Research and Development of Occupant-Centered Building Control Schemes: An Energy Policy Perspective

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Outline

- Introduction to Building Technologies Office
- Challenges for Occupant-Centered R&D
- Occupant-Centered Building Control Scheme Opportunities
- Recent DOE Activity
- Conclusions

Building Technologies Office (BTO): Research & Development

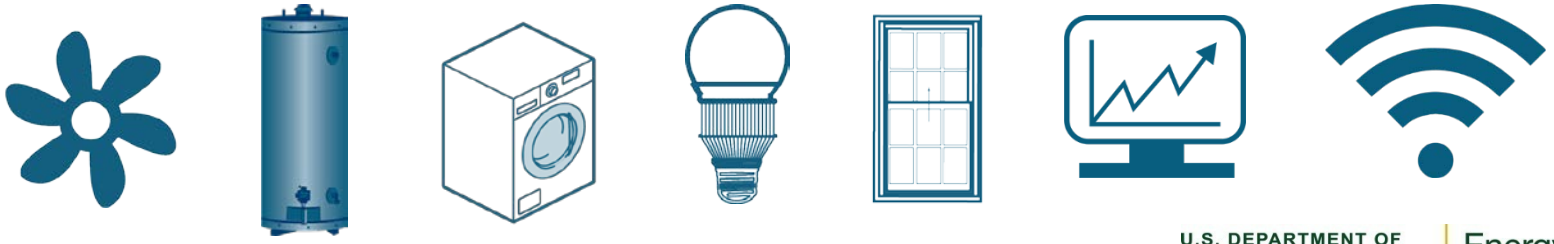
Goal

Develop cost-effective technologies capable of reducing a building's energy use per square foot by **45%** by 2030, relevant to 2010

Strategy

- Identify high-impact technologies with **Scout**, a building energy efficiency impact analysis tool
- **Fund R&D** through competitive solicitations (open to everyone) and direct funding to the DOE National Labs

Technology Areas



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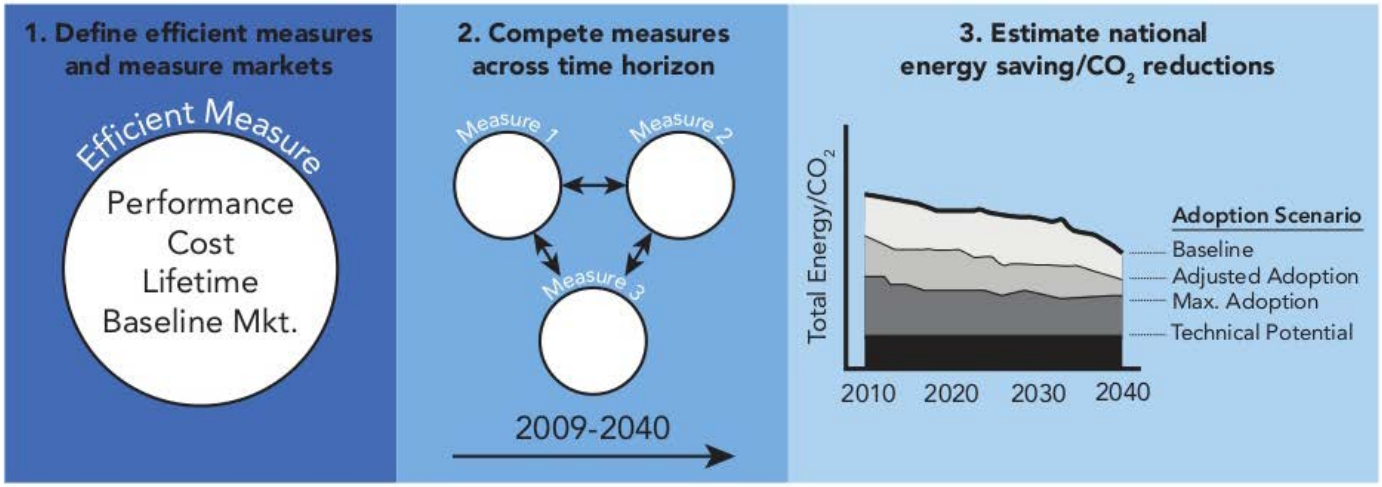
How Does BTO Evaluate Technologies?

Scout: A platform for energy efficiency impact analysis

- Estimates the national impacts of energy conservation measures (ECMs)
- Impacts examined include primary energy, CO_2 emissions, and operating costs
- Provides common analysis approach across multiple technologies/perspectives

scout

Scout estimates long-term energy/CO_2 reduction potentials of U.S. building efficiency measures

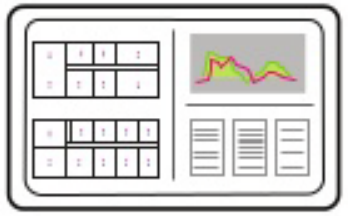


Scout (under development) on Github: https://github.com/trynthink/scout

Challenges for Occupant-Centered R&D

1. Defining Occupant-Centered Measures

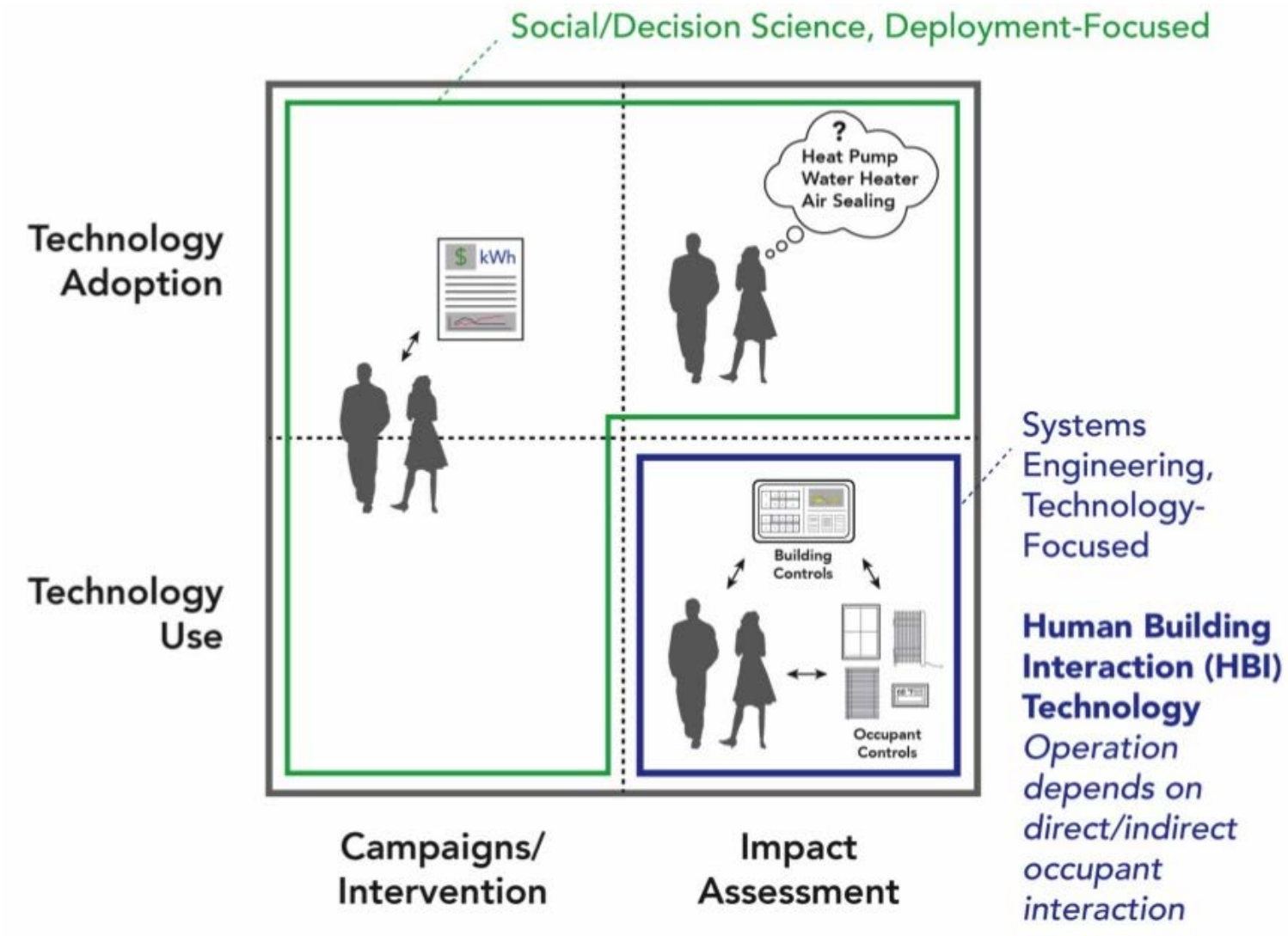
2. Obtaining Supporting Data



3. Communicating Outputs

kWh $/occupant
Net Present Value % energy savings
% uncomfortable work performance
Predicted Mean Vote EUI

Challenge: Defining Occupant-Centered Measures



Challenge: Obtaining Supporting Data

Data Collection

Measurements

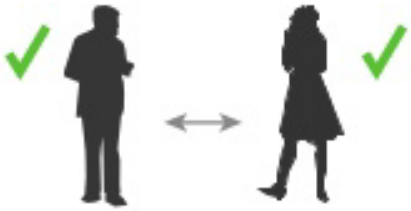
Occupancy Temperature
Light Humidity CO_2
Air Movement Energy
Behavior State

Time/space resolution

Devices

Data Sharing

Negotiating access



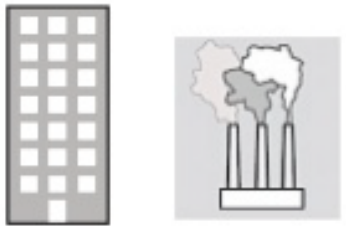
Privacy issues

Platforms

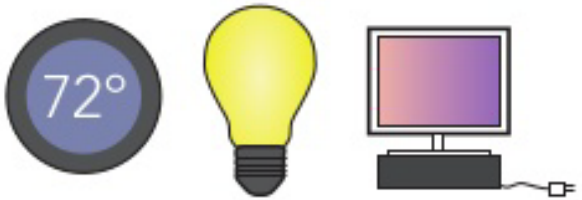
Challenge: Communicating Outputs

Energy Use

Site or source



Affected end use



Zone or whole-building

Indoor Environmental Quality

Quantifying non-energy benefits

Individual or group-level

Design Objectives are Common Across all Building Types

- Low-cost – installation and integration
- Scalable – across building types
- Interoperable – plug-and-play
- Easy-to-use
- Low maintenance
- High accuracy

Achieve all six simultaneously!

Goals:

Priority Area	Sector	Metric[1]	2020 Goal	2025 Goal
Occupant-centered sensors and controls	**Commercial**	Primary Energy Savings	15% (HVAC); 15% (Lighting)	20% (HVAC); 30% (Lighting)
		Installed Cost Premium	$39/occupant	$61/occupant
	Residential	Primary Energy Savings	15% (HVAC); 15% (Lighting)	20% (HVAC); 30% (Lighting)
		Installed Cost Premium	$68/occupant	$95/occupant

Occupancy Counts & Thermal Comfort Preferences in Controls

Summary

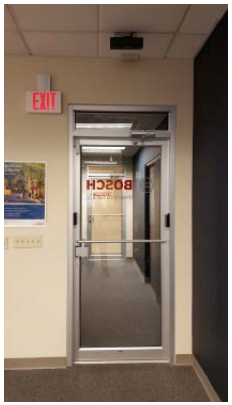
- Depth-based sensing technology utilized to perform fine-grained occupancy estimation in an area with little training and non-invasive setting that works in even in a completely dark environment.
- Design, implement, and evaluate a human-in-the-loop sensing and control system for energy efficiency of HVAC and lighting systems, which takes into account occupant comfort.

Anticipated Results

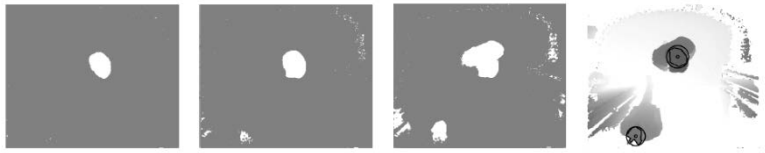
- Comfort model integration with human-in-the-loop control and embedded prototype development.
- Hardware prototype that is low-energy consuming and has average accuracy above 97%.
- Context aware human-in-the-loop controller that can switch between different modes depending on occupancy context and weather condition.

Impact

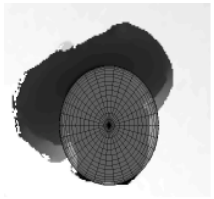
- Reduce significant energy waste (i.e. target 20% energy savings) by accurately estimating occupants in an area to overcome current HVAC systems operation which assumes maximum occupancy in each room.



Placement of a Kinect at a ceiling, Kinect for Xbox One, Embedded computer Odroid-XU4

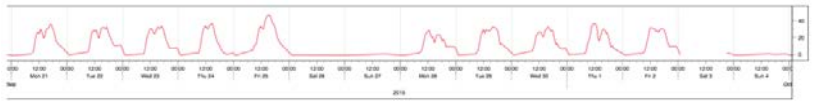


Head detection by multilevel scanning



Head verification

Shoulder verification



Occupancy estimation of two weeks at a Bosch office

Carnegie Mellon University

BOSCH

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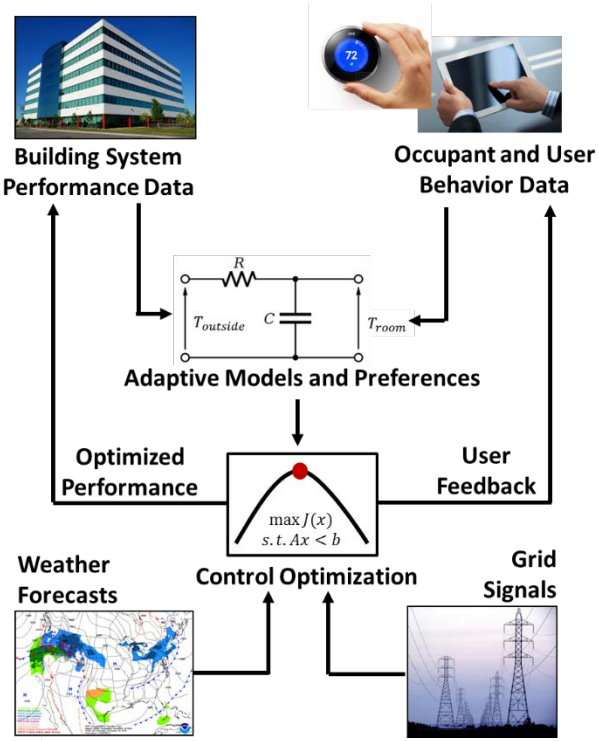
Hierarchical, Occupancy-Responsive Model Predictive Control

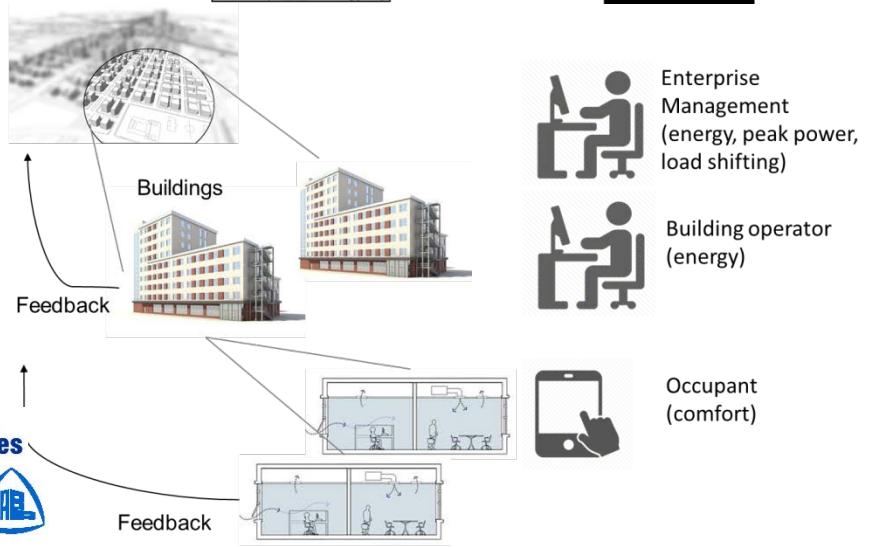
Approach:

- **Develop** - hierarchical, occupancy-responsive model predictive control software (MPC) framework
- **Demonstrate** - multiple buildings sites, showcase robustness and verify performance improvements
- **Distribute** - open-source for industry adoption and research collaboration

Distinctive Characteristics:

- **Data-driven model identification *reduces*** model setup, calibration, and maintenance effort.
- **Hierarchical MPC *enables*** occupant input and feedback at different levels.
- **Modeling and optimization methods *solves faster*** than conventional method (Wetter et al 2015).
- **Occupant integration *detects*** occupant presence (Jia and Spanos 2017) and predict behavior (IEA EBC Annex 66).
- **Open-source software standards *facilitate*** collaboration, scaling, and longevity.





Reducing plug-load electricity footprint of residential buildings

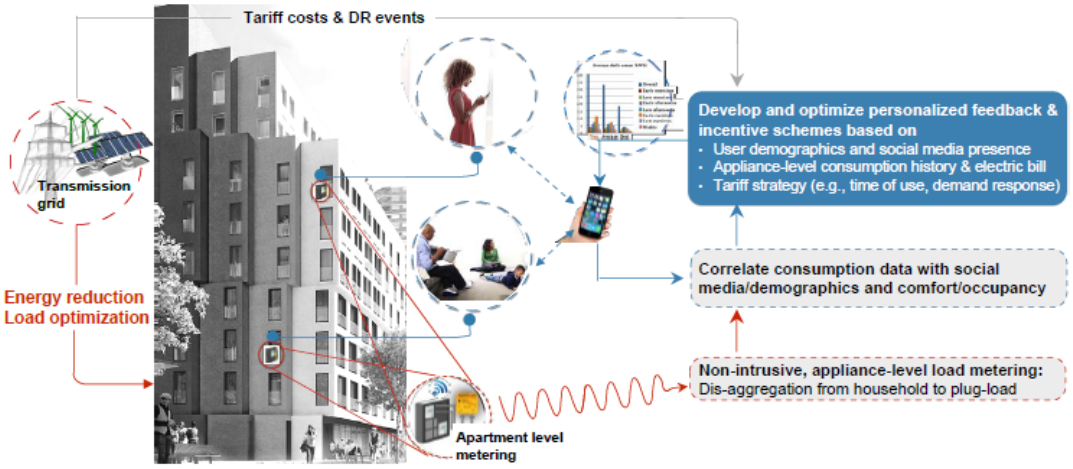
Feedback on residential consumption has been shown effective in modifying consumption behavior …… but jury is still out on what type of feedback works best on what demographic

… so what if:

- Feedback could be **personalized** to improve effectiveness (above and beyond the current ~30% benchmark)
- Feedback could include **appliance level info** (stove, Window AC, etc.) to squeeze out additional effectiveness reported in previous pilot studies
- The overall system could be **low-cost, non-intrusive**, and designed for maximum customer engagement
- The feedback would encourage not only overall **reduction** in electricity consumption but also **load shifting** to consider regional grid constraints, e.g. in order to facilitate more renewables
- Financial and environmental **benefits could be quantified** for each tenant
- … as well as aggregated for **building operators** or local municipalities to show overall value (net of equipment cost) and payback times
- **A public database** were available of hundreds of electricity consumption patterns in multi-family housing, covering multiple years, and including appliance level information

Overarching idea:
Bringing smart building and grid resilience capabilities to the residential sector

Schematic of Technology Solution



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Conclusions

- BTO evaluates investments in developing high-performance, cost-effective technologies based on their resulting energy savings
- Challenges remain in defining occupant-centered measures, obtaining supporting data, and communicating outputs
- Low-cost, human-in-the-loop solutions for occupant-centered building control schemes show promise for significant energy savings

This Community is Key to Advancements in Occupant-Centered Building Control Schemes!

Thank you!

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