U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Emerging Technologies for Smart Buildings

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**Smart Buildings Workshop, University of Nebraska**

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# Who Supports Buildings Energy Efficiency R&D (Federal)?

**Fundamental Research** → **First Commercialization** → **Market Penetration**

## Building Technologies Office (BTO)

**Emerging Technologies (R&D)**

**Commercial Buildings Integration**

**Residential Buildings Integration**

**Codes & Standards**

NSF

arpa·e

U.S. DEPARTMENT OF ENERGY | Office of Science

DEPARTMENT OF THE NAVY ONR Science & Technology

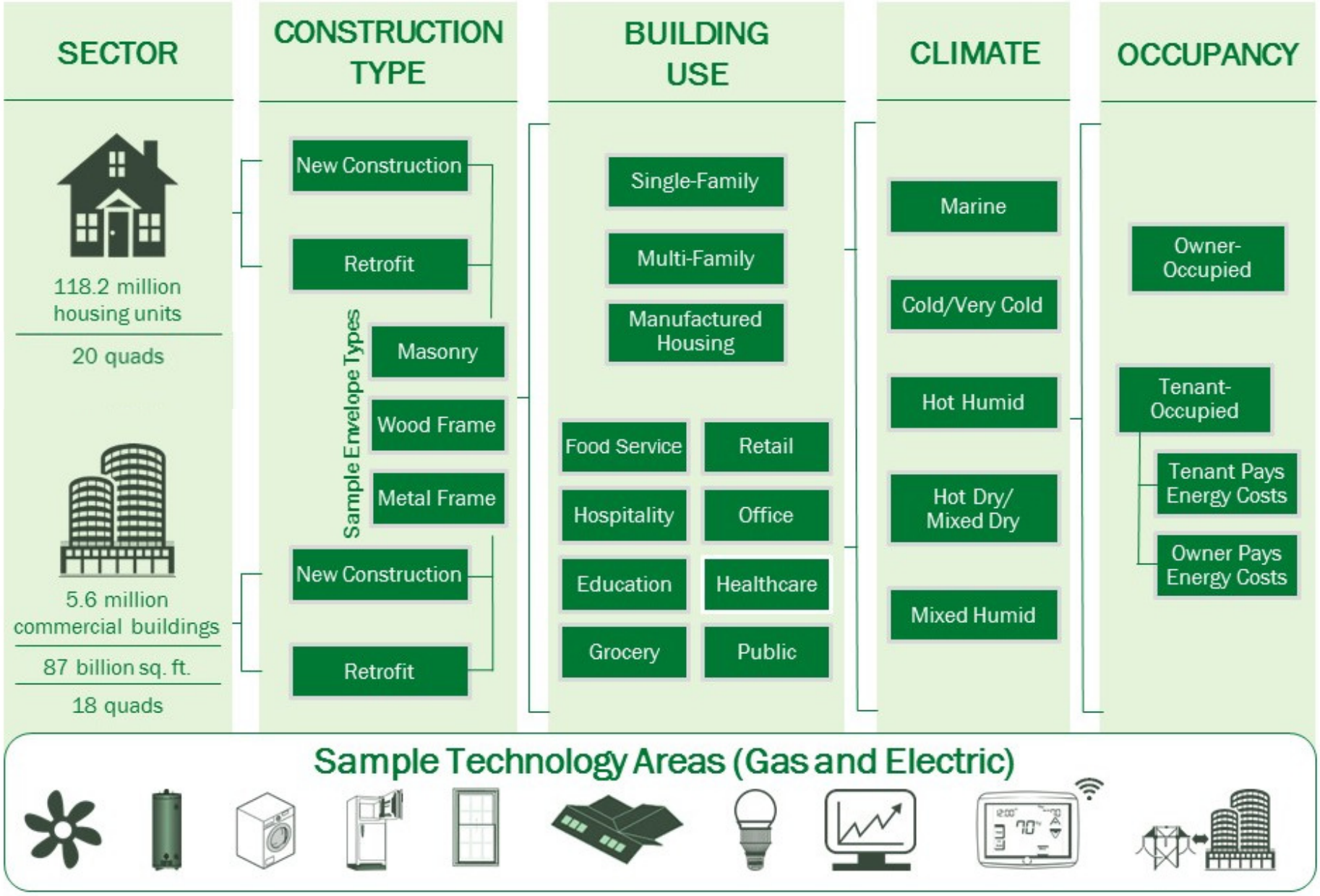
FEMP Federal Energy Management Program

SERDP DOD • EPA • DOE

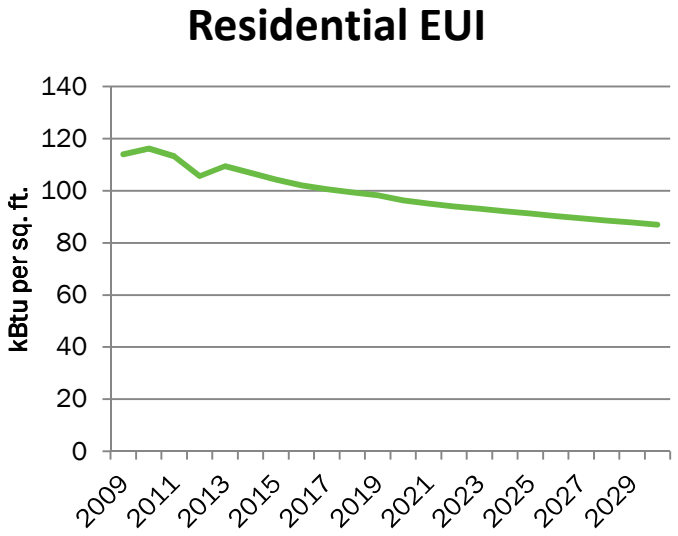
ESTCP

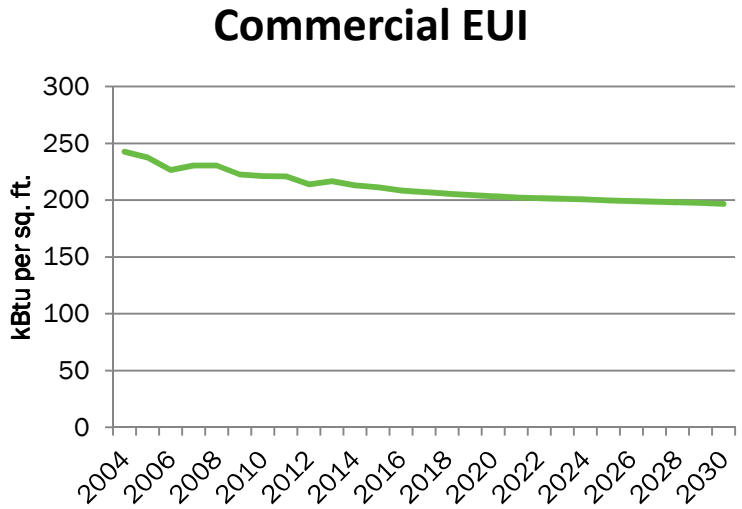
GPG Green Proving Ground Program

# The Complexity of Energy Use in the Buildings Market



# BTO Goal: Reduce Building Energy Use by 30% by 2030




**2030 sector-wide goal:** reduce energy use 30% per sq. ft.

**Long term goal:** reduce energy use 50% per sq. ft.

**Metric:** energy use intensity (EUI)

**Baseline:** 2010

**Rationale:** allows comparisons across fuel types, building types, building sectors, end uses, that are more internationally relevant.

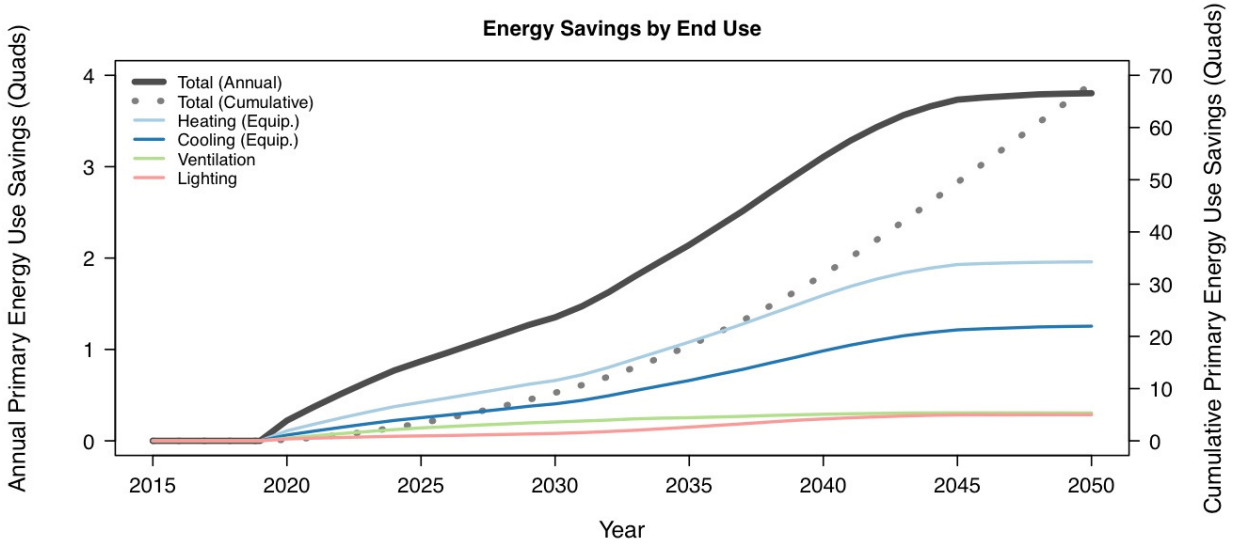
# Why Do Smart Building Technologies Matter?

- **Current state-of-the-art:**

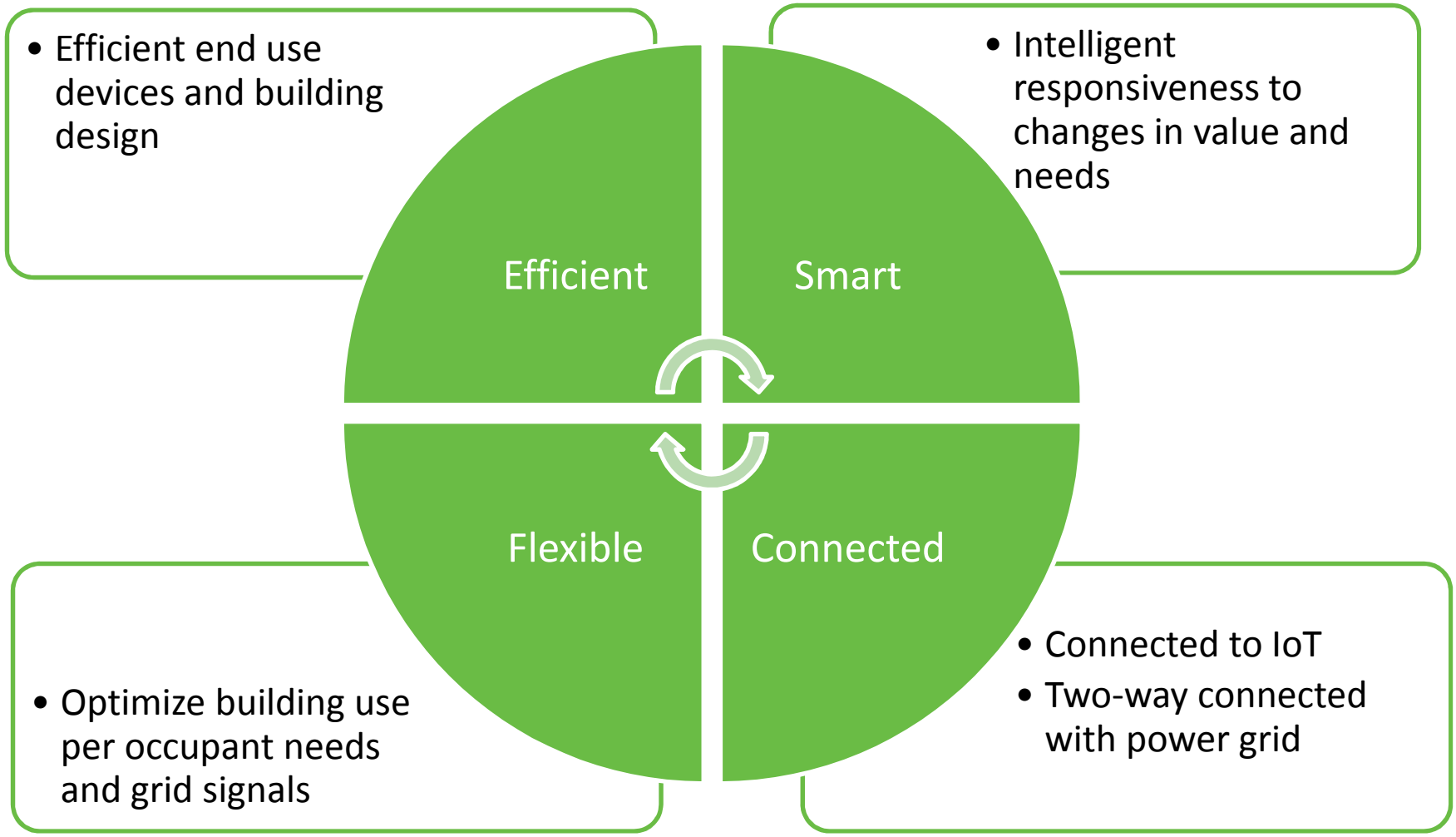
  Aggregated annual energy savings of 29%, or ~4-5% of total national energy consumption through implementation of efficiency measures to optimize programmable settings and to detect and diagnose operational problems in the commercial sector alone.

- **Future technological development:**

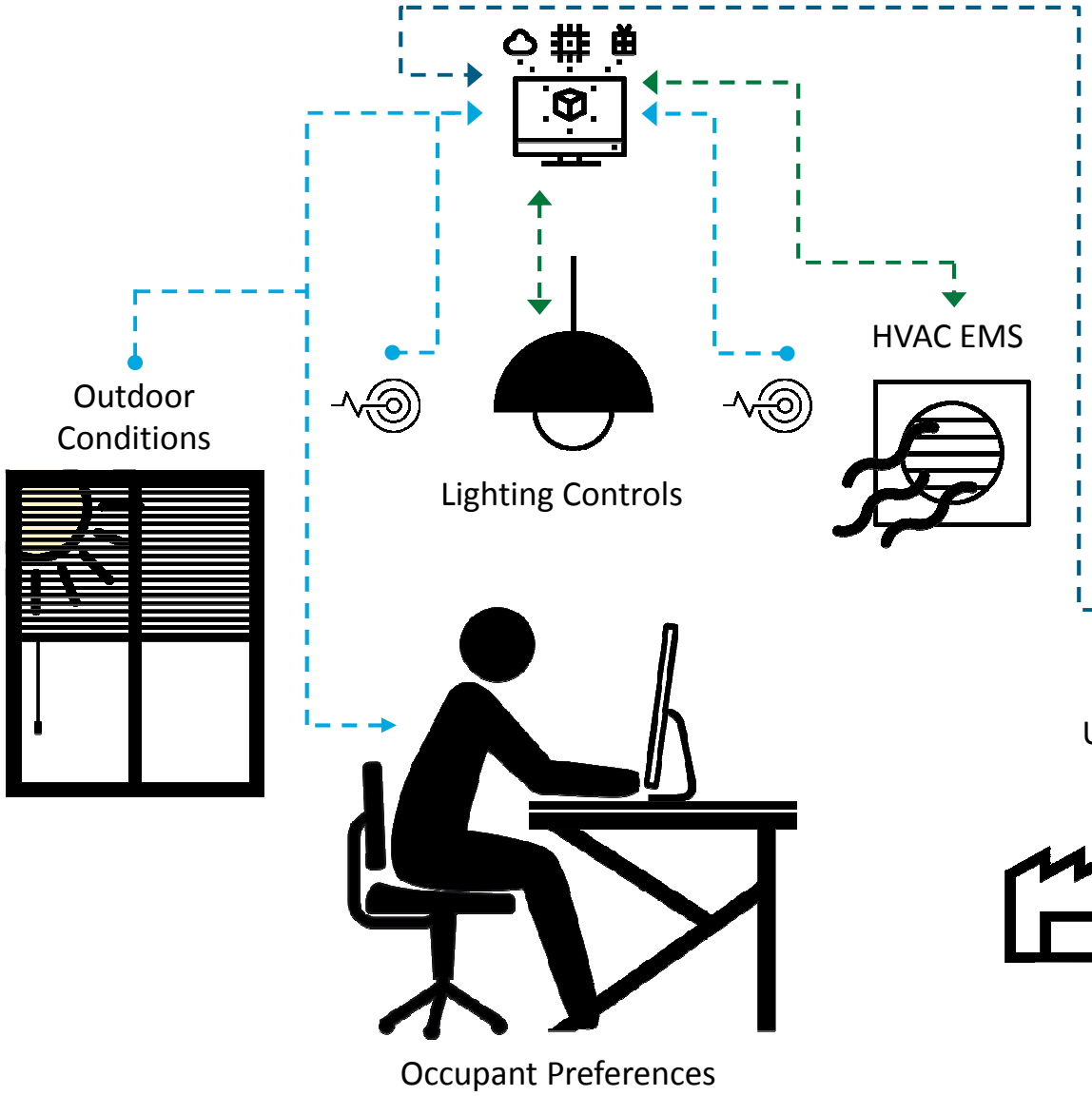
  Additional savings of ~10% of total building energy consumption in 2017 from more sophisticated analytics and control strategies, or 1.4 quads savings in 2030 and 3.8 quads in 2050.



# Grid-interactive Efficient Buildings



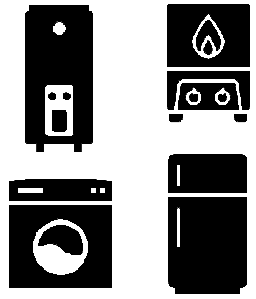
# Smart technologies enabling flexible building loads



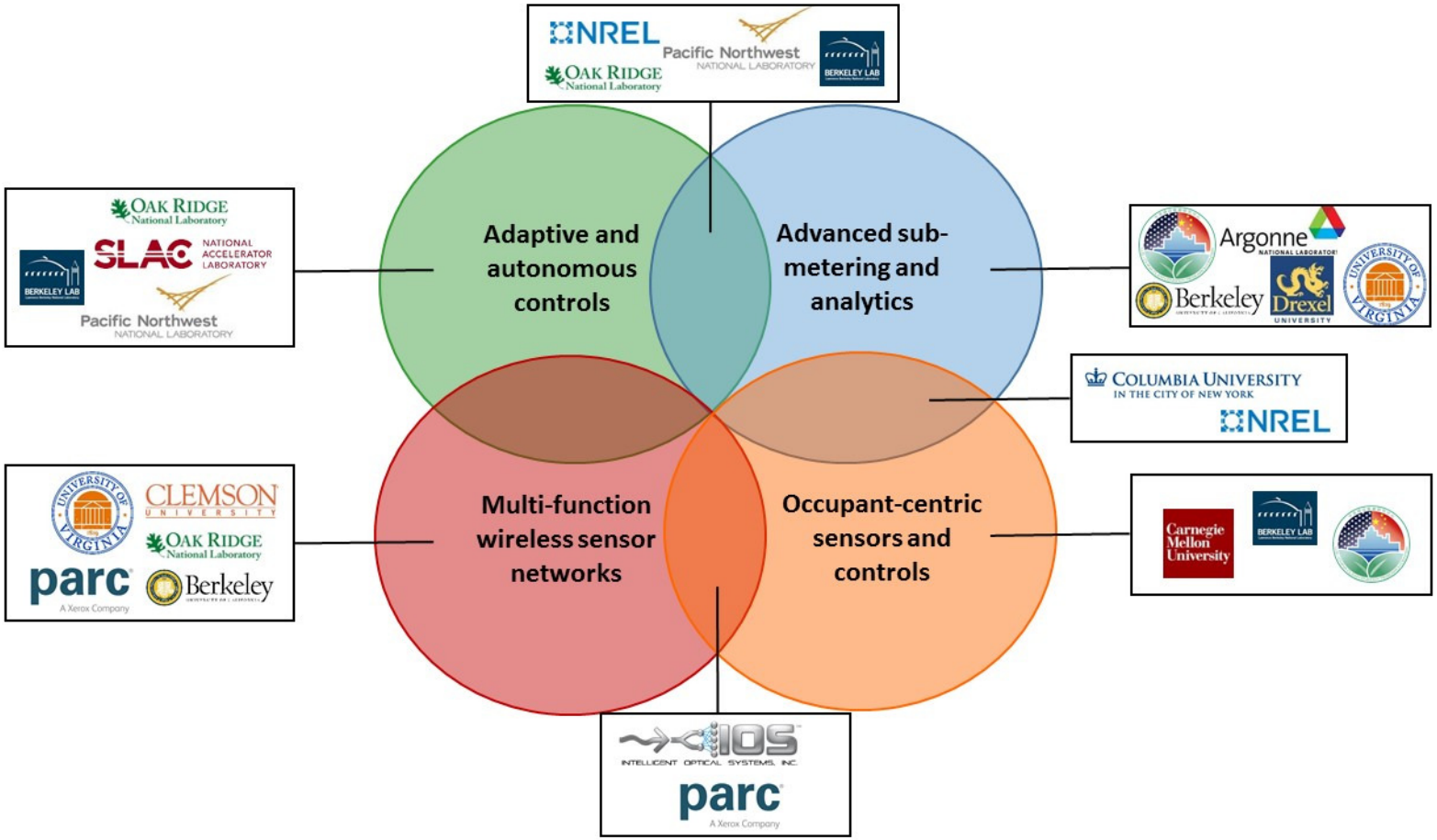

- Interoperable, integrated systems.
- Continuously optimized operation for maximum comfort and efficiency.
- Grid-responsive (e.g. demand response).

Sensor/Occupant Inputs
Control Signal
Utility Communication

***Applicable to Other Technologies, e.g.:***



# BTO Sensors and Controls R&D Portfolio




**Cross-cutting strategies:**

- Advanced Materials and Manufacturing
- Virtual Sensing and Data Analytics
- Data Taxonomy, Models, and Mapping
- Building Energy Modeling

# BTO's Portfolio Approach to Smart Buildings

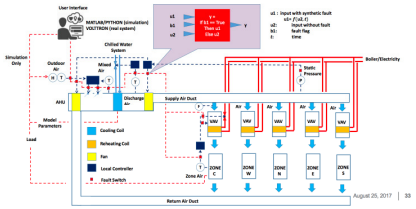
## SOFTWARE DEVELOPMENT

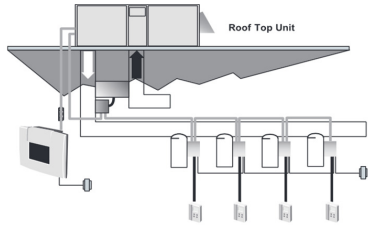
*Co-funded with Building Energy Modeling sub-program to support controls development through long-term software improvements*


EnergyPlus

## BENCHMARKING

*Development of testing frameworks/ methods & curated datasets to spur innovation by establishing expected performance*






## TECHNOLOGY DEVELOPMENT

*Optimization of building operations through competitive, early-stage R&D across programmatic focus areas*


## FIELD VALIDATION

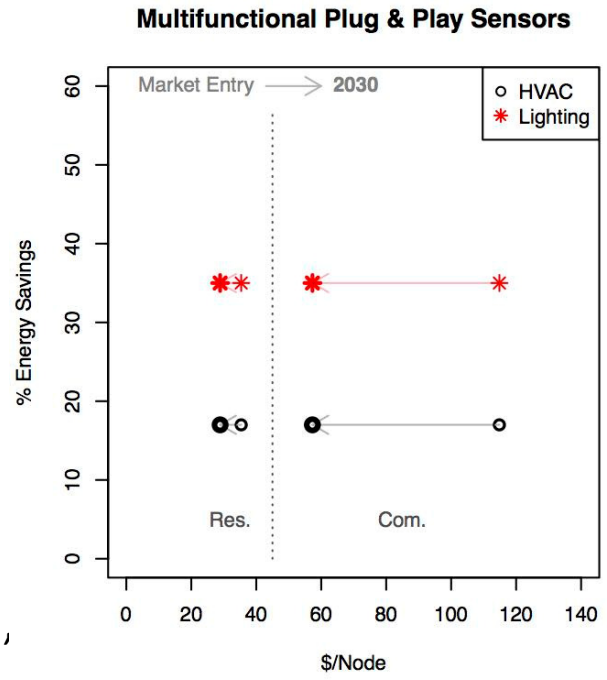
*Verification of technologies / strategies, increasing confidence in the value of intelligence and energy flexibility*

# Multi-Functional, Plug-and-Play Wireless Sensor Networks

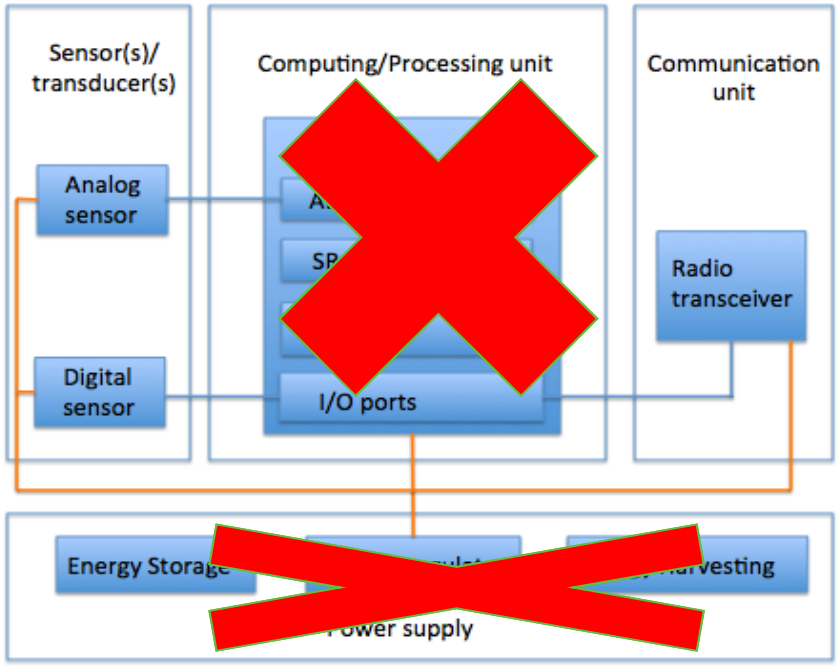
| Focus Area | Relevant ECM | Sector | Installed Cost | | Energy Performance (HVAC, Lighting) | | 2030 Energy Savings Technical Potential |
|---|---|---|---|---|---|---|---|
| | | | Market Entry | 2030 Target | Market Entry | 2030 Goal | |
| Wireless Sensor Networks | Plug-and-play sensors | Residential | $35/ node | $29/ node | 17%, 35% | | 1.14 quads |
| | | Commercial | $115/ node | $57/ node | | | 0.99 quads |

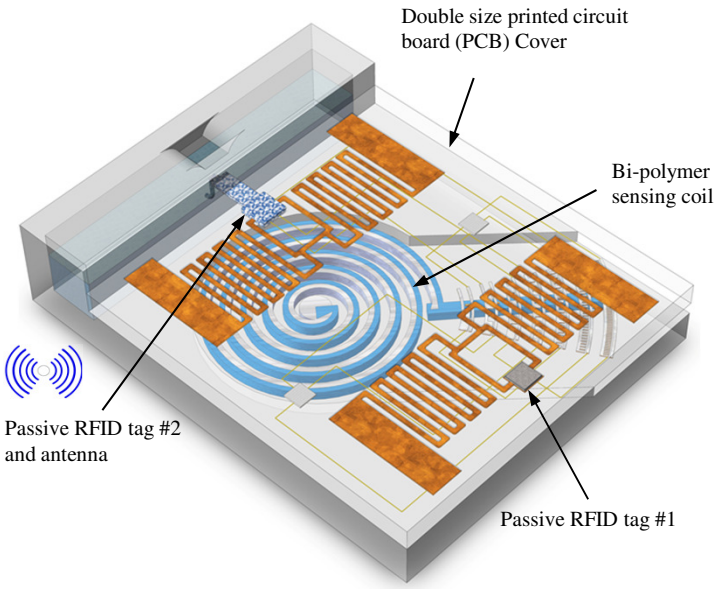
**Technical Barriers**:

- Enhanced wireless communications
- Operational power lifetime
- Accuracy and reliability,
- Modular design and materials cost reduction,
- IT system expansion,
- Automated calibration, recognition and configuration,
- Flexible placement methods

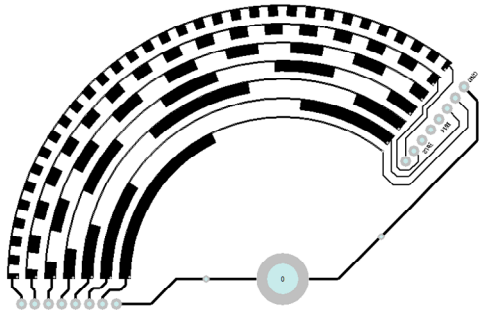


# All-Digital Passive RFID Sensors




- All digital: built-in digitizer with direct On/Off (1/0) outputs
  - No on-node signal processing necessary
  - No on-node power supply (battery) needed
- Passive RFID tags for ID and wireless communication
  - Wireless interrogation
  - Plug & play operation
  - Networking and integration into BMS (BACnet or VOLTTRON)

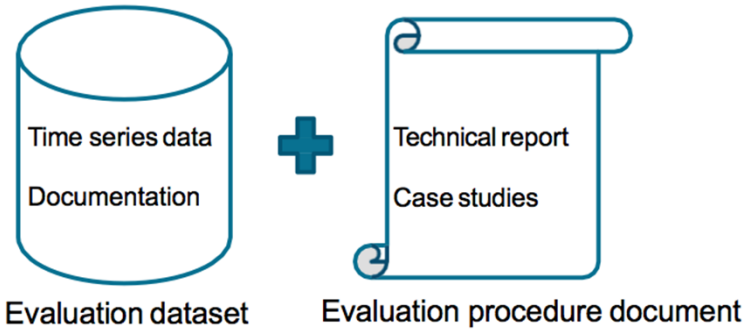


CLEMSON UNIVERSITY

# Automated Fault Detection and Diagnostics (AFDD)

## Performance Evaluation Data Sets:

- For evaluation and benchmarking performance accuracy of FDD algorithms or tools
- Contains operational data from physical experimentation as well as simulation
- Currently covers AHU-VAV systems and RTUs:
  - Operational data from commonly available measurement points, spanning system operations under variety of fault-present & fault-free conditions
  - Ground truth information as to which faults are present during which time periods.




## Performance Evaluation Approach:

- Develop a methodology to evaluate the performance of AFDD algorithms & tools:
  - Make available to public for replication, ongoing use
  - Apply to AFDD solutions from industry and research to generate case studies with examples of insights gained from evaluation
- Leverage TAG to engage stakeholders, inform methodology

# The Building Adapter

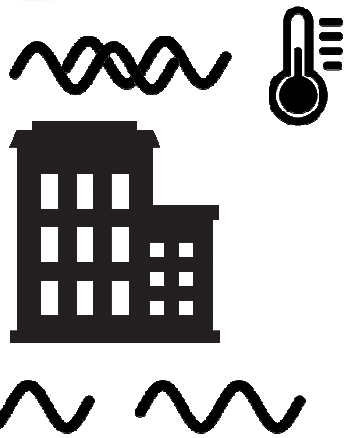
## The Problem (The Need/Challenge)

The costly process of creating a match between a building's sensor data streams and the inputs of a building analytics engine needs to be automated, in order to enable buildings analytics at scale.

**Manual mapping!**

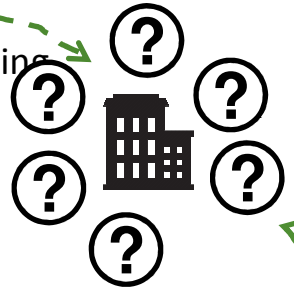
Zone TMP 2 RMI204

Zone 2
Loc.: 204
Type Temp.



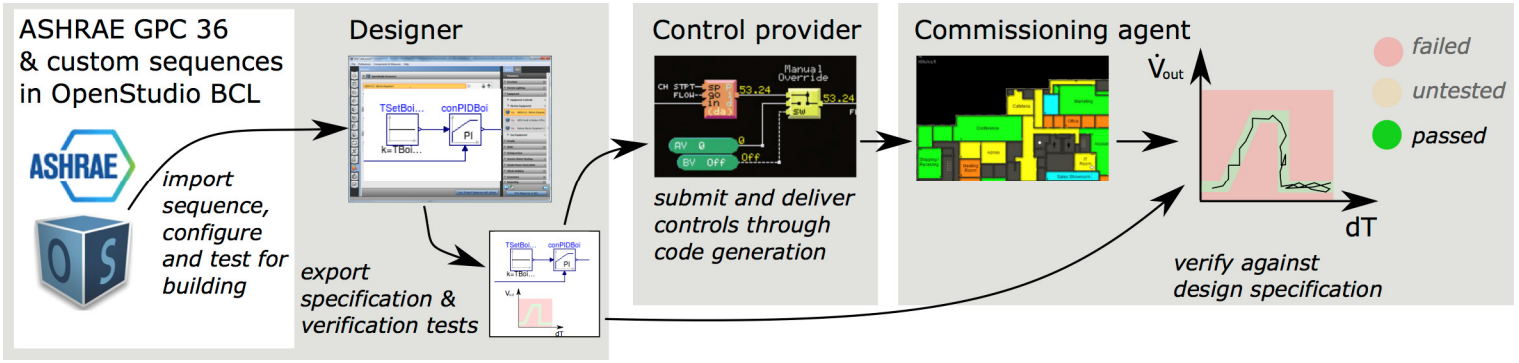
**Microsoft's 88 Acres project: 125 buildings took 2 years**


Transfer Learning




Active Learning

# Controls: The Achilles Heel of Buildings




**EnergyPlus: industry-leading BEM engine, but …**

- Idealized built-in control, bespoke language for custom sequences
- Separate from control workflows ➔ costly, error-prone manual bridges

**Spawn: next-gen BEM engine that also supports control workflows**

- Re-implements HVAC and control in Modelica
- Control models directly usable in control design, test & implementation

**OpenBuildingControl: leverage Spawn to promote high-performance control**

- Open reference implementations of ASHRAE Guideline 36 sequences
- Translation to open & proprietary control execution platforms ➔ vendor partners
- Tools for testing, diagnostics & commissioning along with analysis to demonstrate significant savings

**Example: multi-zone VAV + reheat + economizer**

- Standard ➔ fixed supply-temp, variable airflow; G36 ➔ supply temp reset, load-based airflow
- **A lot less airflow and reheat! → 30% energy savings!**

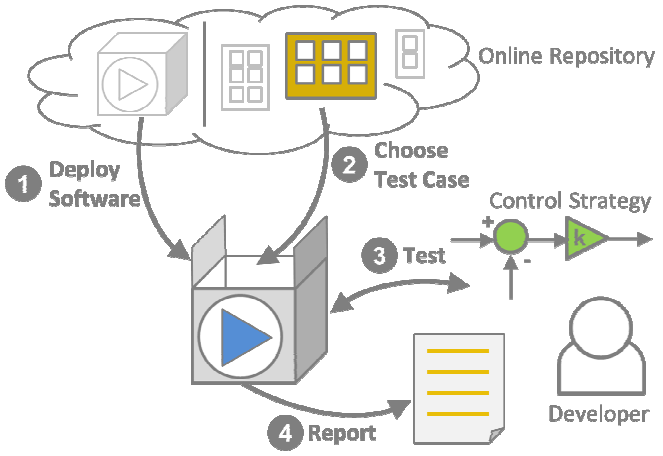
# Testing of Advanced Controls

## Challenge:

While many advanced control strategies show promise in R&D phase, adoption at scale requires low implementation costs to reduce payback period and verified performance to gain the trust of building owners and operators.

## Solution:

- Building emulation can significantly aid in meeting these requirements before the cost and risk of testing new strategies needs to be taken on by building stakeholders
- Made more possible recently by innovations in building performance simulation (i.e. use of the Modelica and Functional Mockup Interface (FMI) standards)




The **Building Operation Testing (BOPTEST)** framework will consist of a series of test procedures, benchmark test cases, and standard emulation environment to validate, compare, and debug advanced control strategies

BERKELEY LAB

Pacific Northwest

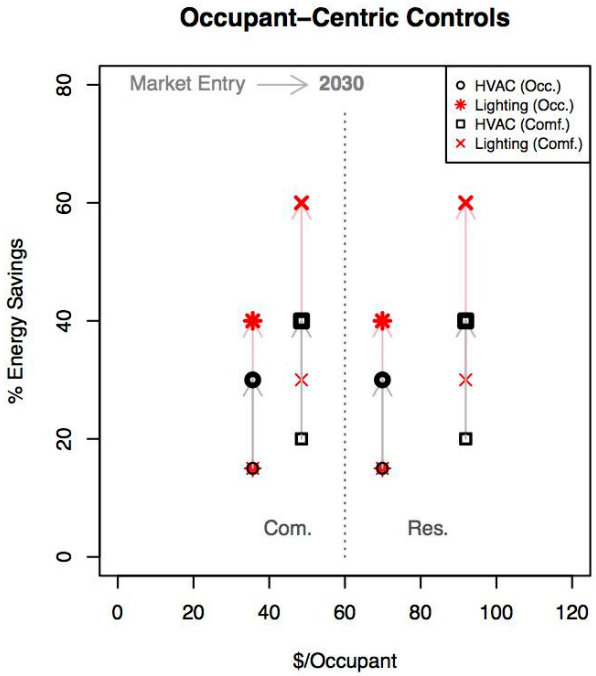
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Occupant-centric Sensing and Controls

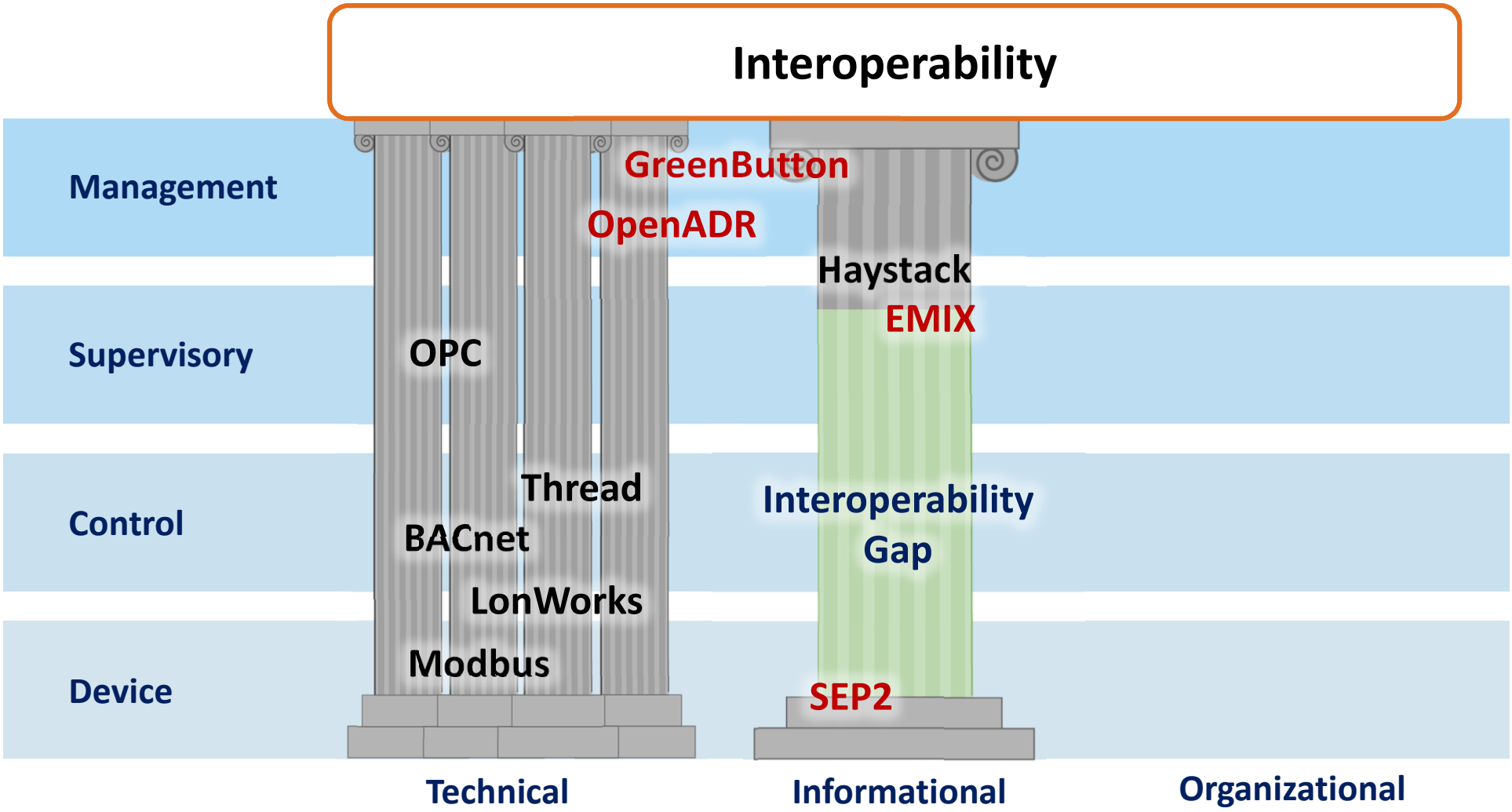
| Focus Area | Relevant ECM | Sector | Installed Cost | | Energy Performance (HVAC, Lighting) | | 2030 Energy Savings Technical Potential |
|---|---|---|---|---|---|---|---|
| | | | Market Entry | 2030 Target | Market Entry | 2030 Goal | |
| Occupant-centric Sensors and Controls | Occupancy Counting | Residential | $70/ occupant | | 15%, 15% | 30%, 40% | 2.31 quads |
| | | Commercial | $36/ occupant | | | | 1.10 quads |
| | Occupancy Comfort | Residential | $92/ occupant | | 20%, 30% | 40%, 60% | 3.14 quads |
| | | Commercial | $49/ occupant | | | | 1.49 quads |

**Technical Barriers:**

- Improved occupancy counting and comfort estimation and incorporation into control schemes
- Adaptive models and controls with near real-time response
- Long-term accuracy and calibration of indoor air quality variables (e.g., $CO_2$, humidity)
- Automated recognition and configuration with existing building automation infrastructure



# Looking to the Future: Enabling Interoperability




***Graphic:*** *Marjorie Schott and Stephen Frank, NREL*

# Cybersecurity Opportunities

- Develop solutions that can easily implement/update security features
- Robustness analysis
  - characterize the robustness of model-based learning controllers to adversarial attacks
- Robust control design
  - learning and decision-making robustness to perturbations in measured data
- Attack detection
  - detect and diagnose control decisions driven by malicious data manipulation

# How to Get Involved with BTO

- **Get on our email list (http://www1.eere.energy.gov/buildings/newsletter.html, and click on "Sign up to receive news and events from BTO")**
- **Attend the annual BTO Peer Review in Washington, DC**
- **Volunteer to be a reviewer (send CV to BTOreviewer@ee.doe.gov )**
- **Use Scout! (scout.energy.gov)**

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