An Open, Cloud-Based Platform for Whole-Building Fault Detection and Diagnostics

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DOE AFDD Project Portfolio

Controls

Pacific Northwest

Active AFDD and Adaptive Controls

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Model-Based, Whole-Building AFDD Platform & Algorithms
(This Project)

BERKELEY LAB

AFDD Market Deployment & Algorithm Evaluation

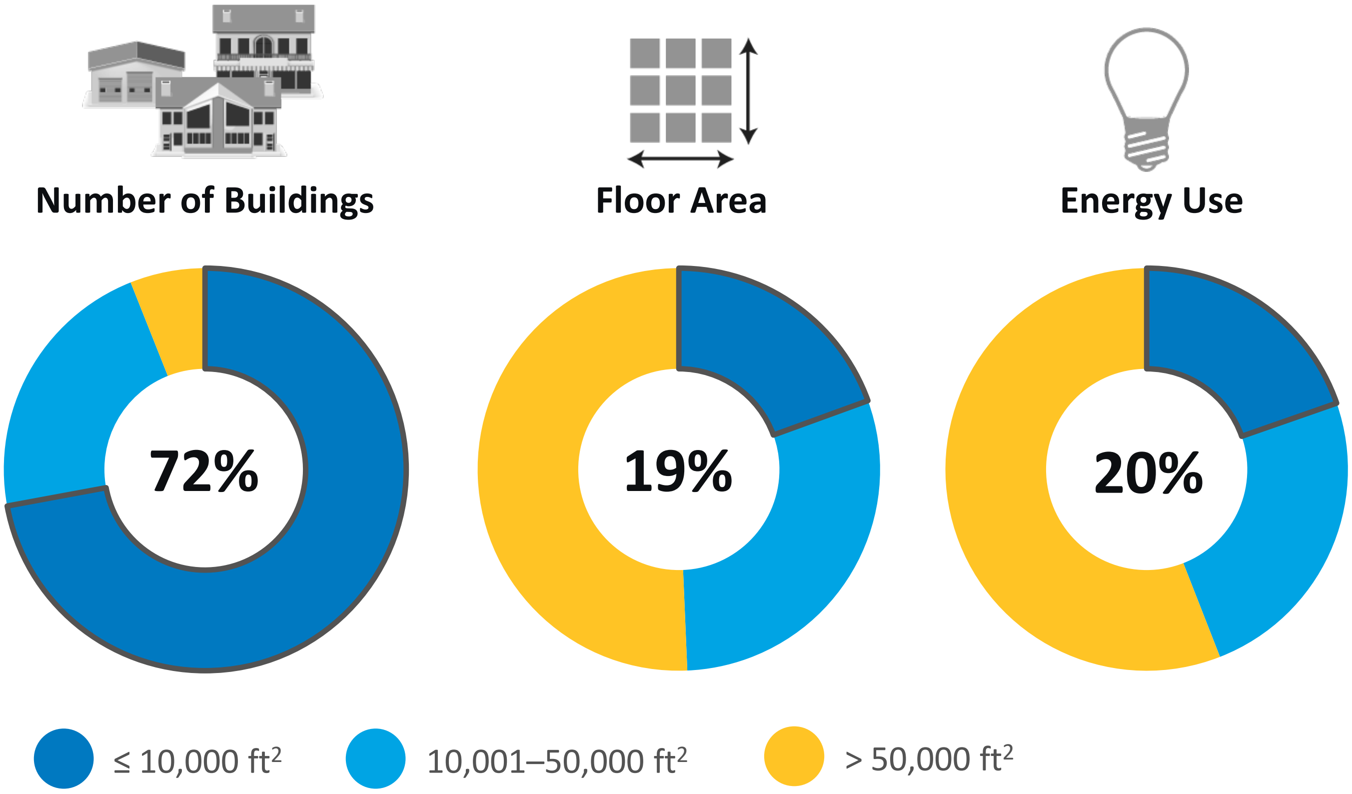
Analytics

Smaller Buildings

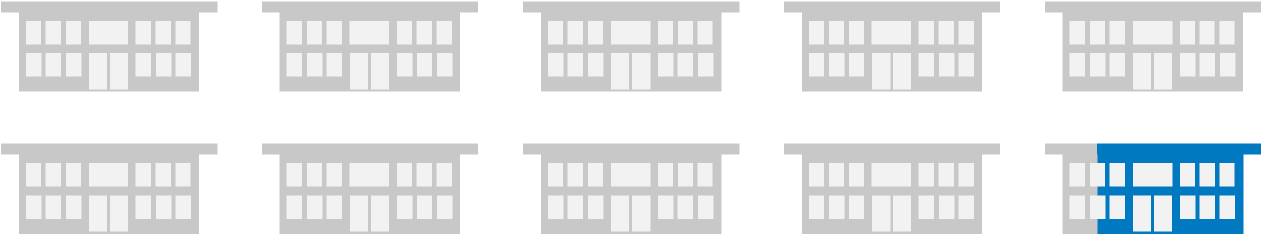
Larger Buildings

Project Goal: Develop cost-effective automated fault detection and diagnosis algorithms for small commercial buildings

U.S. Small Commercial Buildings



Source: EIA (2012)



Automation Systems In
Small Commercial Buildings

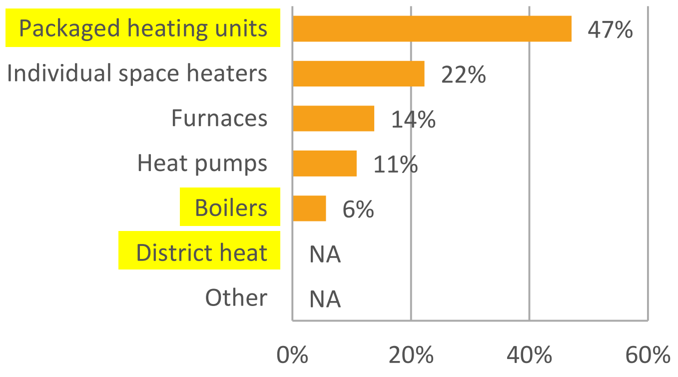
≤ 10,000 ft^2

8%

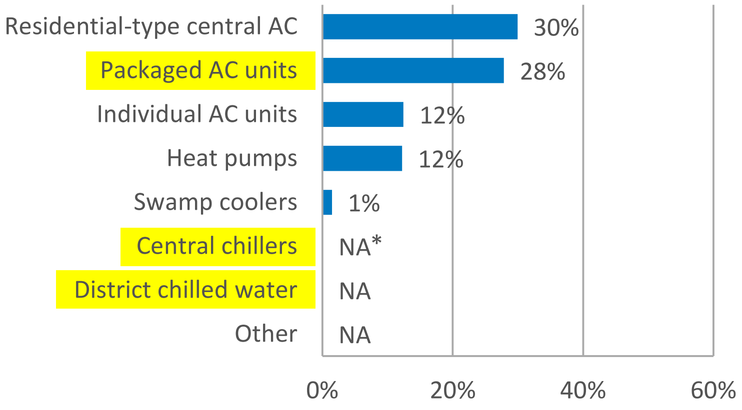
Source: EIA (2012)

Small Buildings HVAC&R Equipment

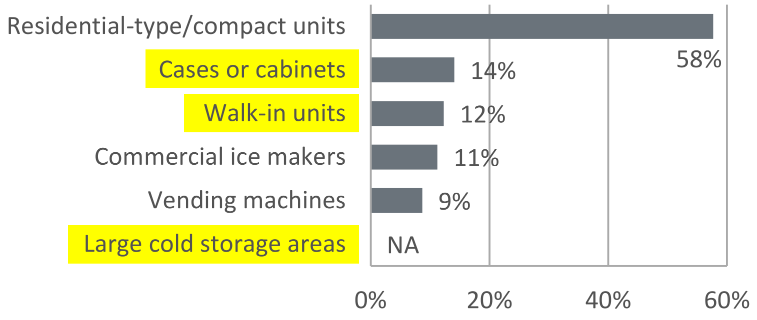
Heating Equipment



Cooling Equipment



Refrigeration Equipment

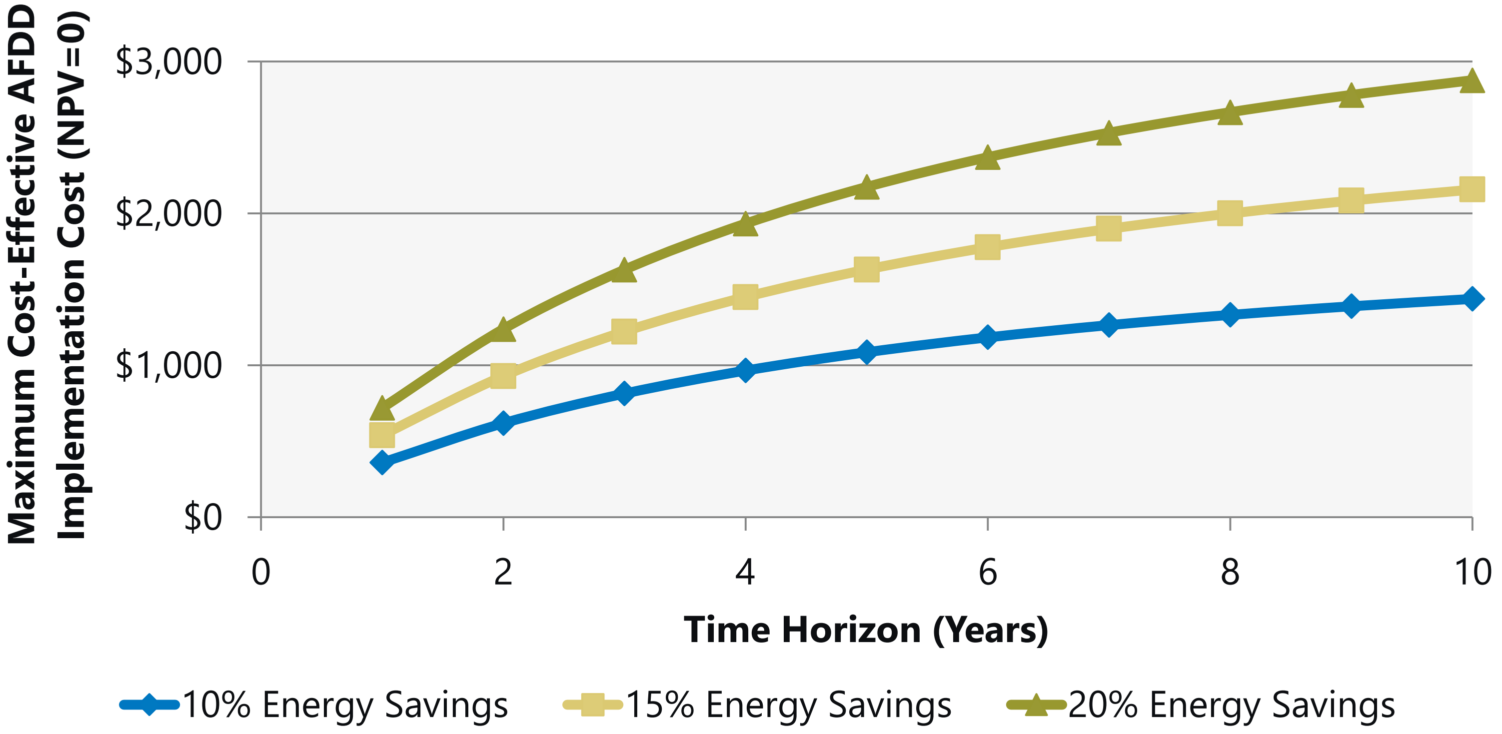


*NA values = No data or no estimate due to small sample size

Source: EIA (2012)

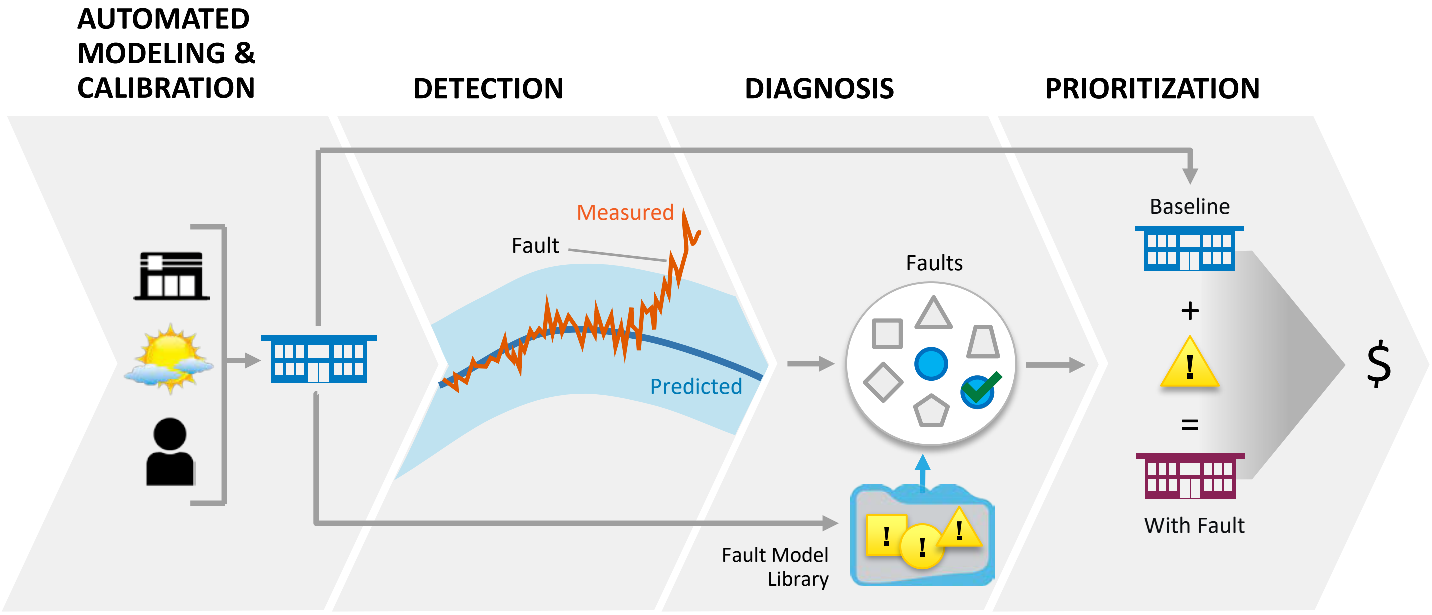
Net Present Value Analysis: 5,000 ft² Building

Annual Cost of Capital: 10% | Cost of Energy: $1.80/ft² | Annual Subscription Cost: 15% of Purchase Price

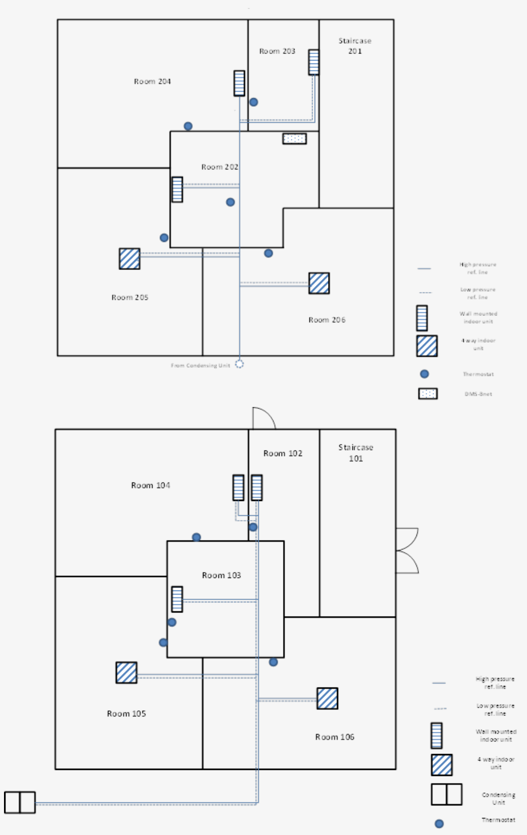


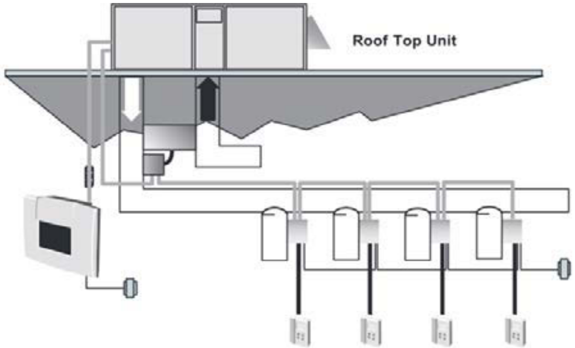
Source: Frank et al. (2018)

Research Approach



Case Study: ORNL FRP #2





Flexible Research Platform (2-Story)

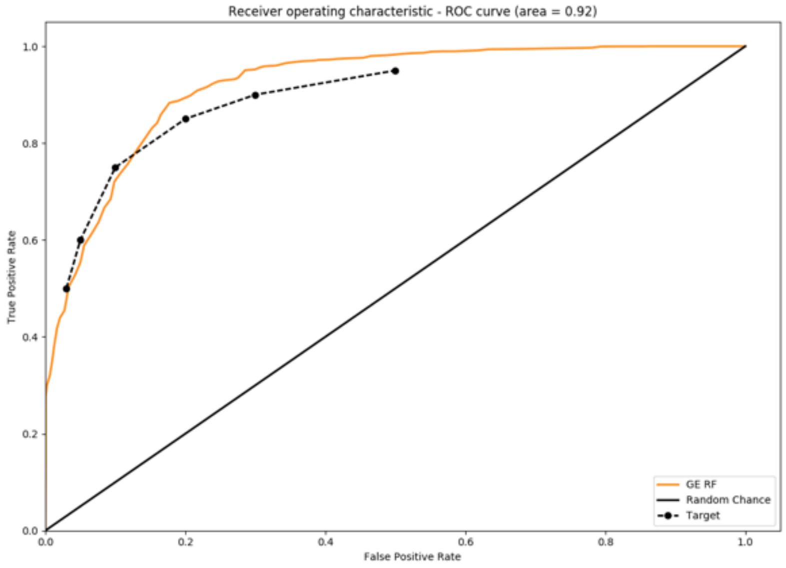
Oak Ridge National Laboratory

- Dedicated experimental facility (not occupied)
- 3,200 ft^2
- Resembles 80's era office building
- RTU + VAV system (10 zone)

We modeled this facility in OpenStudio / E+

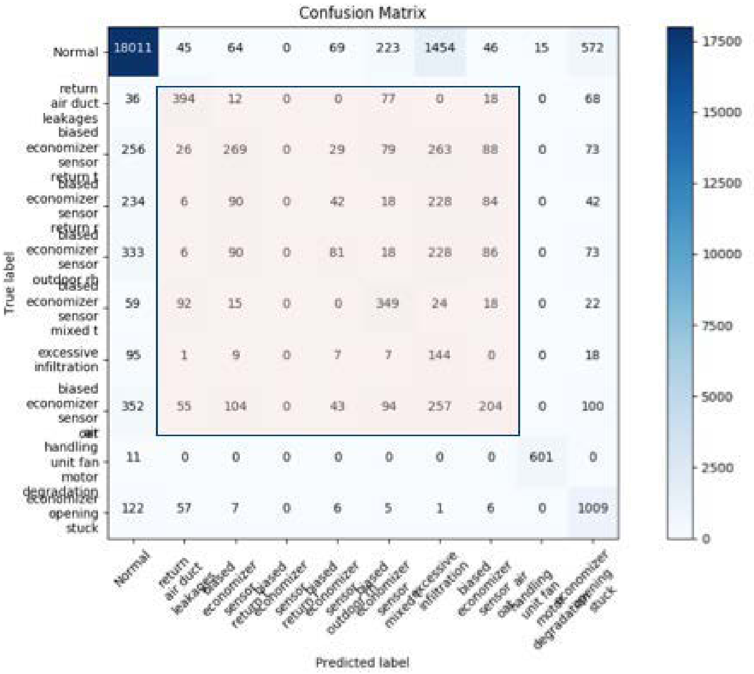
Baseline Results Highlight Challenges

AUC = 0.92



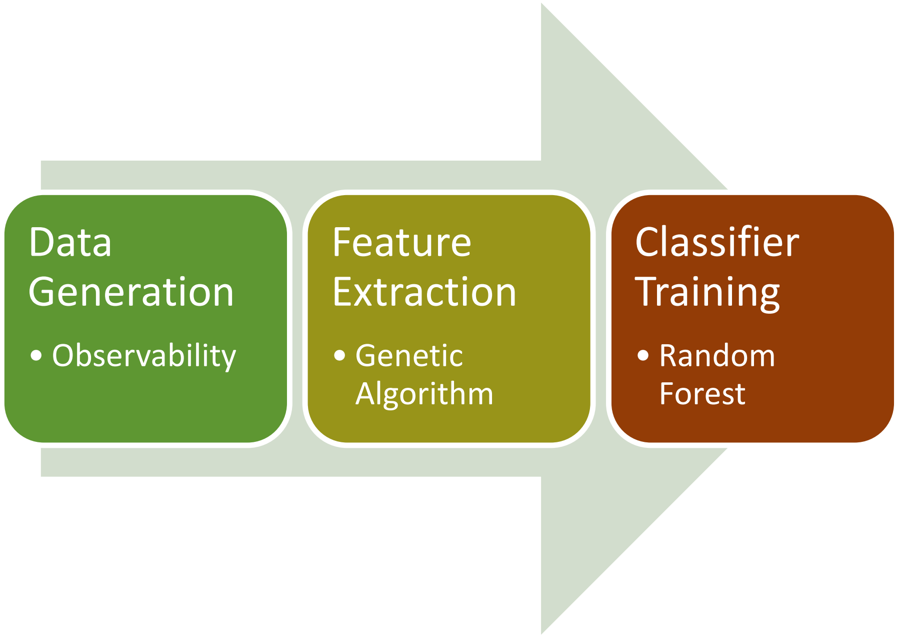
Detection

CDDR << 0.8

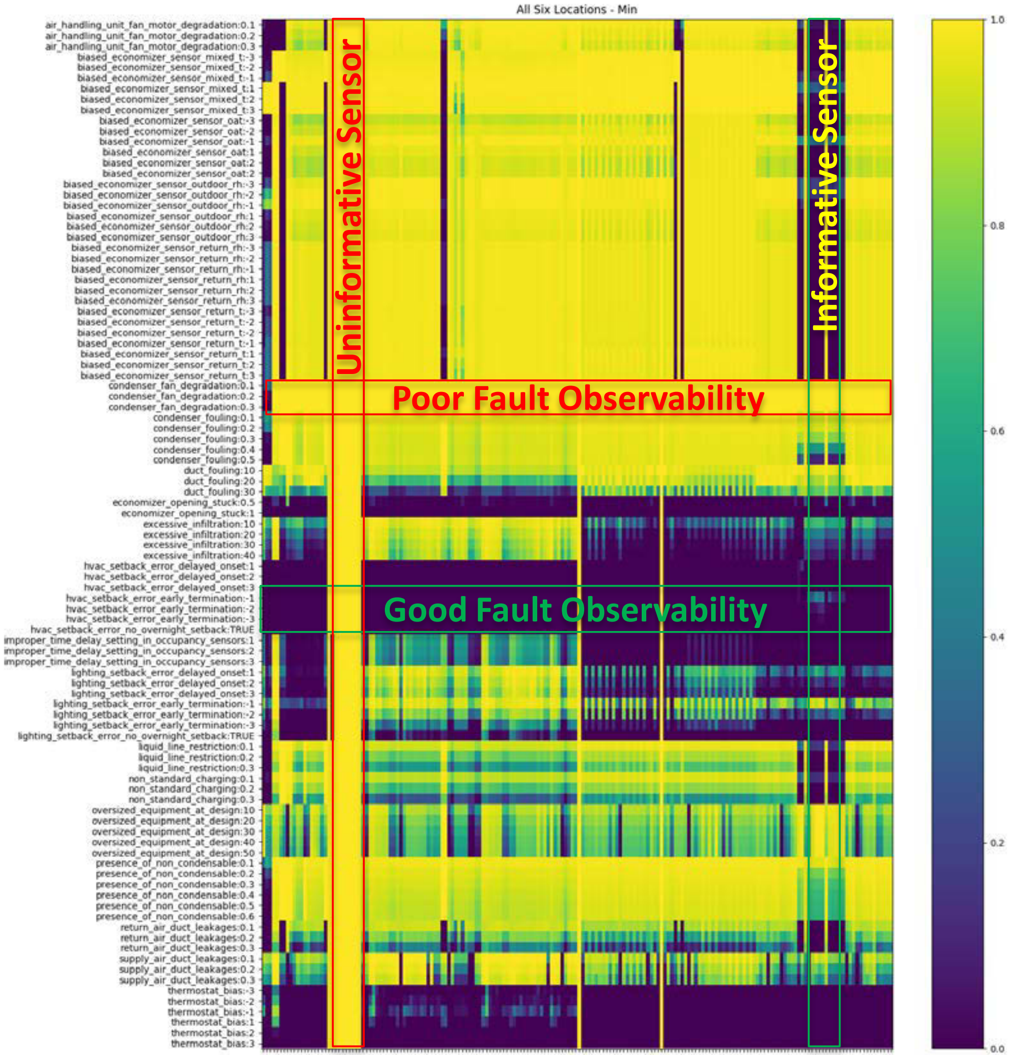


Diagnosis

Automated AFDD Pipeline



Data Generation



EnergyPlus

<u>Training Data</u>

25 Fault Measures

6 climate zones (TMY3)

1 year

<u>Testing Data</u>

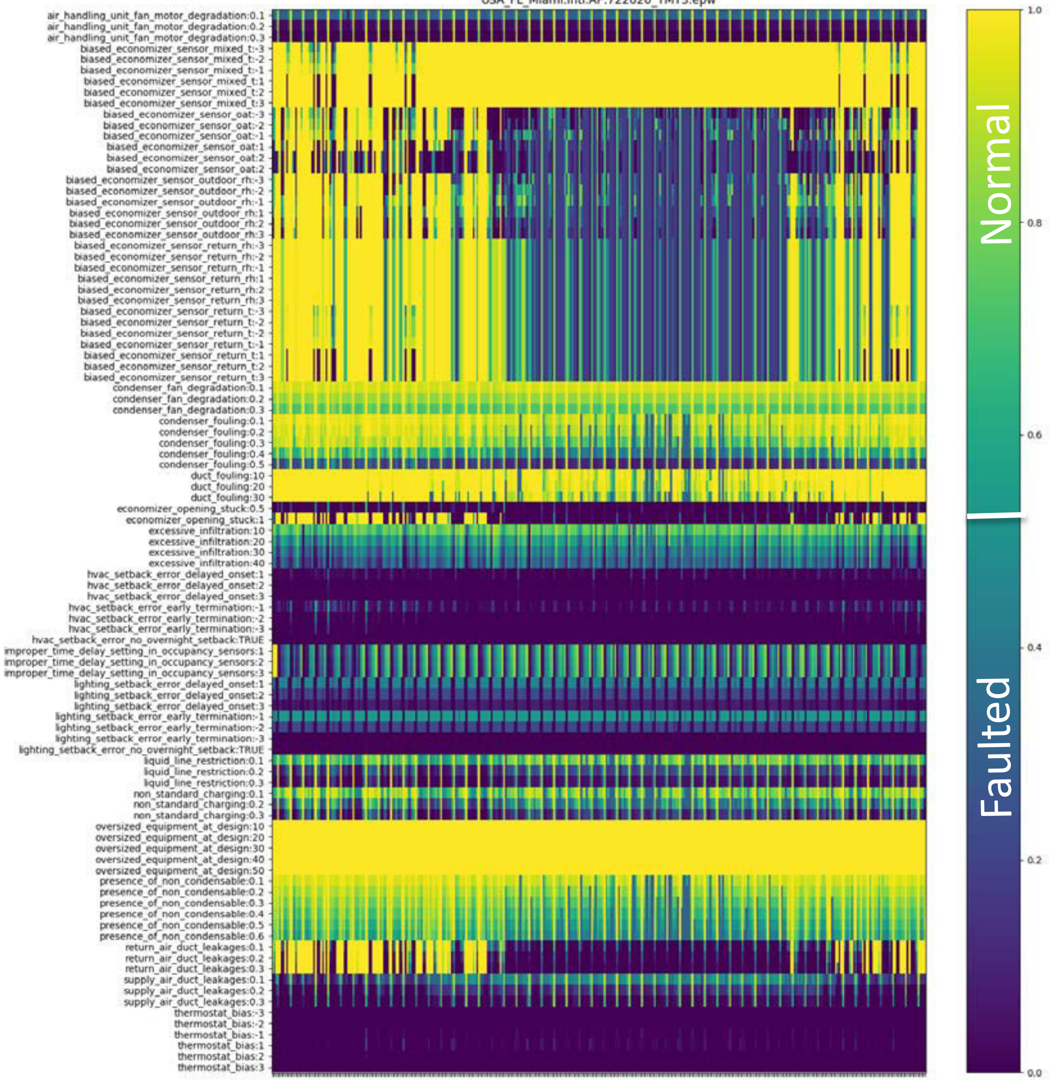
25 Fault Measures

1 climate zone (AMY3)

1 year

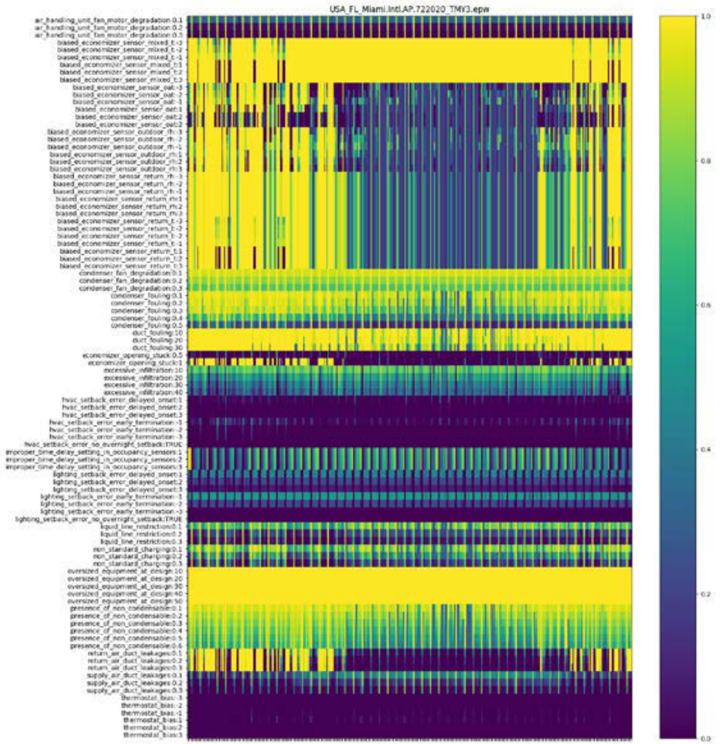
Ground Truth

Recommend that ground truth label of faulted state be based on observability criterion, rather than an energy/performance threshold

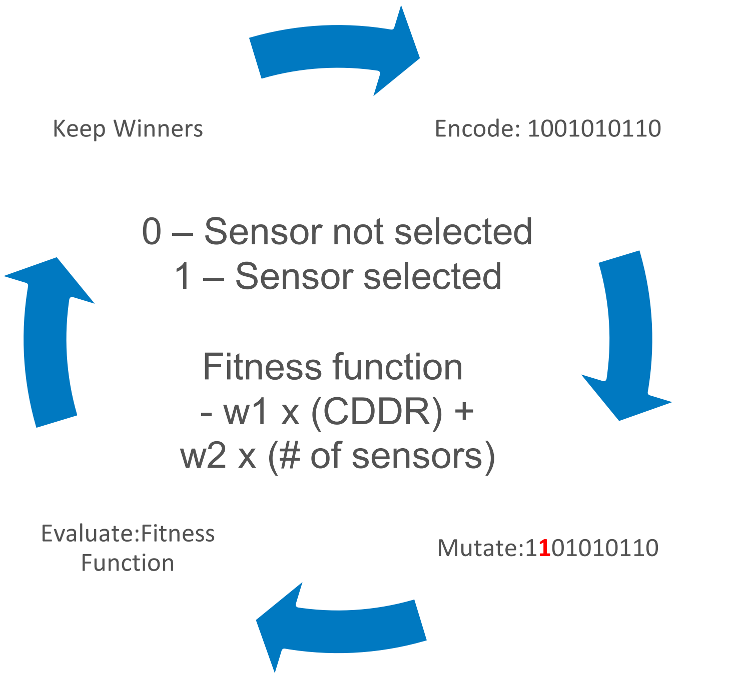


Feature Extraction

Observable Faults



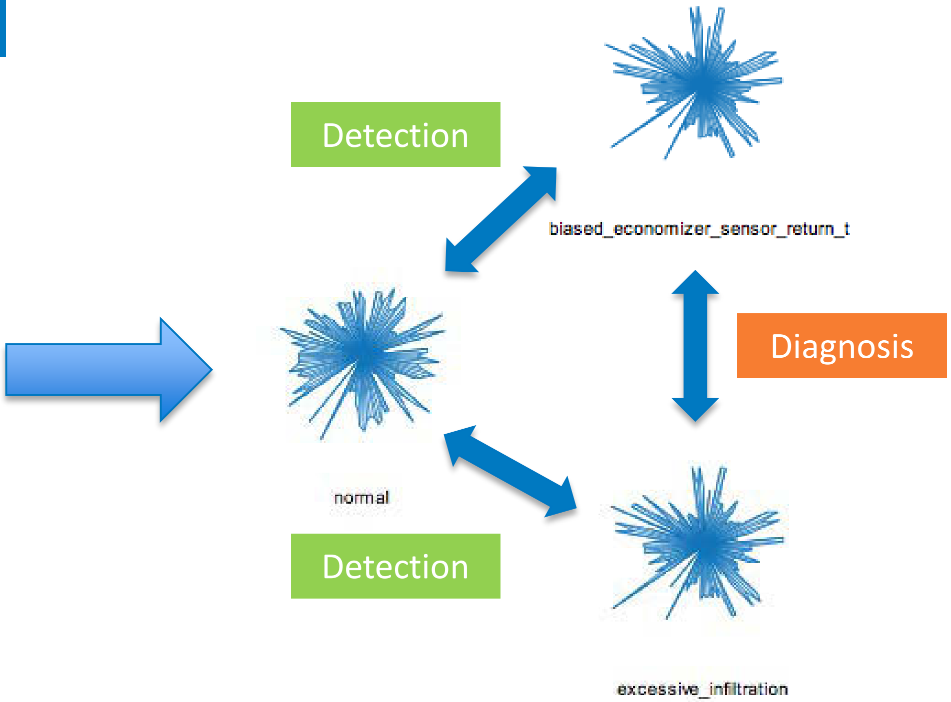
Sensor Selection by Genetic Algorithm



Multiclass Classification Challenge

Features
room_204_zone_air_relative_humidity [%]_mean]
room_204_zone_air_relative_humidity [%]_sum]
rooftop_supply_fan_fan_electric_energy [W]_mean]
rooftop_supply_fan_fan_electric_energy [W]_sum]
rooftop_supply_fan_fan_electric_energy [W]_max]
rooftop_supply_fan_fan_electric_energy [W]_std]
rooftop_mixed_air_outlet_system_node_temperature[C]_mean]
rooftop_mixed_air_outlet_system_node_temperature[C]_sum]
rooftop_mixed_air_outlet_system_node_temperature[C]_std]
rooftop_mixed_air_outlet_system_node_temperature[C]_min]
room_201_zone_mean_air_temperature [C]_min]
2f_plenum_zone_mean_air_temperature [C]_min]
gas_facility [W]_sum]
gas_facility [W]_max]
gas_facility [W]_std]
gas_facility [W]_mean]
heating_gas [W]_mean]
heating_gas [W]_max]
heating_gas [W]_sum]
heating_gas [W]_std]

25 informative sensors
7 maximally informative sensors
20 input features



Remaining Challenges & Paths Forward

Goal	**Challenge**	**Potential Solution**
Automated data generation	Generating data with enough load variation	Building load normalization methods
Improved diagnostic capability	Automatically generating informative features	Include feature types for: • Building hysteresis • Fault sensitivity • Cyclic pattern recognition
Fast feature generation	Compute for observability and genetic algorithm is intensive	• Code optimization • Run-time parallelization

Thank you

www.nrel.gov

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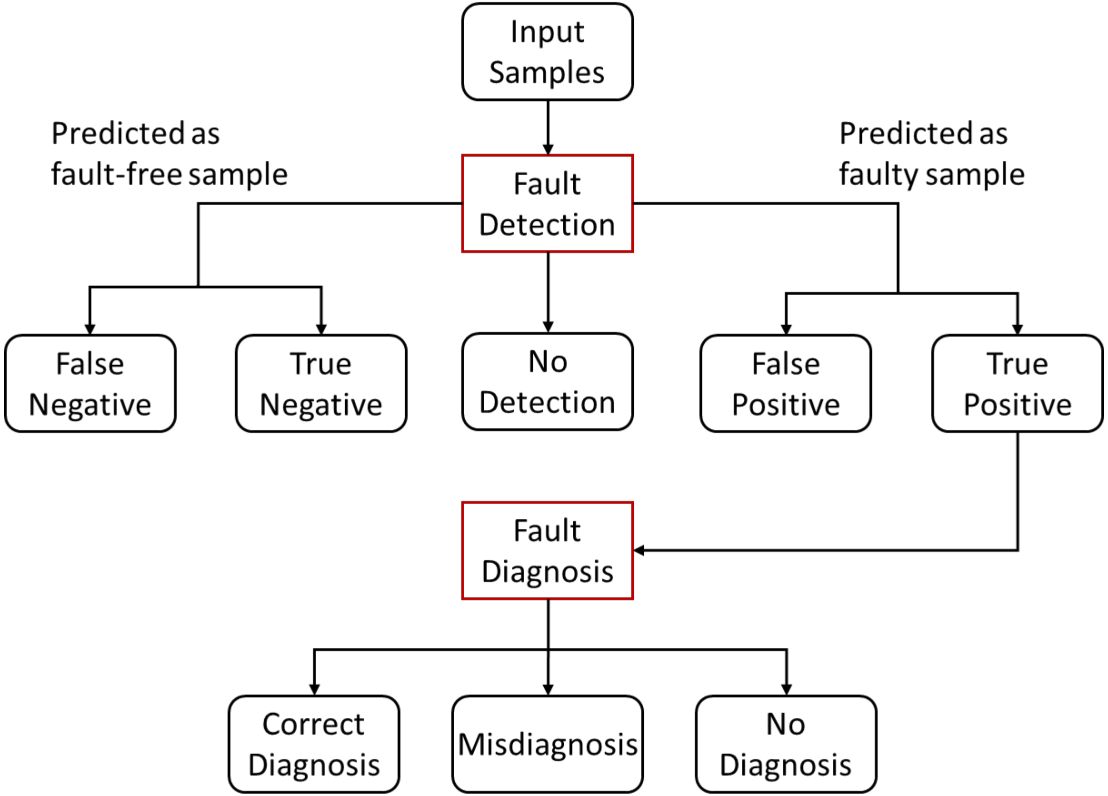
References

(EIA) U. S. Energy Information Administration. 2012. “Commercial Building Energy Consumption Survey (CBECS).” www.eia.gov/consumption/commercial/.

Frank, Stephen, Xin Jin, Daniel Studer, and Amanda Farthing. 2018. “Assessing Barriers and Research Challenges for Automated Fault Detection and Diagnosis Technology for Small Commercial Buildings in the United States.” Draft submitted for publication.

Evaluation: Protocol Outcomes



Evaluation: Confusion Matrix

			Protocol Output (Prediction Condition)					
			Predicted Condition Positive				Prediction Condition Negative (no fault detected)	No Detection
			Fault 1	Fault 2	Fault 3	No Diagnosis		
Ground Truth (True Condition)	Condition Positive	Fault 1	Correct diagnosis (CD_1)	Misdiagnosis ($MD_{1,2}$)	Misdiagnosis ($MD_{1,3}$)	No diagnosis (ND_1)	False negative (FN_1)	No detection positive ($ND_{P,1}$)
		Fault 2	Misdiagnosis ($MD_{2,1}$)	Correct diagnosis (CD_2)	Misdiagnosis ($MD_{2,3}$)	No diagnosis (ND_2)	False negative (FN_2)	No detection positive ($ND_{P,2}$)
		Fault 3	Misdiagnosis ($MD_{3,1}$)	Misdiagnosis ($MD_{3,2}$)	Correct diagnosis (CD_3)	No diagnosis (ND_3)	False negative (FN_3)	No detection positive ($ND_{P,3}$)
	Condition Negative (No Fault)		False positive (FP)				True negative (TN)	No detection negative (ND_N)

Evaluation: Combined Detection & Diagnosis Rate (CDDR)

Combined Detection & Diagnosis Rate: Fault i

$$\mathrm{CDDR}_i = \frac{\mathrm{CD}_i}{\mathrm{CD}_i + \sum_{j=1, i \neq j}^{N} \mathrm{MD}_{i,j} + \mathrm{ND}_i + \mathrm{FN}_i + \mathrm{ND}_{\mathrm{P},i}}$$

Number of Samples where ground truth = fault i

Combined Detection & Diagnosis Rate: Overall

$$\mathrm{CDDR} = \frac{\mathrm{TN} + \sum_{i=1}^{N} \mathrm{CD}_i}{\sum_{i=1}^{N} \left(\mathrm{CD}_i + \sum_{j=1, i \neq j}^{N} \mathrm{MD}_{i,j} + \mathrm{ND}_i + \mathrm{FN}_i + \mathrm{ND}_{\mathrm{P},i} \right)}$$

Number of Samples where ground truth = any fault