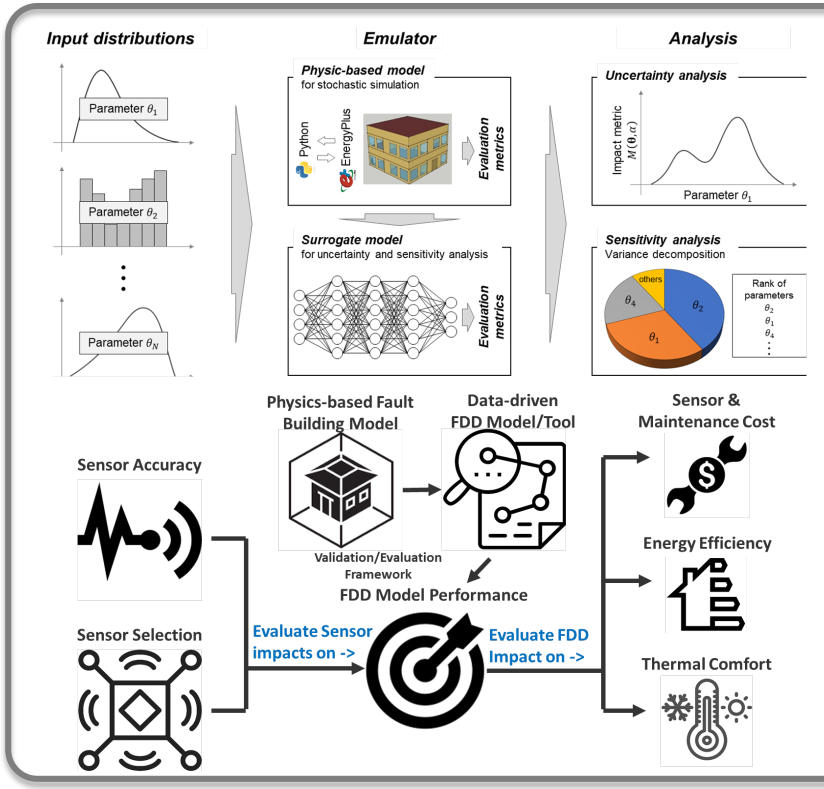
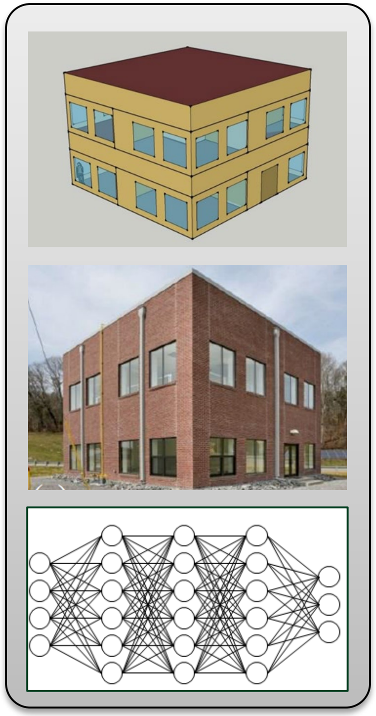
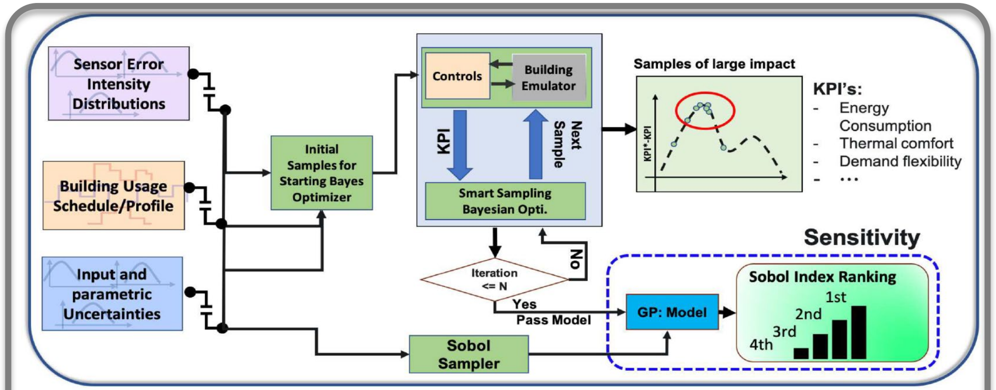
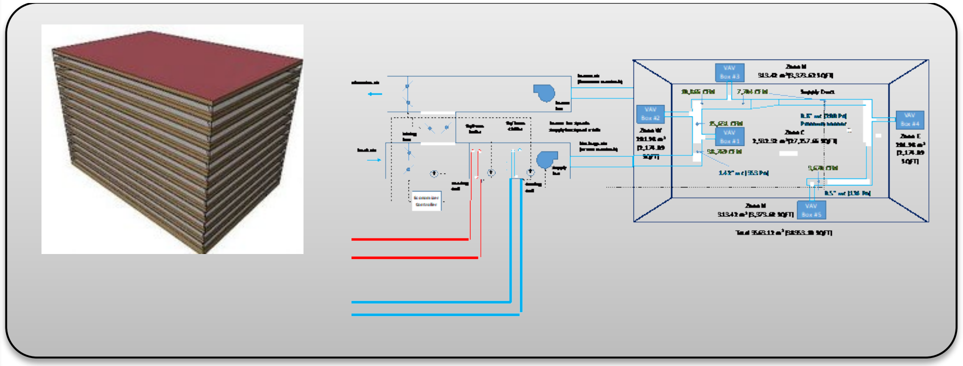
Sensor Impact Evaluation and Verification









Oak Ridge National Lab (ORNL), Pacific Northwest National Lab (PNNL), and National Renewable Energy Lab (NREL)
Piljae Im, R&D Staff
(865)241-2312, imp1@ornl.gov

Project Summary

Timeline:

Start date: 10/1/2019

Planned end date: 9/30/2022

Key Milestones

1. Expert interview, finalize use-cases; 6/30/2020
2. Sensor impact evaluation framework; 9/30/2020
3. Emulator model development: 6/30/2021

Budget:

Total Project $ to Date:

- DOE: $1,062,616
- Cost Share: $0

Total Project $:

- DOE: $2,600,000
- Cost Share: $0

Key Partners:

Purdue University	Bee
Drexel University	Command Commissioning, LLC
Texas A&M	Taylor Engineering
University of Nebraska-Lincoln	Slipstream inc

Project Outcome:

Develop a framework that allows quantitative evaluation of the impact of sensors on building heating, ventilating, and air-conditioning (HVAC) control, FDD, and consequently, building energy efficiency and occupant thermal comfort.

- Transform the conventions of building control to more efficient practices
- Technical support and guidelines
- Improved building energy efficiency and thermal comfort

→ Expedite decarbonization in building sectors

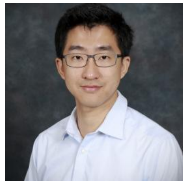
Team

OAK RIDGE
National Laboratory


Piljae Im, ORNL


Yeonjin Bae, ORNL


Yanfei Li, ORNL


Borui Cui, ORNL


Teja Kuruganti, ORNL


Anthony C Gehl, ORNL

- Lead Lab
- Overall Project management
- Sensor impact evaluation for building control
- Test facility: FRP

Pacific Northwest
NATIONAL LABORATORY


Veronica Adetola, PNNL


Saptarshi Bhattacharya, PNNL


Himanshu Sharma, PNNL


Soumya Kunda PNNL

- Sensor impact evaluation for advanced building control
- Occupancy sensing use-case

NREL
NATIONAL RENEWABLE ENERGY LABORATORY


Matt Leach, NREL


Liang Zhang, NREL

- Sensor impact evaluation for FDD
- Sensor cost analysis

- **Technical Advisory Group (TAG)**: vendors, practitioners and researchers
- An expert interview is performed to integrate expert knowledge and experience to develop structured use-case scenarios

Challenge & Project overview

- **“Rules of Thumb” based practices of sensor placement/configuration**
  - – Implemented for stable component operation
  - – Implemented regardless of whole building performance
    - Not necessarily optimal
    - Off from ideal operation In terms of total energy/cost and occupant’s comfort

► Significant opportunities

Investigating **optimal sensor placement / configuration** methods

for different building/HVAC components

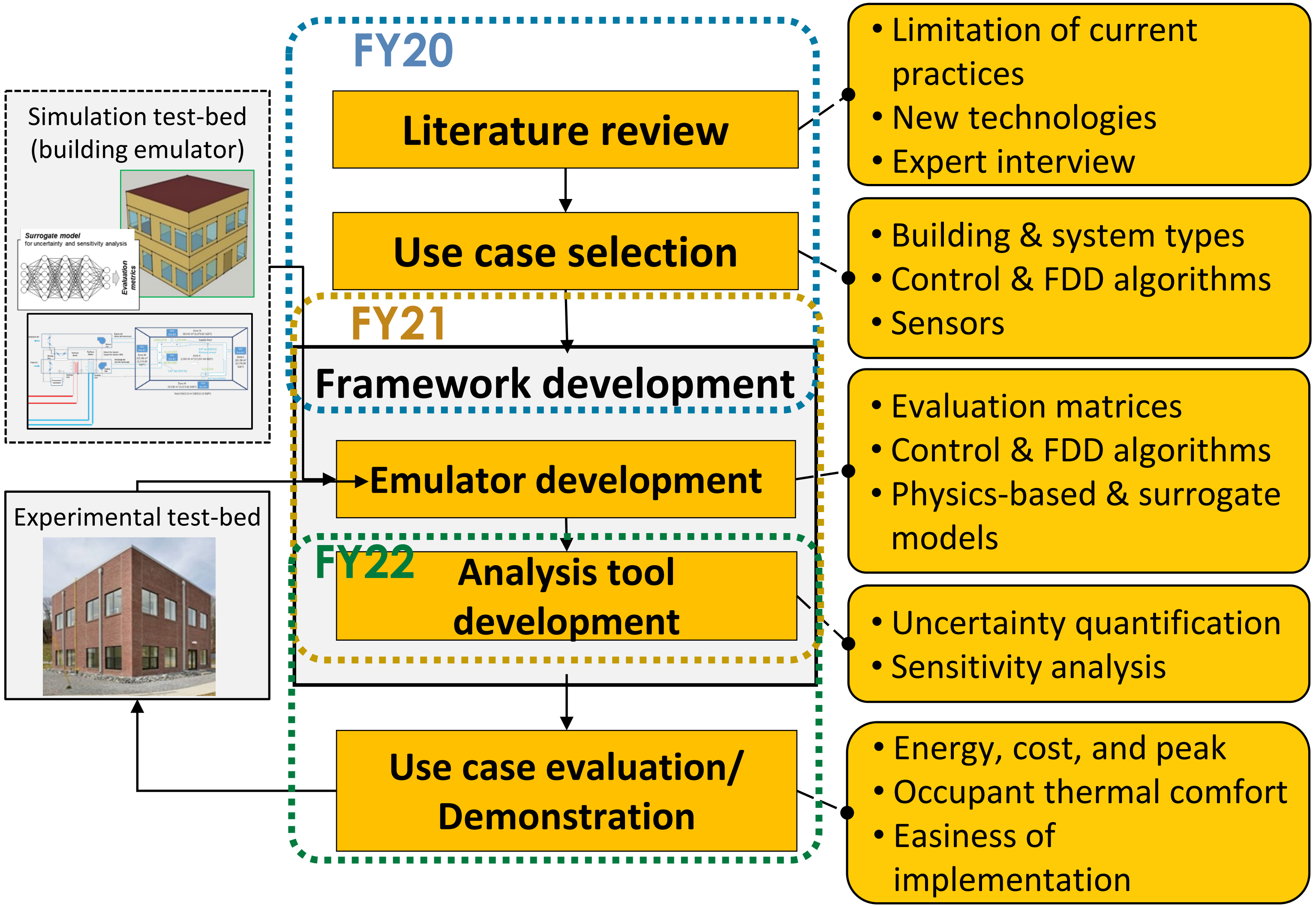
► Bridging the gap between conventional and advanced strategies

► Steering the prevalent conventions toward the energy/cost and comfort efficient strategies.

- **Objective**

  Develop a framework that allows quantitative evaluation of the impact of sensors on building heating, ventilating, and air-conditioning (HVAC) control, FDD, and consequently, building energy efficiency and occupant thermal comfort.

Technical Work Plan & Project Impact



Simulation test-bed (building emulator)

Experimental test-bed

FY20

FY21

FY22

Literature review

- Limitation of current practices
- New technologies
- Expert interview

Use case selection

- Building & system types
- Control & FDD algorithms
- Sensors

Framework development

Emulator development

- Evaluation matrices
- Control & FDD algorithms
- Physics-based & surrogate models

Analysis tool development

- Uncertainty quantification
- Sensitivity analysis

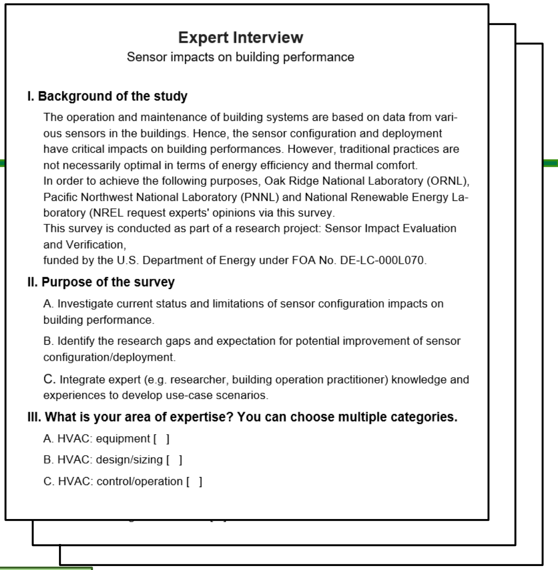
Use case evaluation/ Demonstration

- Energy, cost, and peak
- Occupant thermal comfort
- Easiness of implementation

- **Transform the conventions of building control to more efficient practices**
- **Technical support and guidelines**
  - Serve as an initial pathway to provide the technical support and guidelines for sensor design (sensor selection and placement) in building/HVAC systems
- **Improved building energy efficiency and thermal comfort**
  - To be beneficial to the building owners and tenants while providing the technical innovations to the HVAC industry (manufacturers and vendors) and utility companies

FY20 Progress & Stakeholder Engagement

- Comprehensive literature review and Expert interviews
  - integrate expert knowledge and experiences to develop use-case scenarios
- Interview responses were collected from **31** individuals
  - academia (6), industry (11), and US national laboratories (14)
  - building operations (28), HVAC systems (27), building systems (17), indoor environment (11), and policy (4)



Expert Interview

Sensor impacts on building performance

I. Background of the study

The operation and maintenance of building systems are based on data from various sensors in the buildings. Hence, the sensor configuration and deployment have critical impacts on building performances. However, traditional practices are not necessarily optimal in terms of energy efficiency and thermal comfort.

In order to achieve the following purposes, Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL) and National Renewable Energy Laboratory (NREL request experts' opinions via this survey.

This survey is conducted as part of a research project: Sensor Impact Evaluation and Verification,

funded by the U.S. Department of Energy under FOA No. DE-LC-000L070.

II. Purpose of the survey

A. Investigate current status and limitations of sensor configuration impacts on building performance.

B. Identify the research gaps and expectation for potential improvement of sensor configuration/deployment.

C. Integrate expert (e.g. researcher, building operation practitioner) knowledge and experiences to develop use-case scenarios.

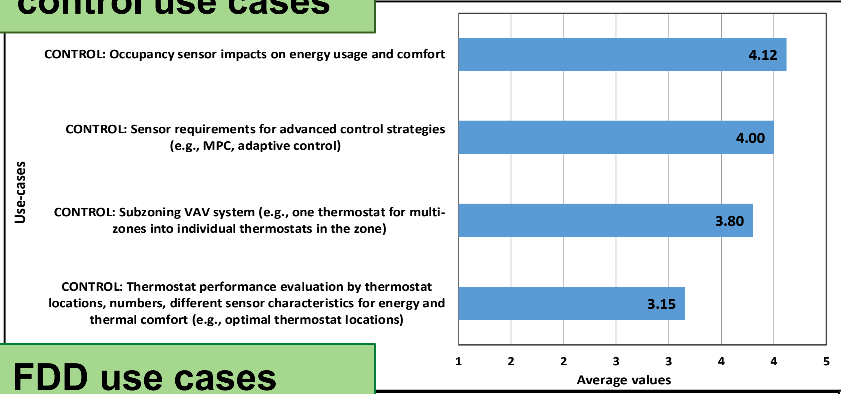
III. What is your area of expertise? You can choose multiple categories.

A. HVAC: equipment [ ]

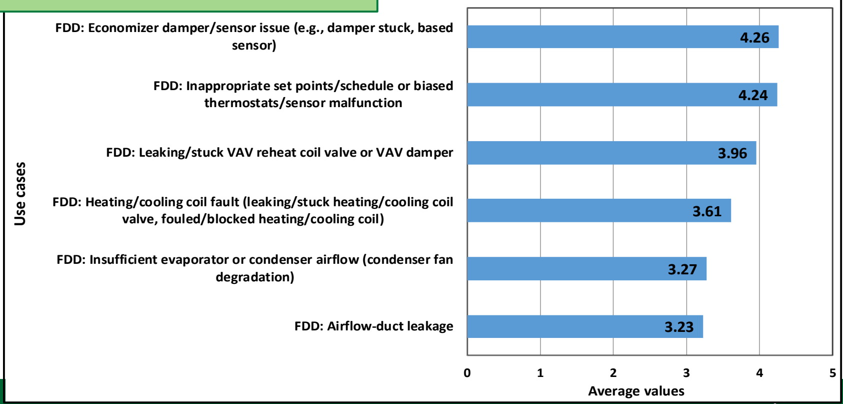
B. HVAC: design/sizing [ ]

C. HVAC: control/operation [ ]

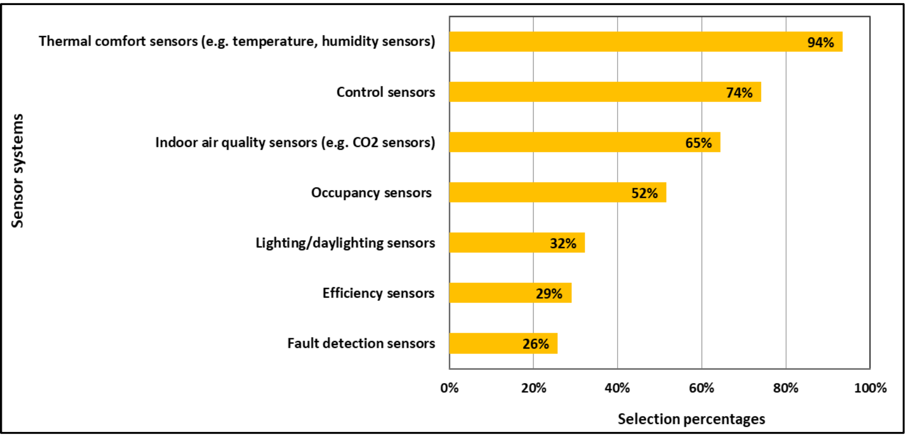
control use cases



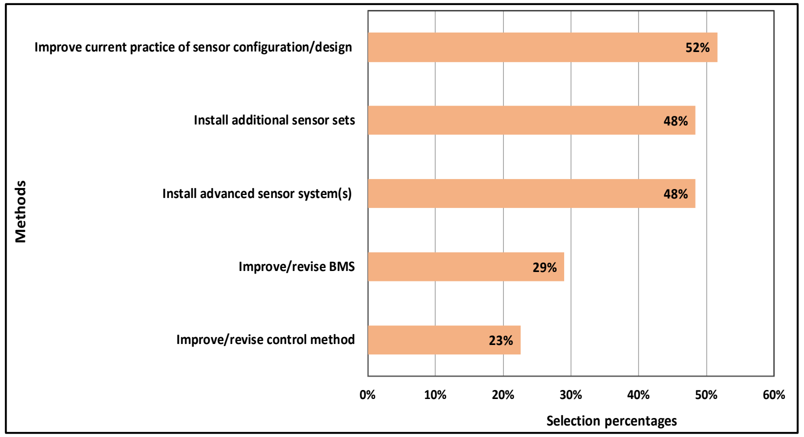
FDD use cases



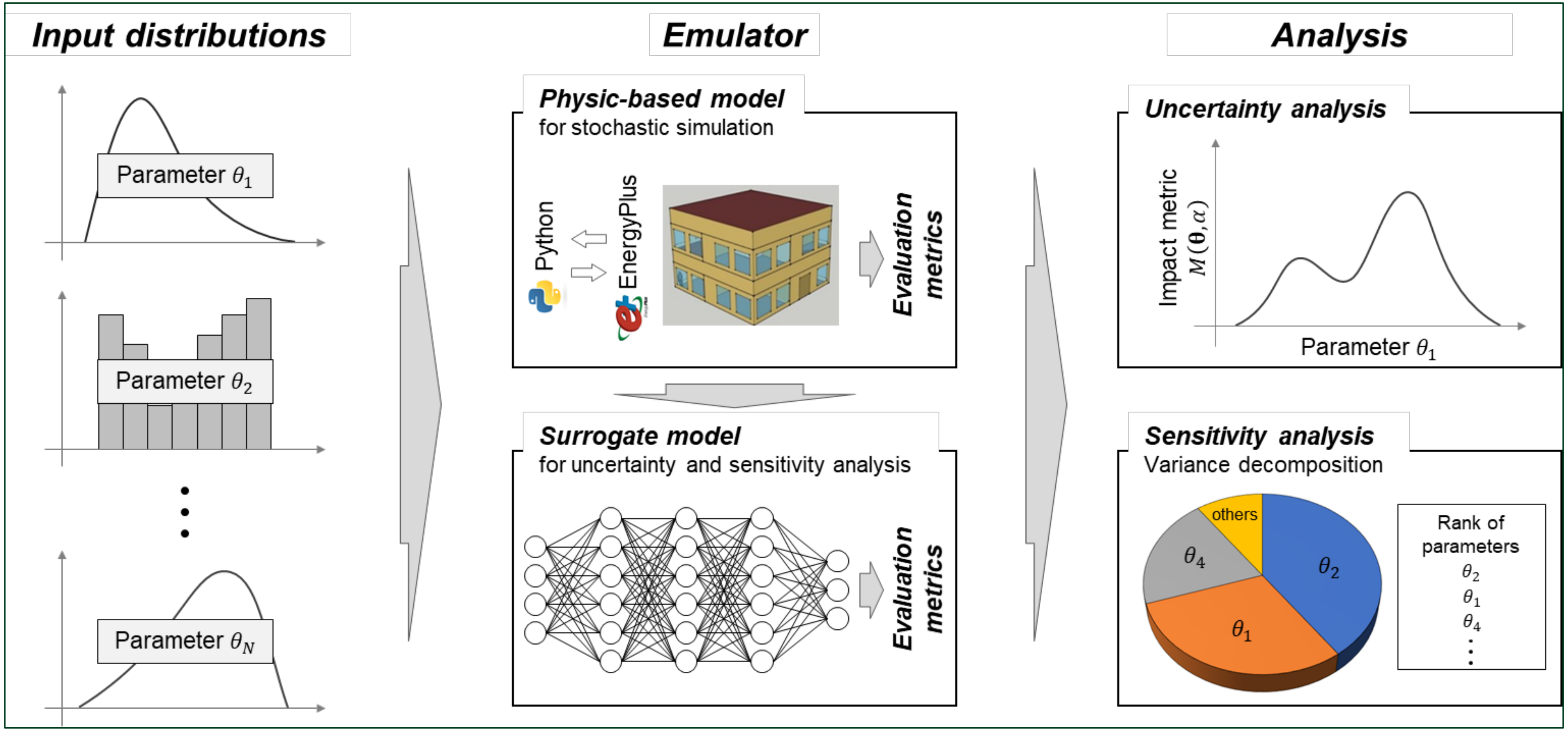
Important sensor systems in terms of building energy/thermal comfort performance



Methods to improve sensor performance for building energy/thermal comfort performance



FY20 ORNL Progress: Framework Overview



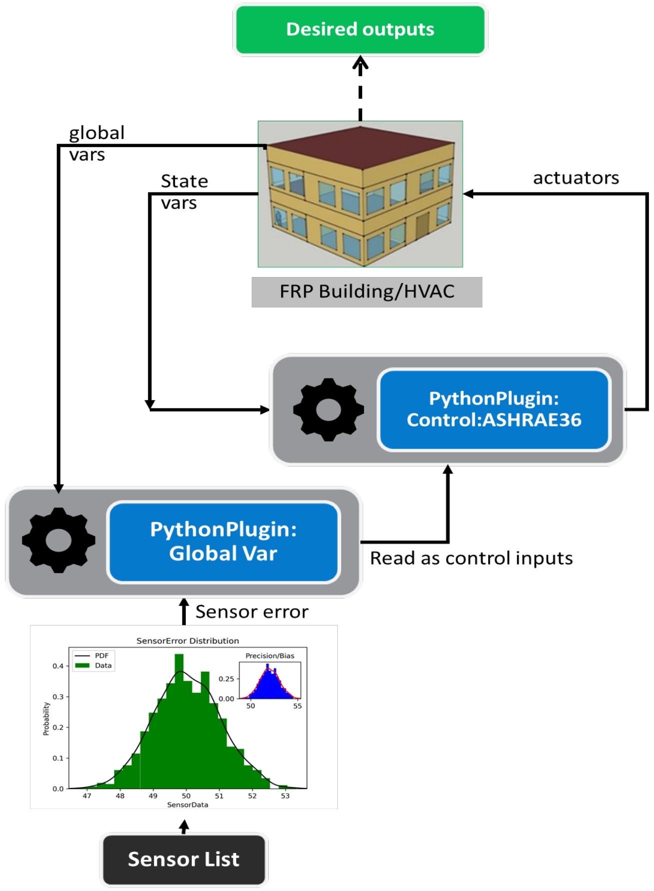
Note: (1) Input distributions are for sensor error samplings for different sensors

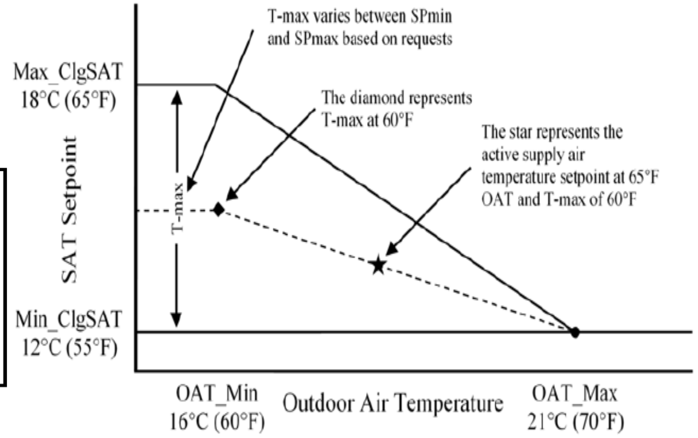
(2) Physic-based emulator includes building/HVAC/controls/sensor errors/sensor locations

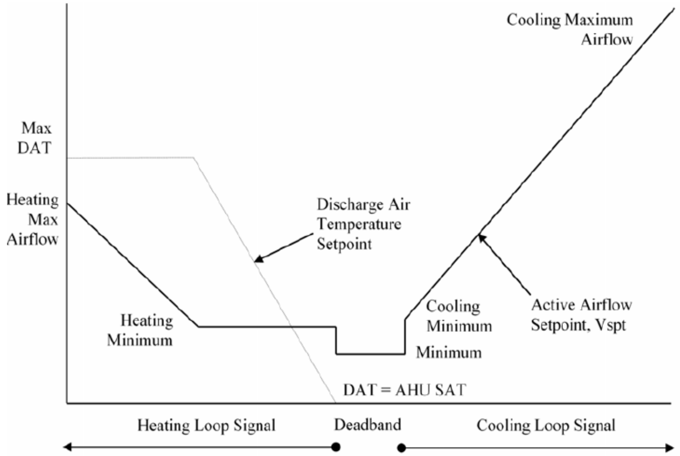
(3) Surrogate model is a representative of physics-based emulator, for sensitivity analysis purpose

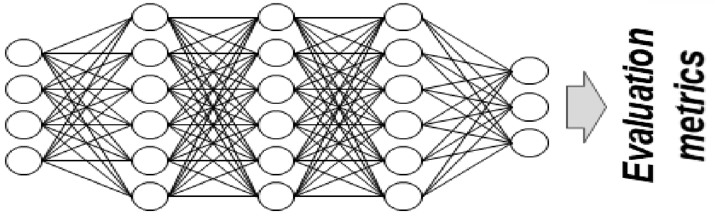
FY21 ORNL Progress: Emulator model development

- Physics-based emulator
  - Leveraging the calibrated EnergyPlus model for ORNL's Flexible Research Platform (FRP).
  - Developed custom modules using Python and the EnergyPlus-Python plugin to evaluate the impact of **(i) sensor location** and **(ii) sensor error** on building control performance
- Surrogate model emulator
  - To enable uncertainty and sensitivity analysis that requires a number of simulation runs
  - Utilize a recurrent neural network (RNN) to make the surrogate model capable of returning the evaluation metrics



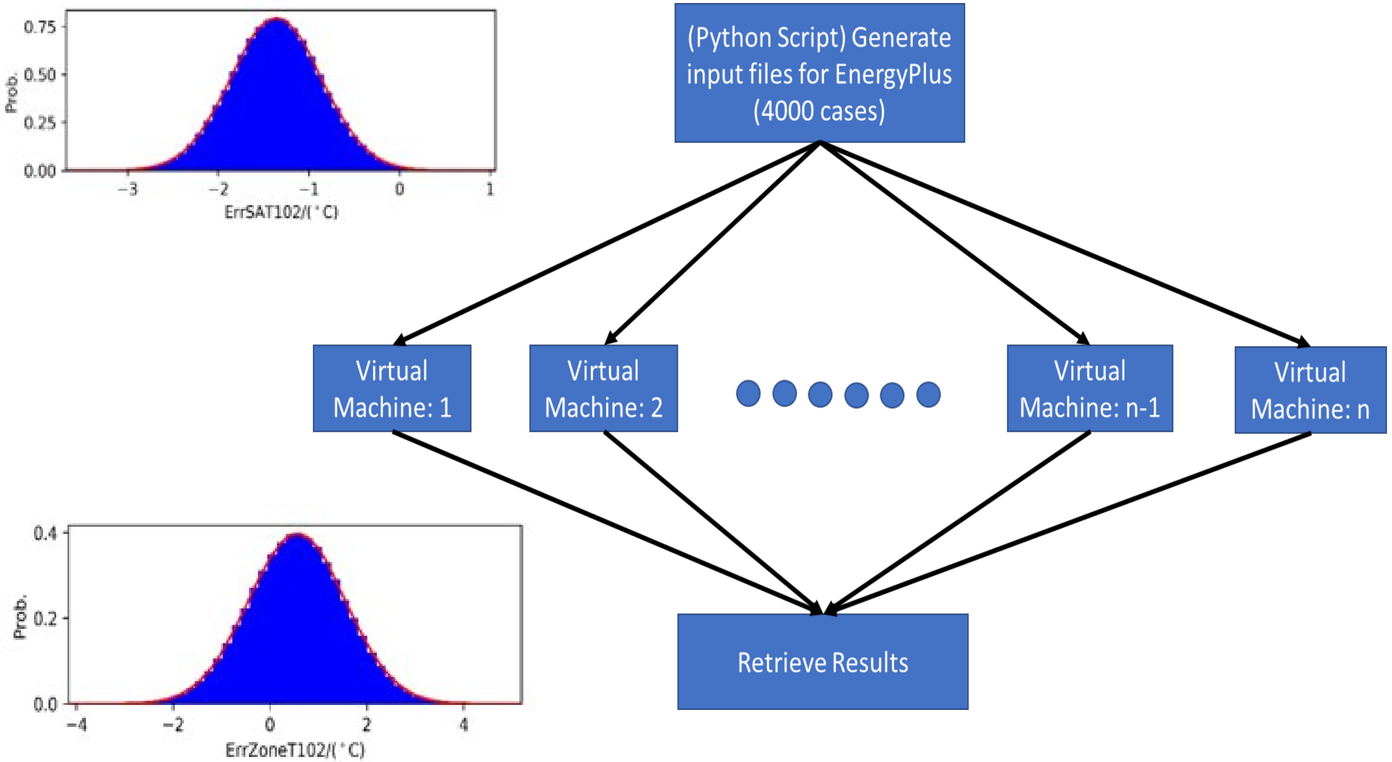






FY21 ORNL Progress: Emulator model development

- **Cloud-based Large-scale Simulation Platform**
  - Based on physical-based emulator
  - Multiple groups: Incorporating sensor types and sensor locations
  - Generating input/output datasets through large scale simulations, for surrogate model creations
  - Each group: 4000 cases x 365 days x24 hours x 60 mins (1 min timestep)


(Python Script) Generate input files for EnergyPlus (4000 cases)

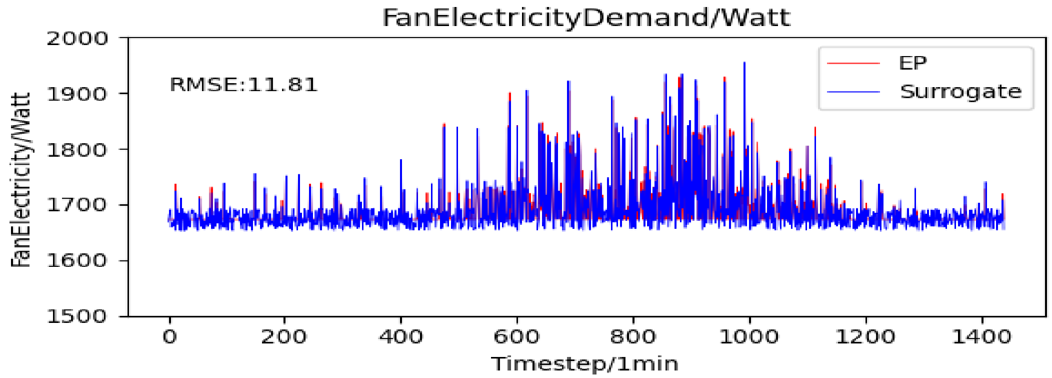
Virtual Machine: 1

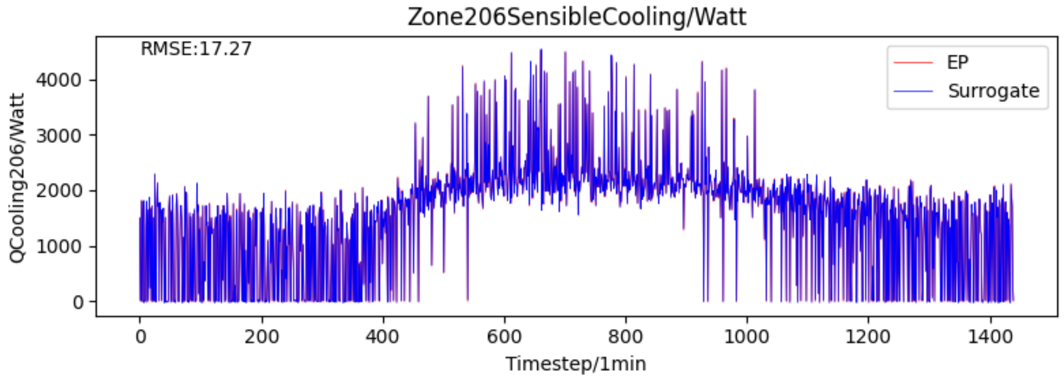
Virtual Machine: 2

Virtual Machine: n-1

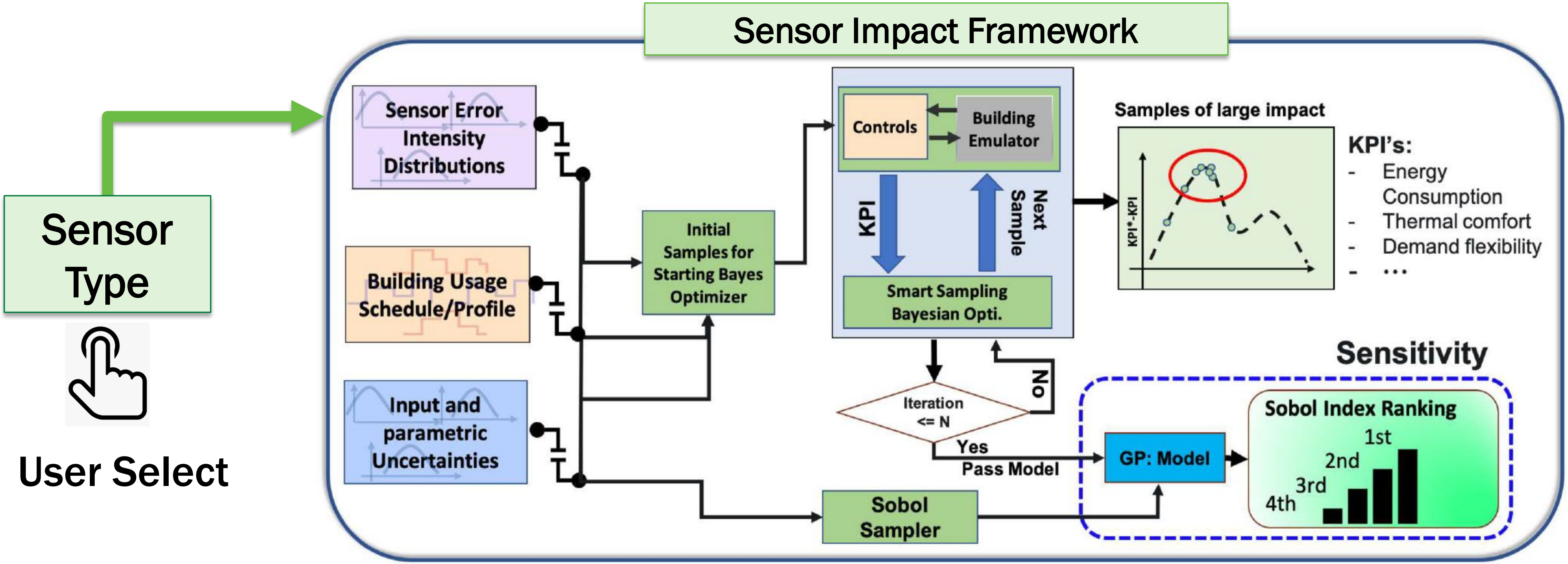
Virtual Machine: n

Retrieve Results





FY20 PNNL Progress: Framework Overview



Sensor Impact Framework

Sensor Type

User Select

Sensor Error Intensity Distributions

Building Usage Schedule/Profile

Input and parametric Uncertainties

Initial Samples for Starting Bayes Optimizer

Controls

Building Emulator

KPI

Next Sample

Smart Sampling Bayesian Opti.

Iteration <= N

No

Yes

Pass Model

Sobol Sampler

Samples of large impact

KPI's:
- Energy Consumption
- Thermal comfort
- Demand flexibility
- …

Sensitivity

GP: Model

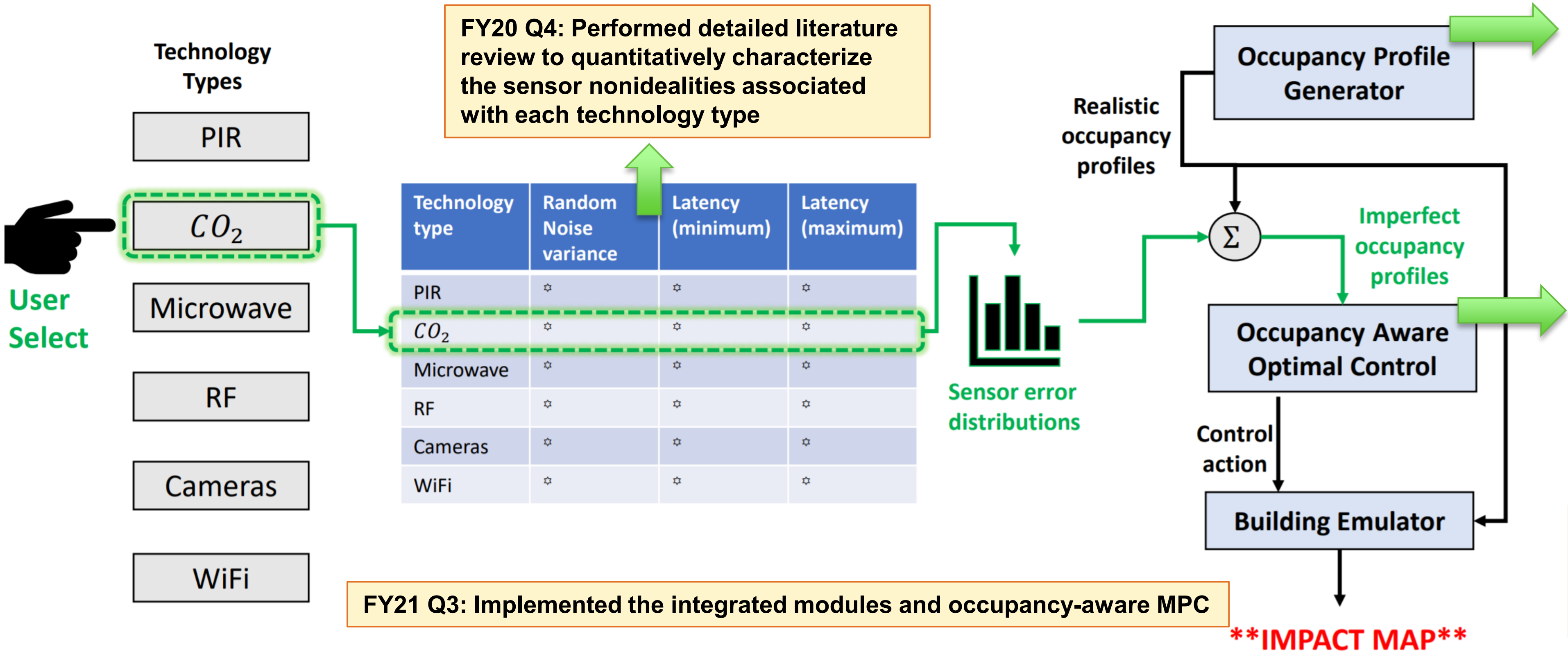
Sobol Index Ranking

- **Approach:**
  - User selected sensor type drives the associated sensor characteristics, to be used for subsequent impact evaluation
  - Simulation-based evaluation using smart sampling methods (e.g., Bayesian Optimization)
  - Bayesian Optimization module automatically generates surrogate models which are used for subsequent sensitivity analysis

FY21 PNNL Progress: Use - Case

Occupancy sensors and Optimization-based control (Model Predictive Control – MPC)

- Large commercial office building
    - 15 zones consisting of single and multi-occupant rooms
    - VAV systems, AHUs, chilled water and heating systems

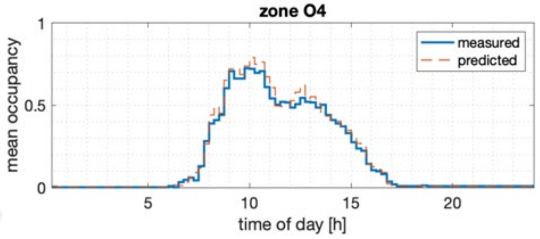


Technology type	Random Noise variance	Latency (minimum)	Latency (maximum)
PIR	✡	✡	✡
CO_2	✡	✡	✡
Microwave	✡	✡	✡
RF	✡	✡	✡
Cameras	✡	✡	✡
WiFi	✡	✡	✡

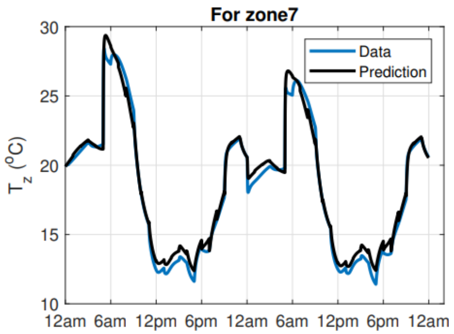
FY20 Q4: Performed detailed literature review to quantitatively characterize the sensor nonidealities associated with each technology type

FY21 Q3: Implemented the integrated modules and occupancy-aware MPC

****IMPACT MAP****



FY21 Q2: Developed probabilistic occupancy models. Validation with real data shows > 85% accuracy



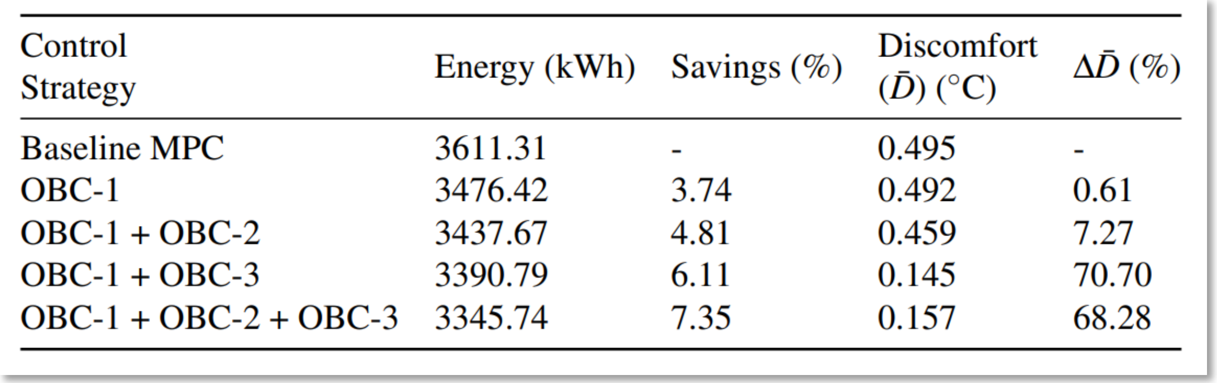
FY21 Q2: Developed and validated reduced order models (ROMs) used in MPC. Achieves 24-hour open loop accuracy of at least 90%

FY21 PNNL Progress: Results and Inferences

Occupancy-aware Control modifies MPC constraints based on building occupancy

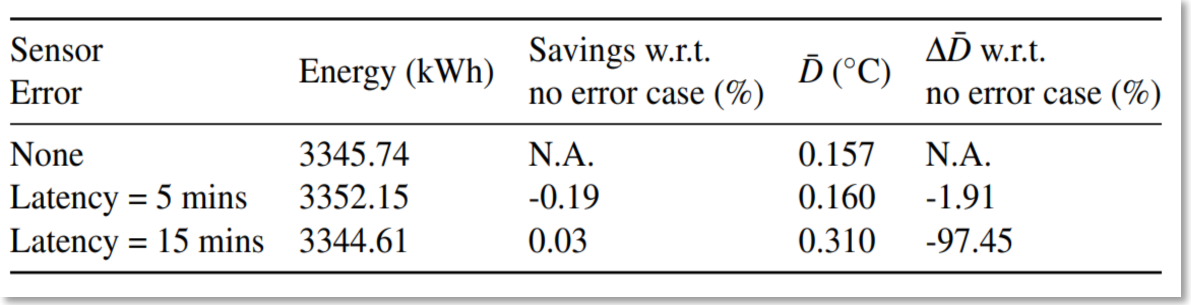
▪ **(Baseline) – MPC with no occupancy information**	▪ **(OBC-2) AHU minimum Air Intake adaptation**
▪ (OBC-1) Temperature bound relaxation	▪ (OBC-3) Zone-level Minimum Air Flow adaptation

- Including occupancy information enables increased energy savings and thermal comfort
- All 3 studied strategies combined yield energy savings of 7.35% (~770 MWh annually) and significantly improve comfort (~68%), without sensor error.
- Measurement latency impacts thermal comfort



Control Strategy	Energy (kWh)	Savings (%)	Discomfort ($\bar{D}$) (°C)	$\Delta\bar{D}$ (%)
Baseline MPC	3611.31	-	0.495	-
OBC-1	3476.42	3.74	0.492	0.61
OBC-1 + OBC-2	3437.67	4.81	0.459	7.27
OBC-1 + OBC-3	3390.79	6.11	0.145	70.70
OBC-1 + OBC-2 + OBC-3	3345.74	7.35	0.157	68.28

Table: Effect of occupancy-aware controls on energy efficiency and thermal comfort (without sensor error) – the combined strategy yields maximum benefit.



Sensor Error	Energy (kWh)	Savings w.r.t. no error case (%)	$\bar{D}$ (°C)	$\Delta\bar{D}$ w.r.t. no error case (%)
None	3345.74	N.A.	0.157	N.A.
Latency = 5 mins	3352.15	-0.19	0.160	-1.91
Latency = 15 mins	3344.61	0.03	0.310	-97.45

Table: Effect of sensor latency on occupancy-aware model predictive control performance (demonstrated result is based on the combined strategy)

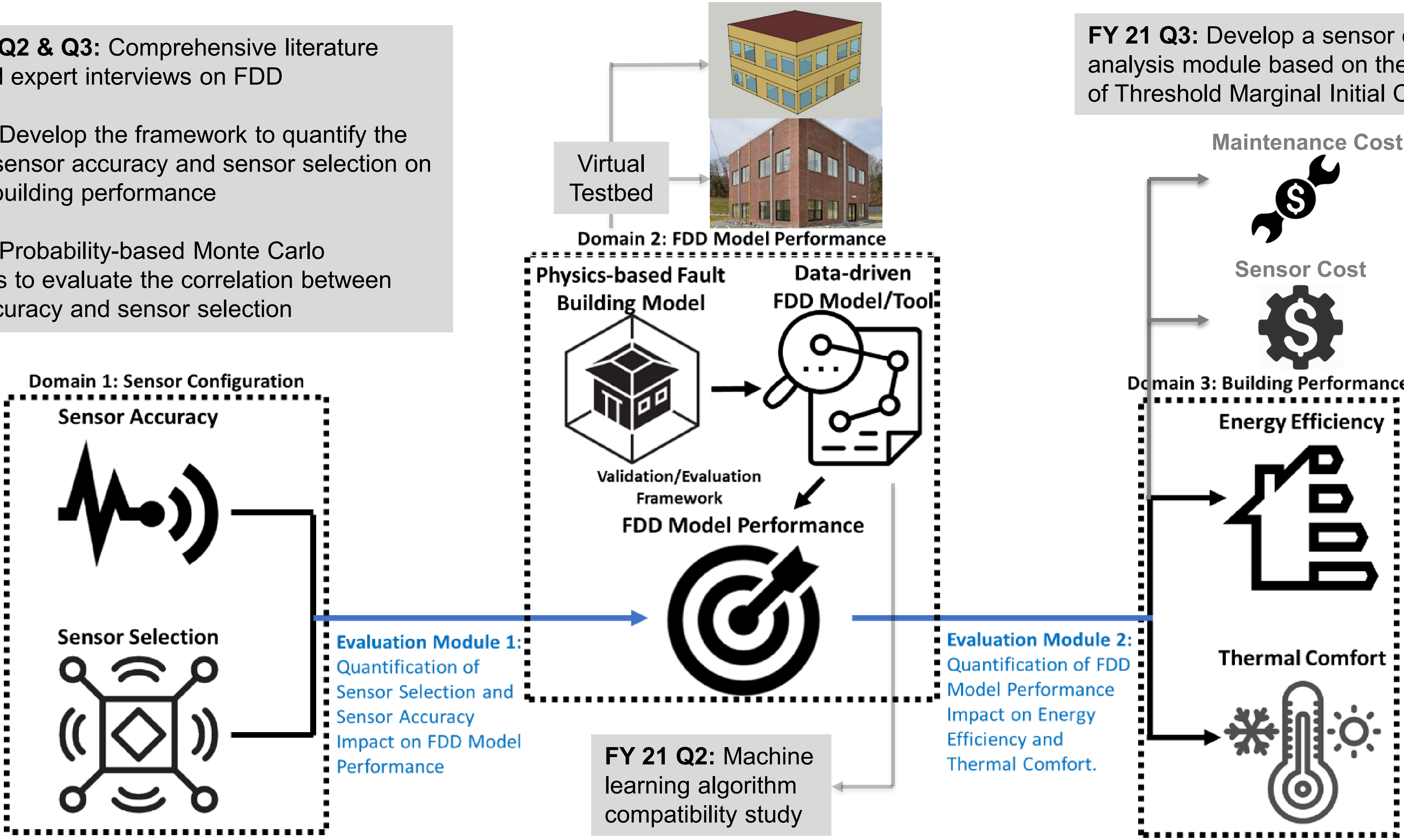
FY20 & FY21 NREL Progress

FY20 Q1, Q2 & Q3: Comprehensive literature review and expert interviews on FDD

FY20 Q4: Develop the framework to quantify the impact of sensor accuracy and sensor selection on FDD and building performance

FY21 Q1: Probability-based Monte Carlo simulations to evaluate the correlation between sensor accuracy and sensor selection

FY 21 Q3: Develop a sensor cost analysis module based on the concept of Threshold Marginal Initial Cost



Virtual Testbed

Domain 1: Sensor Configuration

Sensor Accuracy

Sensor Selection

Evaluation Module 1: Quantification of Sensor Selection and Sensor Accuracy Impact on FDD Model Performance

Domain 2: FDD Model Performance

Physics-based Fault Building Model

Data-driven FDD Model/Tool

Validation/Evaluation Framework

FDD Model Performance

Evaluation Module 2: Quantification of FDD Model Performance Impact on Energy Efficiency and Thermal Comfort.

Domain 3: Building Performance

Energy Efficiency

Thermal Comfort

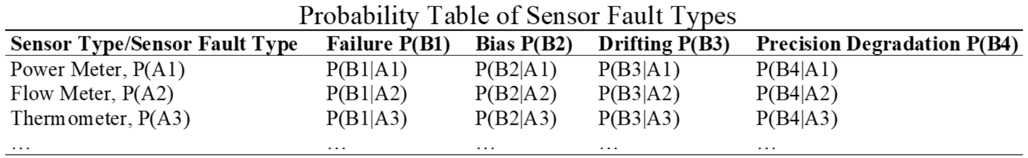
Maintenance Cost

Sensor Cost

FY 21 Q2: Machine learning algorithm compatibility study

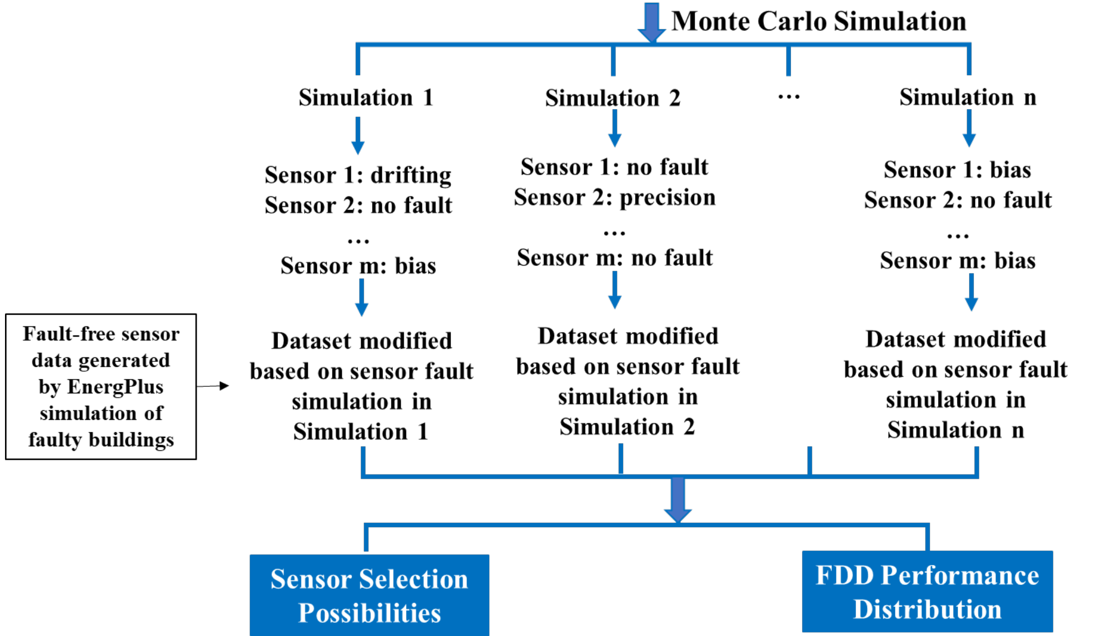
FY21 Q1 & Q2 NREL Progress

FY21 Q1: Probability-based Monte Carlo simulations to evaluate the impact of sensor accuracy on sensor selection and FDD performance



Probability Table of Sensor Fault Types

Sensor Type/Sensor Fault Type	Failure P(B1)	Bias P(B2)	Drifting P(B3)	Precision Degradation P(B4)
Power Meter, P(A1)	P(B1|A1)	P(B2|A1)	P(B3|A1)	P(B4|A1)
Flow Meter, P(A2)	P(B1|A2)	P(B2|A2)	P(B3|A2)	P(B4|A2)
Thermometer, P(A3)	P(B1|A3)	P(B2|A3)	P(B3|A3)	P(B4|A3)
…	…	…	…	…



Monte Carlo Simulation

Simulation 1

Sensor 1: drifting
Sensor 2: no fault
…
Sensor m: bias

Dataset modified based on sensor fault simulation in Simulation 1

Simulation 2

Sensor 1: no fault
Sensor 2: precision
…
Sensor m: no fault

Dataset modified based on sensor fault simulation in Simulation 2

…

Simulation n

Sensor 1: bias
Sensor 2: no fault
…
Sensor m: bias

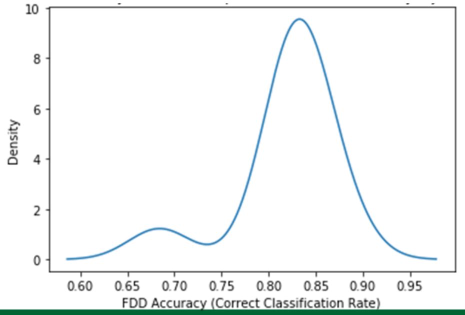
Dataset modified based on sensor fault simulation in Simulation n

Fault-free sensor data generated by EnergPlus simulation of faulty buildings

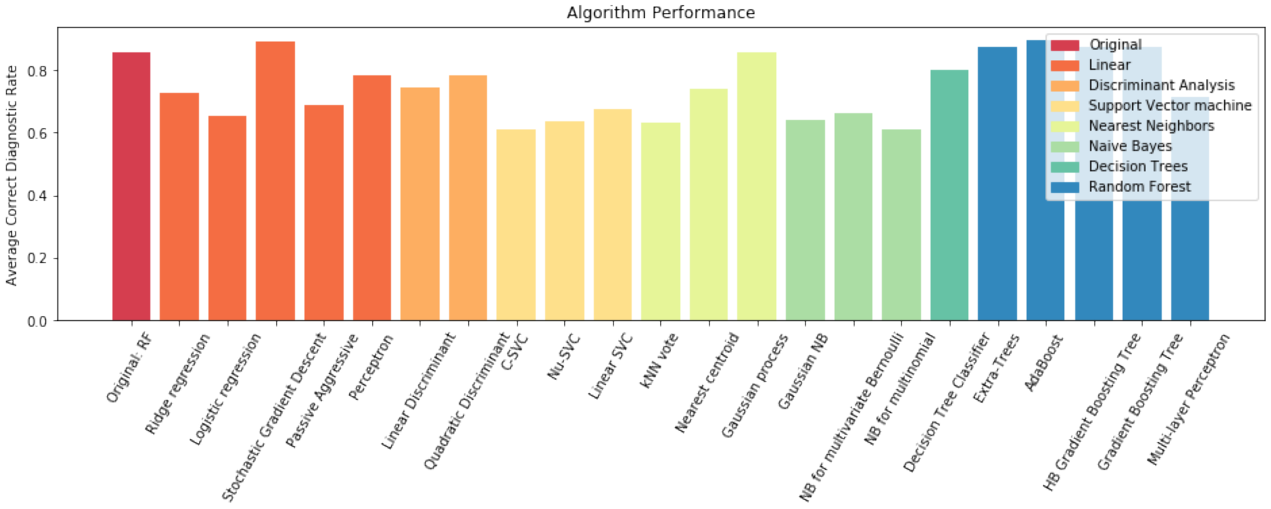
Sensor Selection Possibilities

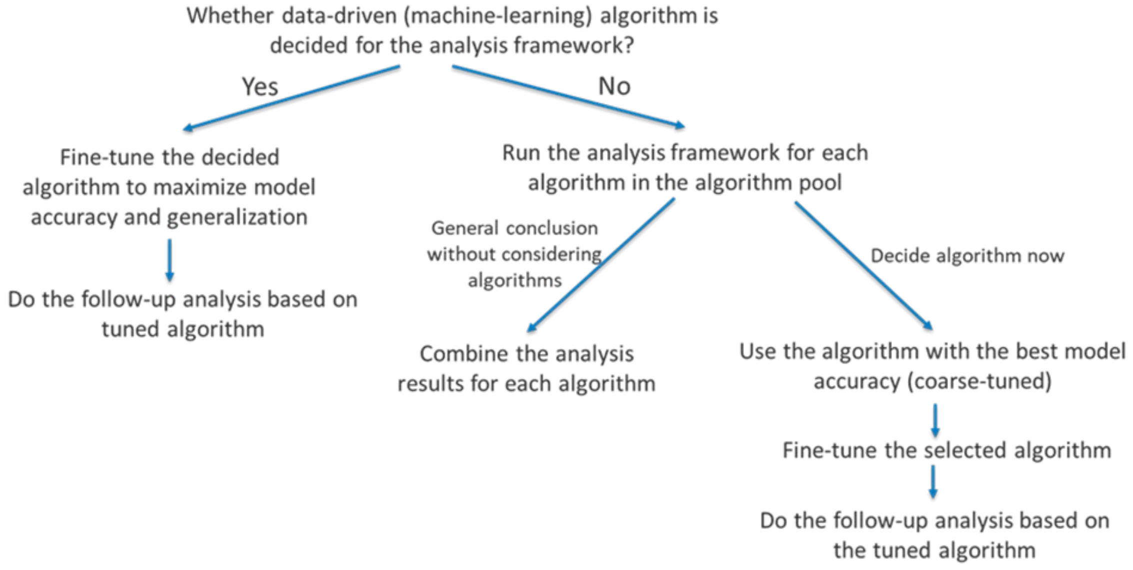
FDD Performance Distribution

Ranking	Sensor	Possibility (%)
1	Fans electricity [W]	99
2	Interior lights electricity [W]	98
3	Rooftop supply fan electric energy [W]	97
4	Node 13 system flow rate [m3/s]	77
5	Node 7 system flow rate [m3/s]	75
6	Node 25 flow rate [m3/s]	73
7	Interior equipment electricity [W]	66
8	Room 106 VAV reheat damper outlet flow rate [m3/s]	63
…	…	



FY21 Q2: Compatibility study of integrating alternative machine learning algorithms into the existing analysis framework





Whether data-driven (machine-learning) algorithm is decided for the analysis framework?

Yes

Fine-tune the decided algorithm to maximize model accuracy and generalization

Do the follow-up analysis based on tuned algorithm

No

Run the analysis framework for each algorithm in the algorithm pool

General conclusion without considering algorithms

Combine the analysis results for each algorithm

Decide algorithm now

Use the algorithm with the best model accuracy (coarse-tuned)

Fine-tune the selected algorithm

Do the follow-up analysis based on the tuned algorithm

FY21 Q3 NREL Progress

Concept of Threshold Marginal Initial Cost

With Actual Sensor Initial Cost Information

$ The “profit ”of installing new sensors for FDD/control, USD/year

The actual initial cost of installing those sensors in USD

Payback Period calculated by initial cost and profit. Compare with the target payback period to make decision

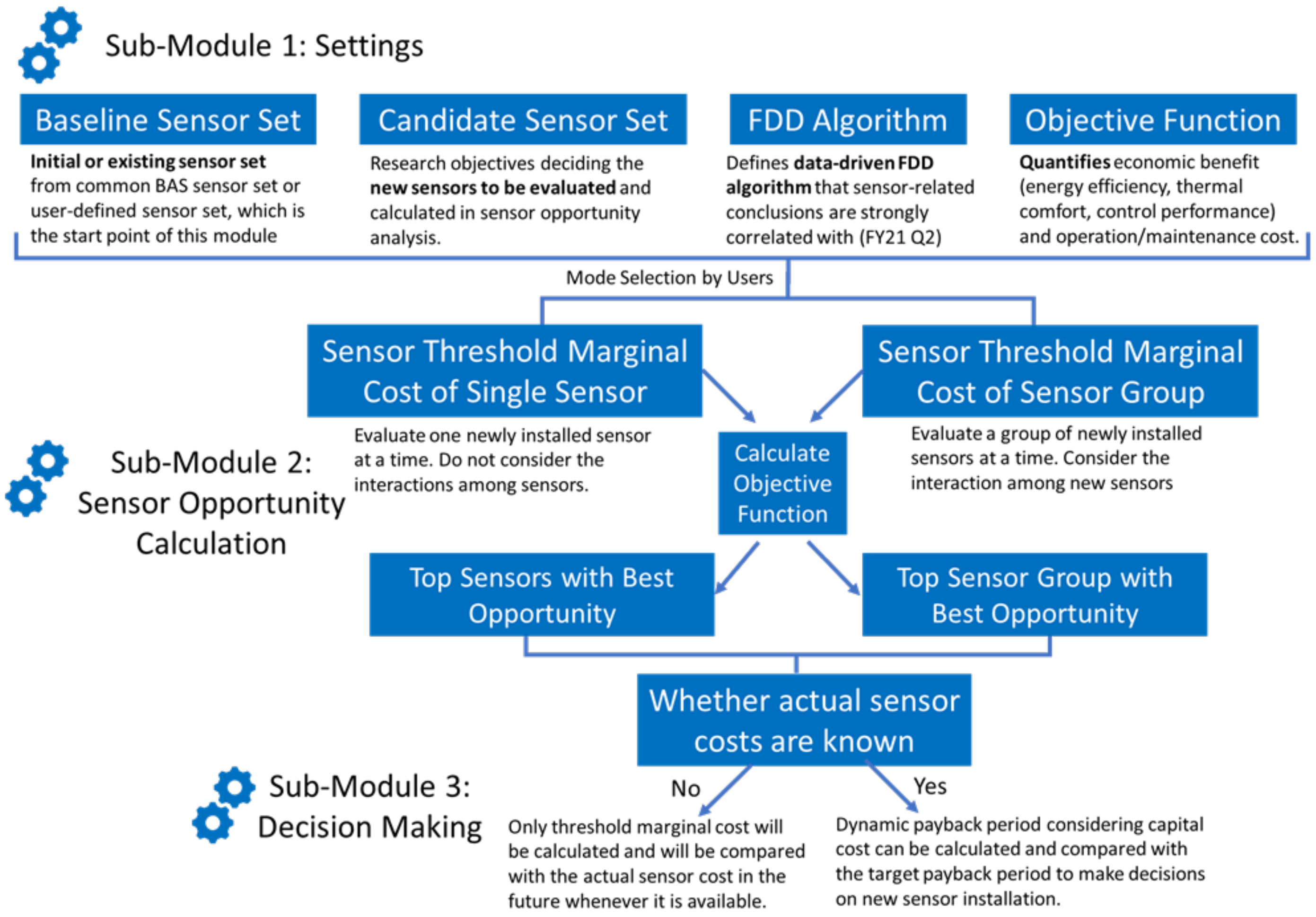
Without Actual Sensor Initial Cost Information

$ The “profit ”of installing new sensors for FDD/control, USD/year

Target payback period that, for example, 3 years or 5 years

Threshold Marginal Initial Cost: Back calculate the threshold of initial cost to achieve the target payback period

Developed Sensor Cost Analysis Module



Sub-Module 1: Settings

Baseline Sensor Set

Initial or existing sensor set from common BAS sensor set or user-defined sensor set, which is the start point of this module

Candidate Sensor Set

Research objectives deciding the **new sensors to be evaluated** and calculated in sensor opportunity analysis.

FDD Algorithm

Defines **data-driven FDD algorithm** that sensor-related conclusions are strongly correlated with (FY21 Q2)

Objective Function

Quantifies economic benefit (energy efficiency, thermal comfort, control performance) and operation/maintenance cost.

Mode Selection by Users

Sub-Module 2: Sensor Opportunity Calculation

Sensor Threshold Marginal Cost of Single Sensor

Evaluate one newly installed sensor at a time. Do not consider the interactions among sensors.

Sensor Threshold Marginal Cost of Sensor Group

Evaluate a group of newly installed sensors at a time. Consider the interaction among new sensors

Calculate Objective Function

Top Sensors with Best Opportunity

Top Sensor Group with Best Opportunity

Sub-Module 3: Decision Making

Whether actual sensor costs are known

No

Only threshold marginal cost will be calculated and will be compared with the actual sensor cost in the future whenever it is available.

Yes

Dynamic payback period considering capital cost can be calculated and compared with the target payback period to make decisions on new sensor installation.

Achievement

- **Published: 2 journal articles, 1 conference paper, 3 technical reports**
  - Zhang, L., Leach, M., Bae, Y., Cui, B., Bhattacharya, S., Lee, S., ... & Kuruganti, T. (2021). Sensor Impact Evaluation and Verification for Fault Detection and Diagnostics in Building Energy Systems: A Review. Advances in Applied Energy, 100055.
  - Zhang, L., Frank, S., Kim, J., Jin, X., & Leach, M. (2020). A systematic feature extraction and selection framework for data-driven whole-building automated fault detection and diagnostics in commercial buildings. *Building and Environment*, 107338
  - S. Bhattacharya, H. Sharma, and V. Adetola, “Towards Learning-Based Architectures for Sensor Impact Evaluation in Building Controls,” in Proc. 12th ACM Int. Conf. Future Energy Syst. (e-Energy 2021) (AMLIES 2021Workshop), Torino, Italy, Jun. 2021
  - Im, Piljae, Bae, Yeonjin, Cui, Borui, Lee, Seungjae, Bhattacharya, Saptarshi, Adetola, Veronica, Vrabie, Draguna, Zhang, Liang, & Leach, Matt. (2020) *Sensor Impacts Evaluation and Verification: Expert Interview Responses*. United States. doi:10.2172/1648918.
  - Im, Piljae, Bae, Yeonjin, Cui, Borui, Lee, Seungjae, Bhattacharya, Saptarshi, Adetola, Veronica, Vrabie, Draguna, Zhang, Liang, & Leach, Matt. (2020) *Literature Review for Sensor Impact Evaluation and Verification Use Cases - Building Controls and Fault Detection and Diagnosis (FDD)*. United States. doi:10.2172/1649168.
  - Bae, Yeonjin, Cui, Borui, Joe, Jaewan, Im, Piljae, Adetola, Veonica, Zhang, Liang, Leach, Matt, & Kuruganti, Teja. (2020) *Review: Sensor Impact on Building Controls and Automatic Fault Detection and Diagnosis (AFDD)*. United States. doi:10.2172/1671427.

ORNL/LTR-2021/XXX

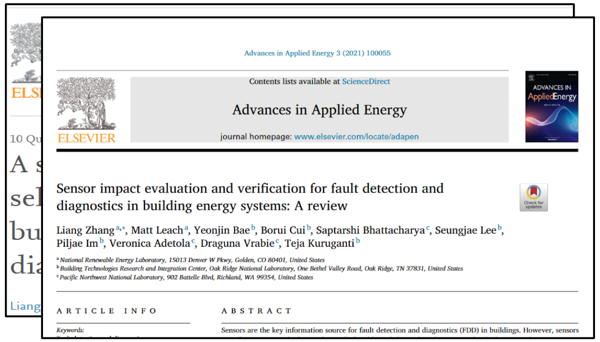
Surrogate Model of Flexible Research Platform EnergyPlus Models to Enable Sensitivity Analysis

Yanfei Li
Yeonjin Bae
Piljae Im

June 2021

OAK RIDGE
National Laboratory

ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY
Draft. Not approved for public release.



Advances in Applied Energy 3 (2021) 100055

Contents lists available at ScienceDirect

Advances in Applied Energy

journal homepage: www.elsevier.com/locate/adapen

ELSEVIER

Sensor impact evaluation and verification for fault detection and diagnostics in building energy systems: A review

Liang Zhang[a,*], Matt Leach[a], Yeonjin Bae[b], Borui Cui[b], Saptarshi Bhattacharya[c], Seungjae Lee[b], Piljae Im[b], Veronica Adetola[c], Draguna Vrabie[c], Teja Kuruganti[b]

[a] National Renewable Energy Laboratory, 15013 Denver W Pkwy, Golden, CO 80401, United States
[b] Building Technologies Research and Integration Center, Oak Ridge National Laboratory, One Bethel Valley Road, Oak Ridge, TN 37831, United States
[c] Pacific Northwest National Laboratory, 902 Battelle Blvd, Richland, WA 99354, United States

ARTICLE INFO

Keywords:

ABSTRACT

Sensors are the key information source for fault detection and diagnostics (FDD) in buildings. However, sensors

- **Submitted 1 journal article, 1 conference paper, 1 technical report**
  - Bae, Y., Bhattacharya, S., Cui, B., Lee, S., Li, Y., Zhang, L., Im, P., ... & Kuruganti, T. (2021). Sensor Impact Evaluation and Verification for Building Controls: A Critical Review. Advances in Applied Energy (under 2nd review)
  - Li, Y., Lee, S., Cui, B., Bae, Y., Im, P. (2021) An Underline Issue of Smart Buildings: Sensor Fault Impacts on Building Control Performance

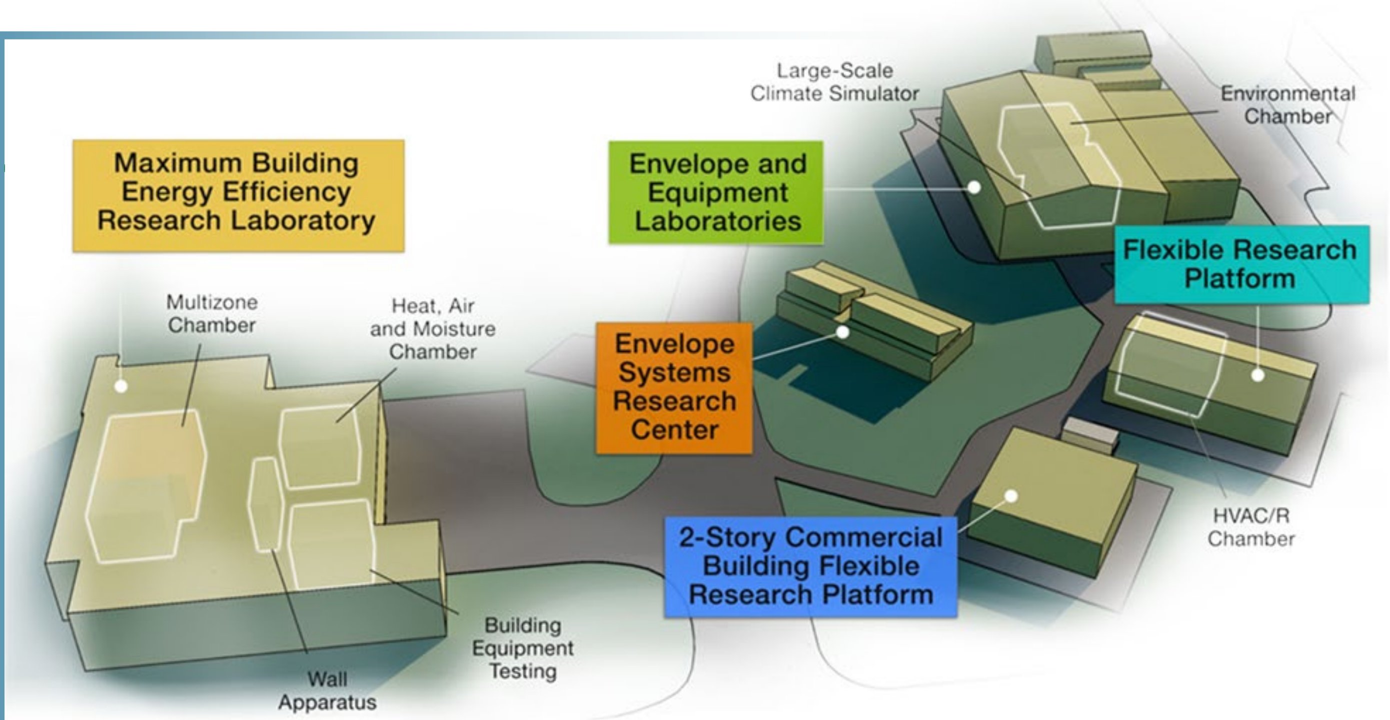
Remaining Project Work

- Q4 deliverables (FY21)
  - ORNL: Demonstration of preliminary sensitivity analysis for heuristic controllers
  - PNNL:
    - Perform comprehensive impact evaluation (different weather scenarios, sensor characteristics etc.)
    - Extend to ASHRAE Guideline 36-based heuristic controls
  - NREL: Develop plan to integrate control-focused findings and workflow(s) to FDD evaluation and verification framework

- Remaining project work (FY22)
  - ORNL: Extension of use-cases and demonstration of sensitivity analysis and uncertainty quantification in different sensor sets.
  - PNNL: Extension to other building sensors and performance metrics (e.g., demand flexibility)
  - NREL: Integrate control-focused findings and workflow(s) to FDD evaluation and verification framework

Thank you

Oak Ridge National Laboratory
Piljae Im, R&D Staff
(865)-241-2312 | imp1@ornl.gov



ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results
238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget: Total: $2,600,000, **ORNL: $1,350,000, PNNL: $750,000, NREL: $450,000**

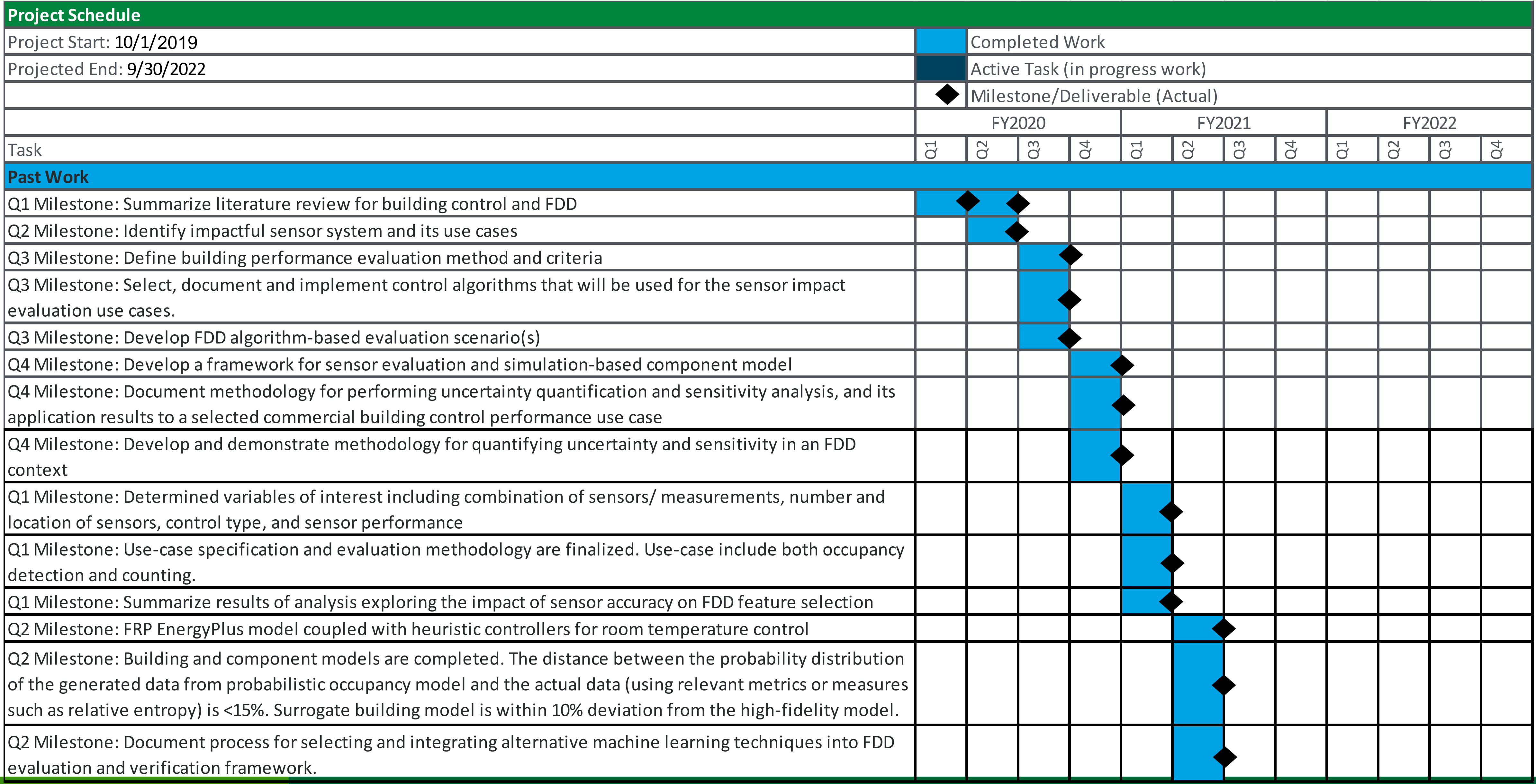
Variances: N/A

Cost to Date: **41% of the project budget has been expended to date.**

Additional Funding: N/A

Budget History					
10/1– FY 2020 (past)		FY 2021 (current)		FY 2022 – 9/30 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$900,000		$850,000		$850,000	

Project Plan and Schedule



Project Schedule

Project Start: 10/1/2019
Projected End: 9/30/2022

🟦 Completed Work
■ Active Task (in progress work)
◆ Milestone/Deliverable (Actual)

	FY2020				FY2021				FY2022			
Task	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Summarize literature review for building control and FDD	🟦◆	🟦◆										
Q2 Milestone: Identify impactful sensor system and its use cases		🟦◆										
Q3 Milestone: Define building performance evaluation method and criteria			🟦◆									
Q3 Milestone: Select, document and implement control algorithms that will be used for the sensor impact evaluation use cases.			🟦◆									
Q3 Milestone: Develop FDD algorithm-based evaluation scenario(s)			🟦◆									
Q4 Milestone: Develop a framework for sensor evaluation and simulation-based component model				🟦◆								
Q4 Milestone: Document methodology for performing uncertainty quantification and sensitivity analysis, and its application results to a selected commercial building control performance use case				🟦◆								
Q4 Milestone: Develop and demonstrate methodology for quantifying uncertainty and sensitivity in an FDD context				🟦◆								
Q1 Milestone: Determined variables of interest including combination of sensors/ measurements, number and location of sensors, control type, and sensor performance					🟦◆							
Q1 Milestone: Use-case specification and evaluation methodology are finalized. Use-case include both occupancy detection and counting.					🟦◆							
Q1 Milestone: Summarize results of analysis exploring the impact of sensor accuracy on FDD feature selection					🟦◆							
Q2 Milestone: FRP EnergyPlus model coupled with heuristic controllers for room temperature control						🟦◆						
Q2 Milestone: Building and component models are completed. The distance between the probability distribution of the generated data from probabilistic occupancy model and the actual data (using relevant metrics or measures such as relative entropy) is <15%. Surrogate building model is within 10% deviation from the high-fidelity model.						🟦◆						
Q2 Milestone: Document process for selecting and integrating alternative machine learning techniques into FDD evaluation and verification framework.						🟦◆						

Project Plan and Schedule (cont.)

Project Schedule												
Project Start: 10/1/2019	🟦	Completed Work										
Projected End: 9/30/2022	■	Active Task (in progress work)										
	◆	Milestone/Deliverable (Actual)										
	FY2020				FY2021				FY2022			
Task	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q3 Milestone: Surrogate model of FRP EnergyPlus models to enable sensitivity analysis							🟦◆					
Q3 Milestone: Sensor impact evaluation tools are implemented for occupancy sensing use-case.							🟦◆					
Q3 Milestone: Summarize results of sensor cost analysis							🟦◆					
Current/Future Work												
Q4 Milestone: Demonstration of preliminary sensitivity analysis for heuristic controllers								■				
Q4 Milestone: Sensor impact evaluation tools are implemented for occupancy sensing use-case.								■				
Q4 Milestone: Develop plan to integrate control-focused findings and workflow(s) into FDD evaluation and verification framework								■				
FY22 Milestone: Extension of use-cases and demonstration of sensitivity analysis and uncertainty quantification									■	■	■	■
FY22 Milestone: Extension to other building sensors and performance metrics (e.g., demand flexibility)									■	■	■	■
FY22 Milestone: Integrate control-focused findings and workflow(s) to FDD evaluation and verification framework									■	■	■	■