Building Systems Diagnostics
Work at Pacific Northwest National Laboratory

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PNNL Diagnostic Project Portfolio

- Introduction to Fault Detection and Diagnostics
- Building Diagnostics Market Deployment
- Diagnostic for Packaged Air Conditioners and Heat Pumps – Ultra Low-Cost Smart Monitoring and Diagnostic System
- Self-Healing, Self-Configuring and Self-Operating Building Systems
- Key Observations about FDD
- Introduction to Other Presentations
Introduction to Fault Detection and Diagnostics
Why do we need Automated Diagnostic Algorithms and Tools?

- Operational faults are pervasive across the commercial buildings sector, increasing energy costs by up to 30%
  - Failed economizer, equipment operating during unoccupied periods, simultaneous heating and cooling, etc.

- Automated fault detection and diagnostic tools provide capabilities essential for correcting these problems and eliminating the associated energy waste and costs
Automated Fault Detection and Diagnostic (AFDD) Tools – A Definition

Convert Data Into Information

Set-Up Data
- Equipment and System Characteristics

Measured Time Series Data
- Various Conditions In Systems, Equipment and Building Spaces

Automated Diagnostic Tool

Actionable Information (e.g., report of faults, fault causes, corrective actions, fault costs, correction costs, other impacts)
AFDD for Buildings Today

- FDD is done mostly by analysts who observe equipment conditions or interpret data from routine operation and tests
  - Labor intensive, costly and requires expertise
  - Some tools are available for assisting with data collection and interpretation

- Alarms are widely used in building automation systems and embedded in some packaged (application specific) controllers – fault detection

- BASs and other software provide data trending capabilities

- AFDD products have been slow to emerge. Some AFDD tools are available:
  - Service Assistant for Packaged Units, for example
  - AFDD tools used in-house to provide services and some companies offering remote monitoring and diagnostics software as a service

- Products of research
  - Many methods have been developed for building applications
  - Algorithms and computer code
  - Research tools and application prototypes – air handlers, package AC units, VAV terminal units, boilers, chillers
  - Demonstrations in the field – mostly tests of engineering performance
Building Diagnostics Market Deployment

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PNNL TEAM: GUOPENG LIU, HUNG NGO, RON UNDERHILL, DANNY TAASEVIGEN, KRISHNAN GOWRI, AND MICHAEL BRAMBLEY
Problem Addressed

- Economizer on both built-up air-handling units and packaged HVAC units are known to fail, leading to increased energy consumption and reduced efficiency.
- Other operational faults are also pervasive across the commercial buildings.
- Transfer the FDD tools developed by PNNL to private sector.

Solution

- Provide technical support to the private sector to help them integrate the FDD tools developed by PNNL.
Objectives, Partners and Major Tasks

Objective
- Enhance and transfer building diagnostic tools/technology previously developed at PNNL to partners for commercialization
- Develop additional automated fault detection and diagnostic (AFDD) algorithms to improve building operations, increase efficiency and reduce operating cost

Industry/University Partners
- KGS Building LLC – CRADA
- NorthWrite
- Purdue University – Buildings HUB

Major Tasks
- Market transfer for Outdoor Air Economizer Diagnostician (OAE) and Whole Building Energy Diagnostician (WBE)
- Development and deployment of AFDD algorithms that improve building operations, increase efficiency and reduce operating costs
Results, Uses and Users

Results to Date

- Commercialized diagnostic software and services for automated diagnostics to improve commercial building operations
- Two companies offering commercial building diagnostic products based on the WBE and OAE
- Technical support documents for use by future commercializers of the WBE, OAE and AFDD algorithms for large commercial buildings

Uses

- Diagnostic tools to improve building operating efficiency
  - Monitoring any end-use and detecting deviation from expected - WBE
  - Monitoring, detecting and diagnosing operational problems with air handler units and packaged RTUs - OAE
  - Monitoring, detecting and diagnosing operational problems with other building systems – new AFDD

Users

- Application service providers
- Building owners
- Building operators
Diagnostic Packages for Packaged Air Conditioners and Heat Pumps: Smart Monitoring and Diagnostic System (SMDS)

MICHAEL R. BRAMBLEY

PNNL Technical Team: Danny Tassevigen, Lucy Huang, Srinivas Katipamula
Problem Addressed

- Packaged HVAC units are generally poorly maintained, operating at degraded efficiency and capacity and with faults present.
- Servicing, when done at all, is generally performed on a semi-annual basis but often is inadequate to correct all important faults.
- Operational faults are pervasive across the commercial buildings sector, increasing energy costs by up to about 30%.

Solution

- Provide a low-cost remote condition monitoring system retrofittable to existing packaged units that identifies and quantifies degradation in performance and the associated increase in operating cost to support owner and service provider decisions to service the equipment.
- The SMDS provides continuous condition monitoring and fault detection using the web so that results can be accessed by authorized users on any device with a web browser.

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Smart Monitoring and Diagnostic System (SMDS)

SMDS Gateway
- Internet Connection
- WiFi Router
- Zigbee router

Performance monitor units measure outdoor-air temperature (OAT) and total unit power and perform fault detection & diagnostics.
Objectives, Partners and Major Tasks

▸ Objective
  ▢ Provide and field test a retrofitable technology, at a market-compatible cost (~$200), for transforming how the maintenance of packaged commercial air conditioners and heat pumps is managed and performed
  ▢ Rapidly commercialize the technology

▸ Major Tasks
  ▢ Develop
    ▢ system-level design (Team)
    ▢ low-cost hardware (Universal Devices)
    ▢ diagnostic algorithms (PNNL)
  ▢ Develop and validate software (NorthWrite and Universal Devices)
  ▢ System integration and bench-top testing (NorthWrite, Universal Devices).
  ▢ Field Testing (NorthWrite, PNNL)

▸ Industry Partners
  ▢ NorthWrite Inc.
  ▢ Universal Devices
Results, Uses and Users

Results
- SMDS system commercially available by January 2013.
- Documented and published performance degradation and fault detection methods/algorithms for use by future commercializers.
- Transformation of packaged unit servicing to condition-based rather than periodic servicing or run until failure.
- Substantially increased average operating efficiency (~10% to 20%) through improved maintenance.

Uses
- Monitoring the condition of packaged units.
- Condition-based maintenance.
- Verification and value of quality of maintenance performed – reinforcement of value.
- Capturing energy and cost savings.

Users
- HVAC service providers.
- Building maintenance staff.
- Building owners.
- Building energy service providers.
Self-Correcting Controls

MICHAEL R. BRAMBLEY

PNNL Technical Team: Heejin Cho, Krishnan Gowri, Hung Ngo, Andrey Liyu, Anne Wagner, Ron Underhill, James Goddard, Darrel Hatley
Problem Addressed

- Operational faults are pervasive across the commercial buildings sector, increasing energy costs by up to about 30%
- Faults occur during installation, commissioning, operation and maintenance (O&M)
- Many faults are not corrected because O&M staff are unaware of their occurrence
- Others are not addressed because of understaffing, staff knowledge/capabilities are inadequate, time is short, impacts are not well understood and faults recur

Solution

- Provide technology that automatically detects and corrects many of the faults that commonly occur in building systems
- Deploy the technology in the form of add-ons to or embedded code in building automation and control systems
Objectives, Partners and Major Tasks

Objective

- Develop and test techniques and algorithms for control systems to automatically and in real time correct and optimally compensate for faults (e.g., biased sensors, improperly set outdoor air damper, hunting dampers) occurring in HVAC systems and their components (FY2011)
- Develop and field test a field deployable software package implementing self-correcting controls for air-handler mixing boxes (FY2011 and FY2012)
- Develop and test a virtual air handler energy performance monitor and diagnostic system
- With industry partners integrate these capabilities with building control systems

Major Tasks

- Establish and interact with industry advisory group and identify potential collaborators
- Develop prototype software module for self-correction of air handling unit mixing boxes for field testing
- Perform field tests.
- Develop and test virtual energy-use performance monitor for air handlers

Industry Advisory Committee

Collaborators: University of Oklahoma
Results, Uses and Users

Results
- Fully-documented and tested methods, algorithms and software modules to enable building systems to:
  - Self-heal
  - Self-configure
  - Self-commission continually
- Algorithms for key building equipment and systems.
- Virtual energy performance meter with automated fault detection and diagnostics for air handlers
- Deployment with industry as embedded parts of building automation and control systems

Uses
- Streamlined operation and maintenance of all major building systems.
- Ensuring persistence of energy savings
- Automation for use during routine operation of commercial buildings
- Solve problems of incorrect installation, operation and maintenance of building systems

Users
- Building O&M staff
- Building energy service providers
- Building controls companies
Key Observations

► AFDD for building systems is behind other fields but not as far as some seem to believe
► Research is far ahead of applications & commercially available tools: research – practice gap
► Tools are beginning to emerge but preferred business models are not clear
  ■ Diagnostic hand tools
  ■ FDD provided as a service in retro-commissioning, new control-system design & installation, third-party services (ASP delivery via Web), embedded in control system and buildings automation systems (BAS, EMCS, etc.). What’s best?
► AFDD shows promise to provide many benefits in the future provided we can find the path to widespread use