, Pacific Grove, California, and published in the proceedings.

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May 2002

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Abstract

Functional tests are a set of detailed instructions for building commissioning that demand extensive HVAC system knowledge to write and perform. Understanding the energy use implications and theory behind the test procedures, estimating the costs and benefits of doing a particular test, implementing the tests correctly, and resolving problems require years of field experience. As part of a large research project now underway, a practical guide is being developed that communicates this knowledge. This paper presents the components and intended use of the *Functional Testing Guide and Model Functional Test for Air Handling Systems*. A series of model functional tests, starting at the outdoor air intake section and proceeding through the air handling unit, distribution system, and terminal equipment and ending at the exhaust air discharge point, are provided for many commonly installed air handling system configurations. The model functional tests contain advice for tailoring the test procedures to specific system configurations, desirable and undesirable testing outcomes, a calculation appendix, references to other resources, and examples of completed test forms. The guide is an educational resource, with background information that clarifies the principles behind testing configurations and results. The functional tests have been selected from an extensive commissioning test protocol library compiled by Pacific Gas and Electric in 2001. The guide also includes a design guideline for the selection of control and monitoring points and a design intent documentation form.

Introduction and Background

Commissioning is increasingly recognized as a valuable method of ensuring performance, reducing energy use, and improving indoor air quality, occupant comfort and productivity. As the commissioning industry continues to expand so does the need for tools for reducing commissioning costs while delivering quality services.

One area where cost reduction is achievable is in the development of a process for producing project-specific test protocols from standardized templates. A project sponsored by the California Energy Commission's Public Interest Energy Research Program (PIER) with co-funding by the U.S. Department of Energy has been initiated to begin to address this task. The work described here falls under Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems (HPCBS, see buildings.lbl.gov/cec) in Element 5, Integrated Commissioning and Diagnostics. The objective of the overall project is to assemble and develop tools, test procedures and guides needed by owners, operators, designers, and commissioning providers to perform tests, analyze results and operate buildings efficiently. The initial version of the guideline will be out for review in the summer of 2002.

The original goal of the task was to research and compile a library of standardized functional test procedures based on a review of the test procedures available in the public domain. In recent work, Pacific Gas and Electric (PG&E) met this goal by compiling a library of test procedures

called the Commissioning Test Protocol Library (CTPL). Since a major part of our original plan was completed, the project evolved to include a Functional Test Guide and Model Test (referred to as the FT Guide or the Guide throughout this document) as a companion document to PG&E's work.

The CTPL is currently made up of four components: 1) a collection of non-copyrighted commissioning protocols, 2) a database containing summaries and reviews of non-copyrighted and copyrighted commissioning protocols, 3) protocol templates, and 4) a library for archiving new commissioning protocols. PG&E's research brings together the best publicly available commissioning test procedures in the industry into a Microsoft Access[®] database.

With the creation of the FT Guide, the best features from numerous tests in the CTPL have been compiled into a Model Test procedure for air handling equipment. The FT Guide also includes extensive references to the CTPL functional tests. Using the educational information in the FT Guide, CTPL users will better understand the philosophy, thinking, and cost effectiveness behind a variety of test procedures as well as the energy implications of problems that commissioning can identify. The Guide is designed to assist users in deciding on the appropriate level of testing for a given project and add significantly to the robustness of the test library. In accordance with the original task, information gaps in the CTPL test procedures used for developing the Guide were identified and new procedures were written to fill these gaps as they relate to air handling applications.

The commissioning test library together with the Guide also provides direction toward standardization and quality control, which continues to be an overarching issue for this industry. Currently, there is a large variation in the interpretation of commissioning test requirements. If tests were standardized, commissioning costs could be assessed more easily.

The guide is oriented toward new construction commissioning, but will also be useful for retro-commissioning of existing buildings. The Guide also includes chapters titled *Guidelines for Control and Monitoring Points* and *Guidelines for Control Algorithm Design*. These chapters work to provide stand-alone documents specifically targeted for designers but also useful for commissioning service providers. A more detailed description of these chapters is presented in the section of this paper titled Important Features. The Guide is to be made available in paper, CD-ROM and Web-based formats.

Purpose and Focus

Developing a commissioning test library is an important step in standardizing and increasing the cost-effectiveness of commissioning services. While a commissioning test library provides information on how and what to test, it does not provide information on why a test is important, when it should be used, and the costs and benefits associated with the test. Building owners new to commissioning will always ask: what will it cost, what are the benefits, and what procedures are involved? For these reasons, Portland Energy Conservation, Inc. (PECI) and LBNL developed a Guide that can be used in concert with PG&E's Commissioning Test Protocol Library. The FT Guide was developed using the best and most complete test procedures in the CTPL and is designed so commissioning practitioners can develop customized functional test procedures for specific projects. The FT Guide includes automation that assists users in accessing the CTPL, customizing tests, and developing their own library of tests. These procedures are described in more detail in the section titled Automation.

The purpose of the FT Guide is to help users:

- Customize test procedures to meet the needs of their specific projects
- Understand why a specific test sequence is being executed
- Understand the possible outcomes of the test sequence
- Understand the costs and benefits of the test sequences

The FT Guide is currently limited to air handling systems and emphasizes energy-efficiency issues. A complete discussion of control system functional testing is beyond the scope of the guide. However, the guide does discuss general control requirements necessary for given test sequences and also contains a section on the integrated operation of the control system with the various components of the air handling unit. It provides information that helps the user understand, anticipate, and test the interactions of the control systems and the components they serve in real time, real world operating environments. For more detailed control system functional tests, refer to the recent addition to the CTPL, “A Commissioning Acceptance Procedure for DDC Systems.”

The FT Guide does not address verification checklist items in detail but provides general information on the importance of completing these checklists prior to functional testing, while directing the user to related verification checklists in the CPTL. The initial FT Guide effort has focused on air handling systems. This focus was selected because of its broad application potential. The majority of HVAC systems have some form of air handling equipment and distribution system. In addition, air-handling equipment consumes a significant portion of a building’s energy, often 30% to 50% or more. Thus, the benefits achieved through the commissioning process could significantly impact overall energy use.

Audience

The FT guide is primarily targeted at commissioning providers, project managers and technically oriented owners or their staff, such as facility engineers. The intention is to provide structure and guidance for functional test development to users who are already familiar with HVAC fundamentals. Designers may also find the Guide useful for understanding how the design affects commissioning, especially in the selection of control and monitoring points and providing adequate design documentation.

Important Features

The FT Guide includes a discussion of why a test procedure is important, the functions it verifies, and the types of problems it typically identifies. The Guide also provides background information for understanding key commissioning and design concepts. Important features found in the Guide are described below:

Model Functional Tests. The prototypical or model functional tests are the heart of the FT Guide. They are the mechanism for delivering the educational and decision-making information that will assist users in developing and executing their own quality functional tests. A model test procedure represents the majority of typical system configurations for a particular equipment class. For example, the model functional test for an air handling unit represents an array of possible system configurations such as constant volume, variable volume, dual or double duct,

multizone, reheat, and single zone. In customizing this model, the user would select the system's central components for any system configuration since functional testing of these component types does not depend significantly on the system configuration. A preheat coil or cooling coil in a variable volume system performs the same function as it would in a constant volume system. The user would then select the distribution and terminal equipment based on their particular type of system configuration.

Illustrations and Textual Information. The Model Functional Test contains informative text and illustrations to better explain the steps and requirements in the test procedure. Generally, each test has a table that outlines the energy and resource conservation benefits as well as other benefits associated with performing the test. There is a second table that provides background information on the test including a brief statement of purpose, costs, instrumentation requirements, precautions, and acceptance criteria guidelines. Some of these components are discussed in further detail later in this paper. Both tables are supplemented with educational information that provides guidance on the theory and purpose behind the test. At the end of the supporting information, the user is linked electronically to a sample procedure that can be reviewed or edited and saved for their particular project, which is further described below. Where applicable, the user will also be linked to procedures in the CTPL that were used to develop the model procedure.

On a large project with several tiers of management, a project manager may have the need to use both the detailed version of the test protocol, with the hidden text turned on and the field version of the test protocol, with text turned off. The project manager would use the FT Guide's educational information to further customize their functional test to the specific requirements of the project. He or she could supplement this information with project specific guidance. Once the procedure was fully customized, a copy could be printed out with the hidden text turned on for use by the site manager. This would help the site manager understand the reasons behind the tests and make them more effective managers of the technicians performing the tests. The same customized protocols could also be printed with the hidden text turned off for the technicians who will execute the test in the field.

Bibliography of Additional References. The guide assumes the user has fundamental HVAC knowledge. However, it will include a bibliography of additional references and/or frequent pointers to additional references. Although there is extensive information available regarding HVAC design, application, commissioning, and energy conservation opportunities, it does not reside in one place.

Expected Outcomes and Cautions. Since functional tests may subject systems to the extremes of operating limits, it is important to discuss potential problems that may be created by tests. Where appropriate, the FT Guide addresses these issues by:

- Discussing the potential outcomes, both positive and negative, of test sequences
- Discussing functional test acceptance criteria
- Identifying test sequences with greater potential for equipment or system damage, and how to minimize those risks

Cost vs. Benefit Estimate and Decision Guide. Where applicable, the FT Guide identifies and discusses the costs and benefits of test sequences. It builds and expands on the cost and benefit information presented in the CPTL. Providing this information will help users determine if the needs of their project or system warrant a given test sequence. For example, a functional test for coil control valve leakage is basically independent of system size and could require several hours of labor and special instrumentation to implement. However, savings potential depends on system size, ranging from a few dollars a year for a 100 cfm fan coil unit to thousands of dollars a year for a 50,000 cfm makeup air-handling unit. Where applicable, the FT Guide provides guidelines on how to estimate the following:

- Costs of performing the test sequence and correcting potential problems
- Energy and resource savings, if any, associated with the test sequence
- Operations and maintenance savings. Improvements associated with functional testing generate savings in areas other than energy. For example, a passive test that assures that filter pressure drop gauges and change-out alarms are functioning correctly and set to the capacities of the fan(s) can generate significant savings in filter purchase, installation, and disposal costs.
- Potential avoided costs. Safety systems are often functionally tested to assure the systems will protect the building, occupants and equipment from damage under unusual operating conditions. For many non-safety systems, the cost of this type of functional test is difficult to justify. For example, it is reasonable to assume a high-pressure safety switch will function properly on a 1-1/2 ton refrigeration system. The time and risk associated with forcing the pressure to the design limits to observe the response is probably not warranted when the likelihood and risk of failure are considered. On the other hand, testing a similar safety switch on a large, built up refrigeration system that serves a refrigerated storage location may be warranted since equipment failure can involve a significant loss of product and factory down time.

For each functional test, the guide includes tables that list the energy and other resource conservation benefits as well as background information that describes the purpose of the test, instrumentation requirements, precautions, etc. This information is supplemented by educational material describing the theory and reasoning behind the test. Finally, the user is linked electronically to a sample of the actual test that can be reviewed or modified to meet the requirements of a specific project.

Guidelines for Control and Monitoring Points and Control Algorithm Design. For buildings to be more easily commissioned and operated, the knowledge gained from commissioning needs to be communicated to designers. Chapters 2 and 3 in the FT Guide, *Guidelines for Control and Monitoring Points* and *Guidelines for Control Algorithm Design*, draw upon commissioning field experience to convey key design principles that will help designers, commissioning agents, and contractors install well-functioning HVAC systems. Specifications for control and monitoring points and PID control algorithms are described to give designers a better understanding of the details necessary to install and commission systems to ensure optimal energy efficiency. An appendix with sample sequences of operation reflecting some of the principles discussed is also included.

The Guide for Control and Monitoring Points is focused on recommendations for selecting and installing input points such as sensors and output points such as dampers, actuators and other final control elements. Recommendations for interfacing the points to the building automation system (BAS) include discussion of point naming conventions, settings, alarms, display graphics, and trending.

The guidelines provide recommendations for control and monitoring point selection and installation, from the sensor to the control system workstation. Understanding sources of sensor error helps designers to avoid these errors and helps commissioning agents interpret inaccuracies in field measurements. The Guide also describes points necessary for commissioning and troubleshooting, beyond what is needed for basic control.

The Guide for Control and Monitoring Points is organized from the general to the specific. First, general concepts for selecting control and monitoring points, understanding sources of error, and calibrating points are presented. Next, sensor recommendations are presented according to the sensor application. The recommendations include a discussion of accuracy requirements and installation and calibration recommendations for each type of measurement. For example, the temperature sensor requirements can be very different for space temperature and chilled water supply temperature applications. To illustrate the format and function of the sensor recommendations, a sample of the temperature sensor applications section is shown in **Table 1**. The sample includes the temperature sensor technology table and one of the space temperature application recommendations. The Guide gives design and installation recommendations for eight different temperature measurement applications, with space temperature shown as an example in **Table 2**.

Table 1. Advantages and Disadvantages of HVAC Temperature Sensor Technologies

	Technology	Function	Advantages	Disadvantages
Temperature Sensor	thermocouple	The voltage generated across a pair of wires made of different metals is temperature-sensitive.	Inexpensive, good for high temperature applications, no external power supply required	Nonlinear, the lowest accuracy (the highest precision wire accuracy is the larger of $\pm 4\%$ of reading or 2°F)
	resistance temperature detector (RTD)	The resistance of a metal (wound wire or thin film) is temperature-sensitive.	Nearly linear over a wide range of temperature (-260 to 650°C). Good long-term stability. Wide range of operating temperatures. Can be utilized as averaging sensor. Little need for recalibration.	More expensive than a thermocouple or thermistor. Requires lead wire resistance compensation or a transmitter at the RTD. Subject to moderate self-heating.
	thermistor	The resistance of a semiconductor is temperature-sensitive.	High sensitivity (-80 to 150°C). Large resistance compared to a RTD, so lead wire resistance errors are negligible. Low cost. Good for point sensing applications.	Non-linear beyond small range. Self-heating due to high resistances can decrease accuracy.

(Continued on page 7)

Table 1. (continued)

	Technology	Function	Advantages	Disadvantages
	integrated circuit	The voltage-current relationship of solid state devices (diodes, transistors) is temperature-sensitive.	Linear high level output at a low cost. Can be easy to interface with other electronics.	Temperature measurement range is smaller than thermocouples or RTDs, but adequate for most HVAC applications. Subject to self-heating.

There may be some spaces that require a closer specification than the example in **Table 2**, like an operating room or a clean room. In general, use thermistors or RTDs, with or without transmitters. The lowest cost approach is typically a thermistor without a transmitter, but the long-term stability of an RTD may make it a better choice.

Table 2. Space Temperature

Accuracy	$\pm 1^\circ\text{F}$ to $\pm 1.5^\circ\text{F}$
Installation	Locate the thermostat away from electronics and other heat sources.
Calibration	Calibrate sensor if complaint calls warrant.

With a limited budget for control and monitoring points, the sensor selection guidelines steer designs toward high-impact control and monitoring decisions. This chapter is also the educational component behind the points-lists that accompany each system diagram in Chapter 4, *System Configuration Diagrams*.

Chapter 3, *Guidelines for Control Algorithm Design*, describes the proper application of proportional plus integral plus derivative (PID) control algorithms as well as some common air handling system control requirements and issues.

PID control can enhance building performance and increase efficiency. However, the misapplication of PID control can cause more problems than it solves. The theory behind PID control and the advantages it offers for precision and energy conservation are presented. The guidelines describe appropriate applications for PID control.

In order for control and monitoring points to be installed correctly, designers and contractors must communicate clearly. The Guidelines for Control Algorithm Design concludes by describing how to convey the control design through detailed sequences of operation and logic flow diagrams. The commissioning agent should facilitate this communication by reviewing the detailed written sequences and logic flow diagrams for completeness. Specific examples of written sequences and logic flow diagrams have been included in appendices.

Overview of Common System Configurations. Chapter 4 provides an overview description of common system configurations. The system configuration diagrams that are included were chosen to illustrate HVAC processes that are referred to throughout the functional tests in the

guide. System configuration drawings include a list of control and monitoring points typical to the configuration. The drawings and points lists are intended to be used by designers and commissioning agents as starting points for their own system diagrams.

Organization and Structure

The FT Guide is essentially a Microsoft Word document that includes five main sections.

Chapter 1—Introduction. This section discusses the background of the project, the relationship of the FT Guide to the CTPL, the purpose of the guide, the audience, how it should be used and the systems based approach that the guide uses.

Chapter 2—Guidelines for Control and Monitoring Points and Chapter 3—Guidelines for Control Algorithm Design. Chapters 2 and 3 are intended to give designers an understanding of important issues in designing a system that is commissionable and operable under real world conditions. The information about control and monitoring point selection and installation as well as the PID control algorithm design and communication chapters are provided to facilitate well-functioning and commissionable system design. These chapters have been described in detail in the Important Features section.

Chapter 4—System Configurations. This section contains information on various common air handling system configurations and the monitoring and control point requirements associated with each of them.

Chapter 5—Model Functional Test. This section is the heart of the FT Guide and will contain the prototypical or model functional test. The user will be able to edit this section to develop customized test procedures for the systems being commissioned. The main elements included in the model functional test are:

- General project information, the project team, project directory, building data, etc.,
- System information including nameplate ratings, design capacities, etc.,
- A discussion of the general and specific tools and instruments required for the project,
- A discussion of the verification checks (prestart and start-up issues) that need to be completed prior to functional testing. This is a general discussion rather than an itemized listing of test requirements.
- Functional test procedures including related information such as:
 - Estimated cost/benefit information
 - Information on what needs to be monitored, where and when to gather the data
 - Recommended acceptance criteria
 - Applicable calculations
 - Potential problems and cautions
 - Example applications where available, relevant, and applicable.

Bibliography of Additional References. The FT Guide includes a bibliography of additional references as an appendix and frequent pointers to additional references such as the ASHRAE Fundamentals Handbook.

Automation

The FT Guide takes advantage of features in MS Word 2000 to provide the automation required to link the user interactively between the educational material, the model test procedures, and any specially edited procedures created by the user from the model procedure. Specifically, the Guide makes extensive use of template files (MS Word documents with the “.dot” file extension) and automation using Visual Basic for Applications (VBA) macro programming code.

The FT Guide system uses a library of document templates that allow the user to edit and print any of the test procedures to suit their needs. The user can also build their own document templates, which they may choose to add to the library within the FT Guide as they gain experience with the Guide and functional testing projects. **Figure 1** presents a flow diagram of the functional test guide automation operations.

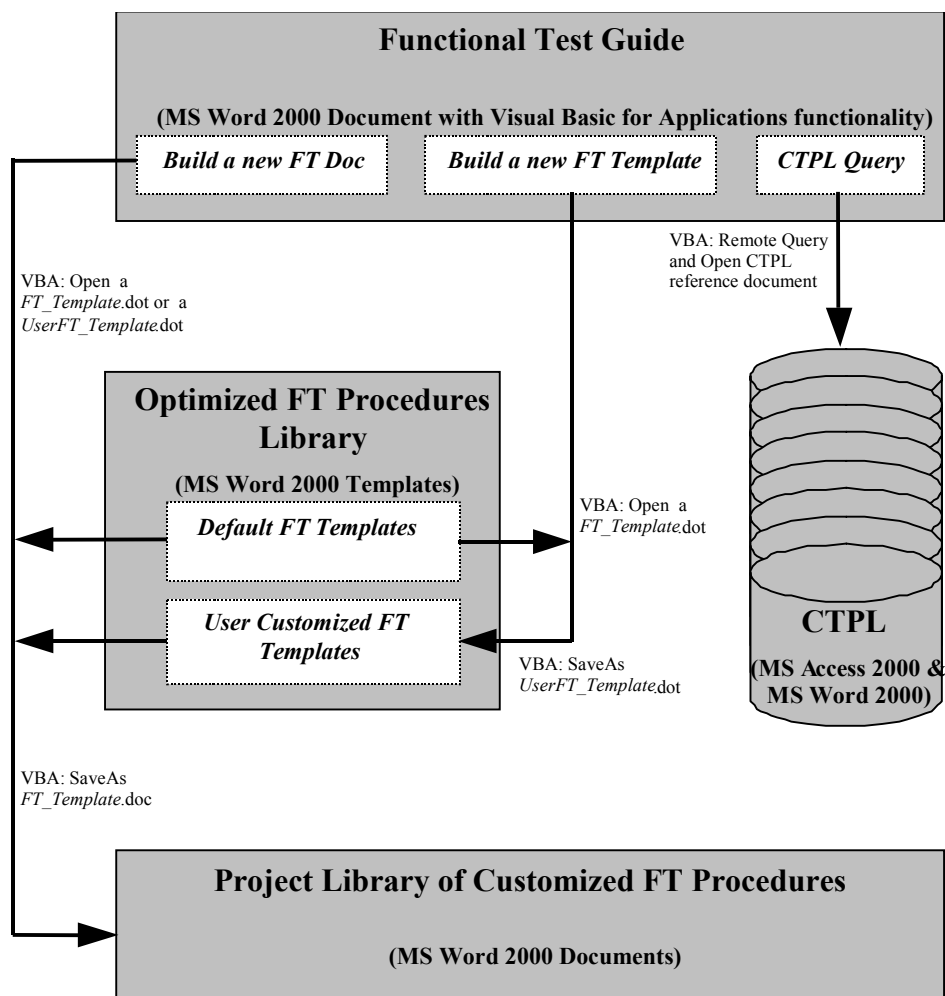


Figure 1. Flow chart of links in the functional test guide.

The FT Guide document serves the dual purpose of providing instructional lessons behind the creation of functional test procedures as well as host-automated customization of test procedures. The basic functions supported are as follows:

1. User activated controls in the document can create a new FT Procedure. The VBA procedure uses a MS Word 2000 template to make a new test procedure in MS Word “.doc” format.
2. User activated controls in the document can create a new FT Procedure Template. The VBA procedure uses a MS Word 2000 template to make a new template in MS Word “.dot” format and then adds the new template to the existing list of available templates.
3. User activated controls in the document can initiate a Remote Query to the Commissioning Test Protocol Library. The FT Guide user can initiate this procedure while reviewing one of the model functional tests. In essence, invoking this feature causes the Guide VBA programming to search the CTPL database and open any procedures that are related to or support the model procedure currently under review by the user. Some of the procedures referenced in the CTPL are included in the CTPL in their entirety and the query will open these procedures for review by the user. The query will direct the user to the source of copyrighted procedures not included in the CTPL, to the extent the information is available in the CTPL.

These features allow the user to utilize the model tests to create both job specific test and edited templates for future use on their projects. These files can be saved to any location on the user’s computer or network. The automation is arranged to prevent the user from modifying the original templates associated with the model tests in the Guide.

Deployment Issues

The original scope of work for this task included publishing a test procedure library and guide available in paper, CD-ROM, and Web-based formats. While these are typical modes of deployment for information, some issues arise with the first two methods regarding updates.

Both the CD-ROM and paper-based library are static methods of disseminating the information thus making updates more difficult. The more dynamic method of deployment is to allow the library and the guide to reside on a web site. This affords the opportunity of frequent (more timely) updates with a provision for notifying all users of the update by email. In this way, all users will have the opportunity of staying current with the changes.

A related issue is determining who will ultimately be responsible for the upkeep and ongoing deployment of the CTPL and FT Guide. Currently PEGI and PG&E are negotiating to have PEGI deploy PG&E’s work on PEGI’s web site. Based on feedback from reviewers of Commissioning Test Protocol Library Developmental Releases 1.0, 1.1 and 1.21, PG&E has recently made available Developmental Release 1.3 by e-mail from Ken Gillespie. This release includes recently created content such as a new DDC Systems Test Procedure and improved database functionality and template forms, in both Access[®] 97 and Access[®] 2000. Version 1.3 may also be made available through LBNL’s web sites and the California Commissioning Collaborative (CCC) web site.

Conclusions and Future Directions

The overall measure of success of this project will be whether it helps to transform the market for commissioning by improving the tools to assist building owners, designers, commissioning agents, and HVAC engineers better define the activities around functional testing. Many large commissioning firms already have well-developed test libraries, but these are generally proprietary. The guide will be disseminated through several methods, as described above. The initial guide will be available in the summer of 2002, and a revised version is planned for summer 2003 based on a formal review process to be defined. Future projects may include expanding the guide to include other building systems.

Beyond this primarily paper-based guide, is the opportunity for automation of test procedures. The current automation simply links database and template files for easy storage and retrieval. Additional research projects around the U.S. are beginning to develop more fully-automated commissioning systems. One such effort at the Minnesota Center for Energy and the Environment has developed software called Facility Evaluation Tool for Commissioning (FACET-Cx) for prefunctional tests (verification checks). It uses a pen-based computer and allows for the efficient management of information and data resulting from the deployment of several field auditors. The foundation of FACET-Cx is a computerized maintenance management system (CMMS). The objectives of FACET-Cx is to provide a convenient way of electronically developing appropriate checklists from templates and collecting and managing large amounts of checklist information that is gathered in the field. Collaboration opportunities will be explored as these technologies mature. HVAC researchers and practitioners have, and will continue to explore opportunities to utilize automated tools and energy simulation models for diagnostics and commissioning (Friedman & Piette 2001, Haves, Claridge & Liu 2001, Piette 1996). A well commissioned building sets the stage for defining optimal performance metrics which ongoing operations can be evaluated against. Integrated information management tools and commissioning techniques are needed to help improve the information management tasks of evaluating building and HVAC system performance.

Acknowledgements

We are thankful to Martha Brook from the California Energy Commission and to David Hansen, U.S. Department of Energy, for their assistance and support. This work was partially funded by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, Building Technology Programs of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. This report was prepared as a result of work sponsored by the California Energy Commission (Commission). It does not necessarily represent the views of the Commission, its employees, contractors, and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the use of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the Commission nor has the Commission passed judgment upon the accuracy or adequacy of the information in this report.

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