AABC Commissioning Group

AIA Provider Number 50111116

MBCx State of the Art Using Fault Detection & Diagnostics Tools

Course Number: CXENERGY1926

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Course Description

Fault Detection and Diagnostics (FDD) is a powerful tool in the fast growing area of monitoring-based commissioning to ensuring efficient building operations. FDD offers the potential to greatly improve performance, and to do so cost effectively. This session will provide an overview of recent Lawrence Berkeley National Laboratory (Berkeley Lab) research on FDD. It will cover the current state of the market, success stories, and outstanding needs in the industry, from a vendor survey and direct engagement with users of FDD technology. It will also present a framework for evaluating the performance of FDD algorithms.

Learning Objectives

At the end of the this course, participants will be able to:

1. Gain knowledge of the current state of FDD market by applying a characterization framework to survey over a dozen FDD technologies.

2. Learn key success factors for using FDD for MBCx projects.

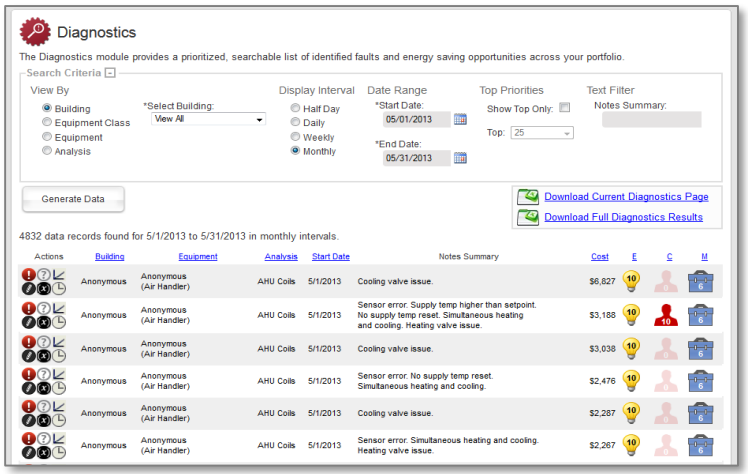
3. Understand the framework for evaluating the performance of FDD algorithms.

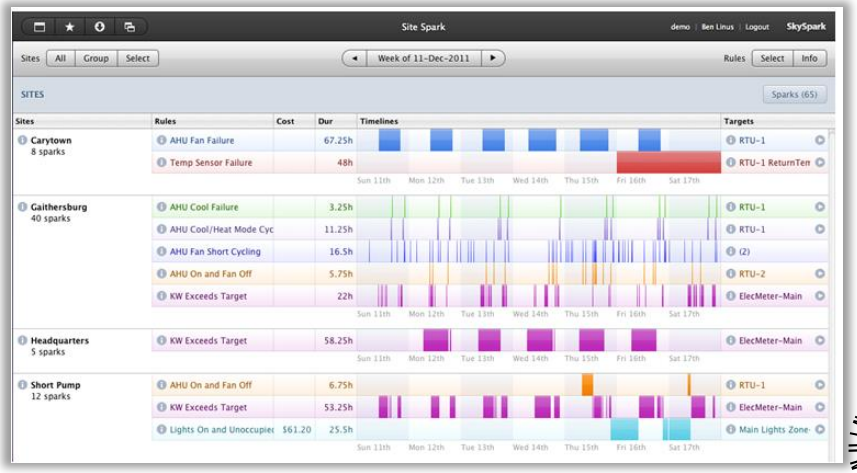
What we'll cover today

- Current state of fault detection and diagnostics (FDD) technology market
- FDD applications in commercial buildings
- FDD algorithms evaluation

Fault Detection & Diagnostics (FDD)

- FDD products represents one of fast growing markets in technology for building analytics – owners, researchers, developers have questions on
  - How to understand market offerings from vendor websites and market materials
  - What are today's users of FDD saving and spending on the technology
  - How to compare/contrast, benchmark performance





Screen shots from KGS Clock Works and SkyFoundry's SkySpark

What we'll cover today

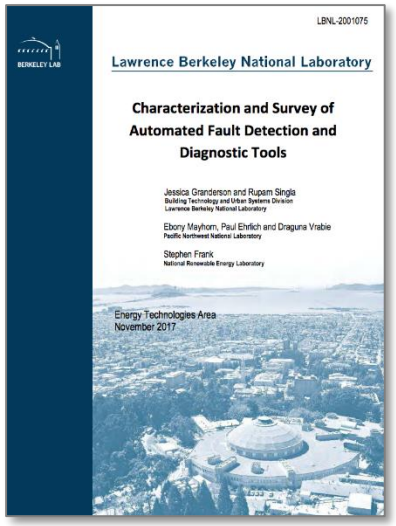
- Current state of fault detection and diagnostics (FDD) technology market
- FDD applications for MBCx in commercial buildings
- FDD algorithms evaluation

Current State of FDD Market

Current State of FDD Market

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

[Characterization and Survey of AFDD Tools report]



Current State of FDD Market, Characterization 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

Current State of FDD Market, 14 Tools Characterized

ANALYTIKA

cimetrics

SkySpark
SkyFoundry

Niagara Analytics 2.0

TRIDIUM

Kaizen
COPPERTREE ANALYTICS

CLOCKWORKS

KGS BUILDINGS

Balance
EEI

transformativewave

CBRE|ESI

True Analytics
ECORITHM

IntelliCommand

JLL

iCONICS
Make the Invisible Visible™

ClimaCheck

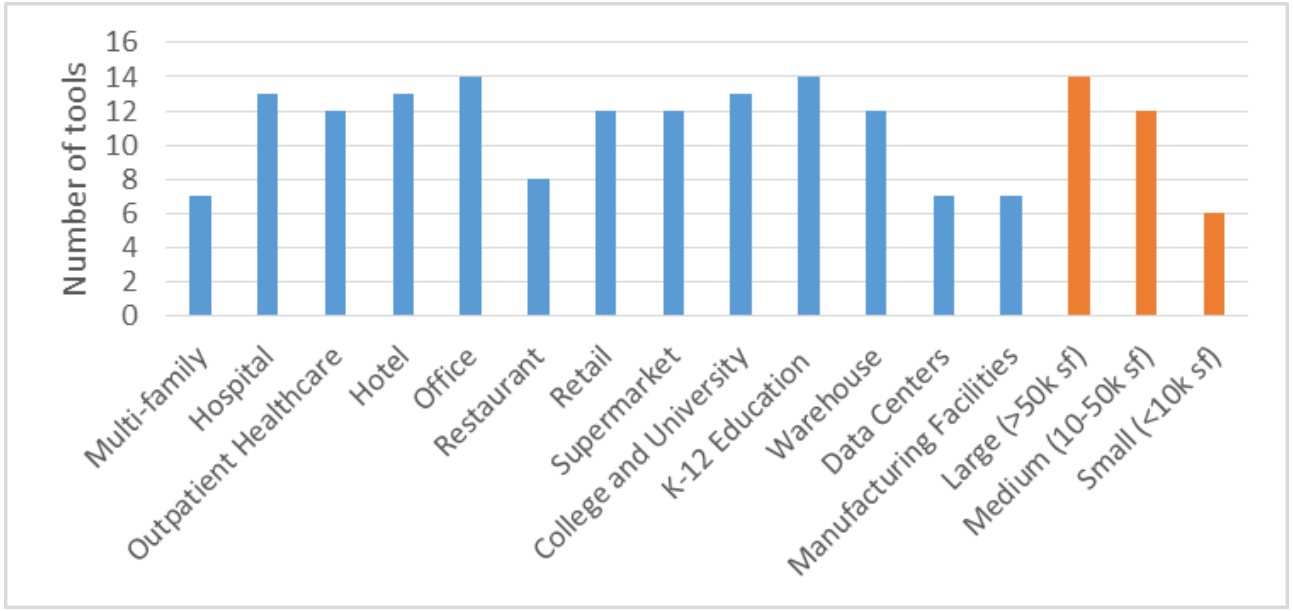
buildpulse

Field Diagnostics

Interviews and surveys with the developers of each FDD tool

Current State of FDD Market, Markets Served

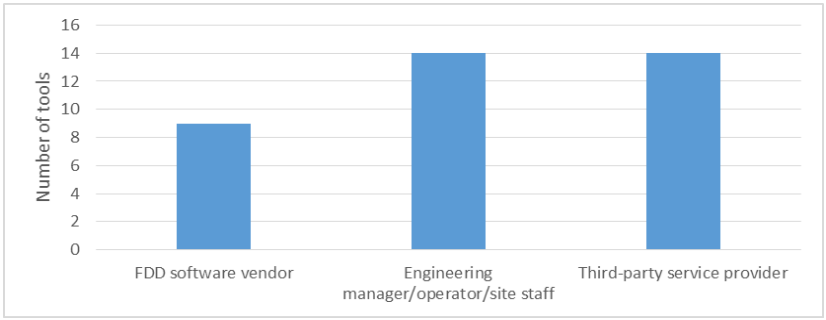
- FDD tech. are used in nearly all commercial building sectors
- Smaller facilities are less commonly served, often through portfolio of small buildings as opposed to single site



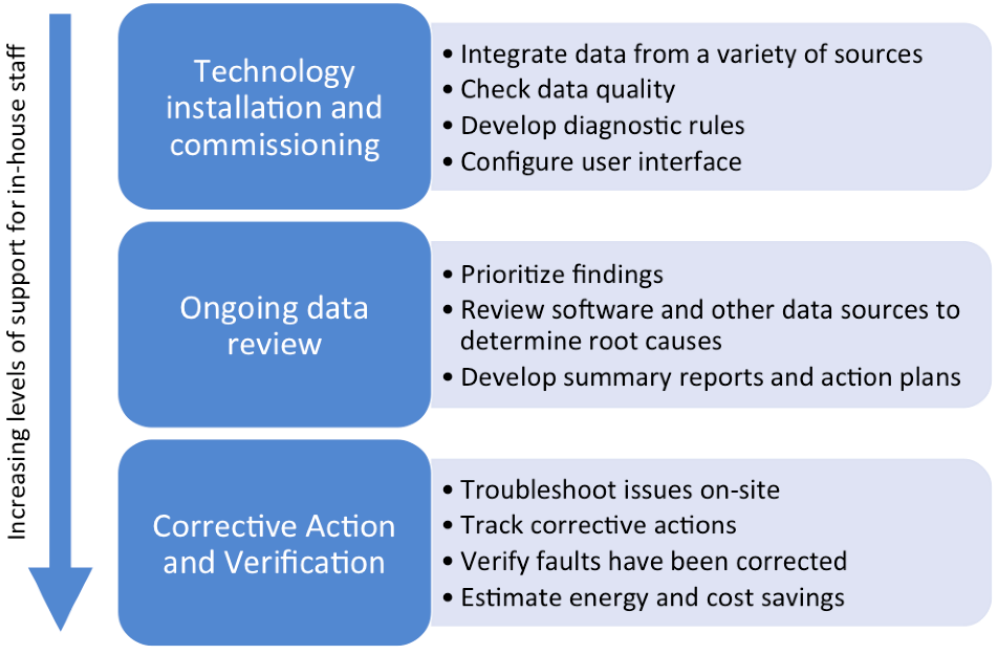
Market presence of surveyed FDD tools

Current State of FDD Market, Delivery Model

- Market delivery of FDD through third-party service providers is growing
  - Use the tools as a way to provide value-add to their customers
- Cloud-hosted tools & SaaS service dominates.



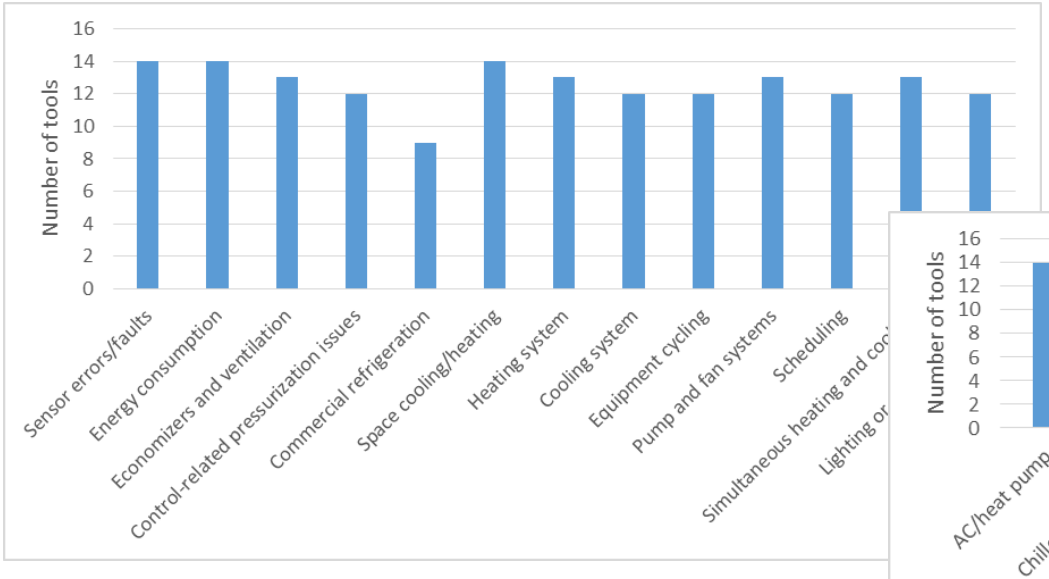
Intended users of surveyed FDD tools



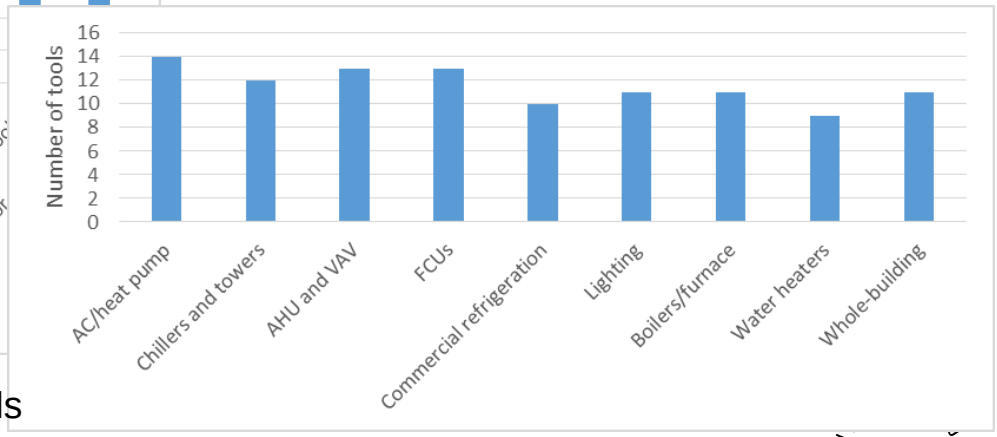
A spectrum of analytics-focused activities that service providers may offer their customizers

Current State of FDD Market, Systems Covered & Detectable Faults

- 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



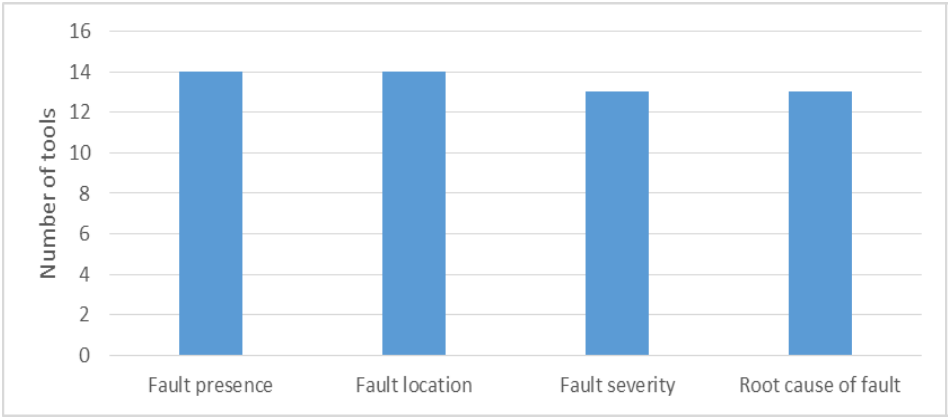
Categories of detectable faults of surveyed FDD tools



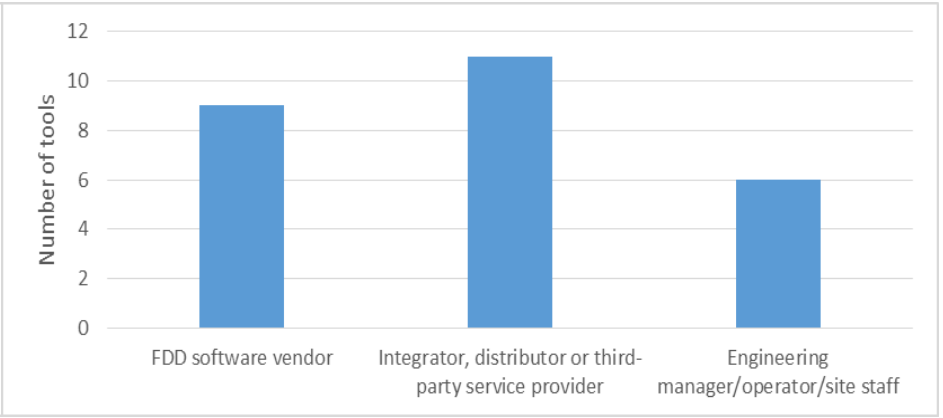
Systems covered of surveyed FDD tools

Current State of FDD Market, Tool Capability

- Most (12 out of 14) use rule-based algorithms
- Almost all tools can identify fault presence, location, degree of severity, and root cause
- Configuration requires site-specific tuning
  - None offer fully automated tuning; 6 vendors provide routines and/or GUIs to automate/streamline some elements of the process



Detection and diagnosis capabilities



Parties involved in software configuration

Current State of FDD Market, Additional Functionality

- Most common additional features
  - Time series visualization and plotting
  - Quantification of energy impacts
  - Fault prioritization

- Other very common features
  - Key performance indicator (KPI) tracking and reporting
  - Meter data analytics
  - Conversion of energy impacts to cost impacts

Current State of FDD Market, 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

Current State of FDD Market, Industry Needs

- Informational needs
  - Challenges on interpreting the **value proposition** to stakeholders
  - Challenges on specific **implementation questions**; need best practices and peer connections

- Organizational needs
  - Translation of analysis result into action requires allocation of resources and effective response processes

- Technical needs
  - Need development of algorithms could **reduce tuning needs**, simplify configuration, and **enhance diagnostic power**
  - Need **streamlining** the process of operationalizing **action-taking** based on the finding from FDD tools, e.g. interface FDD tools with CMMS

FDD Applications in Commercial Buildings

FDD Applications in Commercial Buildings

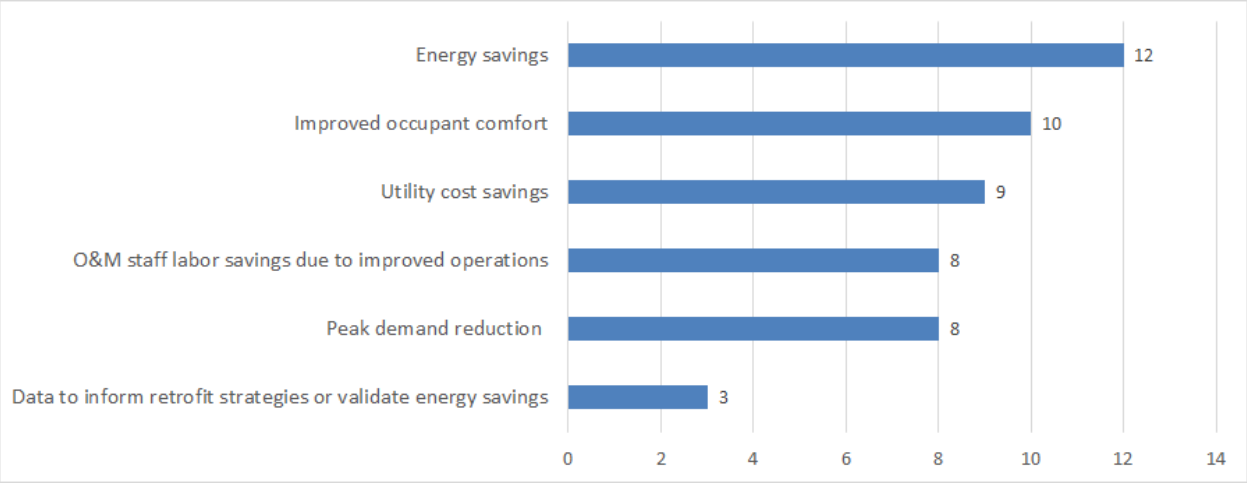
- Goals
  - Support analytics technologies (e.g. FDD) and monitoring-based commissioning (MBCx)
  - Provide cost, savings, use data not available in public domain
- Participants to date
  - 91 organizations, 5000+ buildings, 400+ million sqft

BCA Building Commissioning Association · ComEd An Exelon Company · BOMA International · IFMA International Facility Management Association · Better Buildings U.S. Department of Energy

smart-energy-analytics.org

FDD Applications in Commercial Buildings, Benefits of Implementing FDD

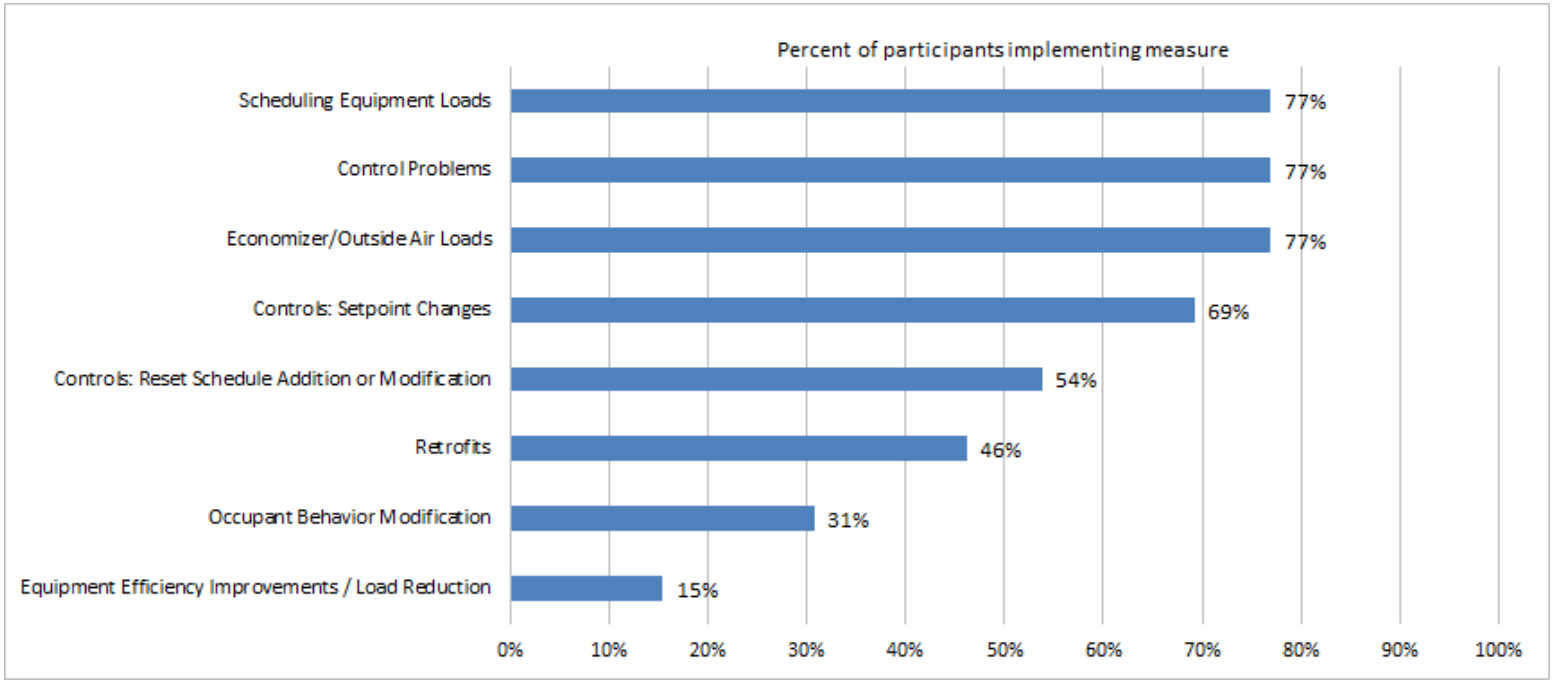
- Multiple motivations to implement FDD
- Energy savings and improved occupant comfort are the top two factors



Frequency of benefits of implementing FDD - respondents were able to select multiple benefits (n=13)

FDD Applications in Commercial Buildings, Benefits of Implementing FDD

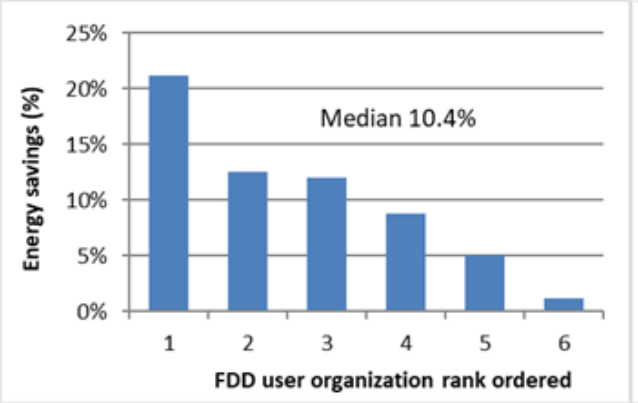
- 10 of the most frequently implemented measures identified through the use of FDD technology, from a list of 26 common operational improvement opportunities



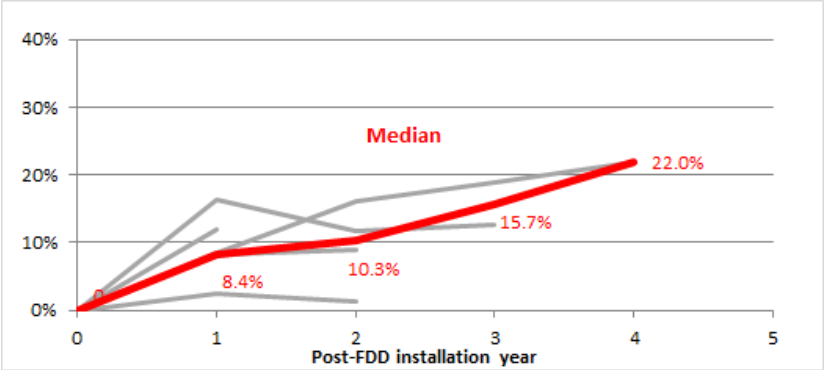
Measures identified and implemented through use of FDD technology (n=13)

FDD Applications in Commercial Buildings, Energy and Cost Savings

- Energy savings ranged from 1%-21% percent, with a median of 10.4%
- Cost savings ranged from 0.02-1.3 $/sf, with a median of $0.23/sf
- FDD a critical component of respondents' energy management process, and a means of achieving persistence in savings



Participant energy savings since installation of the FDD technology (n=6)



Energy savings since installation of the FDD technology, for each year of technology use (n=6)

FDD Applications in Commercial Buildings, FDD Costs

- Median base cost 9 $/pt, median annual recurring software cost 2.6 $/pt, median annual labor cost 7.2 $/pt
- The size of FDD install base ranged from 0.2 to 4 million sqft, and the median was 1 million sqft

Type of Costs		Costs (N=12)		
		[$/pt]	[$/building]	[$/sf]
Base Cost	Range	2.1 to 120	2,400 to 90,000	0.01-0.54
	Median	9	11,000	0.05
Annual Recurring Software Cost	Range	0.4-41	1,100 to 28,000	0.003-0.09
	Median	2.6	4,000	0.03
Annual Labor Cost (internal staff or contracted)	Range	2.1-75	2,200-52,000	0.02-0.32
	Median	7.2	15,000	0.07

Ranges and median values of FDD base costs, annual recurring software costs, and annual labor costs (n=12)

FDD Applications in Commercial Buildings, Best Practice 1

- 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: air-side 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

FDD Applications in Commercial Buildings, Best Practice 2

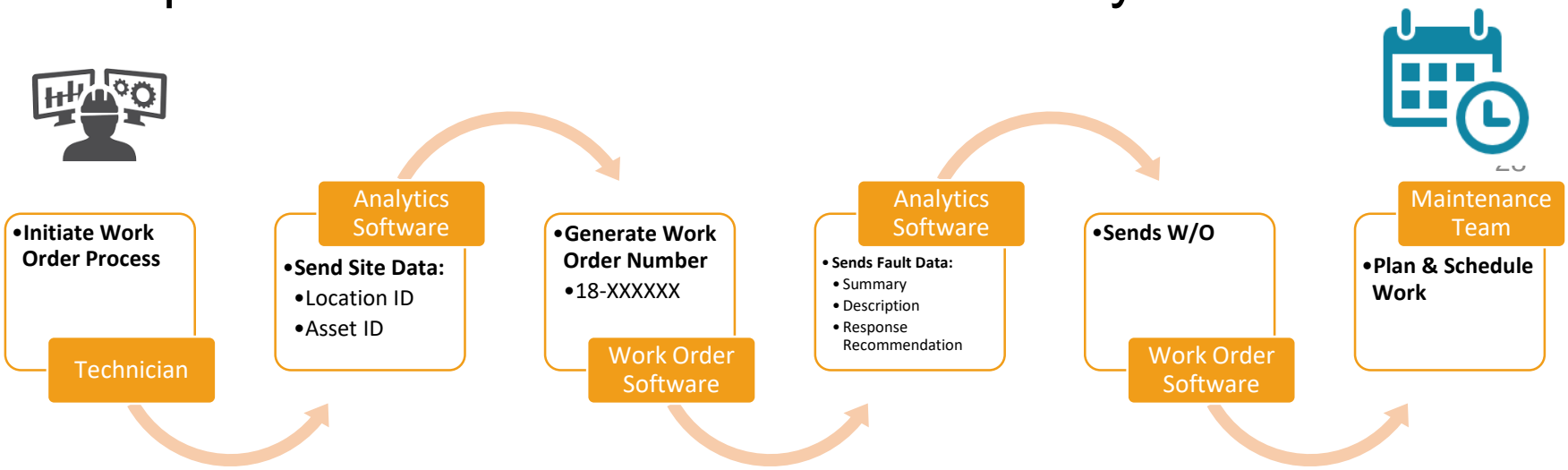
- Increase the threshold for triggering a fault then adjust it accordingly after you address the largest issues, then narrow this range down over time

- Make sure fault algorithms are complex enough to account for the conditions that are related to the same fault

- Calibrating critical sensors can reduce faults

FDD Applications in Commercial Buildings, Best Practice 3

- Use a fault silencer to silence faults that are known issues and are being addressed, or will be addressed in the coming month
- 2-Way communication between CMMS and FDD software helps facilitate the work and “tell the story”

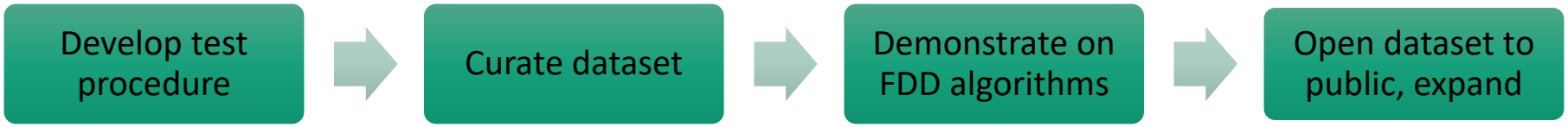


Work order integration with FDD in University of Iowa

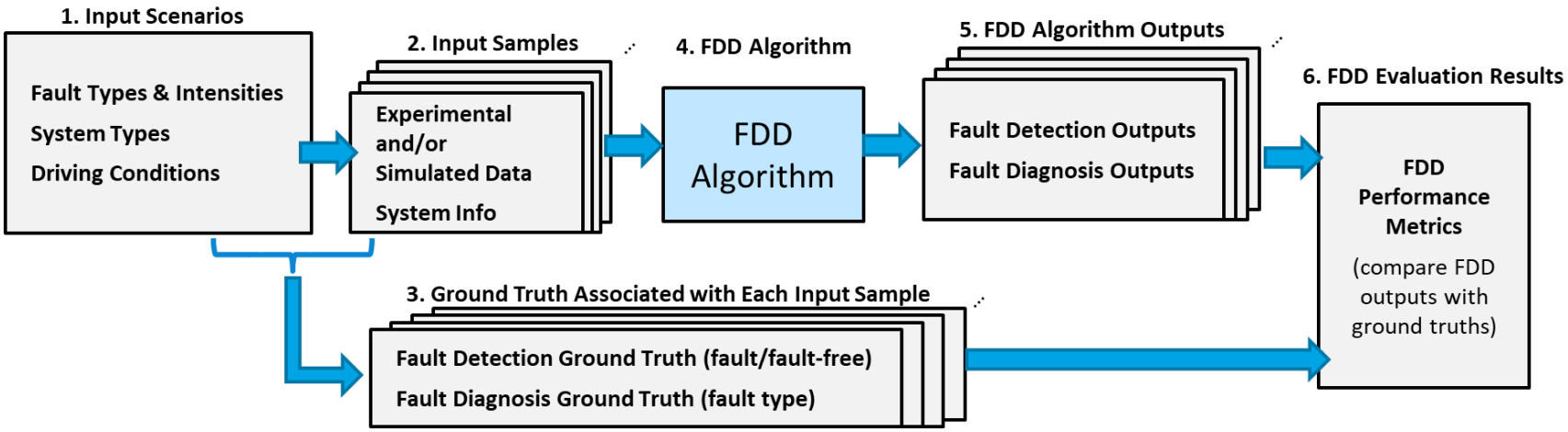
FDD Algorithms Performance Evaluation

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



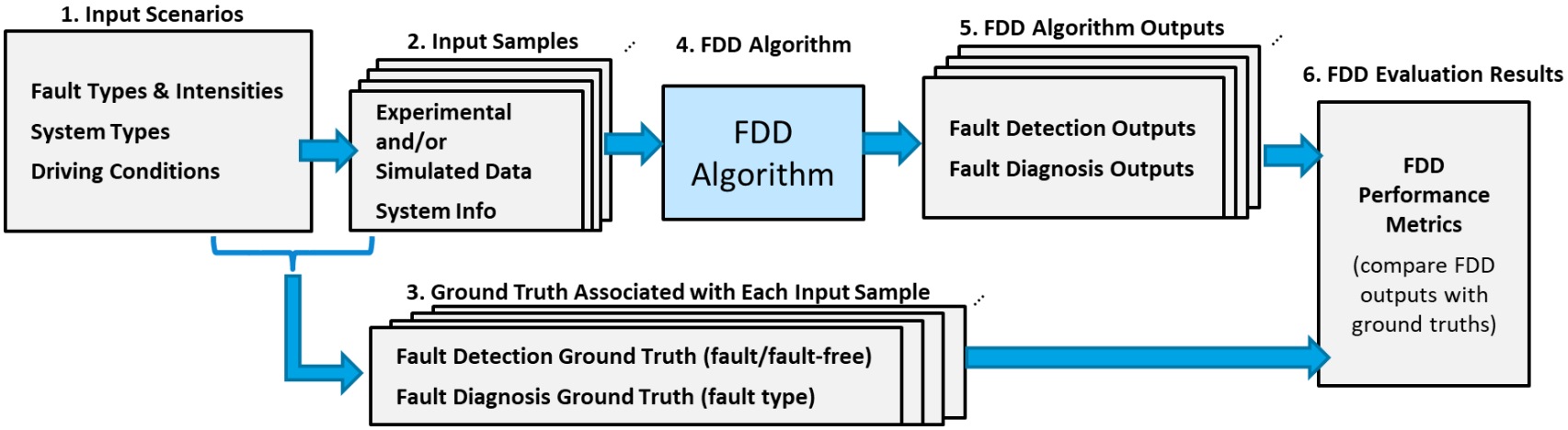
Above: Generalized procedure adapted from Yuill & Braun 2013*

The procedure consists of 6 steps:

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.

*D. P. Yuill, J. E. Braun, Evaluating the Performance of Fault Detection and Diagnostics Protocols Applied to Air-Cooled Unitary Air-Conditioning Equipment, HVAC&R Research 19 (7) (2013) 882-891,

FDD Algorithms Performance Evaluation, Procedure



Above: Generalized procedure adapted from Yuill & Braun 2013*

The procedure consists of 6 steps:

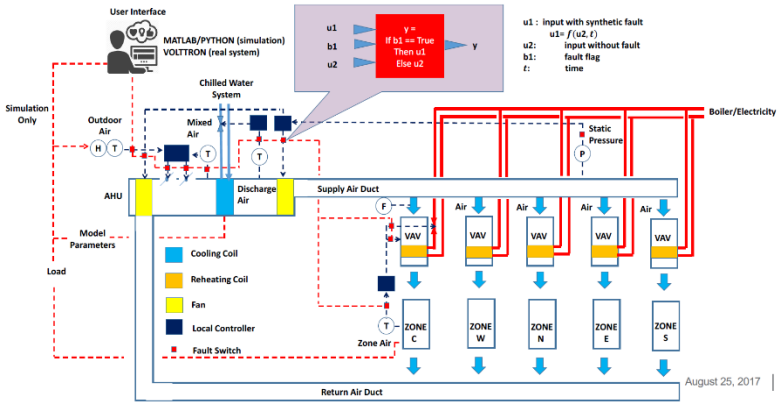
4. Execute **FDD algorithm** for each input sample.
5. **Retrieve FDD algorithm outputs** / results for evaluation
6. Evaluate **performance metrics** by aggregating the algorithm results for individual samples

FDD Algorithms Performance Evaluation, Initial Data Curation

- Most common AHU-VAV faults, simulated and experimental data, single and multi-zone, diversity of operational conditions and fault intensities

FLEXLAB™ experimental facility

Experimental RTU

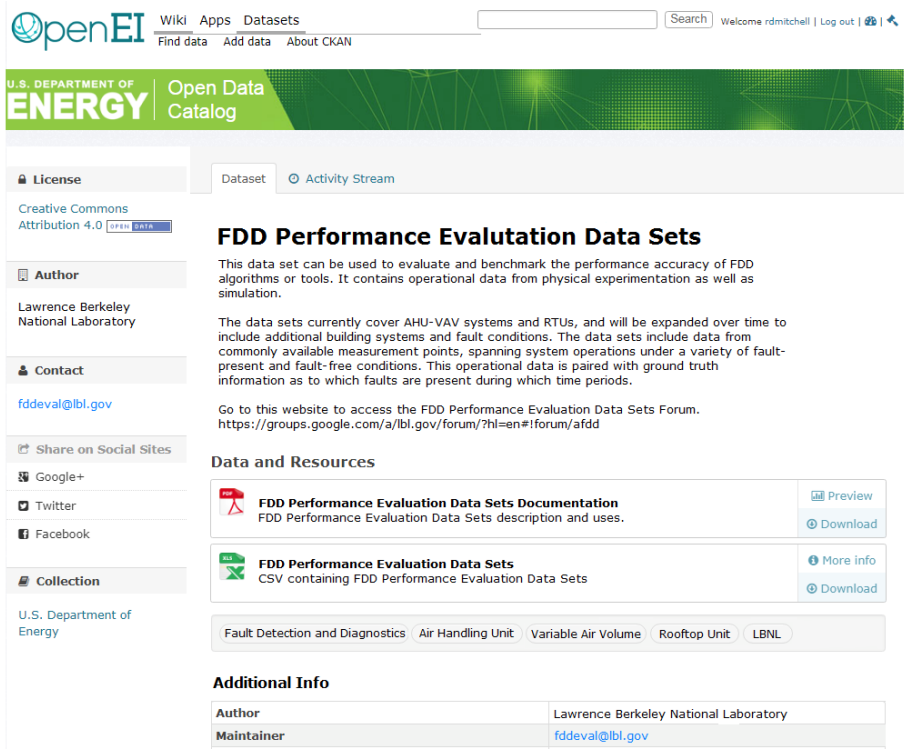


Modelica simulation model

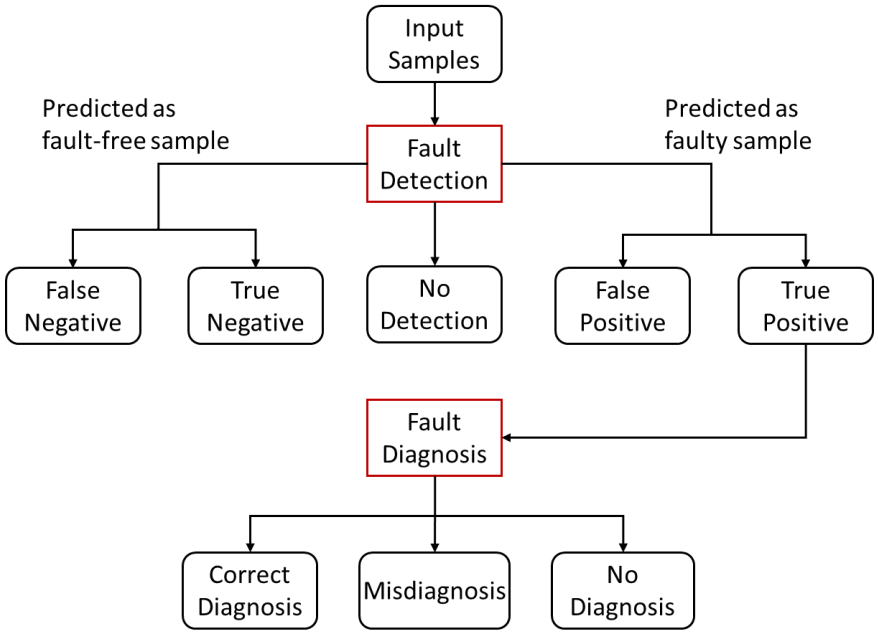
FDD Algorithms Performance Evaluation, Initial Data Curation

- Datasets are on OpenEI

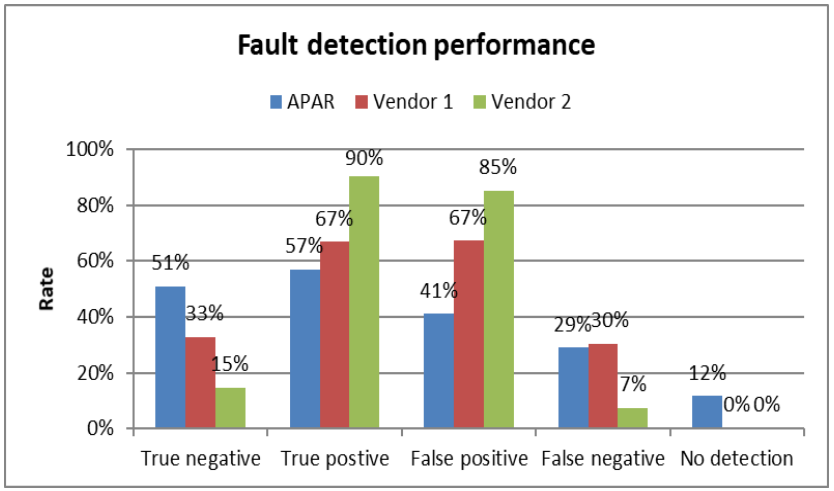
https://openei.org/doe-opendata/dataset/data-sets-for-evaluation-of-building-fault-detection-and-diagnostics-algorithms

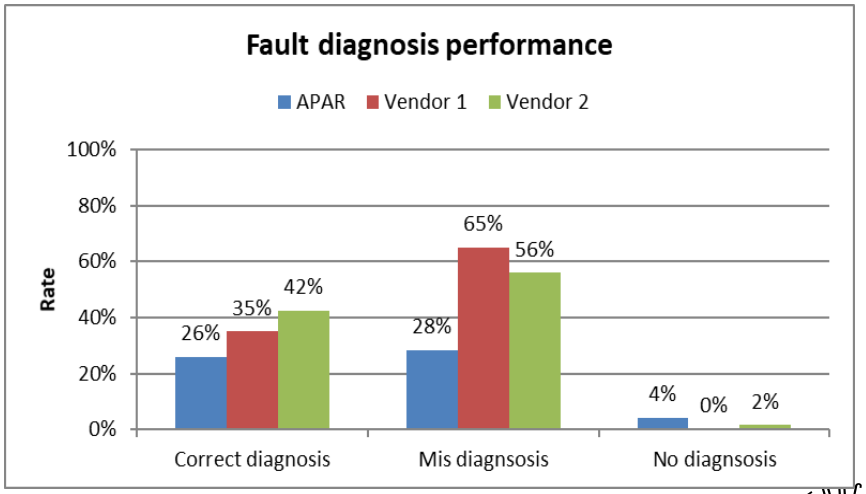


FDD Algorithms Performance Evaluation, Sample Results



Evaluation metrics





Sample Evaluation Results

This concludes The American Institute of Architects
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Thank You!

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