

PNNL-JouleSmart (NorthWrite) Small Business Voucher Project



Pacific Northwest National Laboratory; JouleSmart

Michael R. Brambley, Chief Scientist, Advanced Building Controls

Michael.Brambley@pnnl.gov

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

Total Project \$:

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

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



Michael Brambley



Danny Taasevigen

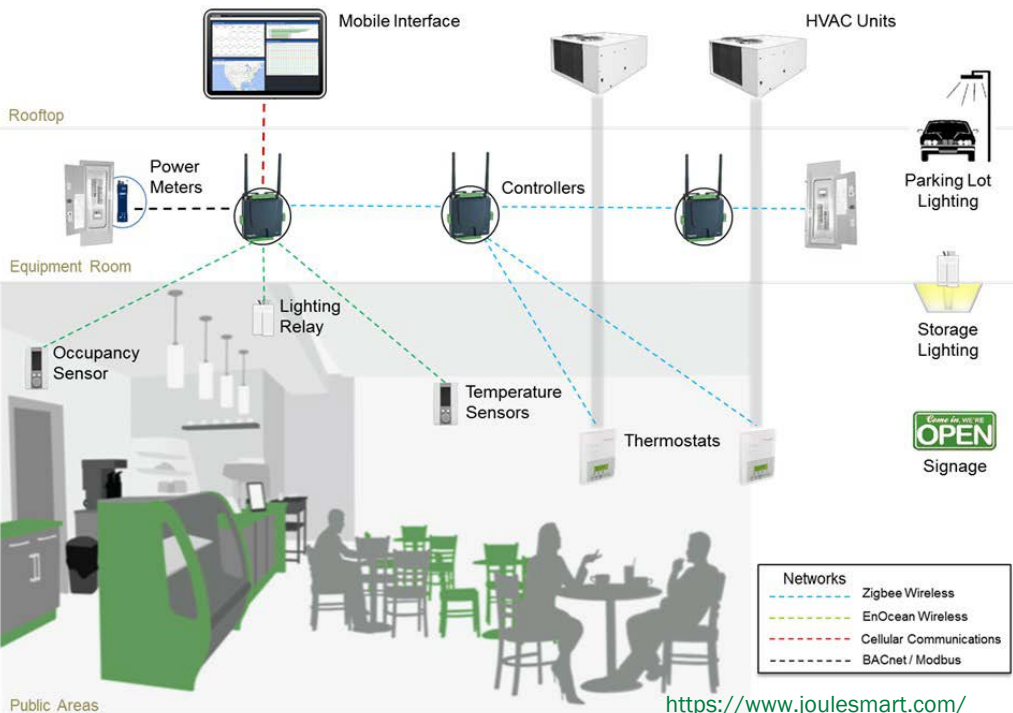


Robert Lutes



Woohyun Kim

NorthWrite Agile Volt™



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 ft²) 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

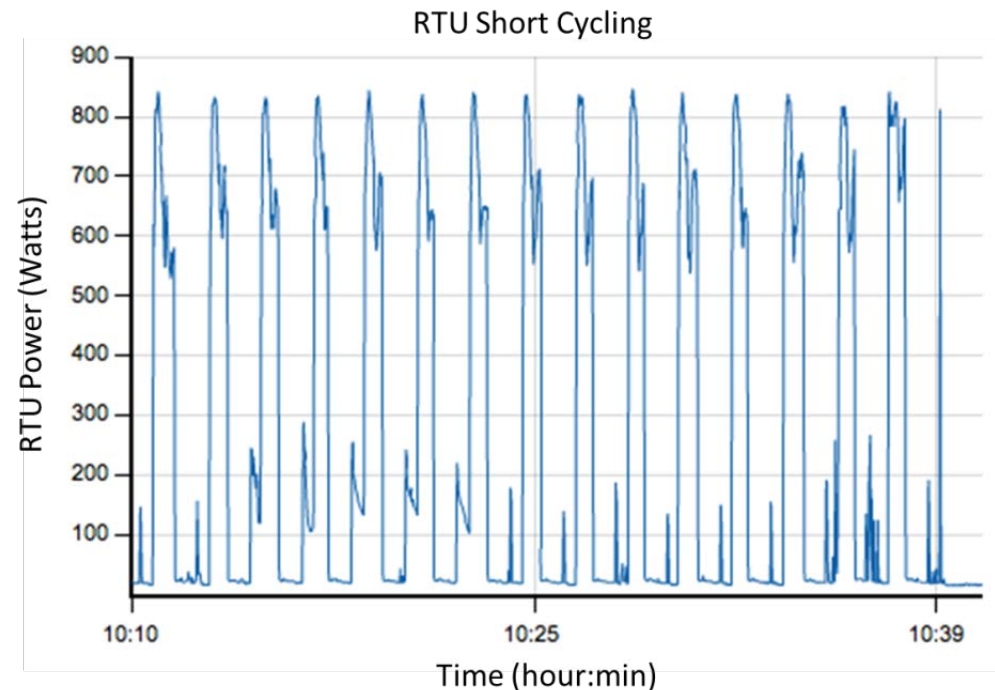
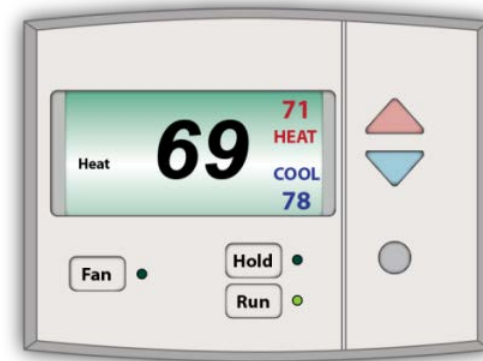
Approach

- 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

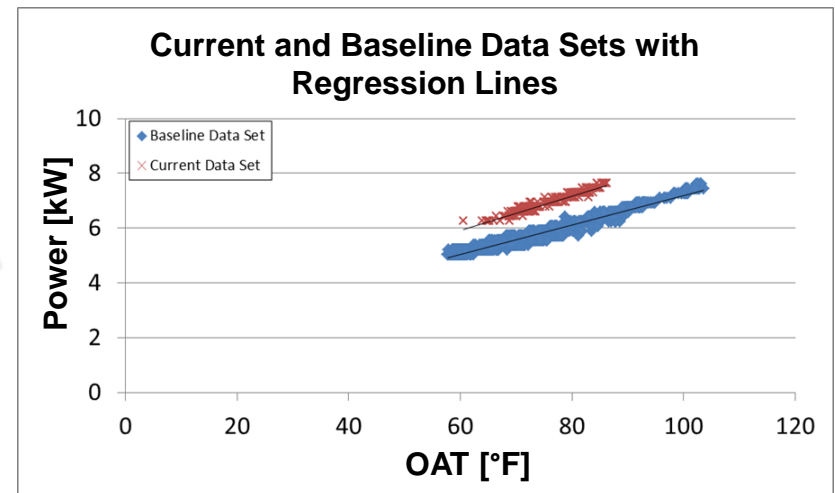
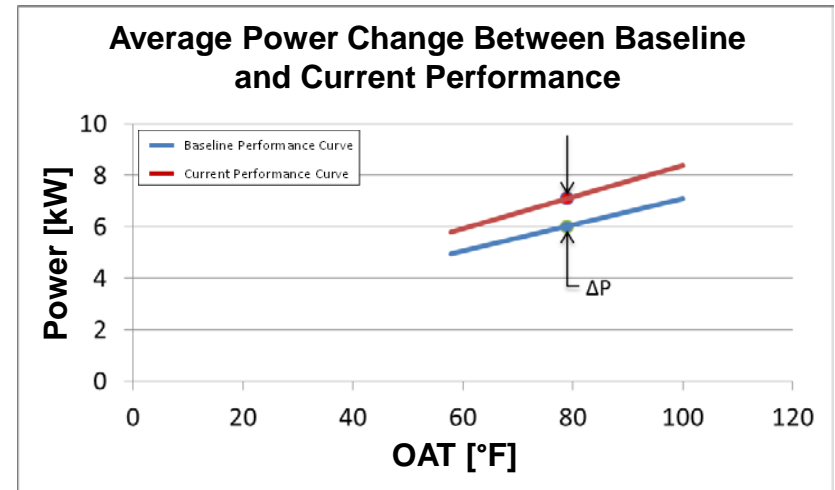
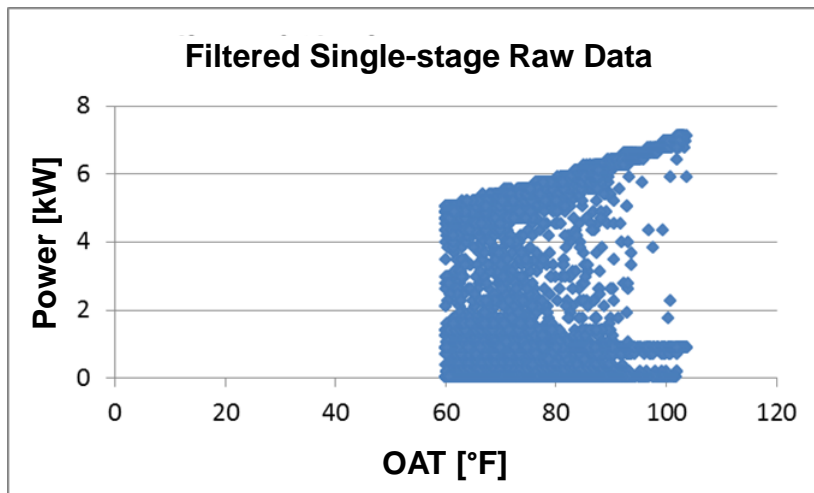
7. Faults in air-side temperature sensors
8. Outdoor-air damper not modulating
9. Fault in specific air-side temperature sensor (outdoor air, zone air, or supply air)
10. RTU is economizing when it should not
11. RTU is not economizing when it should
12. RTU is using excess or insufficient outdoor air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

Set 1 Algorithm 6 Test Procedure

Step 1: Command the Outdoor-Air Damper to 10% Open

Step 2: Command the RTU Supply Fan to Operate at a Frequency of 45 Hertz

Step 3: Command the Electric Heater Signal to 10%

Is the Zone Temperature $> 2^{\circ}\text{F}$ above Set Point?

YES

Step 4: Command First Stage Mechanical Cooling ON and Set Electric Heat Signal to 40%

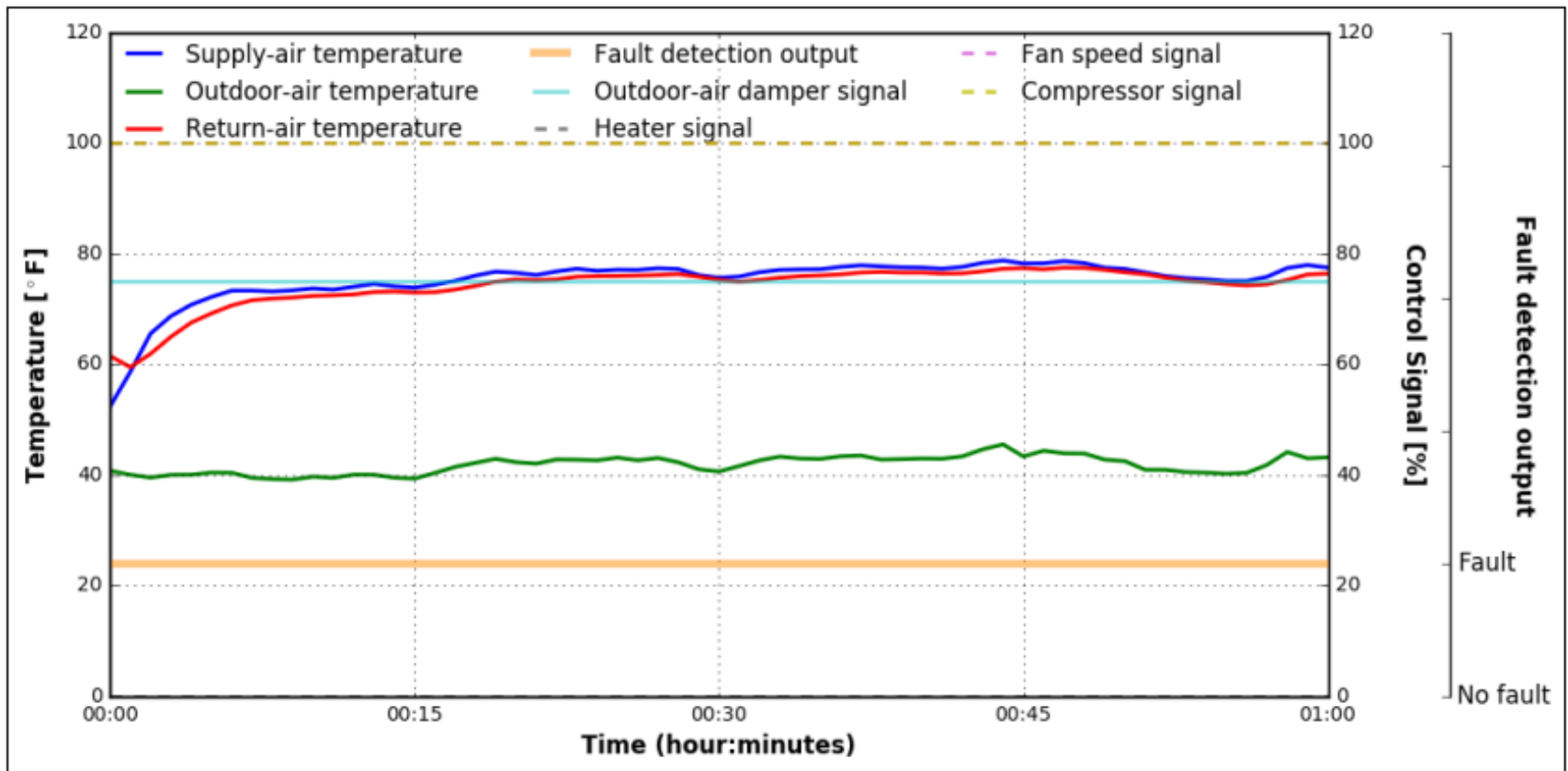
Is the Zone Temperature $> 2^{\circ}\text{F}$ below Set Point?

YES



Example Test Results

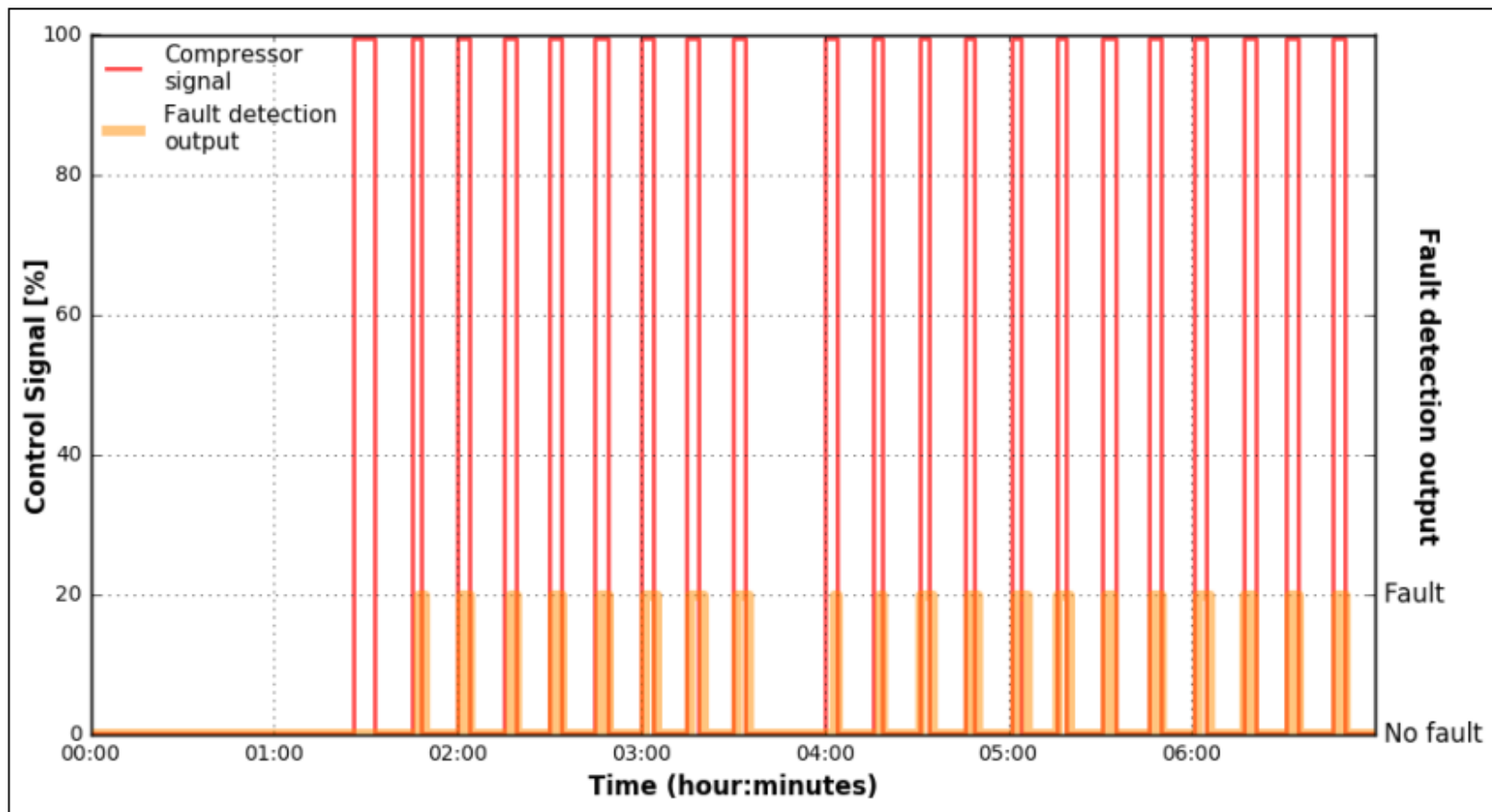
Algorithm Description: Detecting the RTU economizing when it should not
Fault present and **fault detected**: The outdoor-air damper indicates that the RTU (heat pump) is economizing in the heating mode



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?

Pacific Northwest National Laboratory

Michael Brambley

Michael.Brambley@pnnl.gov

REFERENCE SLIDES

Project Budget

Project Budget: \$300K total DOE budget and \$200K in-kind cost share.

Variations: 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 by 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

Task	Months After Project Start																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	8/16	9/16	10/16	11/16	12/16	1/17	2/17	3/17	4/17	5/17	6/17	7/17	8/17	9/17	10/17	11/17	12/17	1/18	2/18	3/18	4/18	5/18	6/18	7/18
Task 1: Smart Monitoring and Diagnostic System (SMDS) Testing, Validation, and Implementation Support																								
Task 1.1: Exploration and Development of SMDS Enhancement for Variable-Speed Compressors																								
Task 1.2: Prepare Documentation of SMDS Methodology																								
Milestone 1: SMDS Documentation Completed																								
Task 1.3: Testing and Validation of SMDS Method																								
Milestone 5: SMDS Testing and Validation Completed																								
Milestone 6: SMDS SMART milestone: SMDS shown in laboratory tests to detect RTU performance degradation for refrigerant charges deficiencies (i.e., low charge) greater than 25% with a false positive rate of less than 2%.																								
Task 1.4: Technical Support to NorthWrite for Completing SMDS in the Cloud																								
Task 1.5: End-to-End Testing of NorthWrite Cloud SMDS Implementation																								
Task 1.6: SMDS User Training Support																								
Task 2: Identification, Testing, Validation, and Implementation Support for RTU FDD Algorithms																								
Task 2.1: Characterization and Prioritization of FDD Algorithms																								
Task 2.2: FDD Algorithm Documentation																								
Milestone 2: FDD and Opportunity Algorithms Documented																								
Task 2.3: Testing, Validation, and Performance Characterization of FDD Algorithms																								
Milestone 4: FDD and Opportunity Algorithms Testing and Validation Completed																								
Task 2.4: FDD Algorithm Refinement (where required based on testing results)																								
Milestone 7: Economizer fault detection algorithms shown in laboratory tests to detect faults with a false positive rate of less than 5%.																								
Task 2.5: Technical Support to NorthWrite for Cloud Implementation of FDD Algorithms																								
Task 2.6: End-to-End Testing of NorthWrite Cloud Implementation of FDD																								
Task 3: Selection, Testing, Validation, and Implementation for Small Building Energy Savings Opportunity Identification Algorithms																								
Task 3.1: Characterization and Prioritization of Opportunity Identification Algorithms																								
Task 3.2: Identification Algorithm Documentation																								
Task 3.3: Non-RTU Algorithms Testing, Validation, Performance Characterization, and Refinement (where required based on testing results)																								
Task 3.4: RTU-Specific Algorithms Testing, Validation, Performance Characterization, and Refinement (where required based on testing results)																								
Milestone 3: Opportunity SMART milestone: Algorithm for RTU short-cycling (excess compressor on/off operation) shown in laboratory tests to detect short cycling faults with a false positive rate of less than 2%.																								
Task 3.5: Technical Support to NorthWrite for Cloud Implementation of Opportunity Algorithms																								
Milestone 8: All Algorithms Implemented																								
Task 3.6: End-to-End Testing of Cloud Implementation of Opportunity Identification Algorithms																								
Task 4: Field Deployment Technical Support																								
Milestone 9: Final Presentation to DOE																								