Moving to High Performance Data Driven Buildings

Current and Future Trends in Fault Detection & Diagnostics

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Outline

- FDD success stories from the Smart Energy Analytics Campaign
 - Market Deployment and FDD Algorithm Testing



FDD Success Stories from the Smart Energy Analytics Campaign

Amy Jiron, US Dept of Energy



Smart Energy Analytics Campaign

Buildings above 50,000 sq ft

- Energy information systems
- Fault detection and diagnostic systems
- Participation Update
 - 92 organizations
 - 5600+ buildings
 - 440 million sq ft
- Join us
 - Participant
 - Supporting Partner
- Benefits to participants
 - Technical Assistance
 - Recognition
 - Peer Networking

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Smart Energy Analytics Campaign Success Stories smart-energy-analytics.org/success-stories

Building Analytics Success Story Commonwealth of Kentucky

Since a state-wide Executive Order in 2009 requiring utility data reporting, the Commonwealth of Kentucky has made energy management and the use of building data analytics the cornerstones of a comprehensive energy management program. Kentucky developed the Commonwealth Energy Management & Control System (CEMCS), a centralized repository of building data for analysis, which not only helps identify energy savings but also improves how each facility runs. In 2016 Kentucky connected 2.5 million sq. ft. of buildings to the CEMCS, which now covers over a thousand buildings totaling 20 million sq. ft.

CEMCS Features and Benefits

The CEMCS incorporates over 188,000 trends captured from building automation systems (BAS), as well as data from 1,350 meters. Kentucky uses a combination of automated CEMCS analysis and engineer review to evaluate central plant HVAC, air handler, and individual zone data. Online reports rank energy performance at each facility by applying a score of 1-10 based on space temperatures, scheduling, and damper/valve operation. Hyperlinks connect to individual system trends for further diagnostics. Mechanical and control drawings are also loaded into the CEMCS platform.

What is MBCx?

Monitoring-based commissioning (MBCx) is an ongoing commissioning process that focuses on analyzing large amounts of data on a continuous basis to improve and maintain building energy performance and comfort.

With this comprehensive aggregation of data, Kentucky's CEMCS Program Manager can prioritize efforts and track performance parameters across the state's buildings. The CEMCS also incorporates regression-based energy models for meter data, to help track weather-normalized energy savings.





If something goes wrong, we have the data to make the case to aet it fixed and verify the result. - Andrew Carter, CEMCS Program Manager

Quick Facts

Location: Kentucky (statewide)

Building types: Office, Higher Education, Healthcare, and Food Service

Gross floor area covered by EMIS: 20 million sa. ft.

Buildings with EMIS: 1,145 buildings connected to an energy information system (EIS) and 118 buildings with fault detection & diagnostics (FDD)

Energy savings: 8% savings (based on data from 136 buildings)

MBCx Service Provider: Interval Data Systems, Inc. (IDS)

EMIS Tool: Commonwealth Energy Management and Control System (CEMCS), built on IDS's

Smart Energy Analytics Campaign: Recognition for Expansion of EMIS

Kentucky Energy Total Buildings Utility Savings Savings Dashboard 624 9.4% Welcome to the Commonwealth Energy On track to meet 2025 Management and Control System (CEMCS) public dashboard. This goal of 25% dashboard tracks the progress of **Total Square Footage** Current energy consumption energy and cost savings initiatives for compared to historic baseline 14,218,805 buildings throughout Kentucky. normalized for variations in weather The CEMCS is an innovative software application which is integrated to utility Annual Utility Cost company billing, building automation systems and statewide accounting Savings **Total Occupants** \$4,805,265 25,571 The data collected from these sources enables the identification of energy-All utilities (energy + water) compared saving opportunities and verification of to historic baseline, weathe corrective actions that reduce energy normalized use, and thus allows the Total Annual Utility Cost Commonwealth to operate as much as 25% more efficiently in integrated \$27,050,829

Kentucky's EIS dashboard is used to engage the public, compare building benchmarks, and track energy and cost savings.

Kev Management Practices

systems

facilities

Kentucky uses the CEMCS to drive three key approaches to energy management:

- Routine data review: CEMCS analytics are reviewed weekly, with the MBCx service provider supplying recommendations for improvements.
- Work order management: Connection of the CEMCS to the state's work order management system supports follow-up and implementation of findings.
- Savings tracking: Implemented projects are displayed in the CEMCS to correlate completion with savings.

Beyond the internal management approach, Kentucky also provides a comprehensive public dashboard displaying energy consumption, costs, and savings.

Systems-Based Approach

Kentucky's analytics approach is to monitor system summary metrics, then drill down to equipment details as problems are uncovered. This approach helps avoid the overload that can happen when tracking multiple fault types across all systems in over a thousand buildings. While some buildings will need new equipment, the first goal is to optimize existing equipment and controls by improving sequences of operation and automation, and upgrading equipment when retrofits are cost-effective.

Bringing CEMCS to New Construction

Kentucky brings new construction projects into the CEMCS as early as possible, to get detailed information on how the building is running so corrective actions can be taken during the warranty period. They have also established a standard for data collection for all new BAS installation work to ensure that CEMCS data input needs are met. The standard addresses BAS points that must be trended, point naming conventions, and data collection frequency. The goal is to have a better specification leading to streamlined controls delivery. recognizing the first year of operation will shake out the problems which are identified quickly using the CEMCS.

The entire CEMCS effort has changed how Kentucky handles construction and controls implementation.

-Andrew Carter, CEMCS Program Manager

Developing a comprehensive EMIS incorporating BAS trends, meter data, a public dashboard, and connection to a work order system is a significant achievement. Now that the 2016 expansion is fully operational. Kentucky is planning further expansion of the CEMCS.

The Smart Energy Analytics Campaign is a public-private sector partnership program focused on commercially available Energy Management and Information Systems (EMIS) and monitoring-based commissioning practices. The campaign couples technical assistance with qualitative and quantitative data collection to inform research. development, and field study priorities. Partnering participants are encouraged to share their progress and may receive national recognition for implementations that demonstrate exemplary practices.

Smart Energy Analytics Campaign Participants Recognized for Exemplary Use of Fault Detection and Diagnostics





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Top 7 Barriers to Implementing and Using FDD

- 1. Users not clear on differences between products (confuse EIS & FDD)
- 2. Lack of control system naming consistency makes integration challenging
- 3. Difficulty extracting data from older BAS
- 4. Data quality problems if we can't trust that the sensors are accurate, can we trust the faults are correct?
- 5. Building staff in reactive/fire fighting mode, limited time to review FDD results, find root cause, and fix
- 6. FDD users experience fault overload if faults are not prioritized
- 7. Lack of M&V process in place to verify the savings, can hinder the ongoing business case





7

FDD Award Winners Show Success

Owner	Example of	Size	FDD Tool
MGM Resorts	Starting FDD at the central plant in a large portfolio	50 million sq ft	SkySpark (Altura Associates)
Emory University	Evolution from in- house FDD to vendor	2.7 million sq ft	CopperTree Analytics
University of Iowa	Moving from reactive to proactive maintenance	2.7 million sq ft	KGS Buildings
Commonwealth of Kentucky	EIS and FDD for a broad portfolio	20 million sq ft	Interval Data Systems
Sprint	Reduces PM costs	4 million sq ft	SkySpark (CBRE ESI)





8

University of Iowa

Quick Facts

Floor area with EMIS: 2,700,000 sq ft

Total buildings with EMIS: 20 buildings, currently adding 29 more buildings

Energy reduction since EMIS: 5% whole building

MBCx Service provider: KGS Clockworks

FDD Software: KGS Clockworks Building Analytics

EIS Software: OSIsoft PI



Key Success Factors

- Refined scope through a pilot
- Fault response workflow
- Service provider installed FDD and integrated with work order management
- Analytic Response Group meets daily





University of Iowa: Pilot

Pilot in a large lab building. Leveraged lessons learned to create an RFP and select an FDD partner for scaled implementation.





- Enhance existing infrastructure-Don't duplicate!
- Understand the skills available to you in-house
 and find opportunities to partner with an integrator
 or software provider to supplement the rest.
 - IT involvement at the early stages is critical
 - The software is only a tool-the key to success will be in the processes you develop to utilize the tool.





MGM Resorts International

Largest Portfolio Using Analytics







"When issues arise involving major HVAC equipment, the first call is to the [analytics] team to see if it can be diagnosed. This process saves an enormous amount of money in avoided service calls and unnecessary equipment replacement." – Chris Magee, VP Sustainable Facilities





Commonwealth of Kentucky

- Best Practice in Expansion of EMIS
- 2016 2.5m sq.ft. added to EIS/FDD system (20m sq.ft. total)
- Building analytics and diagnostics
- Tools & services for Agencies:
 - Building Dashboard
 - Baselining and Benchmarking
 - BAS Operational Analysis
 - Remediation
 - Energy Savings Project Tracking
 - New Construction sequence review
- Development of High Performance Buildings Standard









Emory University

Energy Performance in a Portfolio

- 20 buildings, 2.7 million sq ft
- 25% reduction in whole building energy use
- Reduction driven through in-house existing building Cx paired with FDD algorithms; transitioned to FDD vendor









Sprint in partnership with CBRE

- Best Practice in the Use of EMIS
 - 4 million sq ft portfolio implemented FDD
 - \$431,000 cost savings in 2 years; 5% of campus electric









Thank you

Next Steps: Join the Campaign or Refer a client to the Campaign



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15

Market Deployment and FDD Algorithm Testing

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Motivation and Objective

- Commercially available FDD products represent one of fastest growing markets in technologies for building operations
- New products and algorithms continuously developed no means for owners, utilities, developers to:
 - Understand and distinguish market offerings
 - Compare/contrast, benchmark performance
- Overall objective to
 - Survey & characterize current FDD offerings, capabilities
 - Develop procedure and public data sets to test FDD solutions



Characterization of FDD Tools

- Develop a framework to understand the diverse landscape of FDD offerings
- Survey & characterize a sample of current FDD offerings, capabilities with the framework
- Gain insight into the gaps and needs

Characterization and Survey of AFDD Tools report



Smart Data. Smart Devices. Smart Buildings. Smart Business

LBNL-2001075

Lawrence Berkeley National Laboratory Characterization and Survey of Automated Fault Detection and Diagnostic Tools

Characterization of FDD Tools, Framework

- Current markets served (within the commercial sector)
- Delivery model: location, user, data source, tuning effort, etc.
- Tool capability: fault presence, location, severity, root cause
- System and categories of detectable faults covered
- Method/algorithms
- Other features beyond FDD



Characterization of FDD Tools, Findings

- FDD are used in nearly all comm. building sectors, smaller facilities are less commonly served
- Cloud-hosted tools & SaaS service dominates
- Market delivery of FDD through thirdparty service providers is growing

Increasing levels of support for in-house staff



A spectrum of analytics-focused activities that service providers may offer their customizers

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Characterization of FDD Tools, Findings

- Many tools have libraries that are able to determine some faults across all systems and fault categories
- Coverage of systems and faults is driven more by site data availability than by product offering
- Most use rule-based algorithms; configuration requires site-specific tuning



Characterization of FDD Tools, Findings Interpretation

- Many products are sold with an emphasis on broad-scale applicability, and in analyzing the capabilities across all offerings as whole, there is a high degree of similarity
- However, actual implementation needs can differ widely from one application case to another
- It is critical for prospective technology users to probe providers to understand the precisely what is entailed in a given offering's implementation of a feature of interest, e.g.
 - Ways for diagnostics, fault prioritization
 - Ease of integration with different makes and vintages of BAS



Characterization of FDD Tools, FDD Application Best Practices

- Implement FDD gradually instead of all rules at once, e.g.
 - Only implement a few rules on all AHUs
 - Select one AHU to work out all the kinks before expanding to the other equipment
 - Start with rules for what are typically the largest energy savers: airside economizers, valve leak-by, simultaneous heating and cooling, and supply air temperature or static pressure reset schedules.
 - Start with rules for issues that are known or suspected by operations staff in order to gain experience with the FDD and understand the severity of the fault



Characterization of FDD Tools, FDD Application Best Practices

- Increase the threshold for triggering a fault then adjust it accordingly after you address the largest issues, then narrow this range down over time
- Make sure fault algorithms are complex enough to account for the conditions that are related to the same fault
- 2-Way communication between CMMS and FDD software helps facilitate the work and "tell the story"



FDD Algorithms Performance Evaluation

- Develop procedure and data sets to performance test FDD algorithms
 - Apply to FDD solutions from industry and research community
 - Make procedures available to public for replication and ongoing use (longer-term)



FDD Algorithms Performance Evaluation Procedure



1. Determine input scenarios

2. Create **input samples** drawn from the input scenarios. Single input sample -> single FDD evaluation result

3. Assign ground truth to each input sample, e.g. faulted or unfaulted, and if faulted, which fault cause is present.

019 Haystack Connect

FDD Algorithms Performance Evaluation Procedure



4. Execute FDD algorithm for each input sample.

5. Retrieve FDD algorithm outputs / results for evaluation

6. Evaluate **performance metrics** by aggregating the algorithm results for individual samples



FDD Algorithms Performance Evaluation Procedure, Fault Definition

Presence/absence of a fault depends on whether definitions are

Condition-Based

The presence of an improper or undesired physical condition

Ex. the chilled water valve is stuck open

Behavior-Based

The presence of improper or undesired *behavior* during the operation

Ex. simultaneously heating and cooling

Outcome-Based

a quantifiable outcome deviates from the expected outcome

Ex. chilled water energy is greater than expected

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FDD Algorithms Performance Evaluation Procedure, Input Sample Definition

An input sample is a collection of data associated with *a single ground truth* (faulted or unfaulted, fault cause) for which we expect the performance evaluation to produce *a single result* (correct diagnosis, false positive, true negative. Etc.)

Common definitions:



Single Instant in Time: A single set of simultaneous measurements



Regular Slice of Time: Fixed window that repeats on a fixed interval

19 Haystack Connect

FDD Algorithms Performance Evaluation Procedure, Performance Metrics

- Single results are produced when protocol outputs are evaluated against the ground truth (blue dashed boxes)
- Results from many input samples are then aggregated to yield one or more performance metrics



FDD Algorithms Performance Evaluation Procedure

- Best practices of choosing specific options
 - Full documentation and disclosure of the fault, sample, and metric definition employed
 - Test algorithms using consistent definitions and evaluation data set
- Near-term opportunities for FDD algorithm evaluation demonstration
 - Condition-based ground truth
 - Regular daily time slice input samples
 - Metrics: true/false positive rate, true/false negative rate, and correct diagnosis rate



FDD Algorithms Performance Evaluation, Initial Data Curation

- Most common AHU/RTU-VAV faults, simulated and experimental data, single and multi-zone, diversity of operational conditions and fault intensities
 - OA damper stuck
 - Cooling coil valve stuck/leakage
 - Heating coil valve stuck/leakage
 - Outdoor air temp. sensor bias
 - Condenser fouling



FLEXLAB[™] experimental facility



Experimental RTU



FDD Algorithms Performance Evaluation, Initial Data Curation

- A) Document with 'metadata'
- An overview of the data set, who created it, and whether it was generated through simulation or physical experimentation
- Building and system information
 - Model or experimental facility description
 - System type and diagram
 - Control sequences
- Information on measurement points in the data
- Input scenarios with ground truth
- B) .csv files with time series data
- Internally consistent point names
- 1-min interval of measurement



Modelica simulation model

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FDD Algorithms Performance Evaluation, Initial Data Curation

Datasets are available on OpenEI

https://openei.org/doe-opendata/dataset/data-sets-for-evaluation-of-buildingfault-detection-and-diagnostics-algorithms



Additional Info

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Relevant Ongoing FDD Research, FDD Automated Correction

- Motivation
 - Current FDD products continuously identify faults through a 1-way BAS interface
 - Human intervention to fix faults results in delay/inaction, lost opportunity, and additional O&M cost
 - Automated fault correction promises to advance usability and performance
- 3-year project approach
 - Develop library of automated FDD correction routines
 - Integrate with commercial FDD products
 - Field test efficacy and document findings
 - Evaluate market potential and benefits



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