Automating the Commissioning Process – Information Management in Building Design Through Occupancy

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Effective commissioning of building HVAC and control systems has been increasingly identified a major factor in ensuring the energy effectiveness of a building. Proper commissioning reduces energy consumption, increases occupant comfort, improves indoor air quality, and lengthens the life of equipment. In fact, long-term operation and maintenance can be viewed as a logical extension of the commissioning process (in other words, as "continuous commissioning"). With such large potential impacts, it seems that building commissioning would be required in any new construction or retrofit. However, the commissioning process must address some significant cost-effectiveness questions, first-cost constraints, and implementation problems.

Several approaches are needed to address these economic issues—legislation, better cost justification, and incentives are all likely to play a role. Advanced technology can increase the frequency and improve the effectiveness of building commissioning. This paper evaluates commissioning needs, proposes specific technical approaches and tools, and suggests research and development requirements. The discussion is organized into two main areas:

1. Needs Assessment—An overview of the commissioning process is presented. Problems with implementing this process are discussed and specific solutions are proposed.

2. The Role of Technology—Several technologies and tools are discussed to facilitate these solutions. A focus is placed on the need to maintain and transfer information (data) throughout the commissioning process.

Introduction

Proper commissioning of a building's materials, equipment, and systems is a vital part of any new construction or retrofit. Ensuring that the design intent has been met is necessary if an owner wants to maintain occupant comfort and safety as well as limit life-cycle energy costs. Each stage of the commissioning process is discussed in detail, and some of the challenges of that activity are presented. Automation tools are then proposed to address some of these problems holistically. These tools treat commissioning as an activity that begins during the initial design and continues until the building is demolished.

Ideally, automated commissioning tools would run on standard, inexpensive computers and would manage building design, construction, and check-out information across the range of personnel associated with constructing and operating buildings. It would be best to have an integrated tool set that could integrate across the major building construction and operation phases to ensure that valuable information is not lost, inconsistent, or unavailable when needed.

During the design and construction of a building, a great deal of information is generated and transferred among all of the parties associated with the building. When the building is completed, it is often checked-out and handed over to the new owners with the warranty clock(s) ticking. Unfortunately, the new owners and future building operators are likely to have little or no information about how the building was designed, what was actually installed, and how the building should be operated and maintained. This problem is amplified when ownership changes throughout the life of the building. The use of an interoperable tool set during design, construction, and commissioning would help ensure that information is gathered and maintained during each development phase so it can be passed on to the next phase as required.

Identification of the Automated Commissioning Tool Set Needs

What Is Commissioning?

ASHRAE guidelines define commissioning as "a process for achieving, verifying, and documenting the performance of buildings to meet the operational needs of the building within the capabilities of the design and to meet the design documentation and owner's functional criteria, including preparation of operations personnel. " The commissioning process, when done properly, starts at the beginning of the building design process and continues through the operational life of the building. It is a systematic process of working to ensure that the building performs in accordance with the design intent and the owner's needs (Benner and Bjornskov 1993). In general, the goals of commissioning are to (Lawson 1993):

1. Keep an open line of communication between the owner, designers, and contractors;

2. Ensure that the design and construction of the facility are conducted on time and within budget;

3. Provide the owner with a satisfactory final product.

Typically, the process involves the calibration of instruments, performance of static tests, verification of functional performance, and documentation of all of the above (Krieg and Brohard 1993). Many people involved in building construction, commissioning, and ownership also consider maintenance support and operations training to be part of the commissioning process.

During commissioning, the following building systems are checked out: heating units (e.g., furnace, boiler), ventilation systems, air conditioning units, air distribution networks, chiller units, chilled water distribution systems, evaporative condenser units, lighting equipment, safety systems, security systems, power generation systems (backup), power distribution networks, and building control/automation systems. These are traditionally recognized as the active systems associated with a building. However, to be complete, we must also consider all of the passive "systems" that make up the building interior and envelope—for example, windows, pipes, and insulation. These are as much a part of the building design as the active systems and need to be commissioned for the same reasons. Automated commissioning tools must be able to evaluate their performance as well.

Who Is Involved with the Commissioning of a Building?

The building development process involves many different types of people. It begins with developers who want to quickly build and sell an appealing building. The developers select the building architects and associated designers and engineers. These professionals conceptualize and specify a building that will provide the occupants with a comfortable environment that is cost-effective to construct and install, energy-efficient, and easy to operate and maintain. The building construction crews try to meet the design goals as quickly as possible. The building owners, facility managers, and occupants also want their buildings to be comfortable, cost-effective, and simple to operate and maintain. At the same time, utility representatives are interested in promoting high levels of energy efficiency and energy consumption control. Everyone associated with a building wants accessibility, high quality, low cost, minimal maintenance requirements, and long operational life (Benner and Bjornskov 1993).

Communication among all of the parties associated with a building is a necessary ingredient to meet time, quality, and cost goals. Information transfer among the various people and phases of development and occupancy is essential. Having access to an on-line data management tool through the entire building development and deployment process would be highly beneficial. The tool should serve as a centralizing mechanism and would facilitate required communication about the building and its elements. It would likely take the form of an interoperable tool set with each tool tailored to a specific development phase and/or engineering discipline. A data management layer, integrated across the individual tools, would check for inconsistencies and conflicting specifications and implementations.

The culmination of the efforts of the design and construction teams is the final commissioning of the building. This is a key milestone where the facility management responsibility is handed from the developer to the owner/operator and all warranties take effect.

What Is Done During the Commissioning Process?

The major development phases of a building are: predesign, design, construction, acceptance, and occupancy . In this section, we describe what occurs during each of these phases and how an on-line tool-set can enhance the process.

Predesign. The objectives of predesign efforts are to:

1. Determine building systems' requirements and associated control parameters based on projected occupancy type (e.g., office, hospital, school, factory, residential, etc.) and regional climate;

2. Assign responsibility for design, construction, and commissioning of building systems to meet requirements and objectives;

3. Define test and check-out requirements;

4. Document building system baselines for future reference.

During this phase, the key benefit of automation tools will be to gather and manage data and automatically generate the required documentation. While this is obviously beneficial for the enhancement of information exchange between program phases, it is also beneficial for enhancing communication among the various people associated with design of the building. Having a centrally maintained information repository establishes a framework for data exchange. It can automatically flag inconsistencies or conflicts in information associated with building requirements, control parameters, and check-out procedures early in the building development cycle—prior to expending time and effort in the design and construction of the facility. Further, the tools can be preprogrammed to contain (or be linked to) standard information pertaining to building codes and requirements, guidelines for optimizing and controlling energy consumption, and regional climate models to support early simulations of preliminary designs.

Design. During the design phase, a detailed specification is prepared for the building as well as each of the major systems selected to meet the owner's requirements. For each major building system, the following information is generated and maintained:

- Design criteria and assumptions (e.g., projected occupancy type, locations, environmental conditions and objectives);

- System descriptions (e.g., capacities, manufacturers, accessibility, operational and maintenance procedures);

- Verification and validation requirements and procedures including the specification of metering requirements for monitoring and verification.

Among the types of documentation required from the design phase is the design specification, including all relevant drawings, schematics, as-built documentation, and maintenance and operating procedures. Many of these documents may be in draft form and will be finalized during the construction phase. Some of them will be living documents that will be updated throughout the operational life of the building. The entire design phase is highly documentation intensive. It is the phase of building development where concepts and specifications are formulated and documented for future communication to people associated with building construction, operation, and maintenance.

During the design phase, the interoperable tools should have the capability to model the building, its major systems, and the anticipated environmental conditions to simulate various design alternatives and optimize the building systems and their interactions. This would improve the likelihood that the building would meet its design objectives. Additional features of the automation tools that would enhance the efficiency of design and documentation include checking data for consistency; linking standardized databases (e.g., equipment efficiencies from manufacturer databases for performance modeling and operations and maintenance procedures); modeling building, systems and climate to support simulation and evaluation of designs; and generating documentation automatically.

Construction. During the construction phase, the prime contractor must coordinate the efforts of many subcontractors associated with the various building subsystems. For effective commissioning, each of these subcontractors must support the commissioning process. In general, the commissioning-related objectives of the contractors are to:

- Verify that equipment is properly installed, tested, and placed into operation;

- Ensure proper witnessing and documentation of static and operational tests;

- Verify accessibility for maintenance and repair;

- Confirm correct functional and communication interfaces between units, systems, and controls;

- Conduct start-up and test of individual units and eventually integrated systems.

Specific to each trade, examples of the responsibilities of individual subcontractors are (Lawson 1989):

1. Electrical contractor—check electrical supply voltages and distribution networks, ensure that all equipment has been wired properly in accordance with the

manufacturer's recommendation, verify that all controls, safeties, and interlocks are complete; provide written reports.

2. Sheet metal contractor—confirm that all duct connections are made and that all dampers are installed and operational in time to start the air systems; provide written reports.

3. Control system vendor—verift that all systems are complete and ready to operate, check equipment, schedule final check of the control system in all operating sequences, plan for coordination of equipment testing with automation system (e.g., bypass for testing); provide written reports.

4. Equipment manufacturers—start and verify an operational run for all chillers, multispeed pumping systems, cooling towers, air compressors, chemical treatment, boiler systems, etc.; provide written reports.

5. Testing and balancing contractor—coordinate scheduling of tests for fans, pumps, chillers, and the total system; check status of balancing dampers, valves, test plugs, and gauges; measure in-situ efficiency of equipment; provide written reports.

The future building operator(s) should be on site during the construction phase whenever possible, particularly during the start-up and check-out of equipment, testing, adjusting, and balancing, and during functional performance testing of major building systems. The system designer should also use actual equipment performance data from on site measurements to write the as-built specifications.

During the construction phase, the primary objective of an interoperable commissioning tool set should be to coordinate the communication between the contractor and/or subcontractors and support the generation of required documentation. Given the large number of people involved and their diverse backgrounds and interests, the construction phase is the most likely program phase for information to be overlooked, misused, lost, replicated, or thrown away. It is also the best opportunity for enhanced information management to have a significant and positive impact on the quality of the building and cost-effectiveness of its development and operation.

Another beneficial feature of automated building commissioning tools would be to support training of facility management personnel. While building operations and maintenance training may not be a high priority for those associated with construction of the building, the future building owners or their facility managers are highly motivated to learn how to operate and maintain the building before it is handed over to them. The interoperable tool set, if used from the very beginning of the project, should contain information associated with the design philosophy, operational sequences, manufacturer's recommended preventive maintenance actions, system functionality and connectivity information to support maintenance and diagnostics, and the facility automation system. It should be possible to semiautomatically configure this information into an on-line training aid to enhance understanding by operations and maintenance personnel of the building's major systems.

Acceptance. Acceptance testing of the building and its elements is commonly known as the building commissioning process. While many commissioning-related activities are carried out during the construction phase, there is a critical step in the life of a building that constitutes the transfer of responsibility from the developer to the owner, at which point the major systems are checked out and demonstrated. Three major categories of commissioning activities are: system test and check-out, training of operating personnel, and documentation. Each of these categories is discussed below along with potential automation tools to support them.

Typical activities associated with the system test and check-out portion of building commissioning are (Lawson 1993; Sterling and Collett 1993):

- Observe and verify that the physical installation of components and systems being tested is completed in accordance with the contract documents, observe physical responses of systems under test (not just control signals or other indirect indicators), ensure that 1/0 signals conform to actual physical conditions, prepare appropriate reports and document test results.

- Operate equipment through all specified modes of control and sequences of operation in full-load, part-load, and emergency conditions and run each system through all modes of operation (seasonal, occupied/ unoccupied, warm-up/cool-down, etc., as applicable); document results.

- Inject appropriate failures (e.g., distribution fault, control loss, equilibrium upset, and component failure) at various operating loads to determine system stability and recovery time; document results.

- Issue directions for necessary corrective measures when acceptable performance is not achieved.

- Provide documentation of the commissioning plan and functional performance test results (including redundant equipment) in each copy of operations and maintenance manuals. These manuals, along with testing and balancing reports, control schematics, and any other documents required, should also be submitted to the designers for review.

The use of interoperable tools throughout the design and development of the building should greatly simplify building commissioning efforts. First, as indicated above, the tool set should contain a major portion of the information required during system test and checkout of the building for rapid and simple retrieval as required. Second, an on-line function can support the commissioning process by acting as an interactive guide through a systematic approach for conducting commissioning activities. Finally, the tools could be used to record the results of building commissioning procedures and automatically generate reports, operational recommendations, and necessary corrective actions.

The training of facility managers and related operations and maintenance people is also given serious consideration during the acceptance phase of a building development program. While they typically have a history of related building operations experience, new facility managers need detailed information about the specific building and its installed equipment to properly operate and maintain the facility throughout its life. The primary objectives of training are to review the design, construction, and acceptance documentation and to develop an understanding of system sequences, set points, operation, and maintenance and repair procedures. The topics that should be covered during training are (Lawson 1993).

- System philosophy—design overview;
- System familiarization—location of equipment, as-built documentation, operations and maintenance manuals;
- System sequences and set points and their justification (e.g., energy efficiency, equipment operating guidelines, occupant comfort requirements);
- Maintenance-schedules for preventive maintenance, descriptions of procedures;
- Diagnosis—symptoms, causes, corrections, emergency action recommendations, repair procedures;
- Facility automation system—operation overview and by-pass process for testing, operation optimization, maintenance, and repair.

Automated tools for supporting operator training could provide ready access to required information about the building and its equipment, drawing on the information contained from the design and construction phases. The tool could act as an emulator (similar to a flight simulator for pilots) and allow the operators to work through “what if” instructional scenarios of building setup, operation, maintenance, and repair. By rerunning simulations using actual performance data from the installed equipment, the building operator can be left with a more accurately calibrated model of the building. This model would be useful for future simulations in support of equipment or operation change decisions.

Finally, a major step in the acceptance of a building is the verification that appropriate documentation has been provided to illustrate how the building was designed and what it actually contains to support management of the facility through normal operation, maintenance, and repair. The objectives of the documentation efforts are to provide the building owners and their operations and maintenance personnel with all of the information they will need concerning the building and its installed equipment. This information will be used during building operation, maintenance, and repair and to support future building renovations (which will require documentation updates). Building-related documentation typically takes the form of

- Design and construction documents,
- Operations manuals,
- Maintenance and repair manuals.

The design and construction information needs to be as detailed as possible and typically results in large volumes of information. The operations and maintenance manuals are typically more succinct and will often refer back to the as-designed and as-built documentation for additional details. The design documents should include the criteria used during design, descriptions of the installed systems and their intended operation and performance (e. g., capacity and sizing, redundancy provisions, seasonal and occupancy modes/changeover states), the commissioning plan and records, and a final documentation overview (e.g., as-built documentation and operations and maintenance manuals).

The operations manual should contain a brief summary of the design concept for building operation, a review of the installed equipment, and detailed coverage of operational modes (based on seasons and occupancy types and levels), control variables, and control set points, including specification of their acceptable ranges. The maintenance and repair manual should also include a brief summary of the design concept for building operation and a review of the installed equipment, but this document should focus on preventive maintenance procedures and schedules, equipment failure modes, symptoms of faults, recommended repair actions, and procedures for emergency conditions.

Some of the documentation should be provided in hard copy, but an on-line version is often preferred for broader access to information. It has been demonstrated in the aerospace industry that on-line tools greatly enhance the efficiency of operations and maintenance personnel by bringing required information to them on the job site rather than requiring them to physically sort through paper-based documentation (Funk et al. 1993). Further, on-line tools can enhance the efficiency of authoring the documentation in the first place by serving as a platform for users to collect information as it is generated and to organize it into a structured, accessible format. Finally, it can greatly enhance the continued maintenance of documentation throughout the life of the building by querying for the entry of test and check-out results, maintenance and repair action and results records, and by providing a platform to record renovation and other building reconfiguration changes.

Occupancy and Use. The objectives of the building owners and managers after acceptance of the building are to enable continued performance of facility equipment and to update documentation concerning the results of tests and reconfiguration. A summary of commissioning efforts includes the following activities (Lawson 1993):

- Conduct post-acceptance tests periodically to monitor and measure the actual performance using acceptance test checklists and procedures as a guide;
- Develop and maintain a standard method of recording system and operational complaints;
- Monitor discrepancies between predicted (based on equipment manufacturers' specifications) and actual performance and/or complaints received to determine the need to recommission the system or review the commissioning plan;
- Monitor for changes in equipment, building occupanty, and use and adapt the system to the changes as required;
- Revise documentation to reflect modifications to any part of the facility;
- Evaluate impact of planned alterations to the building and verify the effect of changes on the previously commissioned facility;
- Maintain and service building systems and equipment and keep accurate records of work done.

If used in conjunction with these occupation and utilization activities, an automated system can collect the relevant information and continuously update and maintain the system documentation.

Technology Necessary for Automating Information Management During the Commissioning Process

Commissioning, like all aspects of the building life cycle, has many technology needs—inexpensive sensing, wireless data acquisition, simulation, diagnostics, and expert systems to name just a few. Each of these technologies has been the topic of numerous papers and discussions. We would like to focus on just one technical need that we feel is a cornerstone in the development of an automated commissioning tool set—an integrated data model (IDM).

The availability of comprehensive and accurate information (data) that describes the building design and operation is critical, but it is not just having the necessary data that is important. The data must also be "arranged" properly. We refer to arranging the data in a useful form as the "integration" of the data and to the complete set of data as the "integrated data model" (IDM). In an IDM, data of all kinds are available to each software application (in this case, the automated commissioning tools), and all data are fully related to other data. For example, a data description of a particular piece of HVAC equipment includes not only the specifics of the performance of that equipment but also its physical coordinates (relative to the CAD drawings), related sensor data (from the building management system), complete maintenance information, etc. The IDM also permits the output from some analysis and automation tools to become input to others. One possible implementation of an IDM is through the use of object classes (using an object-oriented paradigm) that are standardized across the building industry.

The following data types and models, which are key to supporting advanced analysis and diagnostics, are likely to be found in the IDM:

- Building Data—These data models would include information that describes the geometry of the building, the construction materials used in walls, floors, and ceilings, and properties of these materials (e.g., acoustic, thermal conductivity, mass, and transmissivity).
- HVAC Data—These data models would describe the HVAC systems and components, such as variable-air-volume (VAV) systems, chillers, dampers, fans, and coils. These models will probably be a combination of first-principles and empirical models. These data would also describe the design intent.

- Cost Information—This would include data such as first costs, operating costs, and maintenance costs. This information is used for design tradeoff analysis, energy cost analyses, and operating cost predictions.

- Secondary Systems Data—While HVAC data are critical to understanding the environmental aspects of a building, other types of information are needed to completely describe the building systems. These include descriptions of the HVAC controls, fire, security, plumbing, electrical, and network systems.

- Operations and Maintenance Data–These data would include detailed descriptions of the maintenance procedures for all equipment and systems in the building. These data would be integrated with operating instructions such as schedules, set points, etc., which would serve as a valuable resource for building operations and maintenance (O&M) personnel. Once the building is operational, these data would be complemented by maintenance records, operational history, and sensor data. Unfortunately, IDMs as described above don't yet exist. The industry has long recognized the value of an IDM, and numerous discussions on its architecture and development have taken place in the nation's laboratories, universities, and industry. Fortunately, there are signs that we may soon see the beginnings of the IDM. European efforts have been driving toward standard definitions of building element data descriptions (class definitions). Also, there is a strong push for the CAD industry to adopt standard data models for ease of integration.

Summary

The commissioning process is an activity that spans the entire building life cycle. The need to ensure that a building is performing as intended begins early in its design and continues throughout its operation. Automation of the building commissioning process would likely require an integrated data model (IDM). The IDM facilitates interoperability of commissioning tools and standardizes the format of communication between people associated with the various phases of a building's development and operation.

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