2009 BFRL Project Description

Project Title: Commissioning, Fault Detection, and Diagnostics of Commercial Heating, Ventilating, and Air-Conditioning Systems

September 5, 2008

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BFRL Program: Cybernetic Building Systems

Objective: To improve the operating efficiency of commercial heating, ventilating, and air-conditioning (HVAC) systems by 10% to 30% through development and demonstration of measurement science that enables more complete and effective system commissioning practices, and automated fault detection and diagnostics (FDD), transferring the proven technologies to the private sector.

Problem:

What is the problem? Commercial buildings in the U.S. represent 18% of the total national energy consumption[1] and Congress has established a national goal of achieving net-zero energy buildings (ZEB) by 2030[2]. According to a 2005 study[3], technologies such as building commissioning and automated FDD can save 20 % of the energy consumed by HVAC, lighting, and refrigeration systems by eliminating operational faults. This represents $17 billion savings for gas and electricity costs, an 80 million metric ton reduction in carbon emissions[1], and substantial non-energy benefits, including greater productivity of occupants and maintenance personnel that can surpass energy savings. However, buildings are rarely commissioned according to any rigorous process due to cost constraints.

The measurement science needed to enable new technologies and practices to achieve these significant efficiency improvements is lacking and the Department of Energy (DOE) has cited it as a critical component to achieving efficiency improvements through new technologies and practices.[4] Without reliable measurements and demonstrated effectiveness new FDD tools and commissioning practices will not be adopted by building owners.

Why is it hard to solve? Buildings are complex systems of interacting subsystems. Mounting expectations, including achieving the vision of ZEBs, are being placed on a combination of different and often conflicting performance measures such as, energy efficiency,

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[1] *DOE 2007 Buildings Energy Data Book http://buildingsdatabook.eren.doe.gov/*

[2] *Energy Independence and Security Act of 2007*

[3] *Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential, TIAX Report No. D0180*

[4] U.S. Department of Energy, *High-Performance Commercial Buildings: A Technology Roadmap,* http://www.eere.energy.gov/buildings/info/documents/pdfs/roadmap_lowres.pdf

indoor air quality, comfort, and reliability. Simple solutions are needed to ensure that the interdependencies of systems and equipment are operating as intended. A 2008 study of performance data from 121 LEED-NC[5] rated new buildings found that a significant number of buildings fail to meet code[6]. Equipment failures and performance degradation often go unnoticed for extended periods of time because there are no tools to detect them until occupant comfort is compromised.

How is it solved today, and by whom? The measurement science needed to solve the problem is not currently available. Industry has responded in a limited way to encourage and improve commissioning practices but the process is generally carried out manually, the quality varies widely, and the initial cost and time investment is prohibitive for most applications. Documented commissioning methods are only available for conventional HVAC systems and do not address the systems and system combinations that are expected to be important for ZEBs. Most attempts to develop automated FDD tools require large amounts of trend data and considerable expertise to interpret the results. The European Commission established a buildings performance directive to promote the improvement of energy efficiency in buildings. Its implementation has driven the development of commissioning tools in the International Energy Agency's Annex 47[7].

Why NIST? This project responds to measurement needs from the commercial buildings industry and addresses BFRL's vision by placing NIST as a resource for the critical solution-enabling tools needed to improve commercial building performance. The project builds on the core competencies of Information, Communication and Automation Technologies for Intelligent Integration of Building Design, Construction and Operation, and Measurement Science for Building Energy Technologies.

Because a mismatch exists between who invests (manufacturers) and who benefits (public), public sector involvement is necessary to overcome the initial barrier of developing the measurement science. NIST is in a position to leverage its strong ties to industry, academia, standards organizations, and stakeholders, both domestic and international.

Approach:

What is the new technical idea? The new idea is to leverage the untapped capabilities of modern building automation and control systems by developing techniques to automate labor intensive commissioning processes and developing measurement systems that can monitor component and system performance, and automatically detect faults. The key to realizing efficiency improvements is combining new measurement technology and performance metrics with analysis techniques that can be implemented in building automation and control products. The resulting systems would have a distributed, embedded intelligence that can detect and respond to faults and operational errors and inefficiencies.

To complement this effort, NIST will work with industry to develop a standard method of test for automated diagnostic tools used in commissioning and performance monitoring. This would

[5] U.S. Green Building Council, Leadership in Energy and Environmental Design (LEED) Green Building Rating System.

[6] Turner, C. and M. Frankel. 2008. "Energy Performance of LEED for New Construction Buildings. U.S. Green Building Council.

[7] International Energy Agency, Annex 47 on "Cost-Effective Commissioning For Low-Energy Buildings" www.ecbcs.org. www.iea-annex47.org

help diagnostic tool developers improve the quality of their products and enhance the confidence of owners and consulting engineers in automated diagnostic tools, and creating a driver for the capabilities deemed most effective. These efforts will speed the development and use of technologies that are needed to achieve ZEBs over the building lifecycle.

Why can we succeed now? Success is likely because of increasing industry demand for the technology as a way to reduce energy consumption and associated environmental impacts[4]. A national market study[3] reported "The combination of greater sophistication and lower cost has the potential to make a wide range of energy-saving controls approaches, including automated FDD, economically viable." It also presented key next steps for greater deployment, including: automation of building commissioning and embedded FDD. At NIST, a successful track record has already been established with both research collaborators and industrial partners who are working to commercialize early results.

What is the research plan? NIST will enable the development and commercialization of automated commissioning tools and embedded intelligence building control systems by:

- Determining, through laboratory experimentation and simulation studies, the number and type of sensors needed to detect common building equipment faults and control errors;
- Developing fault detection metrics and tools for a comprehensive range of HVAC equipment and central plant components that can be embedded in control products;
- Developing hierarchical analysis techniques to determine when an apparent fault in one piece of equipment is actually the result of a failure of a component upstream in the process;
- Develop, test, and demonstrate tools for automated commissioning; and
- Develop information models, validation tools, and performance metrics to enable advanced building control systems with automated commissioning and integrated FDD capability.

The research plan is staged to address the most common types of HVAC equipment first in order to increase the early market penetration potential. NIST will leverage existing CRADAs with industry partners to speed commercialization of research results.

Each tool or process will be developed in a sequence of stages. The early development will be guided by analytical work and simulations. The next phase will be testing under a broad range of conditions using the Virtual Cybernetic Testbed (VCBT) to systematically explore a wide range of weather conditions, mechanical equipment faults, and potential control system logic and configuration problems. Collaboration with industry partners will begin at the laboratory testing phase and continue with field trials in buildings using the partner's control products.

The strategy also involves the task of developing performance metrics, that is: defining critical characteristics that define good performance, determining the methods for measuring and representing performance, and determining how to apply the metrics for specific systems. NIST will partner with DOE labs to establish a standard method of test for air handling units, including a set of test procedures and a test environment.

The work on commissioning tools will build on the results from IEA Annex 47 which NIST co-leads. This provides an opportunity to learn from the experience in Europe and Japan where they already have strong programs in place for construction of low energy buildings.

The expected outcomes are a suite of proven algorithms for FDD that can be embedded in controllers for commonly used HVAC equipment, tools to automate commissioning processes, and a knowledge base that can form the basis for new industry best practices guidelines.

Recent Results:

Output: NIST led the US team of IEA Annex 40 research project. Visier, J.C. et al. 2005. IEA Annex 40: Commissioning of Buildings and HVAC Systems for Improved Energy Performance. Final report, www.commissioning-hvac.org
Outcome: Several Annex 40 commissioning tools have been successfully used in demonstration projects globally. A second commissioning-related annex was established as a follow-on research project to address commissioning needs for non-conventional systems. Castro, N. (2006). Cost-Effective Commissioning for Existing and Low Energy Buildings- A New IEA ECBCS Research Project. *Proceedings of the National Conference on Building Commissioning.*
Impact: The commissioning process detailed in the Annex 40 final report is increasingly recognized internationally as a best practice and is the basis for draft national standards in France, Finland, and Norway.

Output: The Annex 47 team developed a standard cost-benefit methodology documenting commissioning benefits and applied it to several international case studies. N. Castro, H. Friedman, and M. Frank. 2007. "ECBCS Annex 47: Cost-Effective Commissioning Research" European Conference on Energy Performance3 and Indoor Climate in Buildings, Lyon, France.
Outcome: New knowledge of the cost benefit relationship for many commissioning tasks including reviewing/repairing common building system faults.

Output: Developed APAR, a tool for detecting air handling unit faults and developed VPACC, a tool for detecting VAV box faults. Schein, J. 2006. Results from Field Testing of Embedded Air Handling Unit and Variable Air Volume Box Diagnostic Tools. NISTIR 7365. National Institute of Standards and Technology. Schein, J., Bushby, S.T., Castro, N.S., and House, J.M. 2006. A Rule-based Fault Detection Method for Air Handling Units. Energy and Buildings, Vol. 38, No. 12.

Outcome: The APAR and VPACC algorithms are being adopted by industry and incorporated into new products .
Impact: The fault detection and diagnostic capabilities available to consumers have been improved, providing the potential for significant performance improvements over the system lifecycle. Consumer awareness and demand for these performance monitoring tools has increased dramatically.

Output: Several publications and presentations to national and international audiences.

- Schein, J. 2007. *An Information Model for Building Automation Systems.* Automation in Construction Vol. 16, No.2.
- May 2007, *NIST Automated Commissioning and FDD Tools*. National Conference on Building Commissioning, Workshop on Data Analysis and Diagnostic Tools for Commissioning, Chicago, Illinois.

- October 2007, Working Paper, *The International Status of Building Commissioning*. Asian Pacific Conference on Building Commissioning, Kyoto, Japan.
- November 2007, *The Importance of Building System Commissioning for Energy Performance*, APIRAC Workshop, Lisbon, Portugal.
- August 2008, *The International Status of Building Commissioning.* Summer Study of the American Council for an Energy Efficient Economy, Asilomar, California.

Standards and Codes: ASHRAE has a series of commissioning guidelines that would be a natural place for the results of this work. ISO/TC 205 is developing standards for building control systems that can be used to disseminate these results internationally. Mr. Bushby is incoming Vice Chair of the ASHRAE Standards Committee and Convenor of ISO/TC 205 WG 3.