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Rooftop Unit AFDD: Smart Monitoring and Diagnostic System and Proactive Diagnostics

Srinivas Katipamula, Ph.D.

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Presentation Outline

- **Current State of Building and RTU Operations**
- Automated Fault Detection and Diagnostics
- Smart Monitoring and Diagnostics System
- Proactive RTU Diagnostics
- Concluding Remarks

Current State of Building Operations

Lack of cost-effective controls solutions for small buildings

+

Poor operations and maintenance practices

→

Results in up to 30% energy waste in buildings

Energy waste is caused by

Lack of use of energy-savings control strategies

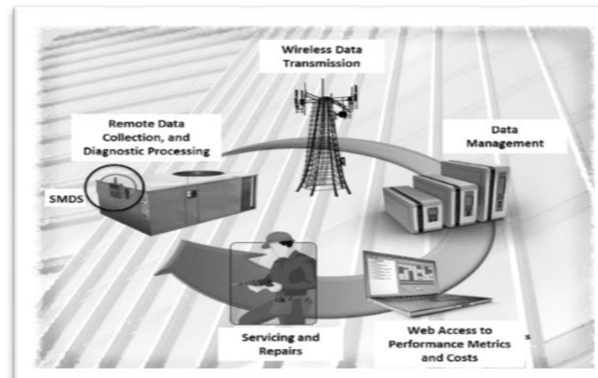
Override of automatic controls

Improper actions

Incorrect original installation

State of Rooftop Units

- Packaged air conditioners and heat pumps (RTUs)
  - Serve about 58% of all cooled commercial buildings,
  - Serving about 69% of the cooled commercial building floor space (EIA 2003)
- Consume almost 2.1 Quads for primary energy
- Installed efficiency of RTUs is low
- Operating efficiency is also low due to lack of:
  - Advanced controls to improve part load performance
  - Lack of adequate equipment maintenance
  - A field study including 503 RTUs, at 181 commercial building sites in 5 states showed only 9% are maintained properly



Automated Fault Detection and Diagnostics

- There is need for automated fault detection and diagnostics (AFDD) tool
- Process to automatically detect, diagnose and evaluate the impact of the fault
  - Generate actionable information
  - Can be passive or proactive
- Passive approaches work in most cases, but sometimes active approach will identify the fault quickly
- Widespread use of AFDD can improve the efficiency of the building stock and support condition-based maintenance practices for RTUs

Presentation Outline

Current State of Building and RTU Operations

Automated Fault Detection and Diagnostics

Smart Monitoring and Diagnostics System

Proactive RTU Diagnostics

Concluding Remarks

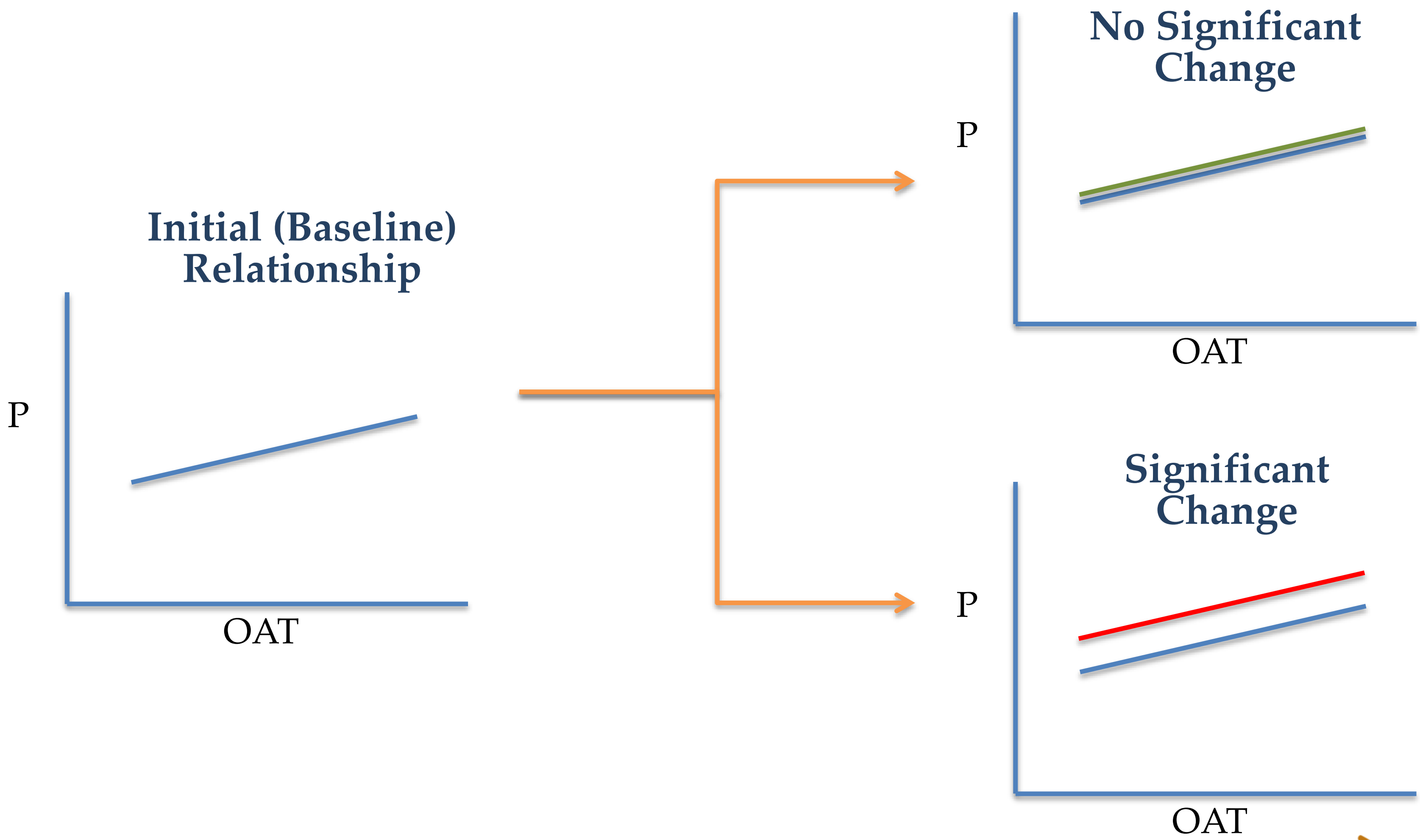
Smart Monitoring and Diagnostic System (SMDS)

Low Hardware Cost

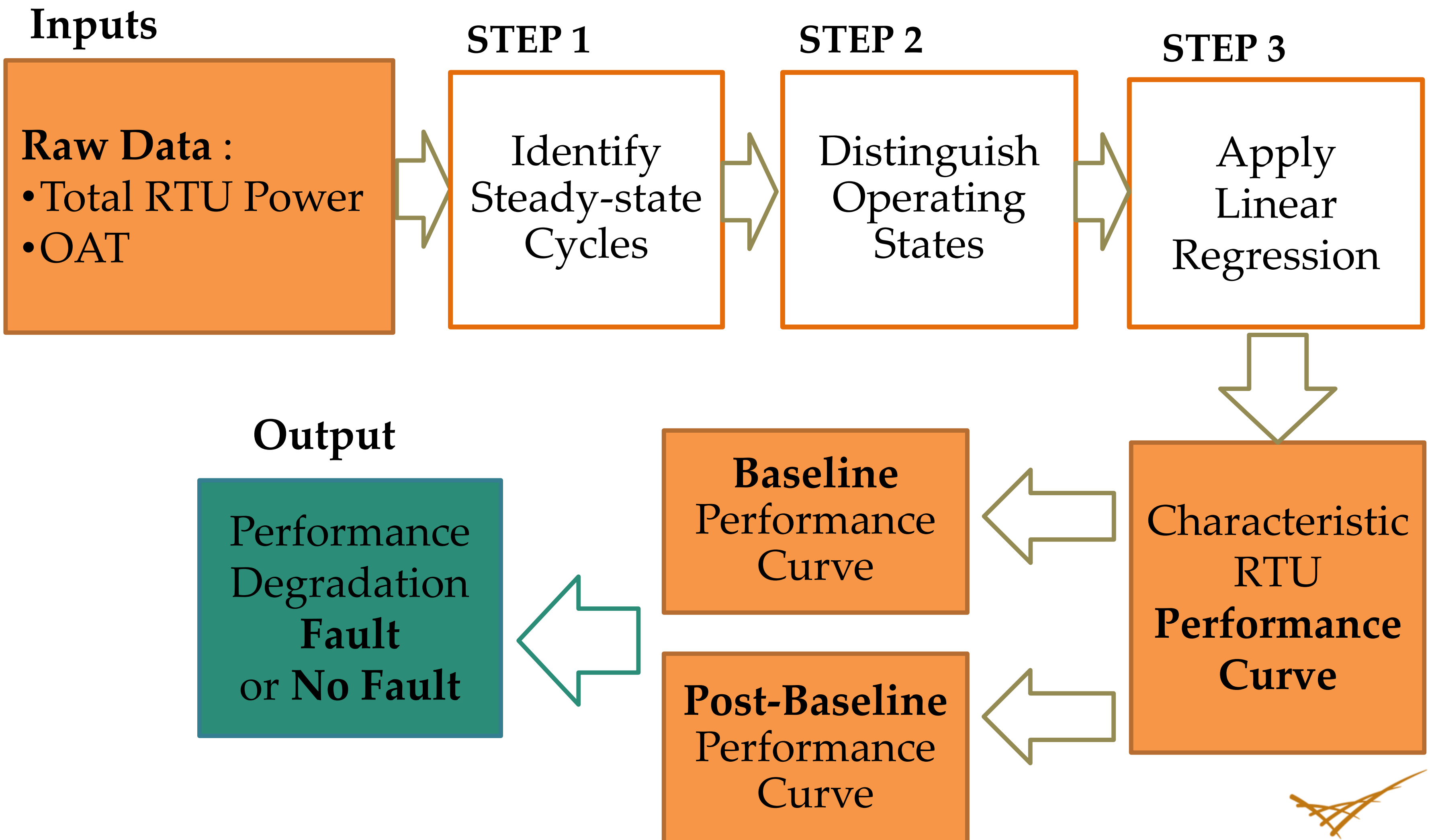
Low Installation Cost

Auto Configuration

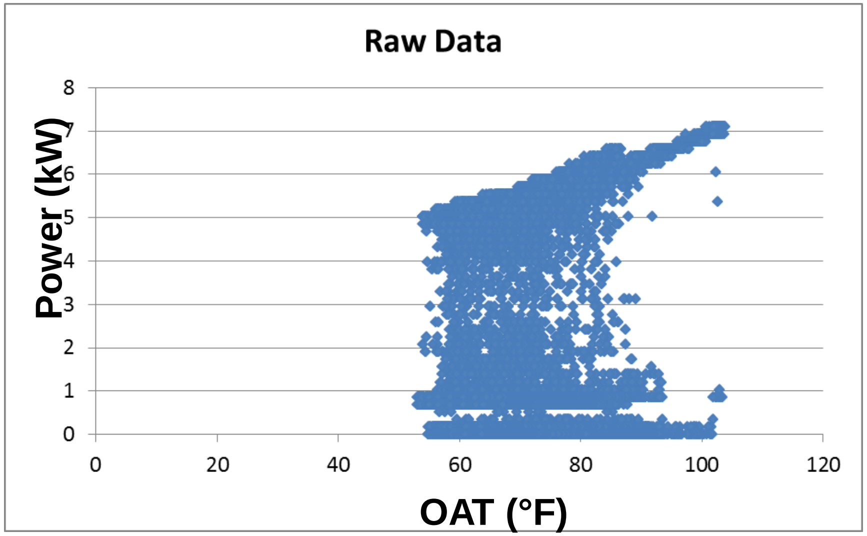
Illustration of SMDS Approach



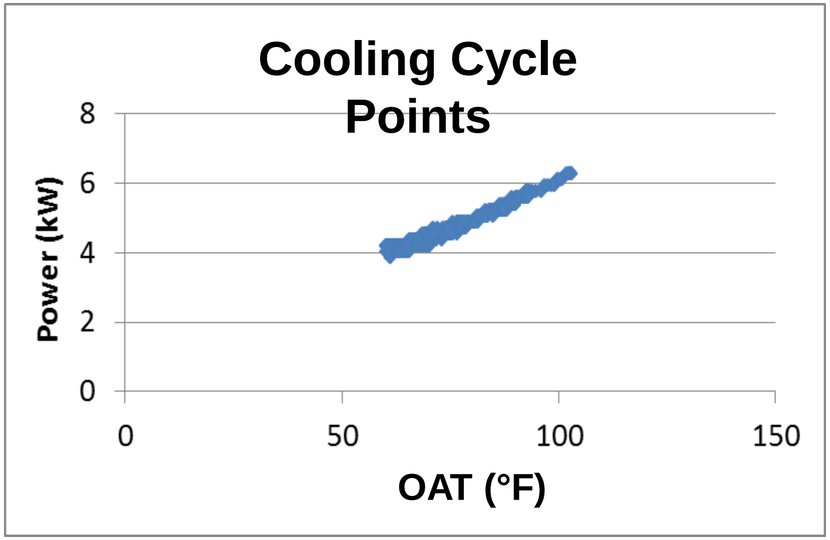
Single-Stage RTU with Constant Speed Supply Fan

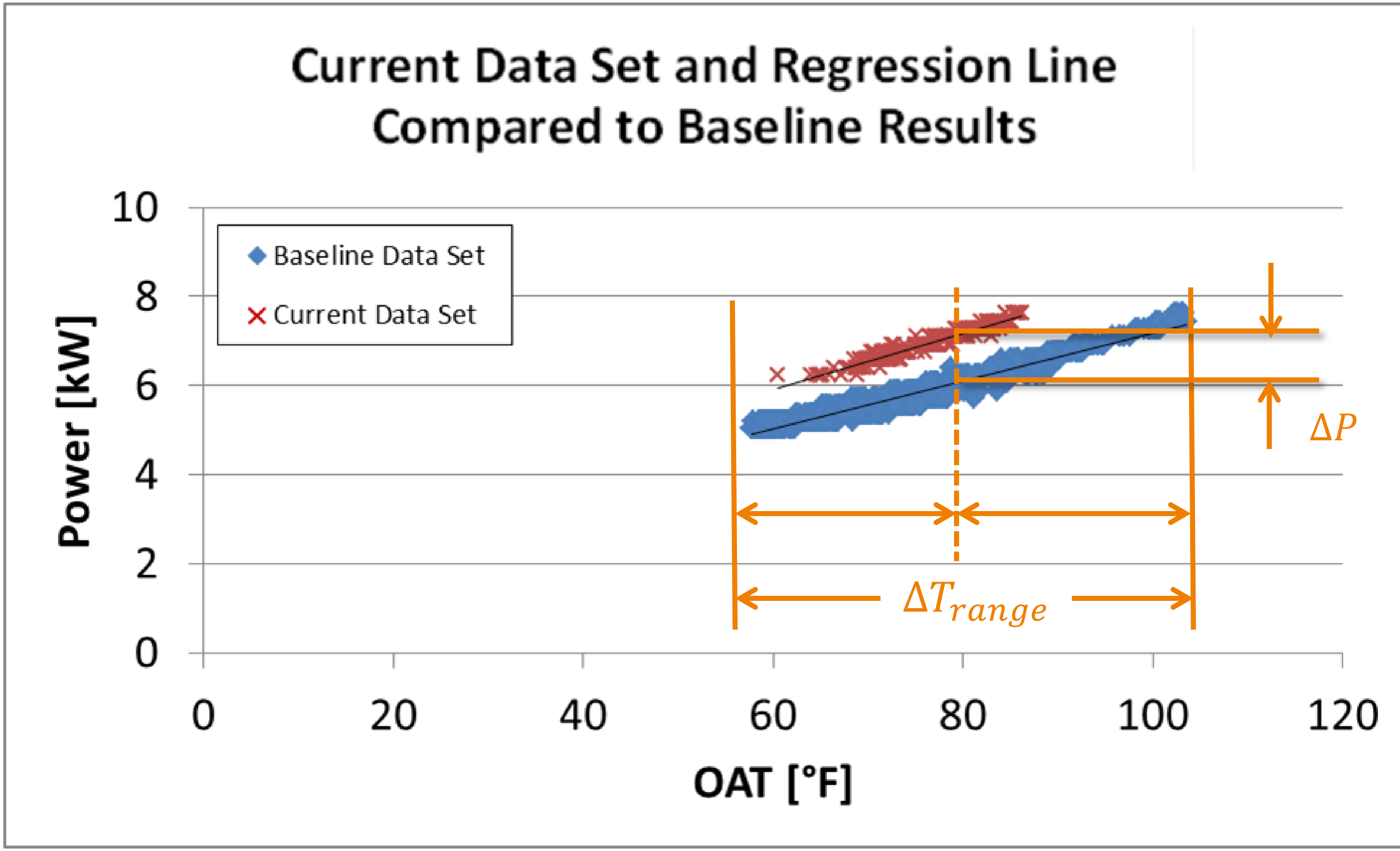


Conversion of Raw Data to Processed



- 30,240 data points
- measured at 1-minute intervals





$P_{inc} = \Delta P / P_{baseline}$

If $P_{inc} > 5\%$ ➔ Degradation Alert

Daily Operation Status and Weekly Degradation Reporting

- Operational faults
  - Compressor runs continuously for 24 hours during the day
  - RTU (compressor and/or fan) runs continuously all day
  - RTU does not turn on during the entire day
  - RTU supply fan cycles with the compressor only, not providing ventilation when the compressor is off and the unit is not cooling
- Compressor short cycling
  - A compressor “on” cycle shorter than t_{on}-limit
  - A compressor “off” cycle shorter than t_{off}-limit
- Degradation in performance is reported on a weekly basis

Performance Results

Units	Faults	Occurrence	Data Period (days w/ sufficient raw data)
RTU 1	Short Cycling 2.3% Degradation	25 days 73 days No degradation	9/12-6/24 (236 days)
RTU 2	Short Cycling 1.7% Degradation	38 days 66 days No degradation	9/12-6/24 (224 days)
RTU 3	Fan Cycling only with Compressor Short Cycling 1.1% Degradation	37 days 2 days 5 days No degradation	9/12-6/24 (230 days)
RTU 4	Fan Cycling only with Compressor Short Cycling 4.2% Degradation	29 days 1 day 26 days No degradation	9/12-6/24 (231 days)
RTU 5	Short Cycling 1.3% Degradation	27 days 1 day No degradation	9/12-6/24 (252 days)
RTU 6	Short Cycling 1.1% Degradation	40 days 2 days No degradation	9/12-6/24 (232 days)
RTU 7	Short Cycling 2.2% Degradation	11 days 40 days No degradation	9/12-6/24 (216 days)

Performance Results

Units	Faults	Occurrence	Data Period (days w/ sufficient raw data)
RTU 1	System Off for the Day Short Cycling 0% Degradation	4 days 73 days Not enough cooling	9/12-6/24 (130 days)
RTU 2	System Off for the Day Short Cycling 0% Degradation	3 days 66 days Not enough cooling	9/12-6/24 (182 days)
RTU 3	System Off for the Day Fan Cycling only with Compressor Short Cycling 0% Degradation	5 days 2 days 5 days Inconclusive Data	9/12-6/24 (237 days)
RTU 4	System Off for the Day Fan Cycling only with Compressor Short Cycling 0% Degradation	3 days 1 day 26 days Inconclusive Data	9/12-6/24 (143 days)

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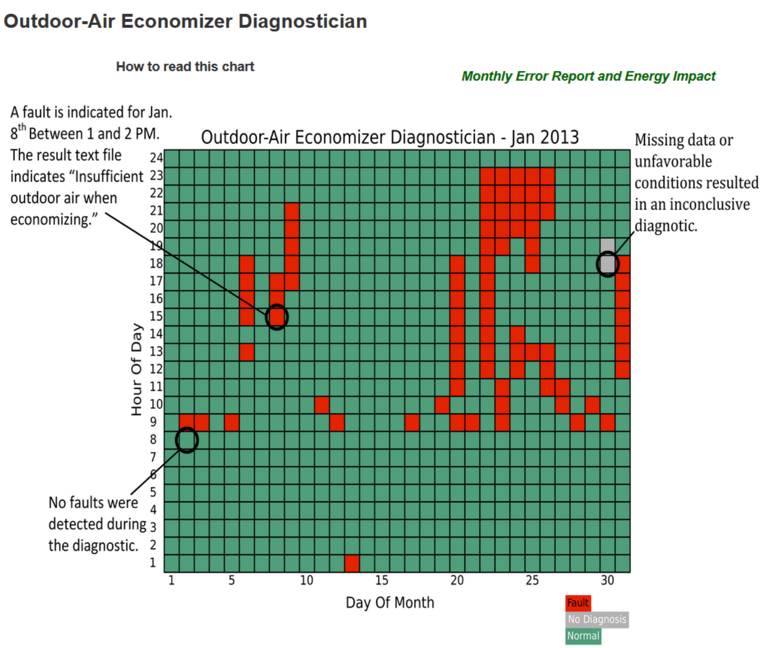
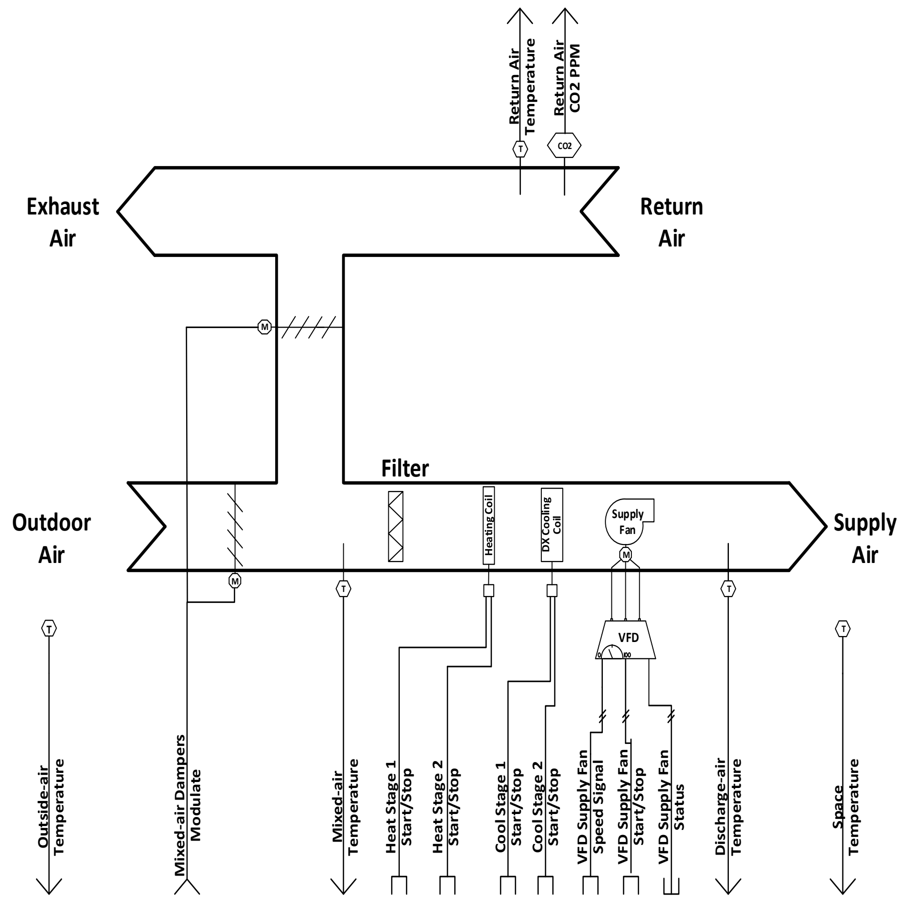
Presentation Outline

Passive vs. Proactive Diagnostics

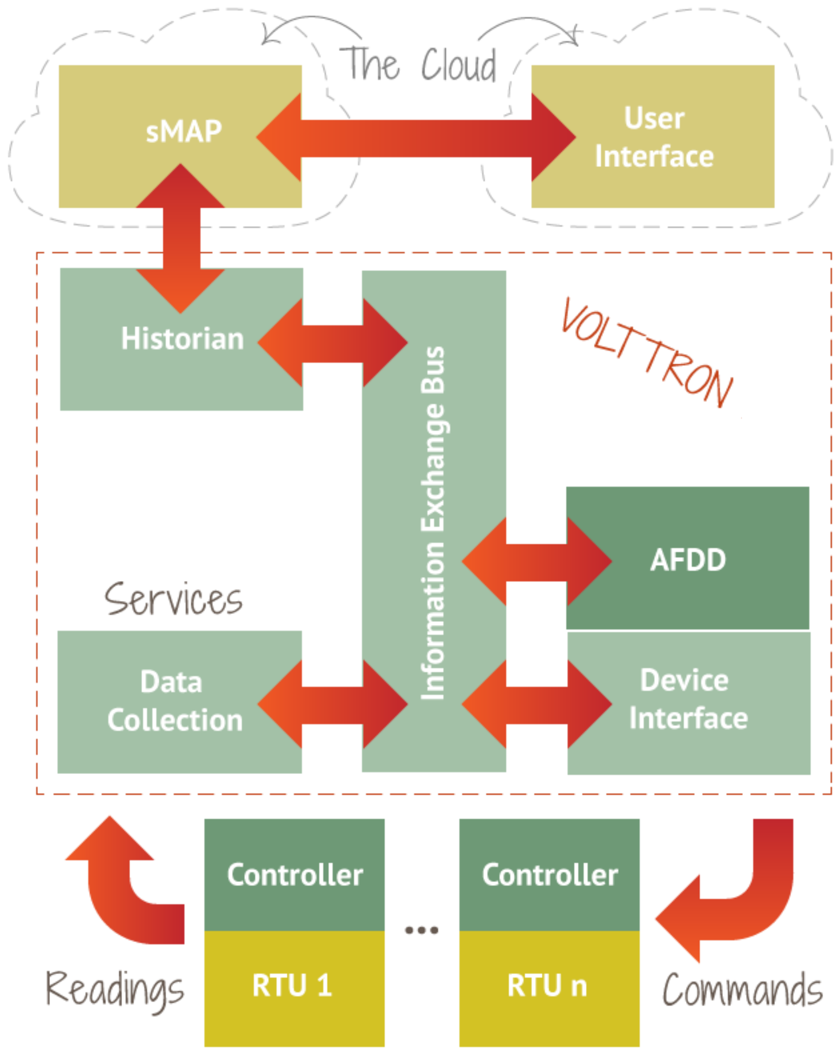
- Passive diagnostics sometimes take a while to detect and diagnose the actual cause of the problem
- Proactive diagnostics can quickly identify the fault and the cause of the fault



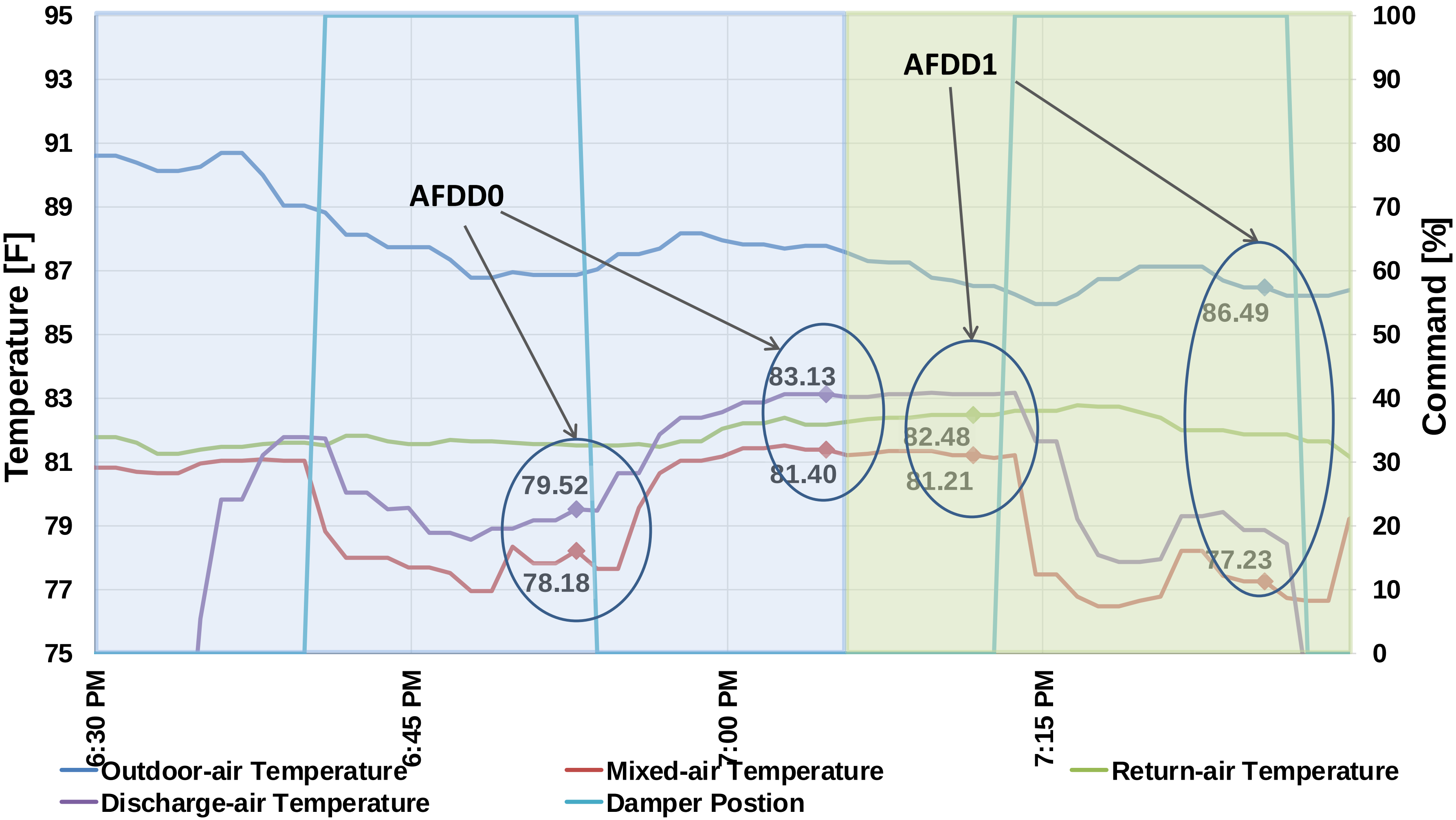


Proactive AFDD: Air-Side

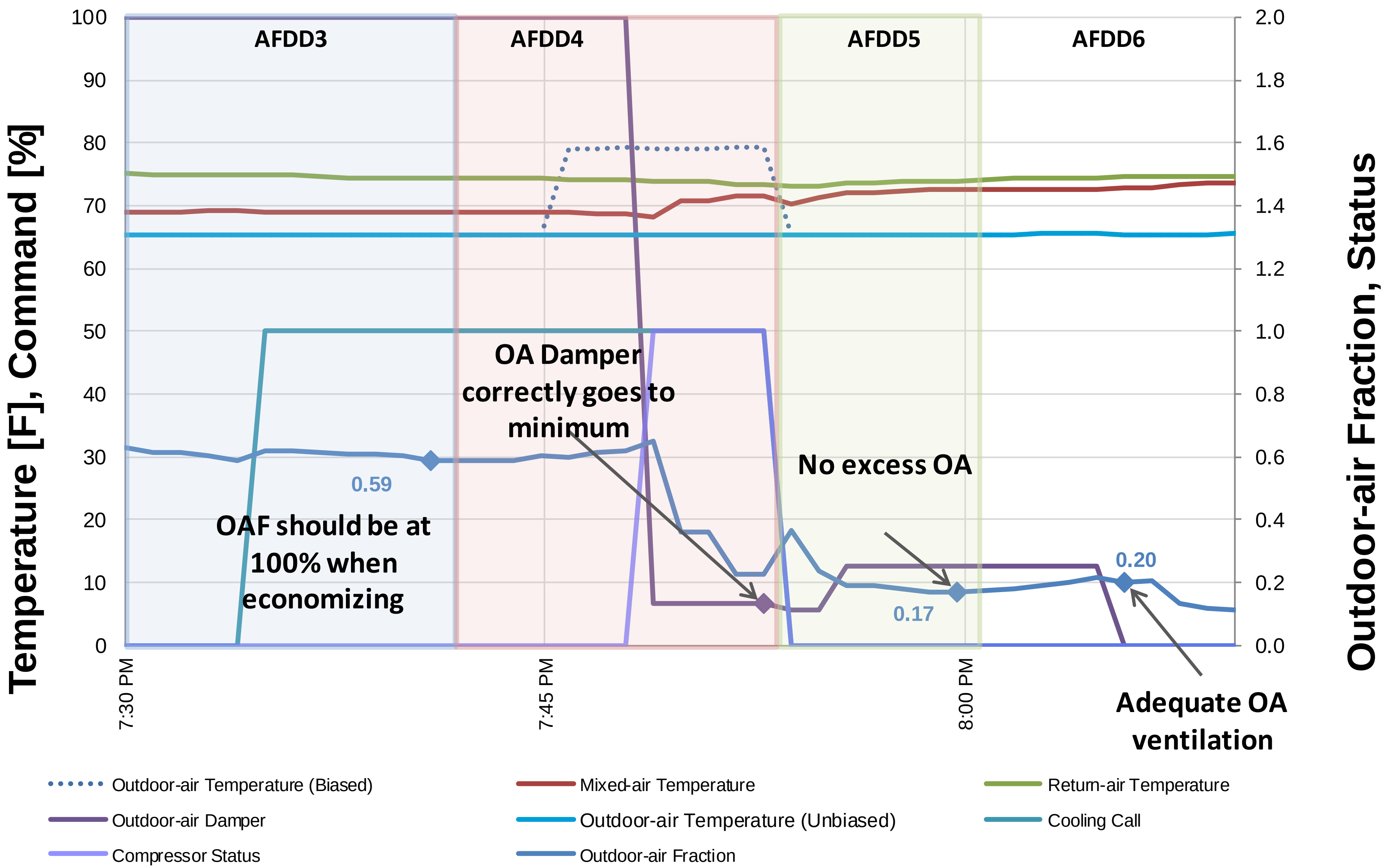
- **AFDD Capabilities**:
  - Comparing discharge-air temperature with mixed-air temperature (AFDD0)
  - Checking damper modulation (AFDD1)
  - Sensor faults (outdoor-, mixed- and return-air temperature) (AFDD2)
  - Not economizing when RTU should (AFDD3)
  - Economizing when RTU should not (AFDD4)
  - Excess outdoor air (AFDD5)
  - Inadequate outdoor ventilation air (AFDD6)
- **Unique**: Diagnostics algorithms will initiate proactive tests on schedule (e.g., commanding damper, etc.)
- **Energy Impacts**: Energy impacts will be estimated for AFDD3, AFDD4 and AFDD5 faults



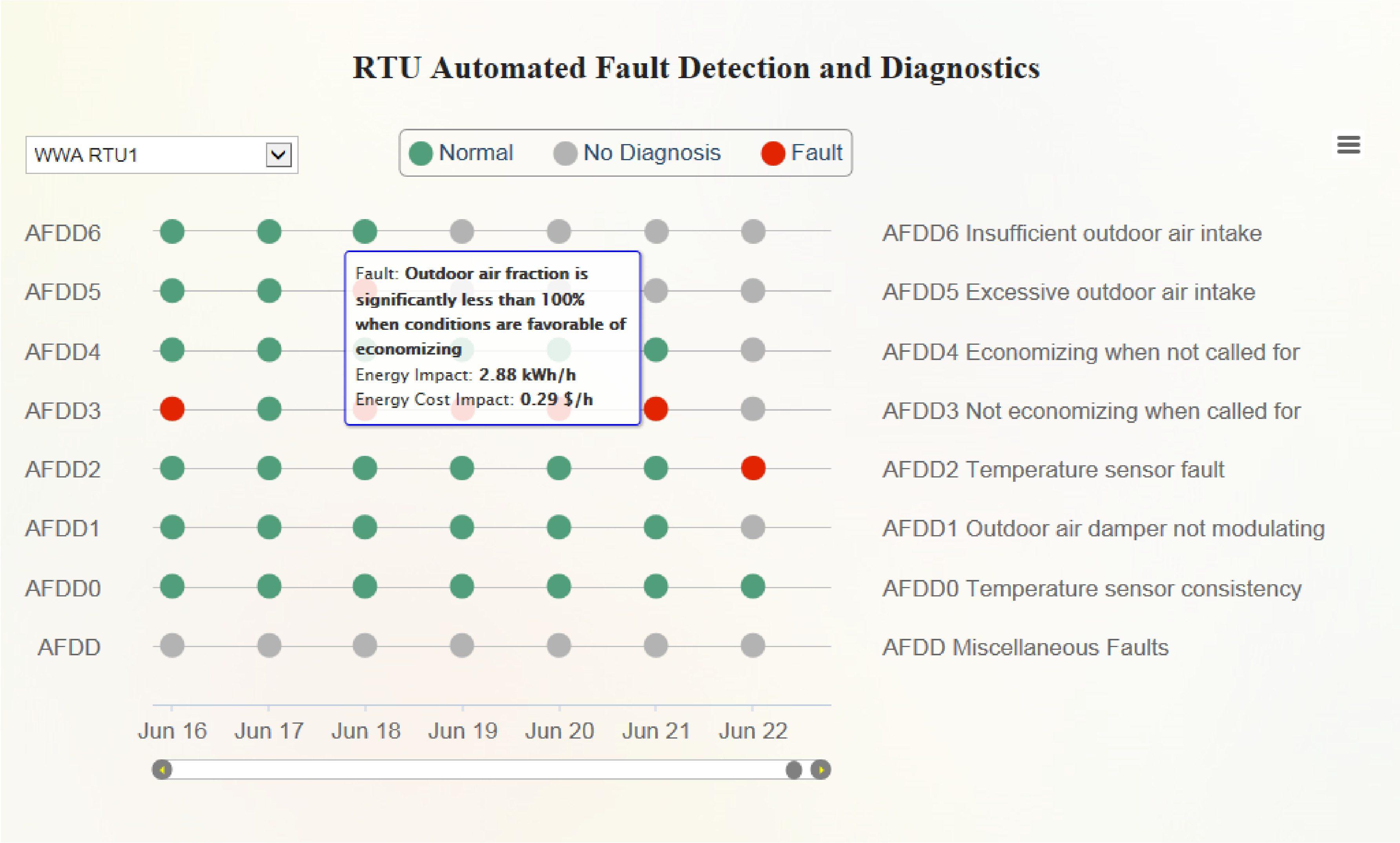
Sensor and Damper Diagnostics



Economizer and Ventilation Diagnostics



Proactive AFDD Air Side Results



Presentation Outline

Summary and Next Steps

- Both active and passive diagnostics algorithms have been released as open source – http://github.com/volttron
  - Meet California Title 24 mandatory requirements
- Proactive diagnostics will work with any controller
  - But the open source implementation only includes MOBUS or BACnet drivers
- Many problems with RTUs can be traced back to damper leakage and unreliable sensors
- AFDD has also been integrated with demand response
- Integrating AFDD with advanced controls
- Future of AFDD is bright, lots of action and interest both from public and private sector

Questions?

Srinivas.Katipamula@pnnl.gov

SMDS - http://buildingsystems.pnnl.gov/building/smds.stm
Proactive Diagnostics - http://buildingsystems.pnnl.gov/building/afdd.stm
Automated RTU DR - http://buildingsystems.pnnl.gov/building/adr.stm
VOLTTRON - https://transactionalnetwork.org/
http://github.com/volttron