Commercial RE Series 5: Fault Detection and Diagnostics

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Today's Agenda

1. What is FDD and Why it Matters
2. Fault Detection and Diagnostics Fundamentals
3. Common Faults in Commercial Buildings
4. Practical Implementation

What is FDD

Defining Fault Detection and Fault Diagnostics

FDD aims at providing proactive maintenance and repairs, essentially detecting "faults" before they become major issues and diagnosing the cause of those faults. However, currently, most FDD remains largely reactive.

Therefore, the purpose of an FDD tool is twofold:

1. Fault Detection - Determine whether building systems and equipment are operating improperly.
2. Fault Diagnostics – In the case of abnormal or improper operation, isolate the root cause.

The Case for FDD

It is estimated that commercial building energy use can be cut by nearly 30% through O&M measures[1].

- On-going Commissioning and FDD have been shown to reduce energy use on average by 10%, but up to 25% in some cases[2]
- FDD on its own showed median savings of 8% in one study[3]

Savings are largely from O&M measure and can get incentivized through performance-based programs such as EPP and EBCx.

1: "Commercial Fault Detection and Diagnostics Tools: What They Offer, How They Differ, and What's Still Needed", Energy Technologies Area August, 2018, LBNL
2: "RP1026: Evaluation of Next-Generation Automated Fault Detection & Diagnostics (FDD) Tools for Commercial Building Energy Efficiency", Low Carbon Living CRC, Feb 2018
3: "Building fault detection and diagnostics: Achieved savings, and methods to evaluate algorithm performance.", Building and Environment, doi.org/10.1016/j.buildenv.2019

BAS Alarms vs FDD

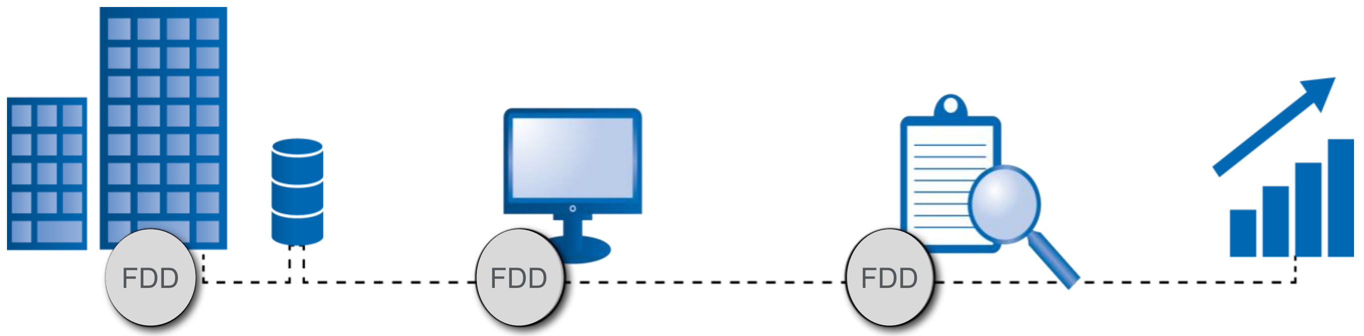
- A traditional building automation system (BAS) provides alarms that identify problems in a building after they have happened, based on system thresholds.
  - For example, am AHU mixed air temperature alarm activates if the air falls below a low limit threshold. The response thus happens after the fact, when the temperature is already too low.
- BAS alarms primarily focus, or should, on critical failures or problems that will lead to significant comfort or repair issues.
- BAS alarms are simple and typically based on single point monitoring and involve minimal diagnostic.

FDD vs BAS Trends

- BAS trends provide valuable monitoring and troubleshooting capabilities but present several challenges:
  - Large and complex building systems can create data overload for operators.
  - Fault identification often requires analyzing multiple trends and interpreting large sets of data.
  - Required trend data may not always be available.
  - Effective fault diagnosis depends on operator expertise and time.

Fault Detection and Diagnostics Fundamentals

Typical FDD Tool Process



Collect building data 24/7

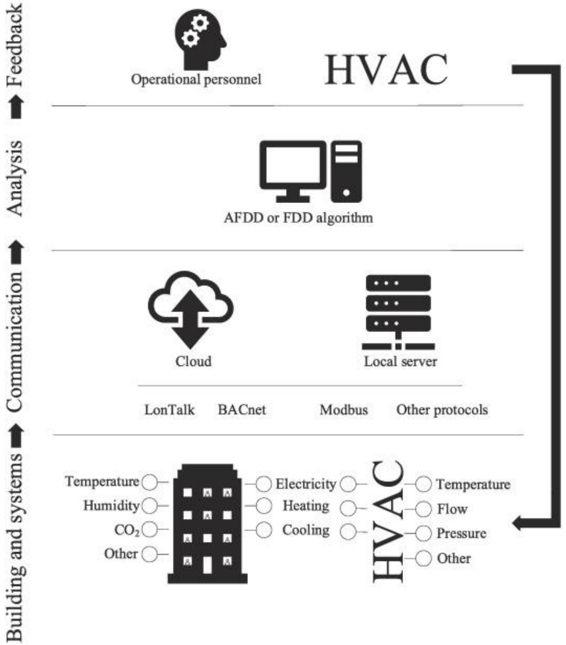
Analyze performance

Detect faults and produce diagnostics

Provide to O&M Staff to correct faults

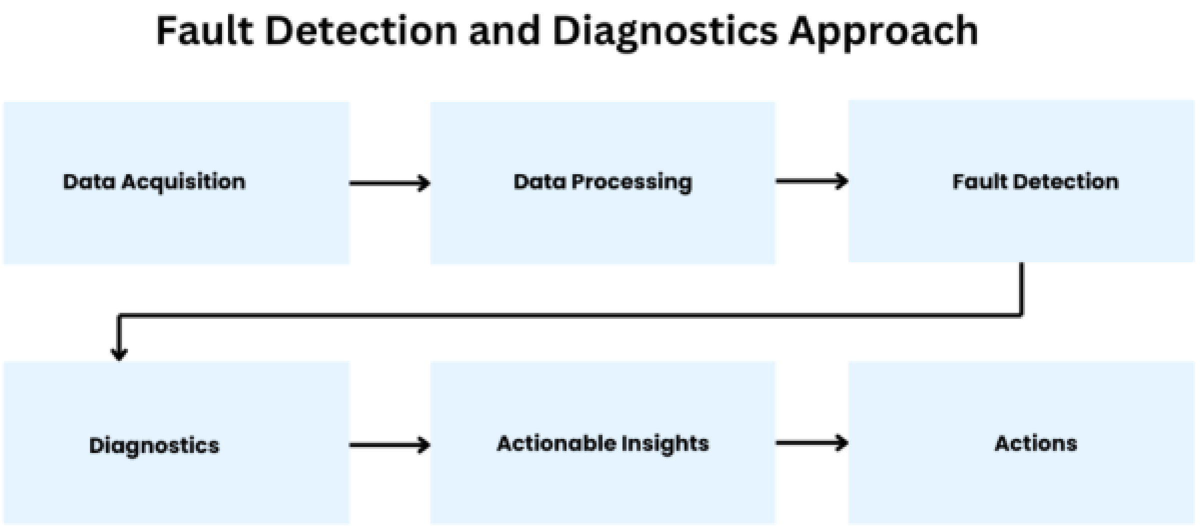
FDD Structure

- FDDs are now mostly cloud-based software packages.
- Good FDD requires sufficient number of DDC points.
- BAS maintenance, especially calibration of critical sensors, will make the FDD more reliable in its diagnostics.
- Note that some FDD will automatically detect sensor issues.



Barriers and drivers for implementation of automatic fault detection and diagnosis in buildings and HVAC systems: An outlook from industry experts, Energy and Buildings, Volume 303, 15 January 2024, 113801

Process within the FDD Tool



Methods used for FDD

Most common methods are:

- Rule-based FDD
- Data-Driven (Machine Learning)
- Model-Based

Many tools use a combination of these methods.

Rule-Based FDD

- Rule-based approaches and implementations
  - Often refer to as "expert rule-based" system.
  - They are the most common form of FDD.
  - Rules are written in an if/then format.
    - For example → "if A and B, then C"
  - The "IF" portion is also called the antecedent, and the "THEN" portion is also called the consequent.
  - Rules can be customized for a specific BAS.

Data-Driven FDD

- Fault signatures, pattern recognition, and classifiers:
  - Some form of pattern recognition is used for FDD. The pattern recognition can be supervised, which is not currently common, unsupervised or semi-supervised.
    - Unsupervised methods are easier to implement as they do not require a training period but require expert-based input for diagnostics.
  - Commercial packages using unsupervised FDD are available and some also offer supervised pr semi-supervised learning.

Model-Based FDD

- Model-based FDD uses a model to make predictions about building energy consumption and identifies faults via statistical analysis of the discrepancy between predictions and actual measurements.
- Model-based methods can achieve high accuracy, but the accuracy achieved depends heavily on the quality of the model
- Development and tuning of the building model is therefore a major cost consideration. Both complex and simplified physical models have been successfully applied to FDD for buildings

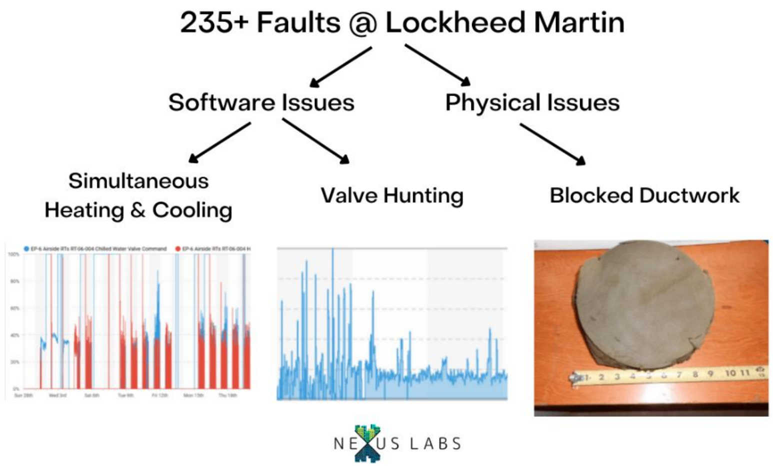
Performance of FDD

- Far more effort has gone into developing FDD algorithms than into assessing performance.
- There is no generally accepted standard for evaluating FDD algorithms.
- The basic form of FDD commonly used is the form of expert systems where fixed boundaries are set by domain experts to trigger alarms based on thresholds. This approach often leads to many false alarms, making it difficult for building operators to prioritize significant faults amid numerous alarms.
- Data-driven FDD is most commonly unsupervised, and this works best for detecting faulty sensors.

Example of FDD Faults

The types of faults that occur often share common patterns.

The most common faults occur because of failed components, faulty dampers and valves, and improperly programmed controllers.



https://www.nexuslabs.online/buyer-guides/the-buyers-guide-to-fault-detection-diagnostics-fdd#marketplace-overview-

Benefits and Pitfalls of FDD

Typical Benefits

- Early fault identification
  - FDD monitors equipment performance in real-time, allowing for the detection of abnormal behavior before it escalates into a major failure.
- Optimized maintenance strategies
  - FDD enables targeted maintenance actions, reducing unnecessary repairs and preventative maintenance costs.

Typical Pitfalls

- False positives
  - Too many alerts for minor fluctuations = operator frustration.
- Poor fault isolation
  - Vague diagnostic leading to inefficient troubleshooting and repairs.
- Data quality issues
  - Inaccurate or incomplete sensor data result in misleading diagnostics.

Benefits and Pitfalls of FDD (2)

Typical Benefits

- Increased productivity
  - Minimizing unplanned downtime through early fault detection leads to increased production and operational efficiency.
- Energy savings
  - Identify inefficient operations and optimize energy consumption.
- Data-driven decision making
  - Valuable insights into equipment health and performance.

Typical Pitfalls

- Limited sensor coverage
  - Insufficient # of points - faults might go undetected.
- System complexity
  - FDD not tailored to the type of system being analyzed.
- Lack of training
  - Improper training on FDD results in misdiagnosis and ineffective maintenance actions.

FDD within an EBCx

- FDD can be a useful tool in an EBCx or following an EBCx:
  - If already in place, it can assist the EBCx team in pinpointing opportunities.
  - If already in place but underutilized or underperforming, it becomes an EBCx target to improve how the system is used and possibly review its rules, thresholds, and limits, which may result in too many false diagnostics and making the system unusable by the O&M team.
  - If planned, or in place, it should be used as the foundational piece of a persistence plan.
- Incentives are available for EBCx

Common Faults in Commercial Buildings

Type of Faults in Commercial HVAC

Faults are divided in three categories:

- Condition-Based: improper or undesired physical condition in a system, typically equipment failure, defer maintenance issues, etc.
- Behavior-based: improper or undesired behavior during the operation of a system, such a simultaneous heating and cooling
- Outcome-based: when a performance metric for a system deviates from a reference outcome, such as reduced COP for a chiller

The majority of these faults are typically operational in nature.

Typical Faults in Commercial HVAC

Scheduling Equipment Loads

- Improve scheduling for HVAC & Refrigeration: shorten operating hours of HVAC & refrigeration systems to better reflect actual building occupancy schedule and service needs.
- Improve scheduling for lighting to minimize the lighting runtimes.

Economizer/Outside Air Loads

- Improve economizer operation/use, repair/optimize the mixed air economizer control in an AHU (e.g., fix dampers, replace damper actuators, modify economizer control sequence, etc.).
- Reduce over-ventilation by adjusting the minimum outdoor air ventilation setpoint to reduce heating and cooling loads.

Typical Faults in Commercial HVAC (2)

Control Problems

- Reduce simultaneous heating and cooling (stuck/leaking coil valve, sensor errors, ...)
- Tune control loops to avoid hunting: adjust controls to reduce cycling.
- Optimize or add equipment staging control
- Zone rebalancing: ensure proper airflow to be delivered to each zone.

Control Problems

- Unintentional manual overrides.
- Adjustment of heating/cooling and occupied/unoccupied space temperature setpoints.
- Reduction of VAV box minimum setpoint.
- Duct static pressure setpoint change.
- Hydronic differential pressure setpoint change.

Typical Faults in Commercial HVAC (3)

Reset Problems

- Supply air temperature reset: optimize control of the supply air temperature.
- Chilled water supply temperature reset: add or optimize control of the chilled water.
- Hot water supply temperature reset or hot water plant lockout.
- Optimize condenser water supply temperature reset

Equipment/Building Performance

- Low Delta-T issues.
- Inadequate VFD speed modulation.
- Drifting chiller performance.
- Inadequate peak demand control

Incentives – EBCx

Resolving most of those faults can provide financial incentives:

Typical measures for the EBCx program :

- set point and scheduling
- optimization air and water balancing
- other operational and maintenance changes
- equipment repairs and minor replacements

Incentives – EBCx Program(2)

- Offers incentives for participants to hire a qualified commissioning provider
- Program has three phases of incentives
  - Investigation, Implementation and Persistence
- Each with it’s own incentive structure
- For more information, please visit Save on Energy - EBCx Program

EBCx Success Story - A University Campus in Toronto

- Total incentive provided (all stages): $25,264
- Verified implementation savings: $588,590
- Baseline energy usage: $4,928,737
- Verified savings compared to baseline: 12%
- Measures implemented:
  - HVAC scheduling optimization
  - Chilled water and hot water system optimization
  - AHU trim and respond
  - AHU glycol heating
  - In-floor heating

Incentives - EPP

- The Energy Performance Program (EPP) rewards customers who are able to make behavioural and operational changes that support capital investment projects.
- Compares building energy use to baseline model.
- Verified energy savings can result in incentives of \$0.30/kWh for on-peak savings and \$0.08/kWh for off-peak savings.

EPP Success Story

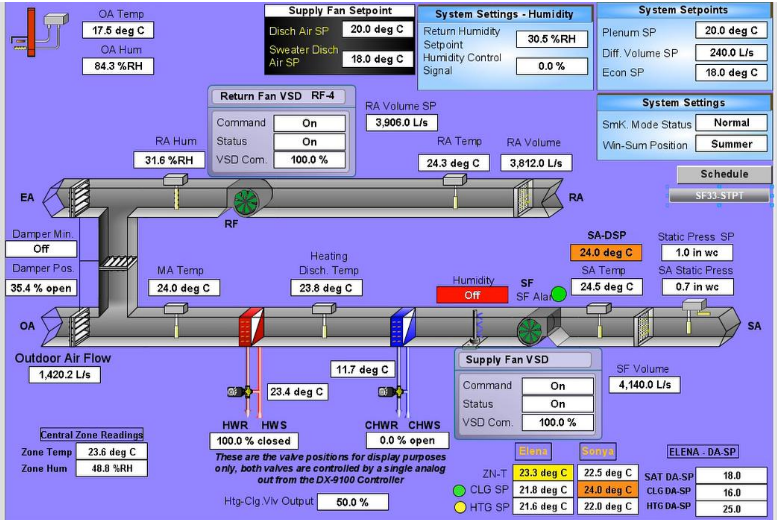
- A public office building in Mississauga achieved a two-year energy target in one year
  - 120,000 kWh in energy savings
  - ~$14,000 in incentives
  - Achieved a 5.7% energy reduction in the first year > 5% program target
  - Key measures: Variable air volume optimization, adjusting airflows based on true building heating and cooling demand.

Example of "Manual Rule-Based" FDD

Faults

- Value in manual override *(2x)*
- Set point not achieved *(yellow box)*
- Mixed air temperature sensor reading is too high for outdoor damper opening
- Supply pressure not met at 100% VFD

- A good FDD would produce actionable diagnostics for each fault.



Sample Diagnostic Report

Priority Level

Low (1)

Medium (8)

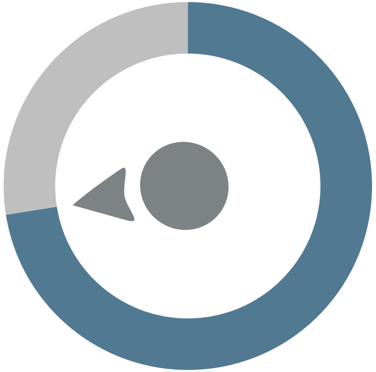
Message	Number of Insights Triggered	First Occurence	Last Occurence	Insight State
Supply Fan SF1 Mixed Air Temperature Monthly Average is Higher than the standard 20C.	11	2014-Jan-01 12:00:00	2014-Nov-01 12:00:00	Active
When the unit is drawing 100% Return Air, SF1's Mixed Air Temperature has been significantly different than the Return Air Temperature over the course of a week. This is likely due to a leaking air damper. Please review the system as a preventative measure.	7	2014-Mar-02 12:00:00	2015-Feb-02 12:00:00	Active
When the unit is drawing 100% Return Air, SF2's Mixed Air Temperature has been significantly different than the Return Air Temperature over the course of a week. This is likely due to a leaking air damper. Please review the system as a preventative measure.	1	2014-Mar-02 12:00:00	2014-Mar-02 12:00:00	Inactive
When the unit is drawing 100% Return Air, SF4's Mixed Air Temperature has been significantly different than the Return Air Temperature over the course of a week. This is likely due to a leaking air damper. Please review the system as a preventative measure.	11	2014-Mar-02 12:00:00	2015-Feb-02 12:00:00	Active
When the unit is receiving 100% outdoor air, SF2's Mixed Air Temperature has been significantly different that the Outside Air Temperature. This is likely due to a leaking air damper, and should be looked at as a preventative measure.	3	2014-Apr-20 12:00:00	2014-Aug-24 12:00:00	Active
The Chillers have been operating below the threshold OAT for more than 2 hours per week. Please review the system scheduling.	4	2014-May-28 12:00:00	2014-Oct-15 12:00:00	Active
When the unit is receiving 100% outdoor air, SF1's Mixed Air Temperature has been significantly different that the Outside Air Temperature. This is likely due to a leaking air damper, and should be looked at as a preventative measure.	11	2014-Aug-17 12:00:00	2015-Feb-09 12:00:00	Active
When the unit is drawing 100% Return Air, SF3's Mixed Air Temperature has been significantly different than the Return Air Temperature over the course of a week. This is likely due to a leaking air damper. Please review the system as a preventative measure.	1	2015-Jan-05 12:00:00	2015-Jan-05 12:00:00	Active

High (1)

Message	Number of Insights Triggered	First Occurence	Last Occurence	Insight State
Supply Fan SF2 Mixed Air Temperature Monthly Average is Higher than the standard 20C.	11	2014-Jan-01 12:00:00	2014-Nov-01 12:00:00	Active

Example of Performance-Based Report

Example of Performance Indicator – Room Temperature



72.5%

Zones with room temperature within the acceptance threshold

Legend

0.0	Temperature deviation above setpoint
0.0	Acceptable temperature deviation
0.0	Temperature deviation below setpoint

Deviation in °C

Acceptance threshold: Deviation greater than ± 1°C

Zone	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Absolute mean
1321.1	-0.5	-0.5	-0.7	-0.7	-0.8	-0.8	-0.8	-0.2	-0.2	-0.1	0.3	0.4	0.4	0.7	0.5	0.5	0.1	-0.2	-0.1	-0.3	-0.4	-0.4	-0.3	-0.3	0.4
1321.2	0.0	0.1	-0.2	-0.2	-0.3	-0.4	-0.4	0.3	0.1	0.1	-0.2	0.2	0.9	**1.4**	**1.2**	0.3	-0.6	-0.1	0.1	0.0	0.1	0.0	-0.1	0.1	0.3
1321.3	0.0	0.0	-0.2	-0.2	-0.2	-0.3	-0.3	0.3	0.5	0.7	0.4	0.6	0.6	0.8	0.8	0.8	0.4	-0.2	-0.6	-0.7	-0.8	-0.8	-0.8	-0.6	0.5
1327.1	-1.6	-1.7	-1.8	-1.9	-2.0	-2.0	-2.1	**-1.2**	0.2	**1.8**	**2.9**	**2.9**	1.0	1.0	0.2	-0.3	**-1.3**	-2.3	-2.7	-1.4	-1.1	-1.1	-1.1	-1.0	**1.3**
1327.2	-1.1	-1.1	-1.3	-1.4	-1.5	-1.5	-1.4	-0.6	0.1	**1.3**	**2.8**	**3.3**	**1.9**	**2.1**	**1.4**	0.7	-0.5	-1.7	-2.0	-0.8	-0.6	-0.6	-0.6	-0.5	**1.2**
1327.3	-0.8	-0.8	-0.9	-1.1	-1.1	-1.2	-1.1	-0.4	0.4	**1.4**	**2.6**	**2.9**	**1.7**	**1.9**	**1.3**	0.6	-0.4	-1.6	-1.9	-0.6	-0.3	-0.3	-0.3	-0.3	**1.1**
1327.4	-0.8	-0.9	-1.1	-1.1	-1.1	-1.2	-1.2	-0.3	0.1	**1.0**	**1.9**	**2.1**	0.7	0.9	0.3	-0.2	**-1.0**	-1.8	-1.8	-0.7	-0.5	-0.6	-0.6	-0.4	0.8
1327.5	-0.1	-0.2	-0.3	-0.3	-0.4	-0.4	-0.4	0.2	0.6	1.0	**1.4**	**1.2**	-0.2	0.3	-0.2	-0.2	-0.7	-1.3	-1.0	0.2	0.2	0.1	0.0	0.1	0.4

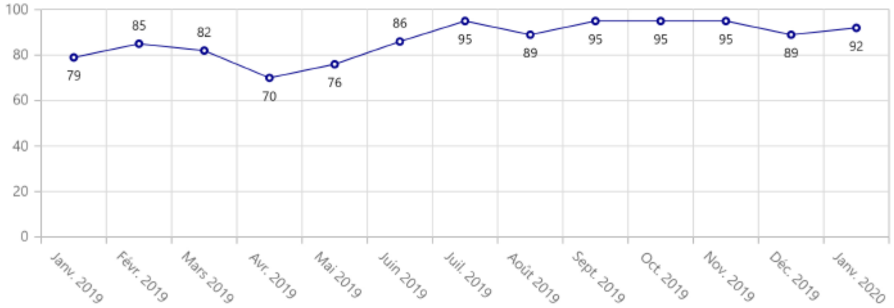
Example of Performance-Based Report (2)

Example of Performance Indicator – Airflow of VAV Boxes

Analyzed System:	Variable Air Volume (VAV) Boxes
Analyzed Parameter:	Airflow differential between setpoint and measurement
Acceptance Threshold:	± 20% Offset

VAV boxes with airflow within the acceptance threshold

92%



Systems With the Lowest Performance				
Systems	**Average Setpoint**	**Average Measure**	**Average Offset**	**Average Offset %**
B215_1B07_CD	9 L/s	46 L/s	38 L/s	100%
B425_Hallway_4B12_HD	170 L/s	0 L/s	-170 L/s	-100%
C315_3C05_HD	0 L/s	50 L/s	50 L/s	100%
C316_3C07_HD	0 L/s	36 L/s	36 L/s	100%
B215_1B07_HD	47 L/s	11 L/s	-35 L/s	-80%

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Implementing FDD in Commercial Buildings

Evaluating Building Readiness for FDD

It is can be a serious error to jump to an FDD just because you have a BAS and a vendor tells you that their “AI-FDD” will solve all your issues!

- GIGO – FDD can only work with the data it is provided with
- Too many faults will overwhelm the O&M team
- Too many false positive will destroy the credibility of the FDD
- Evaluate your systems and BAS, you may require a full-fledge EBCx prior to investing in FDD.

Preparing for Fault Detection and Diagnostics (FDD)

- Have a good PM program in place, that is correctly implemented
- Proper maintenance of the BAS – critical sensor calibration schedule
- Adequate DDC sensor coverage
    - Largely pneumatic systems will get much lower benefits from FDD
- Proper processing of alarms – possibly optimizing their number – numerous unacknowledged (or silenced) alarms are tell-tale signs that the facility may no be ready for FDD
- Known and up-to-date sequence of operations

Sample Checklist

FIGURE 5 Example pre-Implementation FDD readiness checklist.

1. Building and System Candidates
   - ❑ Identify high use, complex, large or critical facilities.
   - ❑ Identify HVAC and other systems as FDD targets.
   - ❑ Inventory control system devices and points in place.
2. FDD Feature Selection
   - ❑ List must-have faults, visualizations and reporting.
   - ❑ Target FDD platform classification and sophistication.
   - ❑ Design or select FDD interface look and interactivity.
3. Data Infrastructure
   - ❑ Validate sensor in-range accuracy and reliability.
   - ❑ Confirm needed data granularity and polling frequency.
   - ❑ Identify naming and schema standardization issues.
   - ❑ Address gaps in coverage or sensor calibration.
4. Data Architecture Constraints
   - ❑ Assess available bandwidth, storage and routing.
   - ❑ Ensure integration compatibility with FDD platforms.
   - ❑ Diagram existing config changes expected or allowed.
   - ❑ Detail legacy systems needing gateways or middleware.
5. Cybersecurity Readiness
   - ❑ Specify secure FDD access (VPN, MFA or zero-trust).
   - ❑ Define change management procedures for config changes.
   - ❑ Enforce role-based access controls.
   - ❑ Coordinate FDD architecture with IT and cyber staff.
6. Organizational Alignment
   - ❑ Establish roles for FDD operation and sustainment.
   - ❑ Map how FDD will be integrated into O&M workflows.
   - ❑ Require specific training on FDD use and reconfiguration.
7. Contracting Templates Selected
   - ❑ Determine contract package needs and templates available.
   - ❑ Incorporate definitions of FDD requirements.
   - ❑ Cite desired targeted industry or organizational standards.
   - ❑ Define additional FDD commissioning and testing tasks.
   - ❑ Clarify licensing terms and data ownership needs.
   - ❑ Attach inventories (DDC list, architecture, interface designs).
   - ❑ Establish deliverables (FDD architecture, test plan, manuals).

"A Framework for Optimizing Your Building Control System Fault Detection & Diagnostics", by B. Clark, R. Renz, ASHRAE Journal, Feb. 2026

Post FDD Integration

- Always remember, FDD is a tool, not a replacement, for human decision-makers and skilled technicians – O&M team must be involved.
- FDDs will provide various levels of reports – establish who needs to see which report is vital.
- User-interface must be adapted to the need of the various users, from management to operators – rarely done as out-of-the-box GUI are often accepted as-is.
- Ensure your team has proper training and that the FDD can be adapted to the specifics of your building – is there additional cost?
- Reports to the O&M must have actionable conclusions

Conclusion

FDD in Commercial Buildings

- FDD is not a panacea, it is a tool for your O&M team
- The tool is only as good as you use it
- Proper Cx of the FDD is critical – adjustments to rules, training for Data-Driven, effective procedures to close the loop – deal with diagnostics.
- The O&M team must be heavily involved and trained – FDD will provide NO benefits if not actively used by the O&M team
- FDD aims to be proactive but as of now is still largely reactive
- A good FDD will produce significant savings, mostly from O&M measures

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[Post-webinar support intake form]

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