U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Building Technologies Office (BTO)

Sensor and Control Technologies R&D Overview

Marina Sofos, Ph.D.

BTO Peer Review

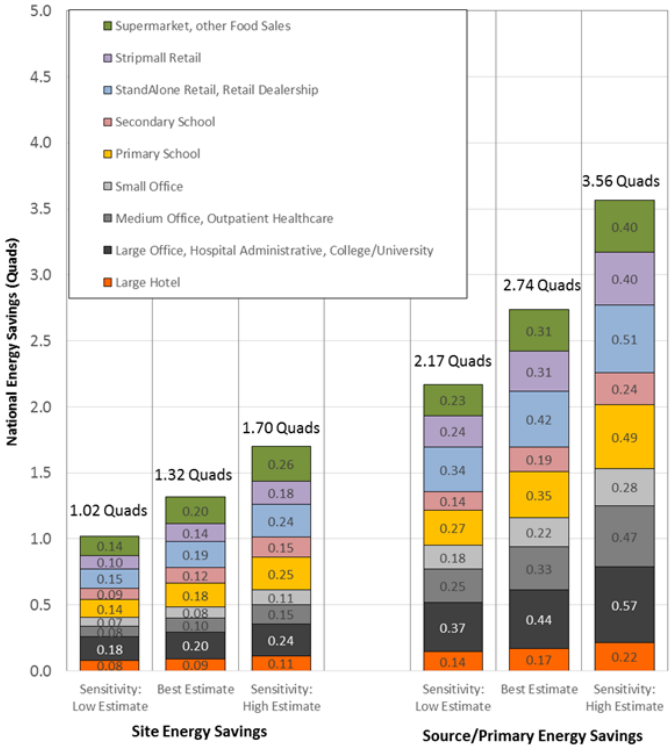
April 30, 2018

Driving up efficiency of component technologies is not enough…

- **Sensors** monitor operating conditions of buildings and building equipment (e.g., temperature, air flow, and daylight levels), electronic **actuators** process these measurements, and device **controllers** initiate appropriate action (e.g., adjust temperature, air flow, light) to maintain operating conditions.

- An aggregated annual energy savings of 29%, or **~4-5% of total national energy consumption**, can be achieved through the implementation of efficiency measures using **current state-of-the-art sensors and controls** to optimize programmable settings and to detect and diagnose operational problems in the **commercial sector alone**.

- Most promising energy efficiency measures:
  - Optimize setpoints
  - Reduce minimum air flow rate through variable-air volume boxes
  - Limit space conditioning to most likely occupied periods



N. Fernandez et al. "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction" PNNL Report 2017. http://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf

And that's just the beginning!

Challenges for Sensor and Control Technologies in Buildings

Ensure savings by monitoring and correcting for faulty operation, as well as additional savings by tuning operations to match environmental conditions and occupancy patterns **(>20-30%)**, however,

Implementation of these savings, as well as incorporation of more sophisticated control methodologies for even greater savings are limited in the buildings sector:

- **Not considered an "operationally critical" application**
- **Adoption still not widespread** – 43% of commercial floor space (mostly large buildings > 50,000 sq. ft.) employ a building automation system and 41% of residential buildings have a programmable thermostat, but only 12% use the functionality
- **Not designed for energy efficiency** – simple, reactive for short-term thermal and ventilation needs
- **Fragmented systems** – HVAC separated from control of other building subsystems (e.g., lighting)
- **Labor intensive** – manual, hand-crafted installation and maintenance
- **High cost** – customized, not integrated into the building design process
- **Limited budgets** – for energy management
- **Limited interoperability** – across systems/vendors
- **Confusion in product offerings** – diversity of system configurations

BTO Sensors and Controls R&D Sub-program

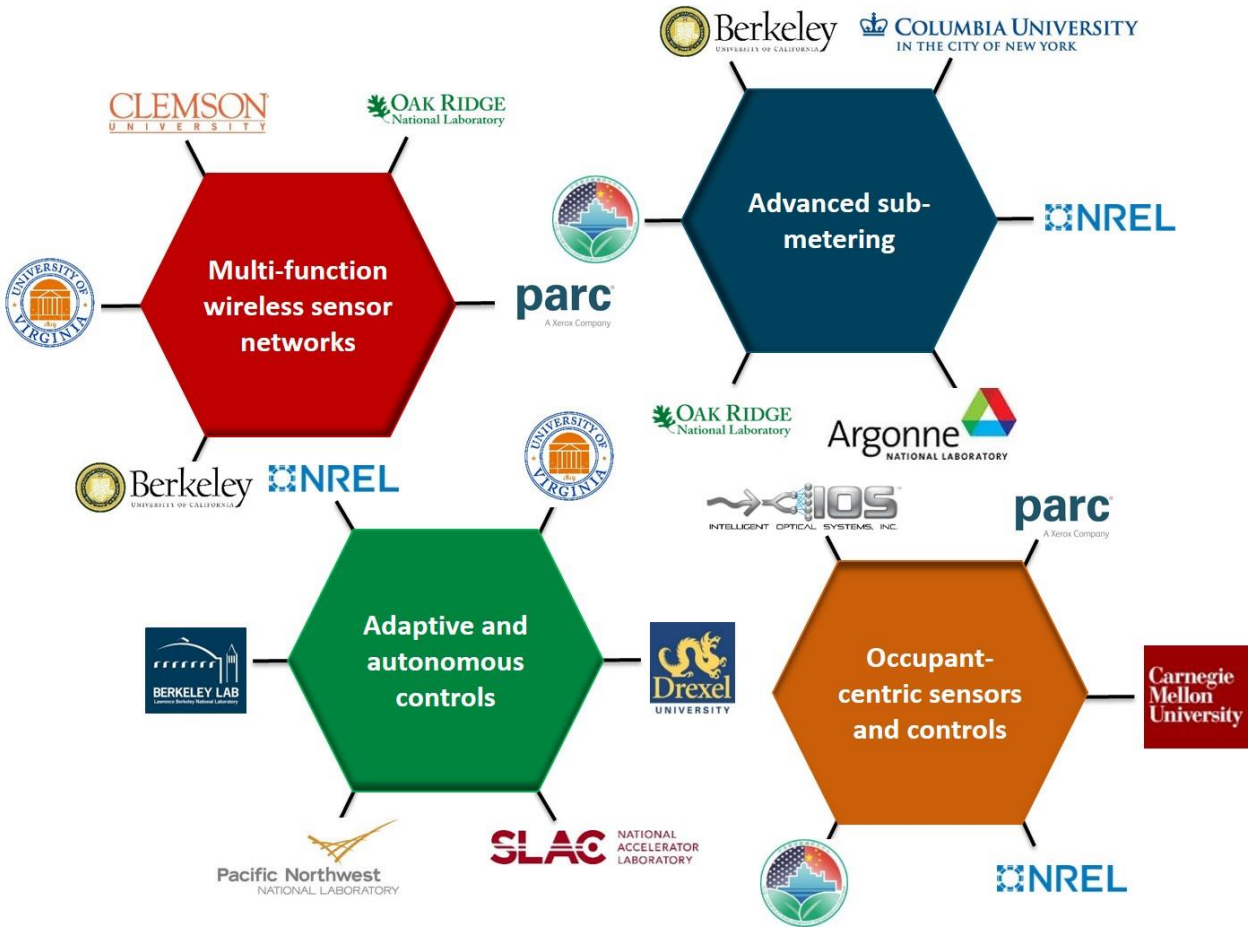
- **Vision:**
  Move beyond simple, reactive controls in buildings intended to meet short-term thermal ventilation needs to optimized controls designed to meet energy efficiency and occupant comfort requirements.

- **Objective:**
  Ensure energy savings (~30%) from efficient equipment through correct implementation of monitoring and control systems while achieving additional savings (>10%) from more sophisticated control strategies.

- **Strategy:**
  - **(1) Sensors and sub-meters** - reducing the cost and improving the long-term performance along with developing new sensing modalities (e.g., occupancy and building equipment health)

  - **(2) Controls** – developing and optimizing model-based and data-driven approaches over longer time periods (e.g., hours and days) and multiple spatial scales (e.g., occupant, whole-building), as well as incorporating additional inputs (e.g., occupancy patterns, weather forecasts)

BTO Sensors and Controls Portfolio of Projects



Cross-cutting strategies:

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

BTO Sensors and Controls R&D Focus Areas and Goals

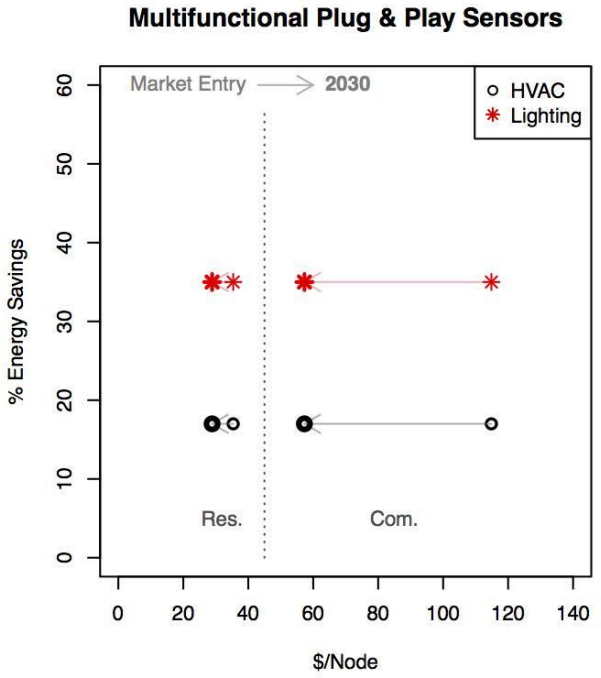
Priority Focus Area	Energy Conservation Measure	Sector	Installed Cost Target[1]		Energy Performance (HVAC, Lighting)		2030 Energy Savings Technical Potential
			Market Entry	2030 Target	Market Entry	2030 Goal	
Multi-functional Wireless Sensor Networks	Plug-and-play sensors self-powered with wireless communication	Residential[2]	$35/ node	$29/ node	17%, 35%		1.14 quads
		Commercial	$115/ node[3]	$57/ node			0.99 quads
Advanced Sub-metering	AFDD incorporating sub-metered energy data	Commercial[4]	$0.14/ ft² floor		25%, N/A	30%, N/A	1.18 quads
Occupant-centric Sensors and Controls	Occupancy counting inputs	Residential[5]	$70/ occupant		15%, 15%	30%, 40%	2.31 quads
		Commercial[6]	$36/ occupant				1.10 quads
	Occupancy comfort inputs	Residential	$92/ occupant		20%, 30%	40%, 60%	3.14 quads
		Commercial	$49/ occupant				1.49 quads
Advanced and Autonomous Controls	AFDD	Commercial[7]	$0.12/ ft² floor	$0.14/ ft² floor	20%, N/A	30%, N/A	1.18 quads

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

Enable low-cost approach to accurately detect and diagnose faults, failures, and resulting inefficiencies in building equipment and subsystems, while also allowing for optimal and localized whole-building control opportunities to improve occupant comfort along with reducing energy use.

Technical Barriers:

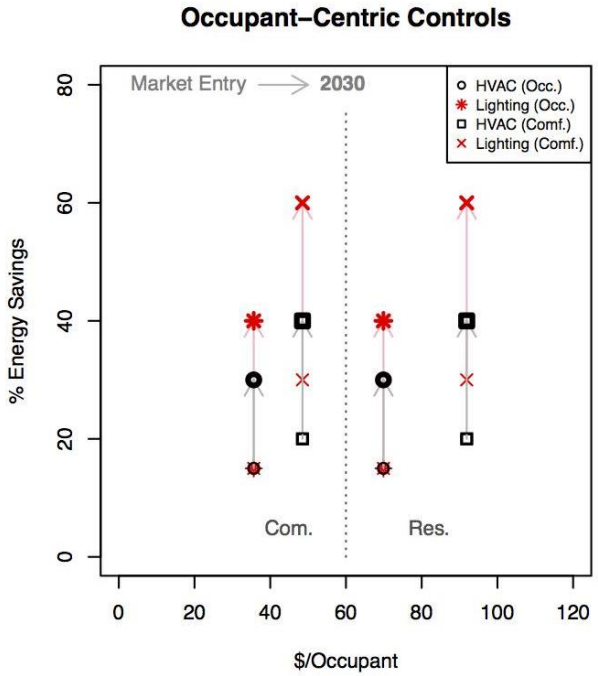
- Enhanced wireless communications
- Operational power lifetime
- Accuracy and reliability,
- Modular design and materials cost reduction,
- IT system expansion,
- Automated calibration, recognition and configuration,
- Flexible placement methods

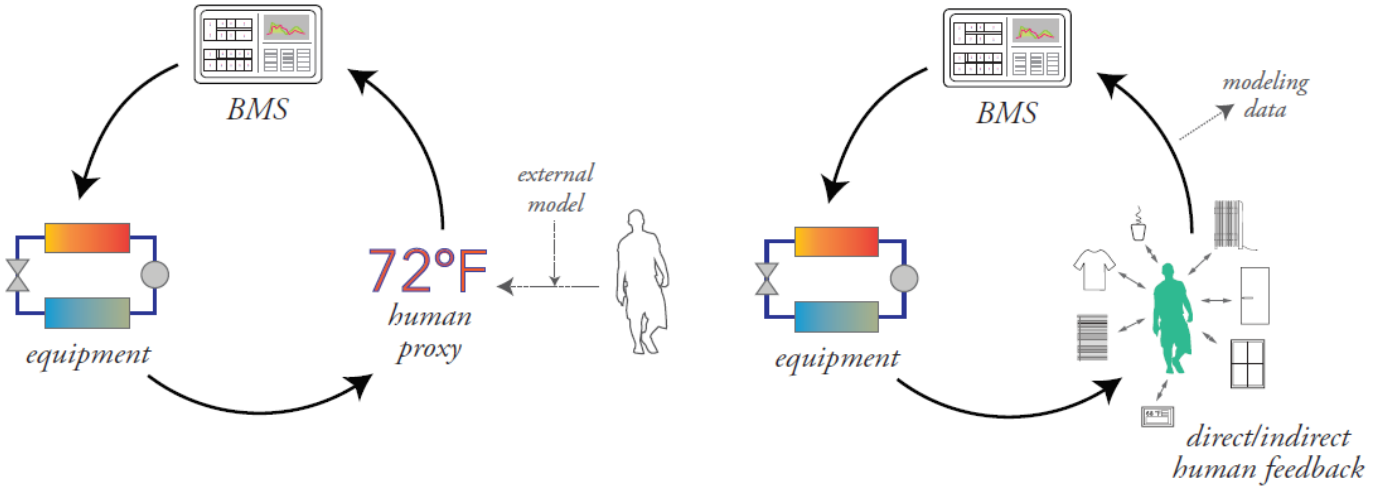


The Role of the Occupant

Technical Barriers:

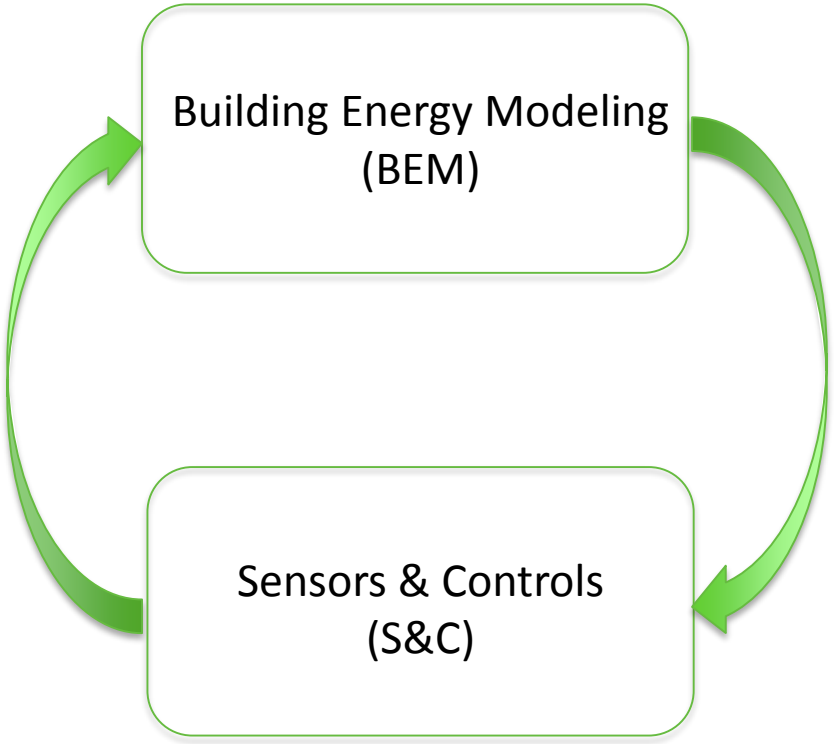
- Improved occupancy counting and comfort estimation and incorporation into control schemes
- Adaptive models and controls with near real-time response
- Long-term accuracy and calibration of indoor air quality variables (e.g., CO_2, humidity)
- Automated recognition and configuration with existing building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





Nexus of Sensors & Controls/Building Energy Modeling

- Provide detailed time-series data that support model input calibration for existing-building applications through sensing and sub-metering



- Evaluate energy savings through large scale BEM analysis on prototype building models
- Design and evaluate control algorithms
- Real-time performance assessment, fault detection, and commissioning during operation

High-Performance Control through BEM

EnergyPlus: industry-leading BEM engine, but …

- Idealized built-in control, bespoke language (EMS) for custom sequences
- Separate from control workflows ➔ costly, error-prone manual bridges
- Not going away anytime soon!

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

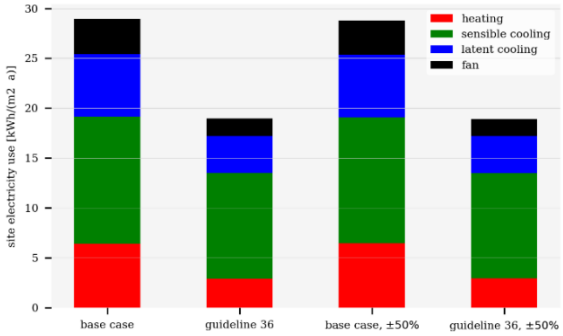
- Re-implements HVAC and control in equation-based language Modelica
- Control models directly usable in control design, test & implementation
- Alpha version later in 2018

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
- Analysis to demonstrate significant savings

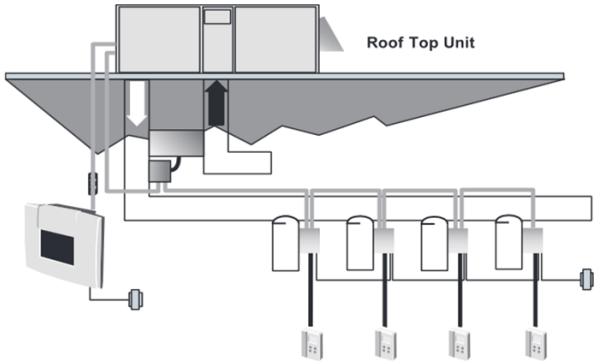
Example: multi-zone VAV + reheat + economizer

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

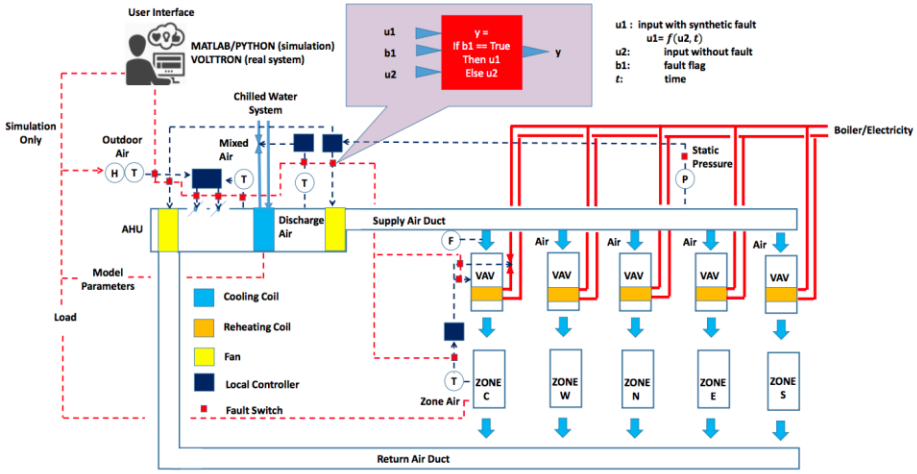


Testing Frameworks to Spur Innovation

- Standard methods, datasets, and use cases for evaluating **advanced analytics (AFDD)** and **control solutions (e.g., MPC)** to establish expected performance, benchmark newly developed methods relative to state-of-the-art, and help converge to consensus on best-practice approaches

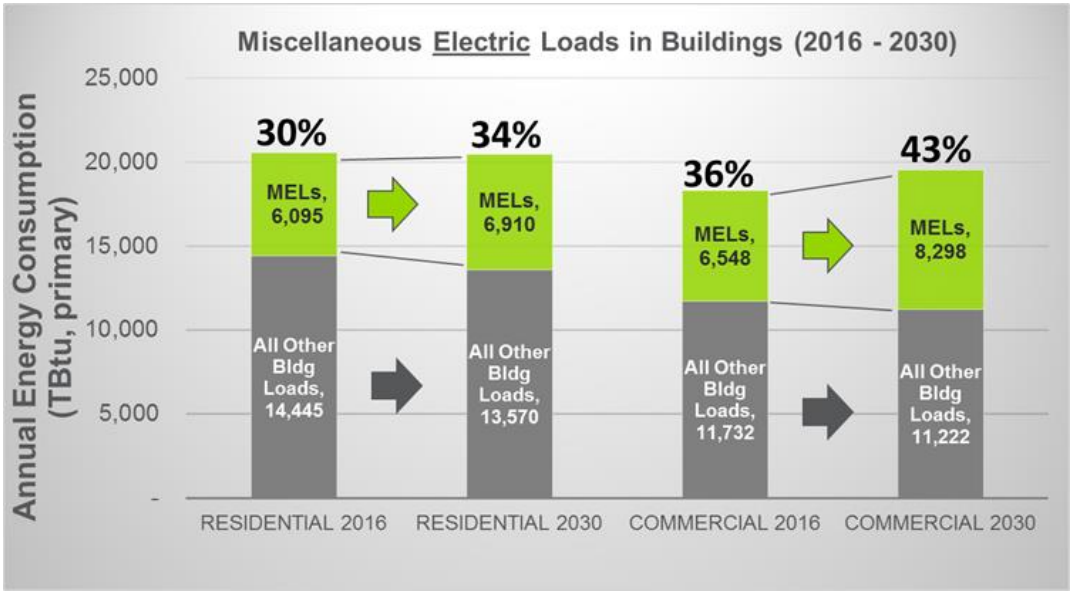


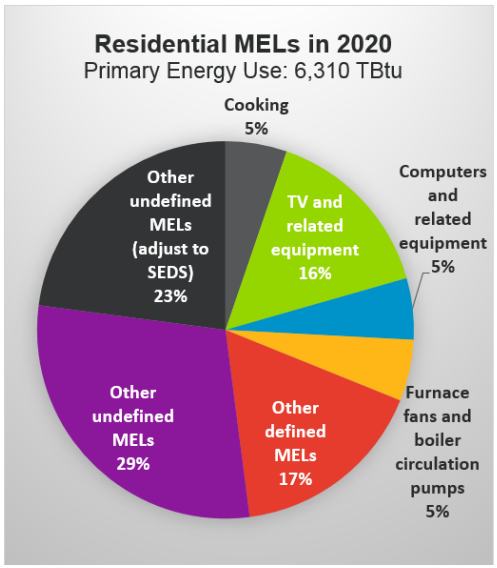
- More on AFDD, **Wednesday AM**
- More on Controls, **Tonight's Poster Session**

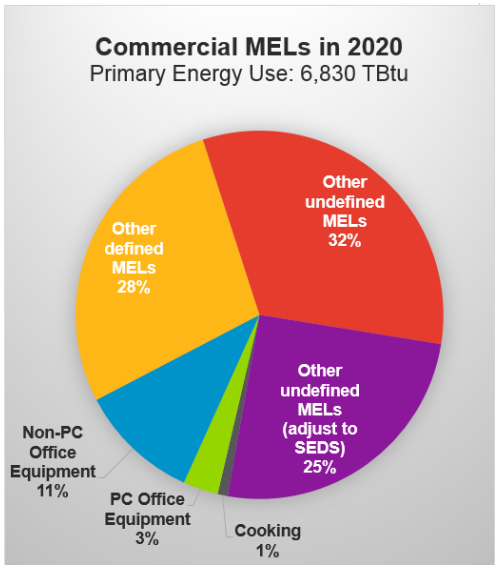


BERKELEY LAB
NREL NATIONAL RENEWABLE ENERGY LABORATORY
Pacific Northwest
OAK RIDGE National Laboratory

Extending Approaches to Miscellaneous Electric Loads







Increase in portion of building energy consumption driven by:

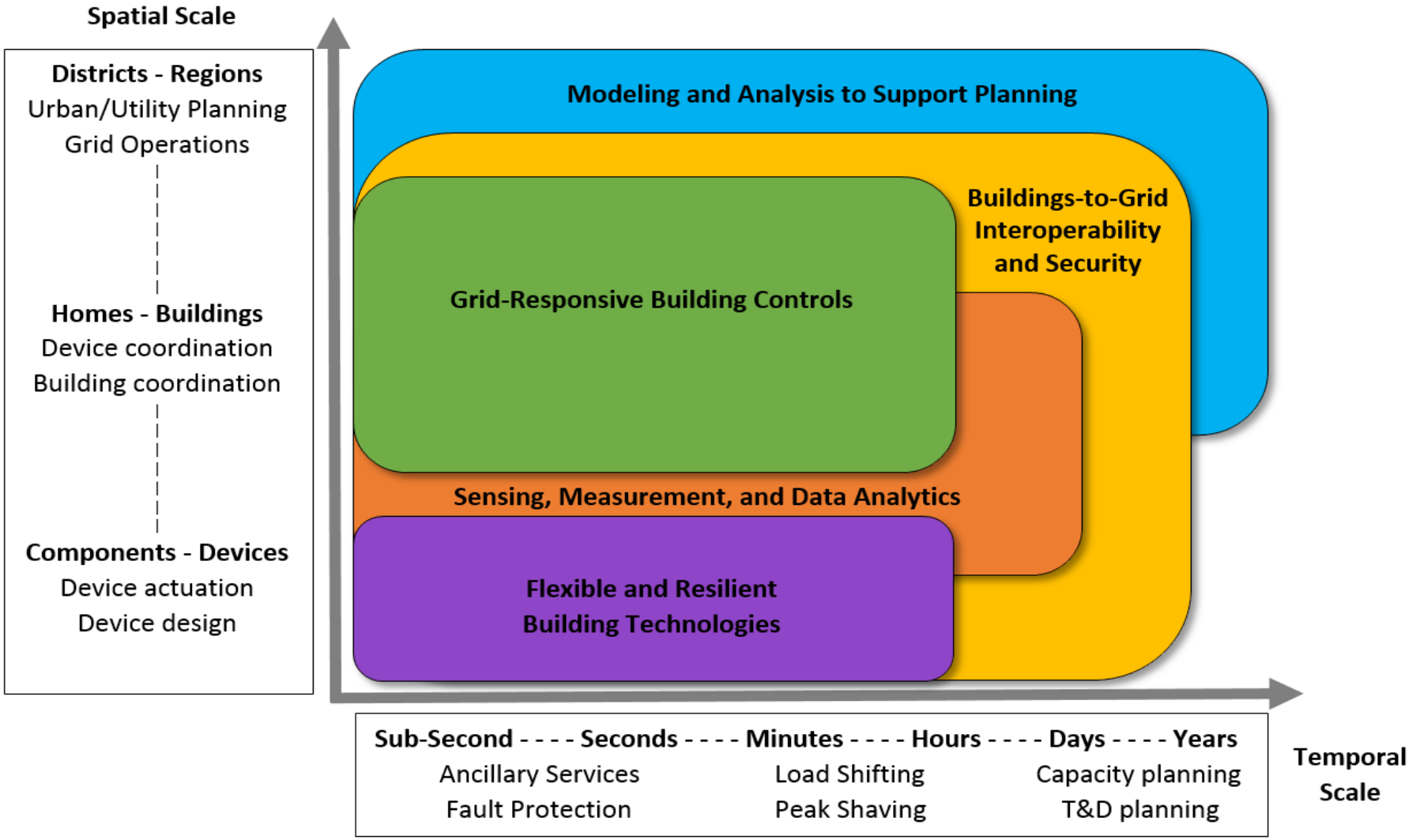
- Improved efficiencies of the major energy end use technologies
- Projected increase in primary energy consumption in residential and commercial buildings from MELs

Reducing consumption poses a unique challenge due to:

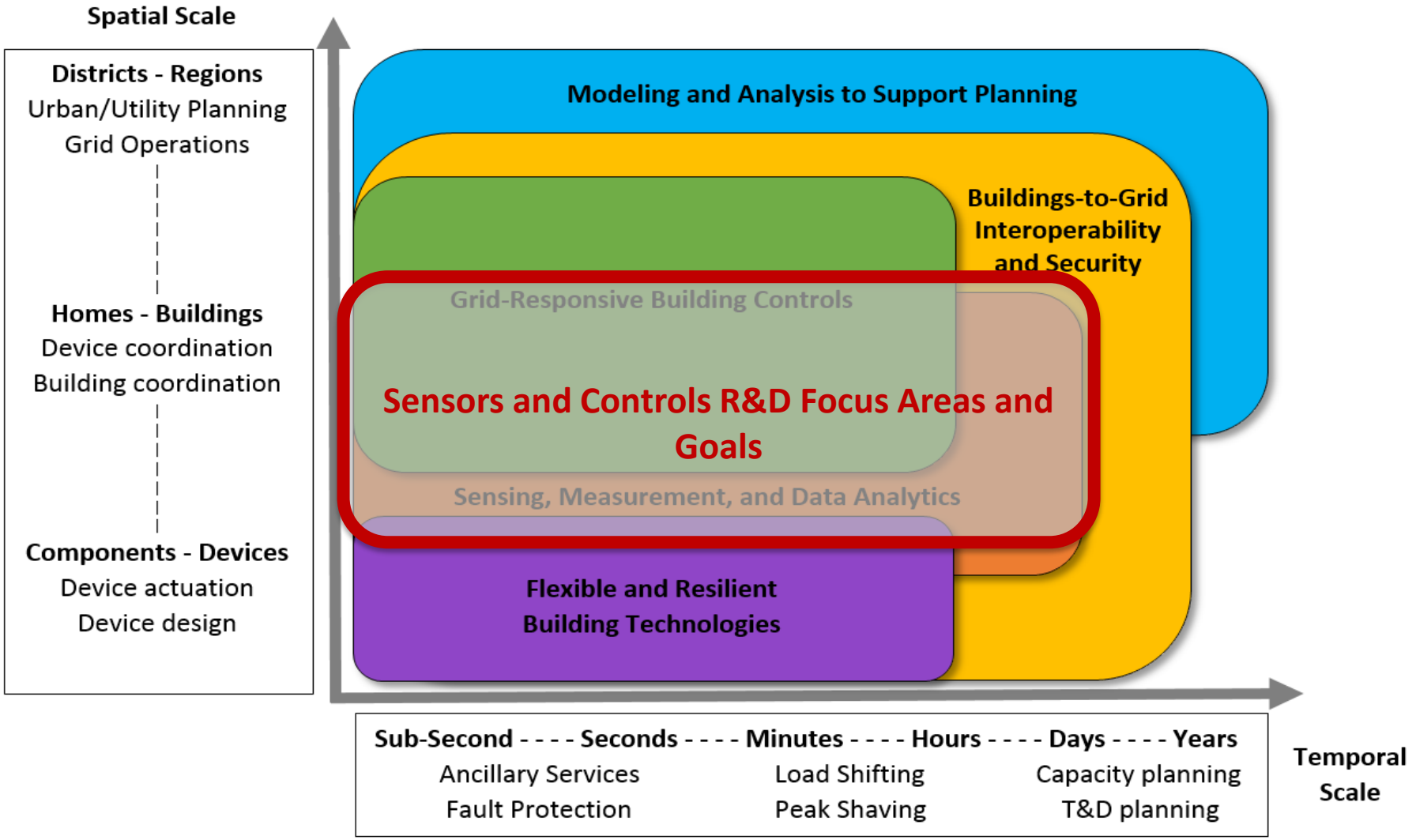
- Total consumption projected to increase significantly by 2030 under current business-as-usual trends
- Significant portion (i.e. the majority) is comprised of undefined loads not yet attributed to individual devices
- Comprise a wide variety of distinct electric loads (e.g., televisions, set-top boxes, office equipment, etc.) that individually consume a relatively small amount of energy

EIA Annual Energy Outlook, 2015. http://www.eia.gov/forecasts/archive/aeo15/

S&C in the Future: Enabling Key GEB Focus Areas



S&C in the Future: Enabling Key GEB Focus Areas



R&D Funding Mechanisms

1. **Directed National Laboratory Efforts – Annual Operating Plan (AOP)**
   a) 1-3 Year Sensor and Controls Lab Call Merit Review Awards: FY17-19
   b) Consortia: DOE Grid Modernization Lab Consortium (GMLC)
   c) Industry Partnerships: CRADAs and Small Business Voucher (SBV)

2. **Awarded by Funding Opportunity Announcements (FOA) to Industry, Academia or National Labs**
   a) FOAs: FY15 BUILD, FY16 BENEFIT, and FY17 BENEFIT
   b) Consortia: US-China Clean Energy Research Center (CERC)
   c) Small Business Innovation Research (SBIR)

Sub-program Evolution: Relevant Solicitations

2015

FOA

Building University Innovators and Leaders Development (BUILD)-2015, DE-FOA-0001167 (Nov 11, 2014)

- University-based teams (both undergraduate and graduate students led by faculty sponsor) with a minimum 50% direct project costs supporting undergraduates in innovative building energy efficiency technologies

2016

FOA

Small Business Innovation Research (SBIR)- 2016 Phase 1 Release 2, DE-FOA-00011417 (Nov 30, 2015)

- Technologies for Sensing and Managing Indoor Air Quality in Buildings – Accurate, stable humidity sensors

FOA

Building Energy Efficiency Frontiers and Innovation Technologies (BENEFIT)-2016, DE-FOA-0001383 (Dec 15, 2015)

- Open Topic for Energy Efficiency Solutions for Residential & Commercial Buildings
- Human-in-the-Loop Sensor & Control Systems
- Plug-and-Play Sensor Systems

2017

AOP

Building Technologies Offices FY2017 National Laboratory Call for Proposals & Merit Review, BTO-LMR-0001719 (Feb 3, 2016)

- Building Equipment Sub-metering
- Adaptive and Fault Tolerant Building Controls

FOA

Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) – 2017, DE-FOA-0001632 (Nov 30, 2016)

- Open Topic for Energy Efficiency Solutions for Residential & Commercial Buildings
- Miscellaneous Electric Loads Research and Development (R&D)

2018

Sub-program Evolution: Relevant Solicitations

2015

FOA

Building University Innovators and Leaders Development (BUILD)-2015, DE-FOA-0001167 (Nov 11, 2014)

- University-based teams (both undergraduate and graduate students led by faculty sponsor) with a minimum 50% direct project costs supporting undergraduates in innovative building energy efficiency technologies

2016

FOA

Small Business Innovation Research (SBIR)- 2016 Phase 1 Release 2, DE-FOA-00011417 (Nov 30, 2015)

- Technologies for Sensing and Managing Indoor Air Quality in Buildings – Accurate, stable humidity sensors

FOA

Building Energy Efficiency Frontiers and Innovation Technologies (BENEFIT)-2016, DE-FOA-0001383 (Dec 15, 2015)

- Open Topic for Energy Efficiency Solutions for Residential & Commercial Buildings
- Human-in-the-Loop Sensor & Control Systems
- Plug-and-Play Sensor Systems

2017

AOP

Building Technologies Offices FY2017 National Laboratory Call for Proposals & Merit Review, BTO-LMR-0001719 (Feb 3, 2016)

- Building Equipment Sub-metering
- Adaptive and Fault Tolerant Building Controls

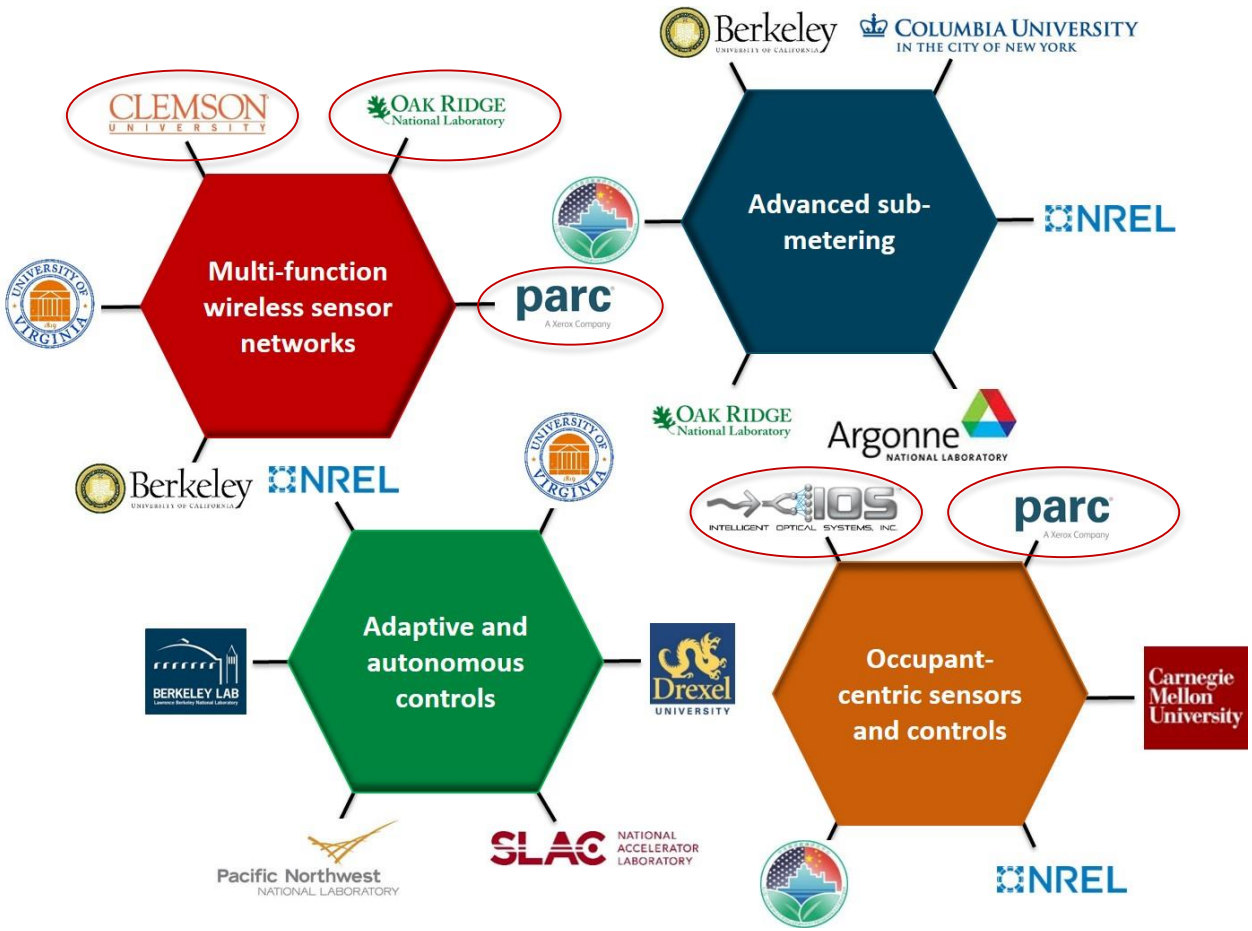
FOA

Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) – 2017, DE-FOA-0001632 (Nov 30, 2016)

- Open Topic for Energy Efficiency Solutions for Residential & Commercial Buildings
- Miscellaneous Electric Loads Research and Development (R&D)

2018

BTO Sensors and Controls Portfolio of Projects



Today's Agenda

Time	Session/Speaker	Project/Topic	Solicitation
1:30 – 2:00 pm	Marina Sofos (DOE/BTO)	Sensors & Controls Subprogram Overview	
2:00 – 2:30 pm	David Schwartz (PARC)	Passively-Powered Adaptively-Located Flexible Hybrid Sensors	BENEFIT FY16
2:30 – 3:00 pm	Hai Xiao (Clemson)	All-Digital Plug and Play Passive RFID Sensors for Energy Efficient Building Control	BENEFIT FY16
3:00 – 3:30 pm	Teja Kuruganti (ORNL)	Energy-harvesting, Self-calibrating Wireless Sensors for Improving Energy Efficiency in Buildings	BENEFIT FY16
3:30 – 4:00 pm	Break		
4:00 – 4:30 pm	Brad Campbell (UVA)	Improving Energy Efficiency of Wireless Communication Circuitry in Miscellaneous Electric Loads	BENEFIT FY17*
4:30 – 5:00 pm	Clinton Smith (PARC)	Ultra-Low SWaP CO2 Sensing for Demand Control Ventilation	BENEFIT FY17*
5:00 – 5:30 pm	Jesus Delgado (IOS)	Optical Humidity Sensors for Building Energy Performance and Air Quality Control	SBIR FY16
5:30 – 5:45 pm	REVIEWERS AND STAFF ONLY	Sensors and Controls Wrap-up	

*not formally peer reviewed today

Thank you!

Mike Atsbaha
Adam DeDent
Carla Dunlap
Christina Dunn
Dr. Robert Fares
Michael Geocaris
Mary Hubbard
Amy Jiron
Mohammed Khan
Marc LaFrance
Dr. Jared Langevin
Gina Lynch
Ryan McCleary
Mary Murray
Valerie Nubbe
Sam Petty
Dr. Janet Reyna
Dr. Amir Roth
Antonio Ruiz
Dr. Karma Sawyer
Dr. Mike Specian
Geoff Walker

Marina Sofos, Ph.D.

Technology Manager, Emerging Technologies
DOE Building Technologies Office
Marina.sofos@ee.doe.gov
https://www.energy.gov/eere/buildings/sensors-and-controls-rd-0

"The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is the automation applied to an inefficient operation will magnify the inefficiency." - *Bill Gates*