U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

PNNL-JouleSmart (NorthWrite) Small Business Voucher Project

Pacific Northwest National Laboratory; JouleSmart

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Project Summary

Timeline:

Start date: July 15, 2016

Planned end date: July 31, 2018

Key Milestones

1. All three packages of fault detection algorithms fully documented; 2017-05-31
2. Testing and validation of first and second packages of fault detection algorithms completed; 2017-09-29

Budget:

Total Project $ to Date:

- DOE: $300K
- Cost Share: $200K

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Key Partners:

PNNL
JouleSmart*

Project Outcome:

1. Three sets of algorithms for packaged rooftop units (RTUs) successfully deployed after testing in laboratory conditions with up to 15% whole-building energy savings potential
2. Algorithm performance and sensitivity to select parameters tested and validated
3. Algorithms formally documented and publicly disseminated for use by other building analytics companies

*JouleSmart is a Small Business Voucher (SBV) partner

Team

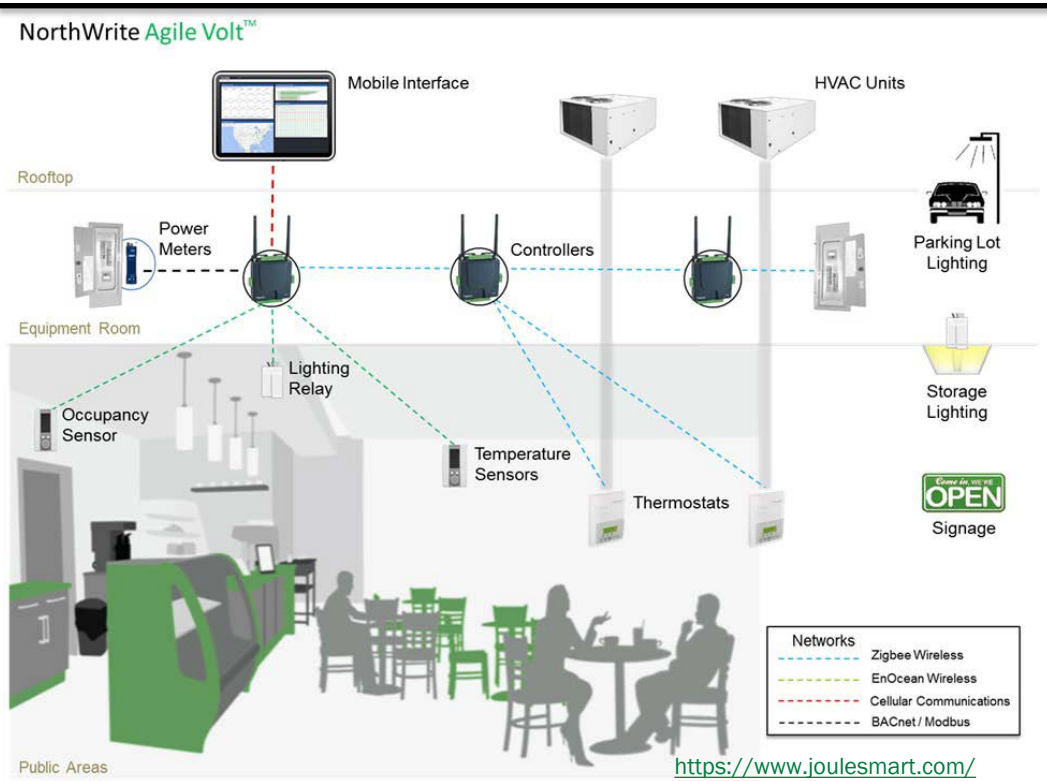
Pacific Northwest NATIONAL LABORATORY

Michael Brambley

Danny Taasevigen

Robert Lutes

Woohyun Kim



https://www.joulesmart.com/

JouleSmart℠

Developer of cloud- and device-based analytics that provides automated energy and load management services to small building owners

Challenge

Problem Statement:

- Small commercial buildings (<50,000 ft^2) represent 94% of all U.S. commercial buildings and consume 44% (6.9 quads) of commercial building primary energy
- Roughly 1.0 quads (~15%) of energy is wasted in small commercial buildings as a result of operational and equipment-related faults
- Availability of capital is much lower than for large commercial buildings, limiting energy management budgets and associated personnel

Solution:

- Tackle waste attributed to HVAC operations, which represent **42%** of total energy use from small buildings
- Field test automated fault detection and diagnostic (AFDD) solutions for the most prevalent HVAC equipment in these buildings (i.e., packaged air-conditioners and heat pumps)
- Provide technical assistance to provider of energy and load management analytic services (i.e., JouleSmart) for small building owners to more effectively incorporate AFDD into their operations

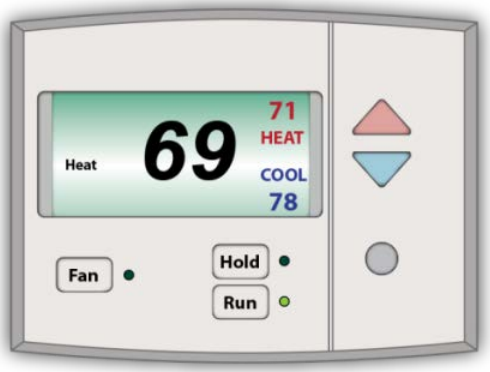
Approach

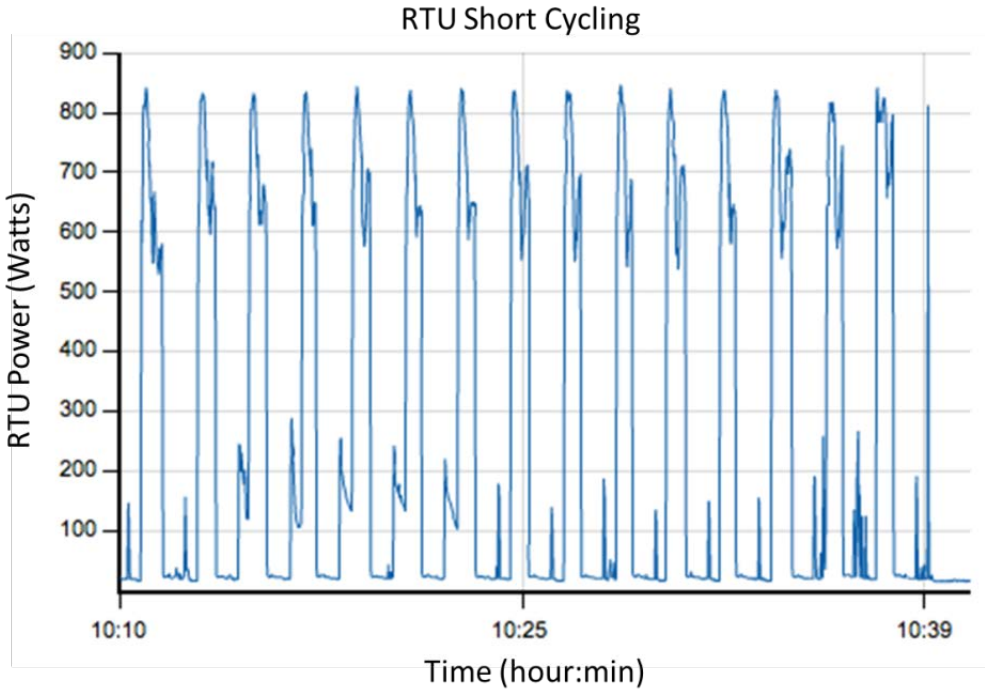
- Provide technical assistance to small business partner (JouleSmart) in implementing three sets of AFDD algorithms previously developed through BTO funding and focused on operational improvements into the partner's analytics platform
- Formally document algorithms in pseudo-code and make publicly available for use by other interested energy and load management service providers
- Validate algorithm performance and accuracy through laboratory tests on a specially-equipped and instrumented representative RTU at PNNL
- Provide technical support to JouleSmart in interpreting unexpected results and other issues during initial installation and deployment in real world, operational buildings

Rooftop Unit Fault Detection Algorithms

FDD Algorithms: Set 1

1. Thermostat setbacks not enabled for unoccupied hours
2. Over-cooling or over-heating during occupied hours
3. Heating and cooling setpoints too close together
4. Under-conditioning during occupied hours
5. Short cycling of RTU
6. Under-use of air-side economizing





Rooftop Unit Fault Detection Algorithms

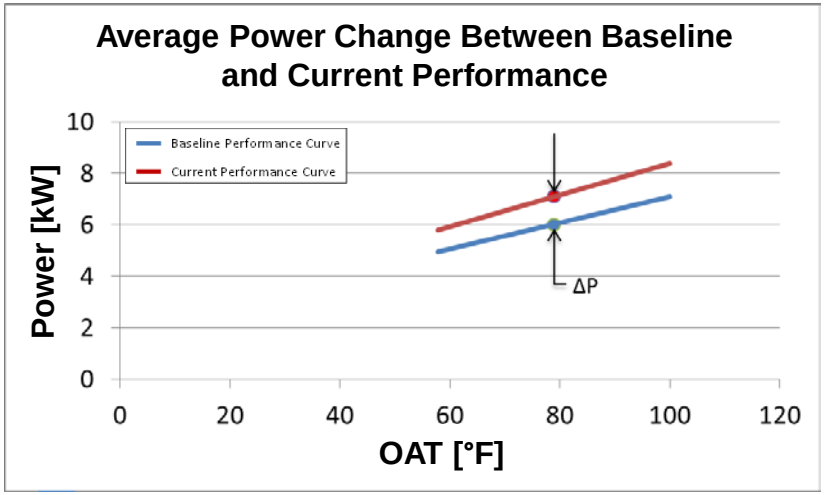
FDD Algorithms: Set 2

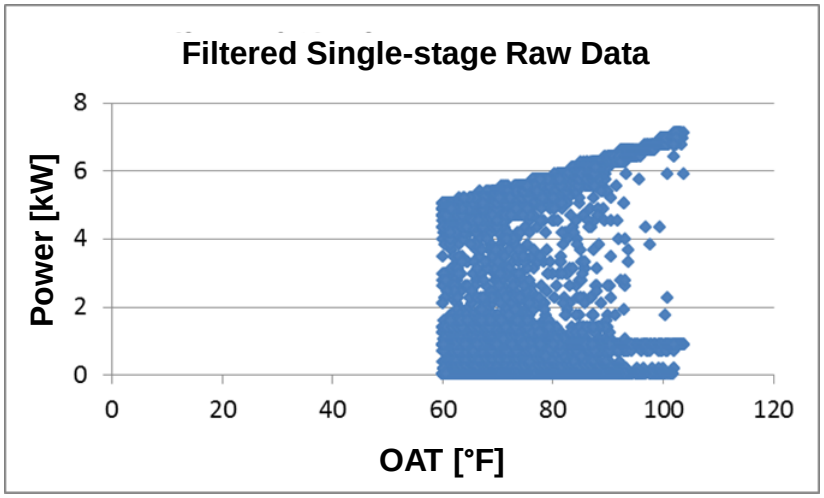
7. Faults in air-side temperature sensors
8. Outdoor-air damper not modulating
9. Fault in specific air-side temperature sensor (outdoor air, zone air, or supply air)
10. RTU is economizing when it should not
11. RTU is not economizing when it should
12. RTU is using excess or insufficient outdoor air for ventilation

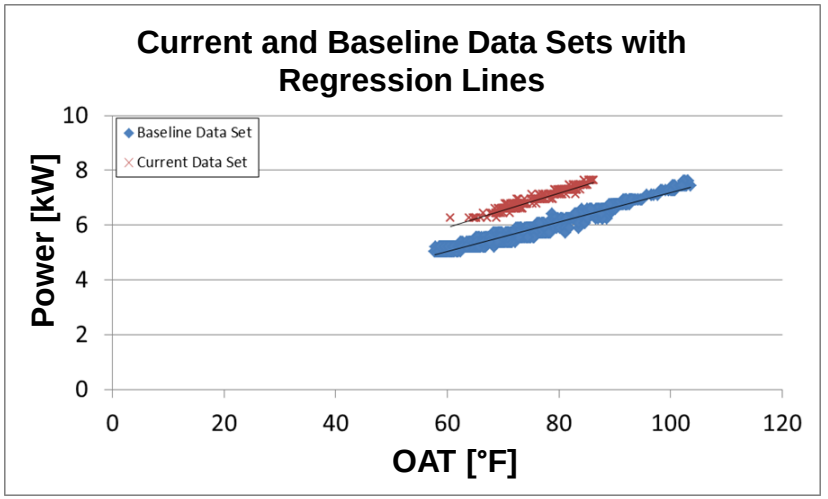
Rooftop Unit Fault Detection Algorithms

FDD Algorithms: Set 3

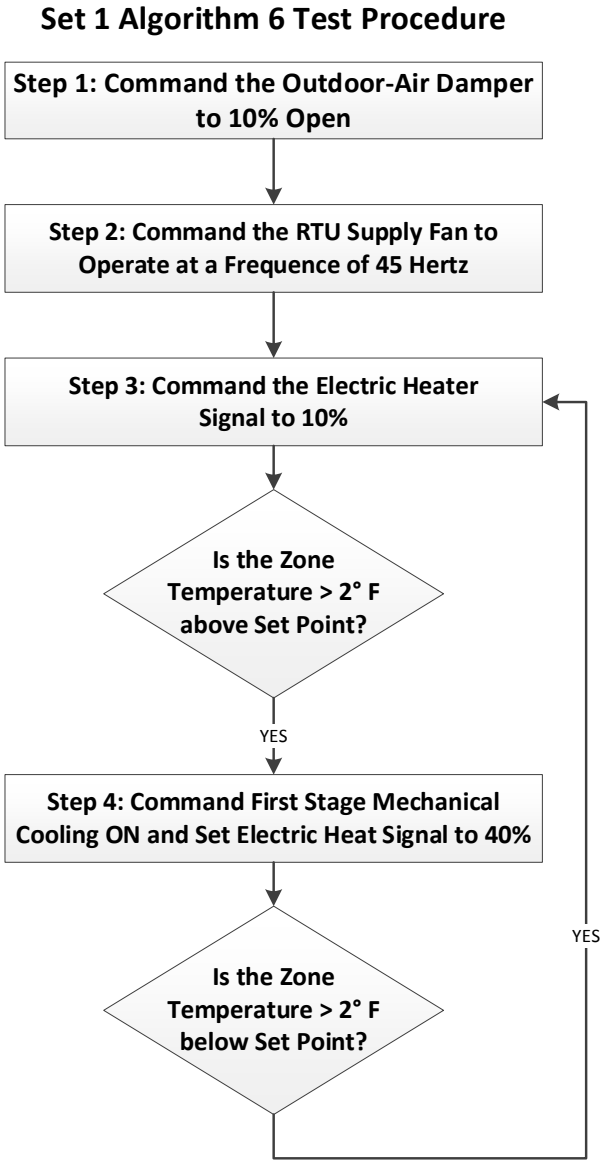
13. Degradation in the performance of the vapor compression cycle
14. Compressor short cycling
15. Compressor operates continuously
16. RTU runs continuously
17. RTU always off
18. RTU cycles with compressor only







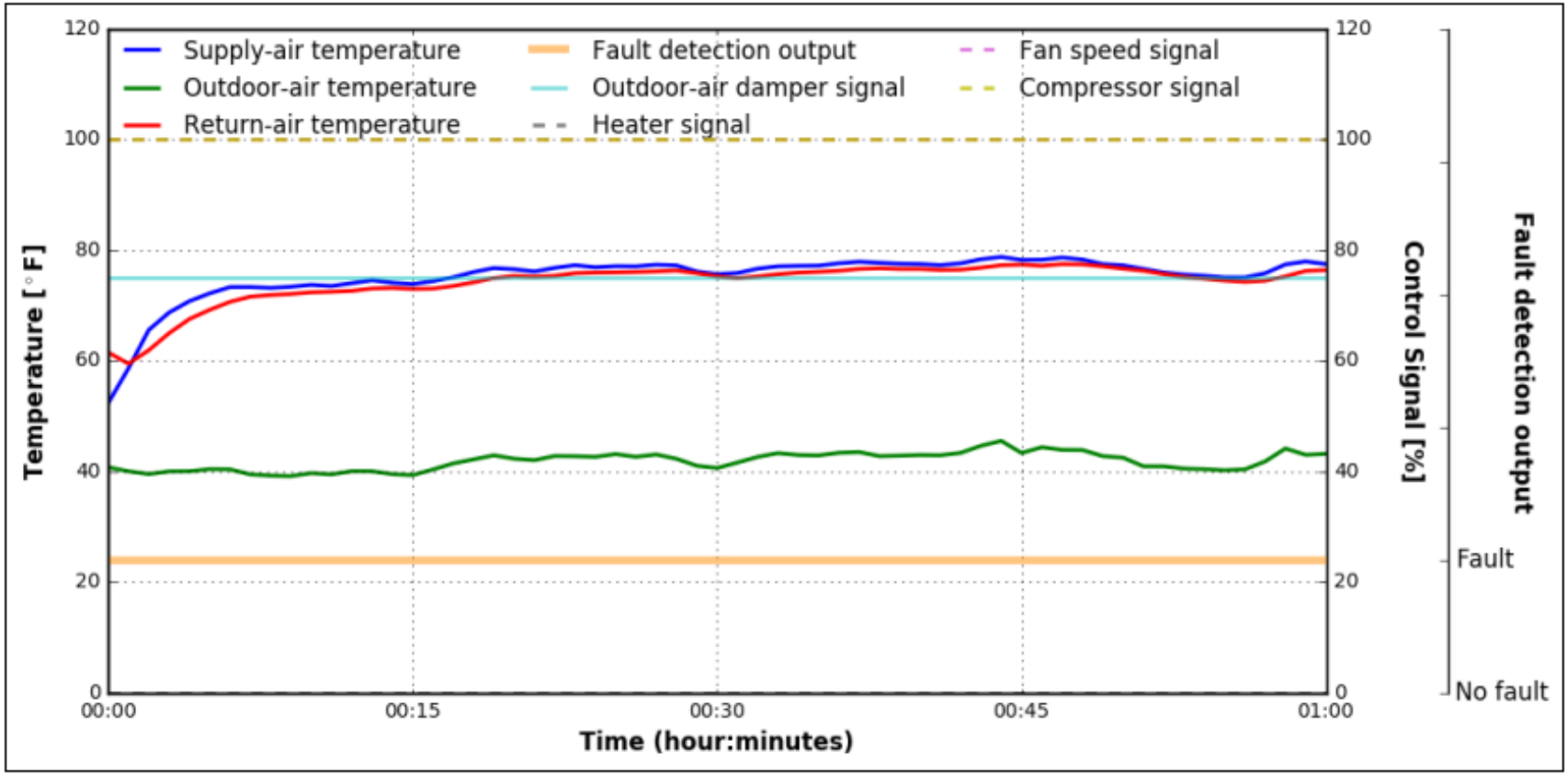
Example Algorithm Test Procedure



Example Test Results

Algorithm Description: Detecting the RTU economizing when it should not

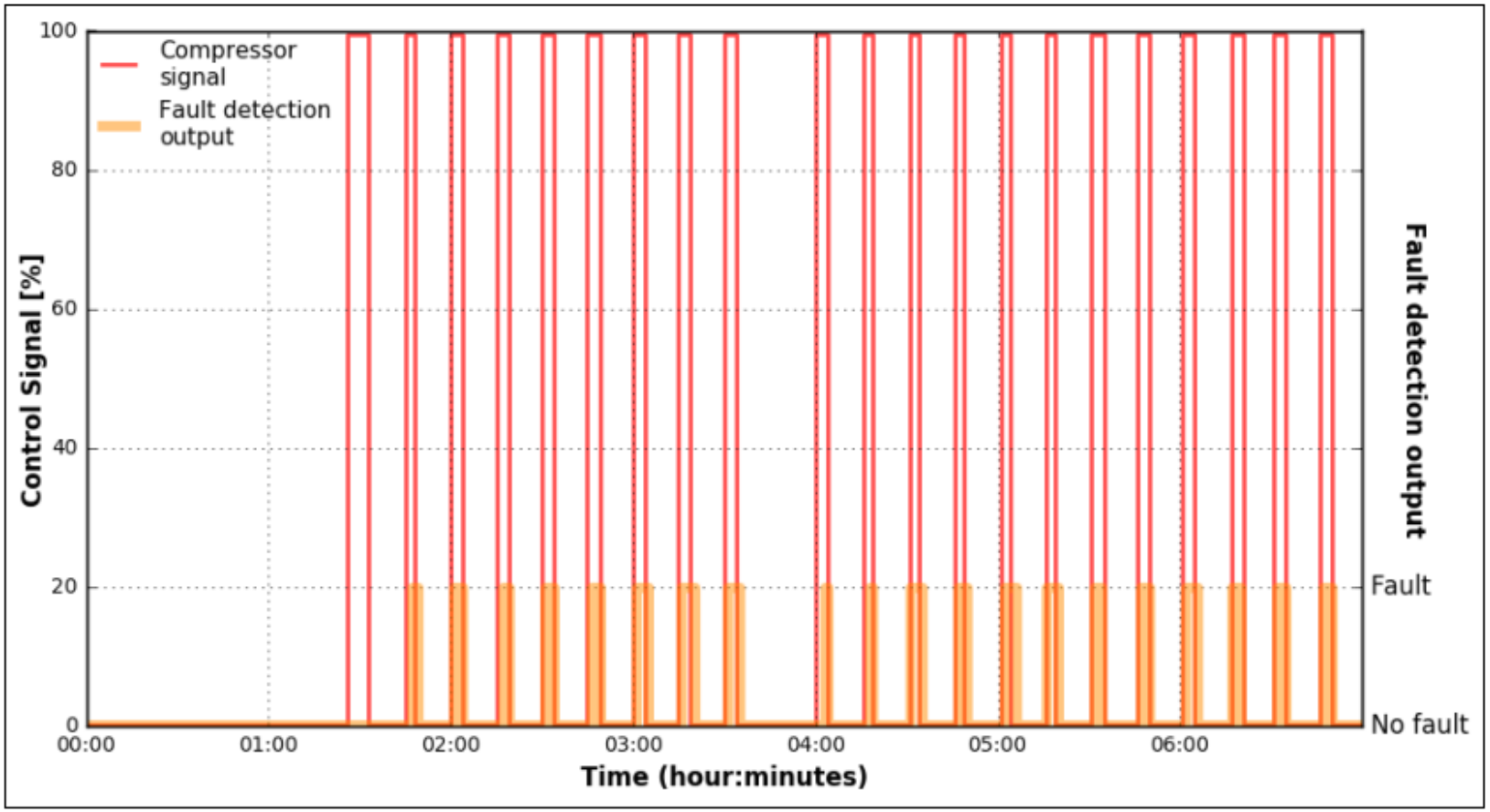
Fault present and **fault detected**: The outdoor-air damper indicates that the RTU (heat pump) is economizing in the heating mode



Example Test Results

Algorithm Description: Detecting the RTU is short cycling

Fault detected when present and not detected when not present: The RTU is short cycling during the vapor compression cooling cycle operation



Impact

Documented and tested AFDD algorithms for rooftop packaged HVAC systems will:

- Facilitate adoption in the underserved small commercial buildings sector
- Enable ~15% savings in whole building energy consumption or 1.0 quad primary/year from proper implementation of AFDD algorithms and repair of faults found
- Inform future research and development (R&D) to overcome limitations identified in the field that will contribute to meeting BTO 2030 goals of 30% energy savings from AFDD in advanced and autonomous controls for the commercial sector as a whole

Progress

- Three sets of AFDD algorithms selected for deployment by JouleSmart fully documented in the form of pseudo-code
- Modified the exhaust air damper of the test-RTU to allow for maximum achievable outdoor-air fraction
  - Baseline testing successfully performed on modified test-RTU
- Testing completed on two of the three sets of AFDD algorithms except for testing requiring warmer outdoor conditions to detect an economizer fault
- Testing of third set of AFDD algorithms will be underway in May 2018

Stakeholder Engagement

- Through EERE SBV program, PNNL provided technical assistance to small business stakeholder, NorthWrite (now JouleSmart)
- Algorithms selected by JouleSmart tested by PNNL with results reviewed by JouleSmart
- JouleSmart responsible for implementing algorithms into their commercial platform to provide enhanced services to their customers
- Algorithms will be made publically available at the conclusion of the project

Remaining Project Work

- Testing and validation of the third set of AFDD algorithms (Milestone 5)
- Technical support to JouleSmart to implement algorithms in their cloud- and device-based platforms and in initial rollout to customers (Milestone 8)
- Technical assistance to JouleSmart to validate software implementation
- Post pseudo-code of developed algorithms in public, online repository for other energy and load management companies, researchers, and developers to leverage and use
- PNNL commercialization office will assist with dissemination of the algorithms and test results

Thank You

Questions?

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REFERENCE SLIDES

Project Budget

Project Budget: $300K total DOE budget and $200K in-kind cost share.
Variances: JouleSmart priorities for the algorithms in order are Sensor Suitcase, FDD, and SMDS. Completion of the Sensor Suitcase Opportunity algorithms was moved to December 2016 in place of Milestone 1, Completion of the AFDD algorithms was moved to January 2017, and Milestone 1 (Completion of SMDS algorithms) was moved to May 2017. These milestone date changes were driven JouleSmart's prioritization of the algorithms for implementation in the order Sensor Suitcase Algorithms, AFDD algorithms, and SMDS algorithms. Testing was delayed from project outset from later start date than originally planned and through summer of 2017 because of time and effort required to prepare test RTU significantly exceeding plans.

Cost to Date: As of the end of March 2018, of the $300K total lab project budget, $268K had been spent
Additional Funding: In-kind cost share from JouleSmart $200K

Budget History			
07/16/2016– FY 2016/2017 (past)		FY 2018 – 07/31/2018 (current)	
DOE	Cost-share	DOE	Cost-share
$239K	$133K	$61K	$150K

Project Plan and Schedule