Requirements for an Effective Fault Detection and Diagnostic System for Automated Continuous Commissioning of Building HVAC Systems

Prepared by:
Adrian Armstrong, EIT
Prism Engineering Ltd.
○ Agenda
  - FDD System Overview
  - Distinction between Alarms and FDD
  - Building Requirements
  - Review of Key Characteristics
Fault Detection Opportunity

• Correcting sub-optimal equipment operation represents a significant opportunity to reduce building energy consumption and provide improved occupant comfort
• Based on information published by ASHRAE in 2012, faults relating to HVAC systems represent between 1 - 2.5% of total commercial building consumption

FDD System Overview

- Use information from the existing building automation system to identify faults / suboptimal operation of equipment.
- Trend data from the DDC system is run through an analytics engine.
Typical FDD System Architecture

Inside Building Network

- BAS Trends
- Server / Database interface with DDC
- Cloud based analytics
- Fault Reports
FDD System Goals

- Increase energy efficiency
- Improve occupant comfort
- Reduce maintenance costs
- All the FDD systems in the marketplace have the same goals however systems vary in their approach and sophistication
  - objective is to generate actionable tasks that can be addressed by the facilities team
Rules based approach

• One of the main approaches used to identify faults is applying “If/Then” logic to appropriately mapped points

• Simple economizer rule example:
  – If a system is operating in 100% outside air and MAT is greater than OAT by 2°C then trigger a fault recommending sensor calibration and verification of proper damper actuation.

• Extension of the previous example:
  – Trigger a fault if a system is operating in economizer mode AND calculated MAT differs from sensed OAT by 2°C

• Equipment maintenance example:
  – If a heat pump cycles more than a maximum number of times per hour, trigger a fault recommending setpoint or deadband revision.
Example Faults

- AHU with simultaneous heating and cooling
- Excessive ventilation air supply
- System not using free cooling
- System operating outside of schedules hours
- Manual overrides
- Excessive equipment cycling
- Equipment hunting due to inappropriate control loop tuning
Faults vs. Alarms

• Most FDD systems include “deviation from setpoint”
  – Duplication of existing functionality, such as space temperature setpoint alarms
  – Often better left in the DDC systems
  – FDD focus is primarily on gaining deeper insights

• ex: space is over setpoint, flow setpoint is being achieved, may indicate sensor mis-calibration
Faults vs. Alarms

- A large focus of FDD is identifying non-critical problems before they would reach a DDC alarm state.
- Allow for pro-active maintenance by identifying equipment which is short cycling, out of calibration, etc.
- Identifying equipment which is functioning as programmed, but where additional savings opportunities exist.
Suitability for FDD

• Is there enough DDC / trending capability to provide meaningful insights?
  – Greater value at sites with terminal equipment on the DDC system
• Is there enough equipment and usage at the site?
• Fixed cost for onboarding, hardware, licensing
  – Generally best suited to sites 100,000 ft² or greater
• Are appropriate resources available to follow through on recommended corrective action.
  – People & Funding
Features of an Effective FDD System

1. Vendor experience and developed rules appropriate to your site
2. Appropriate level of rules sophistication
3. Hierarchical relationship between equipment
4. Fault Suppression / filtering
5. Fault Prioritization
6. Beyond ‘If/Then” statistical / Peer based approaches
Vendor Experience & Developed Rules

• Is the suite of rules already developed by the vendor appropriate to your requirements of your site?
• Large amount of variation exists in the marketplace in terms of number of developed rules for different vendors and the extent of their deployment of some rules
• Main emphasis is on cooling from some products
• Need to ensure that the FDD system under consideration has appropriate development appropriate for the HVAC topology in place
  • Dual duct systems
  • Data Centers
Fault Sophistication

• Basic Fault
  – Simultaneous heating and cooling
  – Fan operating outside of scheduled hours
• What about sub-optimal sequences / opportunities for optimization?
Fault Sophistication

Typical Operation

21°C

13°C

35%
Fault Sophistication

Basic Fault – Simultaneous heating and cooling

21°C  ↓  13°C  ↓

5%  40%
Fault Sophistication

Advanced Fault – Opportunity to increase SAT

21°C

13°C

35% 20%
Fault Sophistication

Reduced Cooling load while still meeting space loads

- Exhaust Air
- Return Fan
- Return
- Outside Air
- Preheat Coil
- Cooling Coil
- Reheat Coils

21°C → 14.5°C → 0%
Fault Sophistication

• Other advance faults
  – AHU Static Pressure reset
  – Pump speed reset
  – Chilled water / heating water supply reset

• Generally speaking these types of faults are moving towards optimizing the sequence of operations for the site
Hierarchical Relationship

- Hierarchy / parent – child relationship between systems
  - Associate plant equipment with terminal equipment served.
    - Chiller and distribution pumps with all the served cooling coils
    - AHU with all the downstream terminal devices such as reheats, VAVs or mixing boxes
Hierarchical Relationship - Example

- AHU is operating with the preheat coil as well as all terminal reheats 100% open
System Hierarchy - Example

– Possible root causes:
  • Failed sensor(s)
  • Boiler supply water temperature below setpoint (or setpoint is too low)
  • Heating water plant not operating (either boilers or distribution pumps)

– If a hierarchical structure is in place to identify root causes at the plant level which may be affecting served systems.
System Hierarchy

• An effective strategy to link plants together with served systems is key to a scalable FDD system.
• Many of the more sophisticated faults require looking at the ‘bigger picture’ in order to diagnose faults and identify optimization opportunities.
Fault Suppression

• For an FDD systems to be effective, it must include provisions to minimize false positives / nuisance faults.
  – Comes back to generating *actionable items*
• This item can be closely related to the hierarchical relationship previously noted.
• Provisions should be in place to prevent a fault within a plant level system from triggering dozens or hundreds of faults within the served system.
  – Alternatively, faults in the served systems should be grouped or connected with the parent system.
Fault Suppression - Example

[Diagram showing various components and setpoints, including SF HD Fan VSD, SF CD Fan VSD, EF VSD, and Setpoints with specific values for CD, CD Lo, CD Hi, HD, HD Lo, HD Hi, and Static SP, along with values for Exhaust Air Flow, Exhaust Air Temp, Filter Status, Preheat Temp, Low Temp Alarm, Humidity Output, Preheat Output, Interconnect Damper, Reheat Output, CD Temp, and Cooling Output.]
Fault Suppression – Example (cont’d)

- AHU is operating at 100% speed but not achieving static pressure setpoint
- VAV is showing reduced HD flow relative to setpoint (typical for 15+ units)
  - Root cause is at the AHU
  - VAV faults should either be suppressed or linked to the AHU level fault
Fault Suppression

- By including provisions to either suppress the faults in the served terminal devices, or link those faults to the fault in the parent system, key information is brought to building operators attention
- This is critical to ensuring that timely corrective action can be undertaken
- More signal, less noise
Fault Prioritization

- This is key to giving the facilities team an actionable fault list
- Basic approach undertaken by some vendors is to flag main systems (AHUs, boilers, distribution pumps) as high priority
- More sophisticated approach involves prioritizing in some or all of the following areas:
  - Energy impact
    - GJ, kWh, $
  - Occupant comfort impact
  - Equipment wear / maintenance impact
Fault Prioritization

- Allows you to tackle the biggest problems first
- Typically provides options to sort reports based on some or all of the different options.
Fault Prioritization

- Energy Impact approaches
  - Projecting savings forward
  - Quantifying what’s been lost already over a pre-determined time scale.
Fault Prioritization

- Projecting savings forward
  - Takes the amount of energy wasted over a pre-determined period and projects that forward
    - End result in a prediction of the energy that will be wasted if some corrective action is not undertaken.
    - Due to the complex interactions of systems, accuracy of this approach is suspect.
    - Ex: Predicted savings from simultaneous heating and cooling during summer would most likely not account warm weather shut down of the heating water system.

- Quantifying what’s been lost already
  - Tracks the energy lost either since the fault was first detected or over a pre-determined period.
  - Rely on basic engineering thermodynamic calculations. ex: Fan HP and runtime to estimate energy cost
Beyond “If/Then”

• The main tool used in most of the marketplace is based on IF/Then logic.
• Additional approaches include:
  – Peer analysis
  – Comparison to KPIs and past performance
• Snapshot of proper system operation after building commissioning which becomes the benchmark the building is compared to
• Comparison to past performance implies that past performance was correct.
  – This may not be the case
  – Alternatively, space requirements may have changed.
Conclusion

• FDD is an emerging area in the building controls sector.
• Pilot deployments have in some cases identified substantial savings which have resulted in short paybacks for some installations.
• When considering if FDD is appropriate for your site consider some of the following:
  – Building size
  – DDC system complexity
  – Is there a plan in place to take corrective action based on the identified faults.
Conclusion

• Key items to consider when selecting an FDD system for your site:
  – The amount of rule development, and their applicability to your HVAC systems
  – The level of fault sophistication
  – Hierarchical structure
  – Fault suppression
  – Fault prioritization
  – Capabilities beyond IF/Then style rules
Questions?
Thank you.