



EXECUTIVE SUMMARY

FINAL REPORT ARTI-21CR/610-30040-01 METHODS OF AUTOMATED AND CONTINUOUS COMMISSIONING OF BUILDING SYSTEMS

Background and Goals

Effective commissioning and maintenance of building systems and equipment extends equipment life, improves or maintains occupant comfort, and improves equipment availability. Conversely, poorly maintained systems and equipment will have shorter lives and will experience more frequent failures, leading to lower levels of equipment availability and greater occupant dissatisfaction. Currently, effective commissioning, ongoing manual maintenance, and recommissioning can be expensive.

To address this issue, the Air Conditioning and Refrigeration Technology Institute (ARTI) launched an investigation into methods for automating the continuous commissioning of building systems. The overall goal of this project is to develop methods for improving the commissioning and maintenance of HVAC systems and equipment through automation. To achieve this, the project was broken down into five tasks.

Task 1: Investigate Building Commissioning Processes and Procedures

Using a literature search and interviews with commissioning providers, the project team documented current commissioning processes and procedures. Separate commissioning processes for new construction and existing buildings are presented, but both integrate with the typical phases of the corresponding design and construction processes.

Current efforts to automate commissioning fall into four categories: developing and managing building design information, developing test procedures, managing data, and automating functional testing.

Currently, functional testing methods are either “active” or involve monitoring. Active testing uses hand-held instruments, immediate control system readouts or direct observation to verify performance. Monitoring records the parameters of equipment operation using data loggers or the trending capabilities of the building automation system. Only monitoring methods are currently automated.

The literature search and interviews identified several HVAC systems and system components that are frequently commissioned or are time consuming and challenging to commission. The queries also identified the typical processes executed during the commissioning process for both new and existing buildings. Commissioning

providers, when asked to gauge their interest in automated tools, were most interested in automated diagnostic tools and tools that reduced document handling and repetition. Some were concerned, however, that any automated tool might not be versatile enough to accommodate the diverse situations seen in commissioning projects.

Task 2: Identify Systems and Processes for Automated Commissioning

The project team prioritized classes of components, equipment, systems, and commissioning processes according to how amenable they are to, and how much they would benefit from automated or continuous commissioning.

A group of seven engineering and commissioning experts analyzed three matrices (each of which are included in the Appendix). The first matrix listed 139 problems associated with 19 common building systems. The second matrix listed 69 new construction commissioning tasks in all phases of the typical new construction commissioning process. The third matrix listed 39 existing building commissioning tasks.

The system problems most amenable to automated or continuous commissioning include:

- diagnosing faulty economizer operation;
 - diagnosing uncalibrated or malfunctioning sensors;
 - diagnosing uncalibrated or malfunctioning valves, dampers, or actuators;
 - diagnosing faulty or improper ventilation control strategies;
 - diagnosing malfunctioning economizers and dampers; and
- identifying improper setpoint settings.

New construction commissioning processes amenable to automation included:

- perform checkout and functional tests;
 - collect data used for performance verification; and
- retain completed functional test sheets.

Existing building commissioning processes amenable to automation included:

- perform functional tests;
 - collect monitored data; and
- retain functional test and monitoring data results to confirm initial findings.

Task 3: Select the Equipment and Systems and the Commissioning Processes and Procedures to Automate

The project team identified and recommended specific commissioning activities and procedures that are most appropriate for automation. Based on the matrix scores from Task 2, we condensed the list of processes amenable to automation and compiled a short list of seven potential items for further investigation as part of this project. The

short list included two categories of activities: data management and functional testing.

Data Management

- Make design information available for commissioning
- Develop a method to record, use, and store building data

Functional Testing

- Assess faulty economizer operation
 - Identify improper setpoint settings
 - Identify malfunctioning sensors
 - Identify malfunctioning valves and dampers
- Identify faulty ventilation control strategies

The team considered each item on the short list in terms of the potential impacts and benefits of demonstrating automation potential for the item, the risks and costs associated with demonstrating each item, the range of applicability of each item, and whether each item could apply to continuous commissioning. The final recommendations proposed to the Project Monitoring Subcommittee are:

- Import recorded building data into a functional test procedure template
 - Automatically assess faulty economizer operation
- Automatically identify malfunctioning sensors

(**Note:** By agreement, a fourth item was added later: automatically identify malfunctioning valves and dampers.)

Task 4: Identify Automation Techniques and Methods

The project team reviewed technologies and techniques that may be applicable to automated and continuous commissioning of building systems. The goal was to provide background information for selecting specific commissioning procedures to automate in this project, and to provide information critical for selecting the analytical tools and techniques to be used in the prototype applications that will be developed to automate these procedures. We surveyed available tools and techniques and described the technology context into which automated commissioning applications will be introduced.

Key findings for the major categories of tools are as follows:

Tools and Techniques for Managing Commissioning Data Various new technologies and applications of technologies promise to be useful in streamlining and automating aspects of the commissioning process. Chief among these are the Internet and World Wide Web, wireless communications, lightweight portable and hand-held computers, high capacity data storage devices, and standards for data representation and data sharing between commissioning participants. These technologies and the software applications built on them show considerable promise for speeding, making continuous, and reducing the cost of commissioning processes.

Analytical Techniques A variety of techniques are available, from first principles–based models to classical statistical methods to artificial neural networks. Currently, it appears that methods based on parametric models are likely to best match the analytic modeling and processing needs of commissioning processes. The ability to tune parameters will likely best match the need to accommodate a broad range of equipment and unique characteristics of individual buildings.

Analytical Tools Existing mathematical, statistical, and data processing tools and software toolkits are likely to prove immensely valuable in testing and developing techniques for automating parts of the commissioning process and will be required in this project. Programming languages, such as C++, may prove valuable for prototyping automated commissioning processes in this project and will certainly prove critical in developing tools for commissioning providers in follow-up work to develop and deploy these tools.

Task 5: Develop Methodologies for Automating Selected Procedures and Processes for Continuous Commissioning

Following the recommendations and findings of the previous tasks, we develop and document a generic, automated, continuous commissioning process that involves detecting, diagnosing, and evaluating faults and choosing a course of action. We use that generic process to adapt and develop specific and detailed methods and procedures (upon which automated tools can be built) that continually detect and assess the operation of economizers and outdoor air ventilation. In doing so, we discuss topics such as data requirements, passive versus proactive detection and diagnosis, and balancing analytical sensitivity with false alarms.

We then take a similar approach to faulty sensors. We develop a generic method for detecting faulty sensors, then use that to develop detailed procedures for identifying which sensors are faulty and for diagnosing problems with each type of sensor.

We develop a generalized approach for detecting malfunctioning valves and dampers that can be applied in a variety of HVAC applications.

Finally, we specify and prototype a methodology that formalizes and expedites determining what information is needed for commissioning and then compiling that information into a database.

Conclusions

Summary

This research project identified methodologies that could be used to develop commissioning tools for the four problems and processes that emerged as the top candidates for automation within the commissioning process:

- 1** Faulty economizer operation;
- 2** Malfunctioning sensors;
- 3** Malfunctioning valves and dampers; and
- 4** Project data management.

The need and desire for automated tools to help reduce the time and cost associated with commissioning is prevalent in the commissioning community. Fault detection and data management techniques can be integrated into proactive fault detection tools which can use measured data, design data, and equipment operating parameters to perform actual functional tests to improve system diagnosis. Methodologies for detecting system operation faults were developed and demonstrated through flow diagrams and simplified mock-up applications. Data management techniques were demonstrated through examples illustrating how prefunctional and functional test forms could be populated with design information and equipment operating parameters.

Future Research

This project focused on developing methodologies for automated tools for two broad commissioning tasks: 1) detecting faults in system operation, and 2) managing commissioning related data. In each of these areas, we have identified future research that is key to advancing the widespread implementation of automated continuous commissioning.

Detecting Faults The methodologies and diagnostic logic recommended in this report should be validated. This validation should include testing the methodologies using mock-up software in the laboratory and in the field, and empirically investigating the effect of tolerances on sensitivity and false alarms. Comprehensive automated fault detection software tools should also be developed. The most effective way of integrating these tools into the continuous commissioning process should be determined.

Managing Data Current efforts to develop data schemata for identifying and classifying building and construction data should be expanded to include information specific to commissioning building systems and equipment. Software tools for gathering, organizing, and managing this information should be developed. That data management software should be integrated with the emerging automated fault detection software.

It is evident that significant additional research and development are necessary to produce automated tools and to develop an implementation framework around an automated continuous commissioning process. The potential for practical application of automated commissioning tools by building operators and commissioning providers is high. However, resistance to new technology and practices exists in every market segment. Therefore, an important element in the implementation strategy will be market transformation initiatives to train building operators and commissioning providers to integrate the new tools into their existing practices.