U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Hierarchical Occupancy-Responsive Model Predictive Control (MPC) at Room, Building and Campus Levels

Lawrence Berkeley National Laboratory

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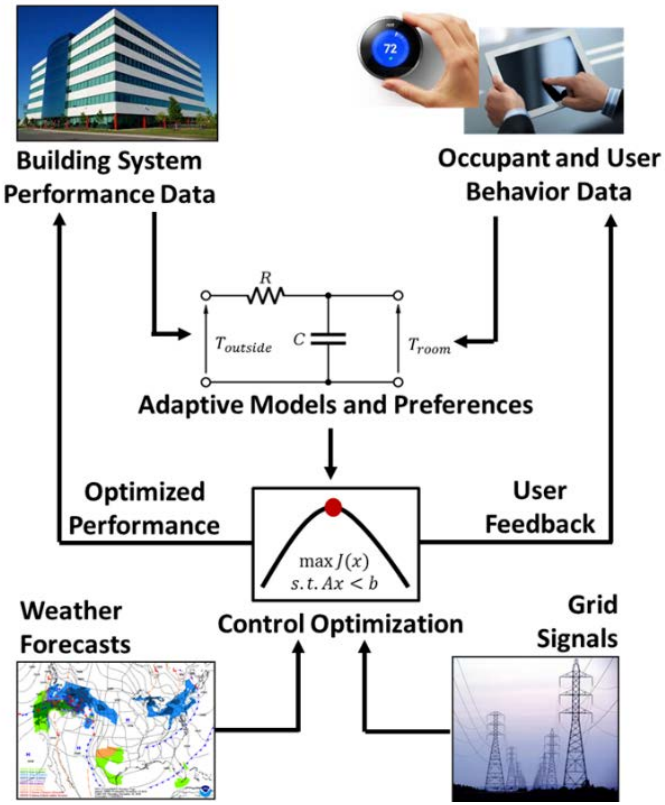


Project Summary

Timeline:

Start date: 4/1/2016

Planned end date: 3/31/2021

Key Milestones

1. MPC software MPCPy v0.1 released (FY17Q4)
2. Completing the building level MPC field test (FY19Q2)
3. Occupant module developed and integrated (FY18Q1)

Budget:

Total Project $ to Date:

- DOE: $890k
- Cost Share: $3,062k

Total Project $:

- DOE: $2,390k
- Cost Share: $4,490k

Key Partners:

U.S.	China
Johnson Controls	Tsinghua University
Disney	China Academic of Building Research
United Technologies	Ministry of Housing & Urban-Rural Development
Lutron	
Lend Lease	

Project Outcome:

- Develop and demonstrate cost-effective occupancy-responsive building and district scale MPC
- Develop and open-source MPC software to spur innovation and promote further exploration through additional research, field testing and industry adoption
- Support BTO Goals for Occupant-Centric Sensors and Controls

Team

U.S. Researchers

Name, Affiliation	Roles & Responsibilities
Mary Ann Piette, LBNL	PI
Tianzhen Hong, LBNL	Co-PI and Occupant Module Lead
Michael Wetter, LBNL	MPC Task Lead
David Blum, LBNL	MPC Researcher
Baptiste Ravache, LBNL	Occupant Module Researcher

U.S. Industry Partners

Name, Affiliation	Roles & Responsibilities
Clay Nesler, JCI	Industry Lead
Robert D. Turney, JCI	Lead Researcher at JCI
Bruce Rauhe, Disney	Industry Co-Lead and Campus Demonstration
Jinlei Ding, UTC	Lead Researcher at UTC on Commissioning and MPC demo in China
Joe Qiao, Lend Lease David Nieh, Lend Lease	Researchers at Lend Lease and Commissioning Task
Robert Nachtrieb, Lutron	Lead Researcher at Lutron

Team

China Researchers

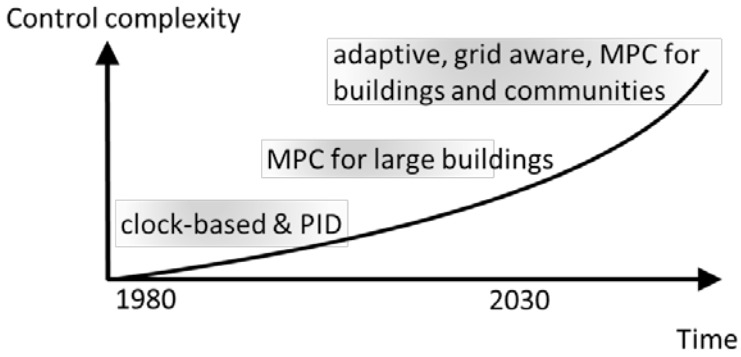
Name, Affiliation	Roles & Responsibilities
Wei Xu, Director, CABR	PI
Da Yan, Tsinghua University	Lead Researcher at Tsinghua and Occupant Module
Shicong Zhang, CABR	Joint Research on Demonstration Sites, Model Identification to Aid Continuous Commissioning
Liu Haizhu / Zeng Di, MoHURD	Data Mining for Commissioning

Challenge

Problem Statement:

Conventional building control systems unable to meet future building system requirements effectively:

- Energy cost reduction
- Electric grid integration
- Fault detection and diagnosis
- Occupant-responsiveness

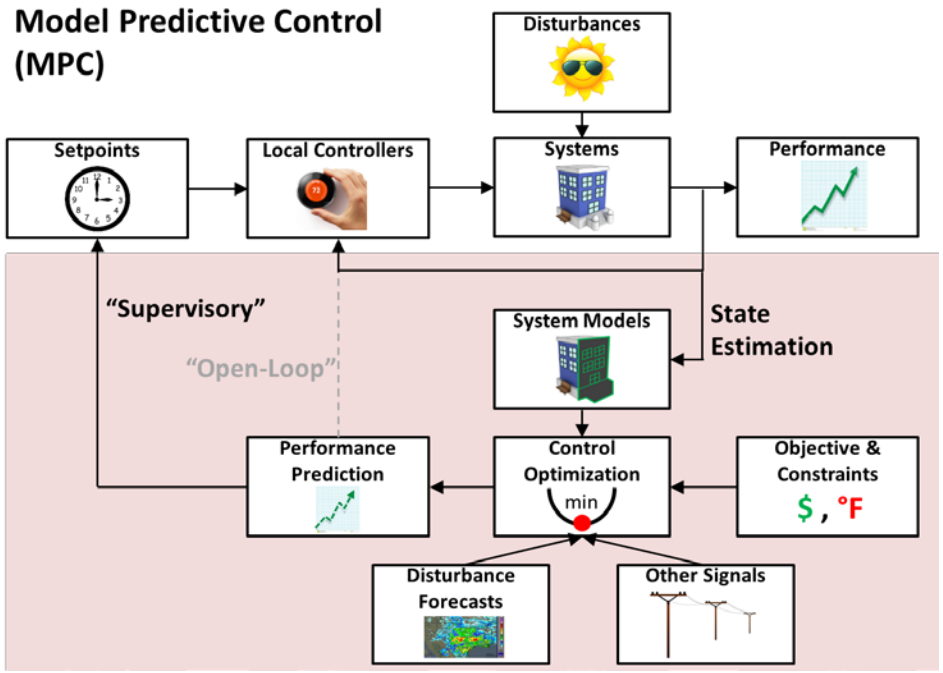


Key MPC Advantages

- Consider future disturbances and incentives
- Coordinate multiple systems
- Occupant integration

Key MPC Challenges

- Model development and calibration
- Optimization formulation
- Building installation
- Lack of common framework



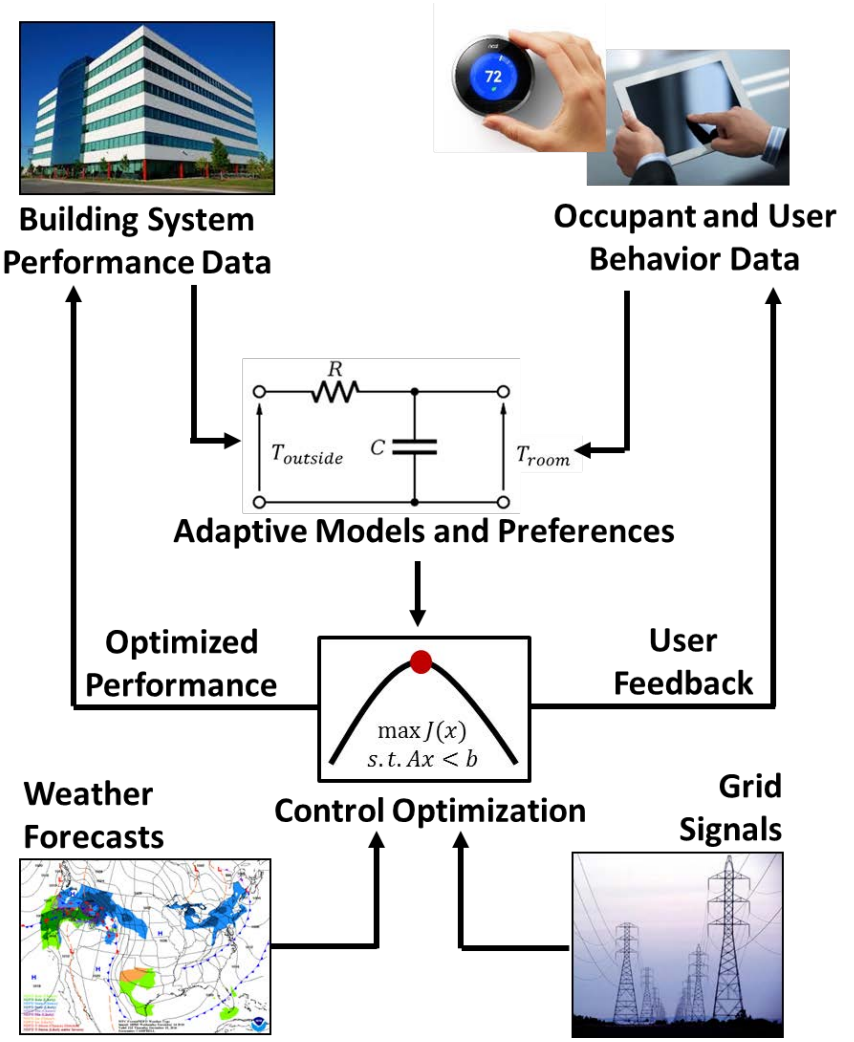
Approach

Technical 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

Key Issues:

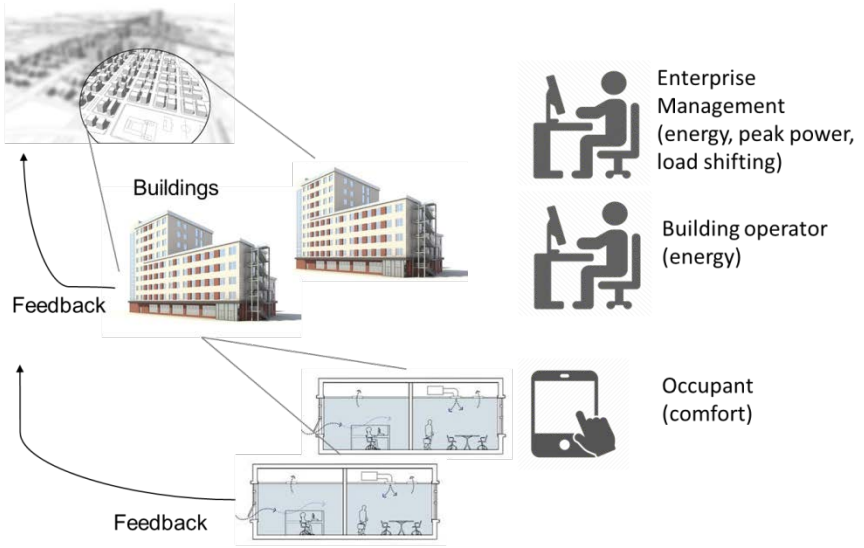
- Data and control requirements
- Model structure and calibration algorithms
- Optimization algorithms
- Occupant integration
- Ease of use and robustness



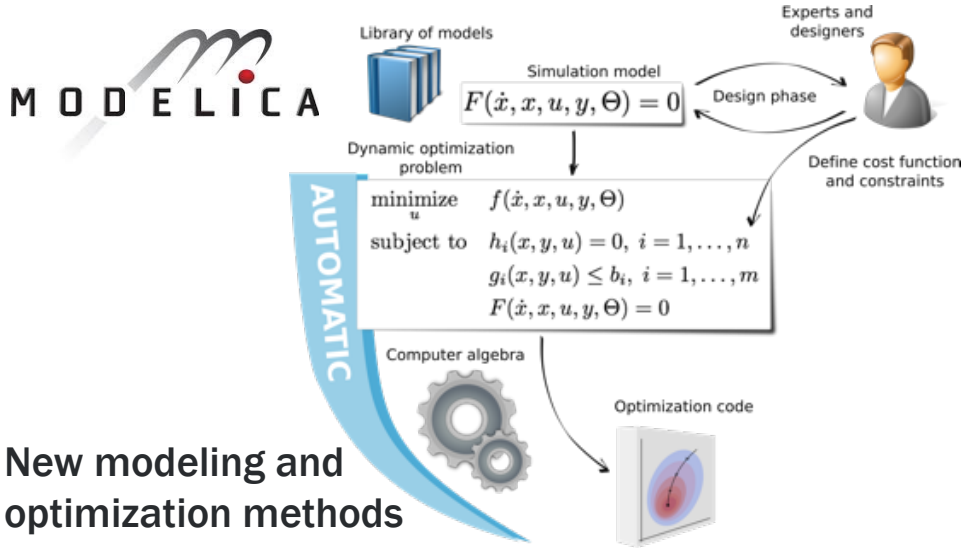
Approach

Distinctive Characteristics

- **Developed in this project**
  - Data-driven model identification *reduces* model setup, calibration, and maintenance effort.
  - Hierarchical MPC *enables* occupant input and feedback at different levels.
  - Occupant integration *detects* occupant presence and count (Jia and Spanos 2017).
- **Leveraging other projects**
  - Predict behavior (IEA EBC Annex 66)
  - Modeling and optimization methods *solve faster* than conventional method (Wetter et al 2015).
  - Open-source software standards *facilitate* collaboration, scaling, robust API, ecosystem of tools and vendors, and longevity.



Hierarchical MPC



New modeling and optimization methods

Approach

Target Market and Audience:

- Target commercial building HVAC and lighting end uses
- Enable startup and major control companies to enter this new market segment in both the U.S. and China.
- Strong U.S. and China industry consortium with key players of JCI, UTC, Disney, Lutron, and Lend Lease.

Impact

Energy and Other Impacts:

- **Potential Savings**
  - ~20% HVAC from MPC (Zakula et al. 2014)
  - Overall ~1.9 Quad in U.S. and 1.0 Quad in China
  - 30% commercial building energy for occupant-integrated controls (Dong and Lam 2014).
  - $6B per year in US if all commercial buildings
  - Contribute to BTO's 30% EUI savings by 2030
- **Grid Integration Benefits**
  - Renewable integration through load shifting and shedding
  - Reduce risk of blackouts to avoid estimated costs of $16 - 22 billion, and an anticipated loss of 136,000 jobs just in California (National Energy Policy 2001)
- **Accelerate MPC Technology Adoption**
  - Application of efficient optimization algorithms to reduce computation time
  - Test effectiveness of model learning techniques to reduce setup time
  - Study of how model accuracy affects energy savings and performance
  - Documented software using open-source standards

Impact

Global Impacts:

- Optimize building operations in U.S. and China to reduce energy use and environmental impact
- Provide software platform to test, evaluate, and scale MPC technologies by researchers and industry
- Establish a strong foundation for future international collaborations on MPC and other advanced building technologies

Progress

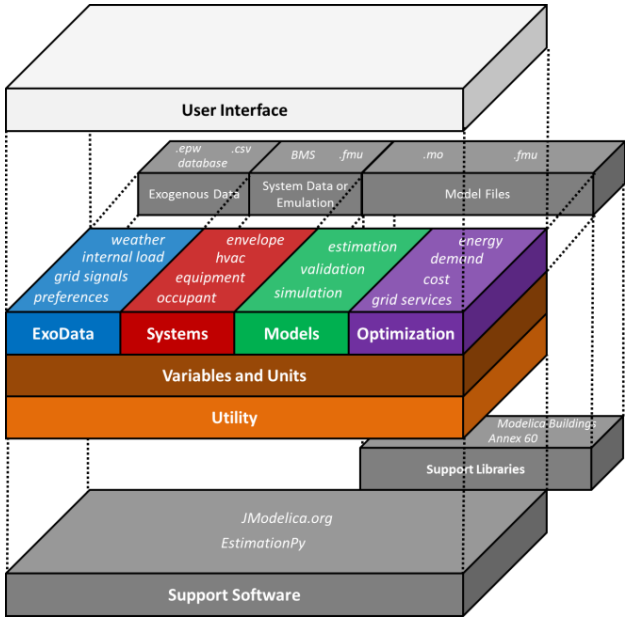
Software Development

MPCPy v0.1: Open-Source Platform For MPC in Buildings

https://github.com/lbl-srg/MPCPy

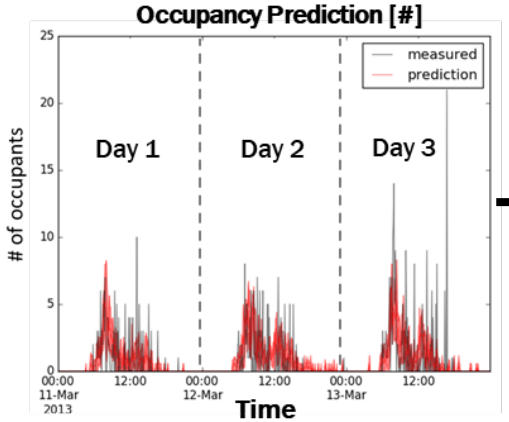
(Blum and Wetter 2017)

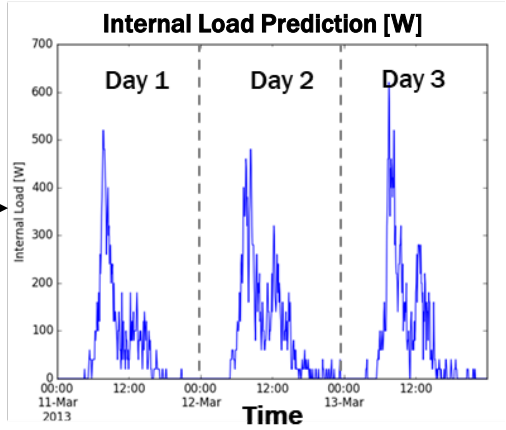
- Exogenous data collection
- Building system emulation or data collection
- Adaptive model learning
- Control optimization
- Continuous maintenance and development



Occupancy Modeling and Prediction

- Statistical "queueing" approach (Jia and Spanos 2017)
- Predicts occupant count
- Applicable to room and building scales
- Integrated into MPCPy





obModelica: Modelica Library of Occupant Behavior models

- Window opening and closing
- Thermostat interaction
- Blind and light operation
- Integration underway into Modelica Buildings Library

Progress

Field Test of MPC at Room and Building Levels at LBNL Building 59

Building Description

- Computational Research Facility
- 2 Office Floors of ~ 50,000 sf
- UFAD w/ Reheat, 4 Water-Cooled DX RTUs

Timeline

- MPC test started in April 2018 and to complete in March 2019

Data (~420 Points)

<u>HVAC Perimeter Zone</u>

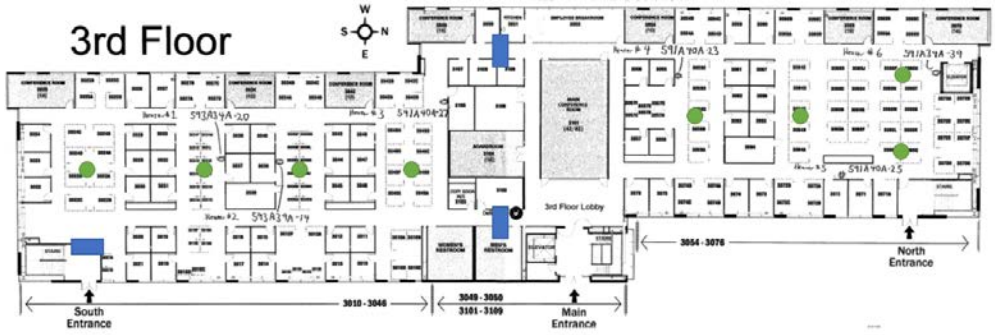
- Temp
- RH valve position
- TU fan speed

<u>Electric and Lighting</u>

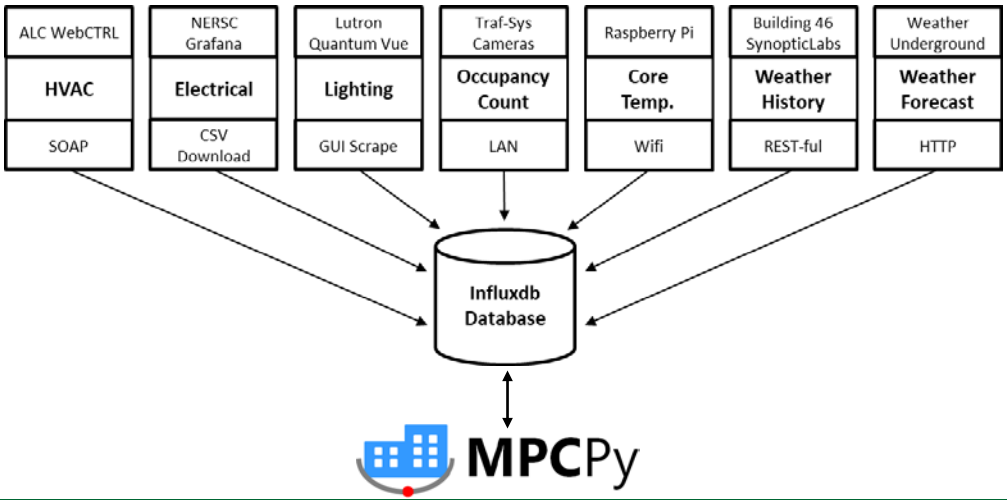
- Plug panels for north/south wings
- HVAC panels for RTUs
- Lighting energy for zones

<u>Added Sensing</u>

- Temp for core zones
- Image-based occupancy sensors for south wing



System	Number of Points	Sampling
BMS – Zone TU (50)	150	1 min
BMS – RTU (4)	113	1 min
Electric Metering	6	15 min
Lighting	130	1 hour
Added Core Temperature	16	10 min
Added Occupancy	6	10 min



Progress

Field Test of MPC at the Room and Building Levels at LBNL B59

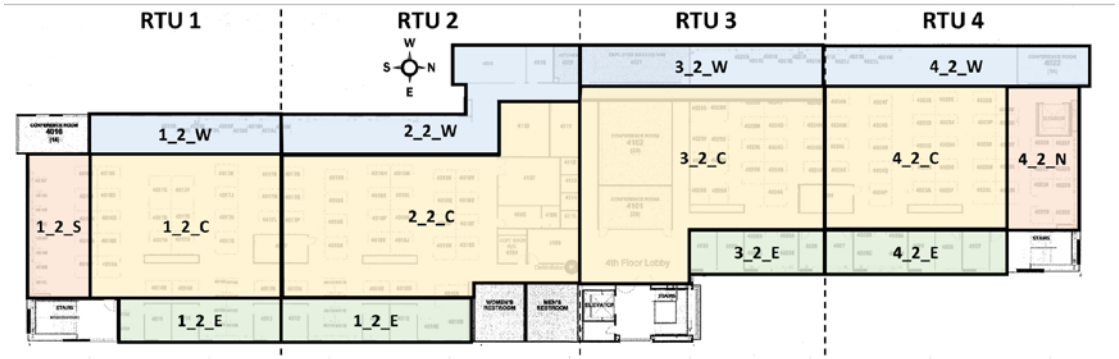
Challenges	Abatement
System and Modeling • UFAD system design • Undersized heating system • Model size for learning and control optimization	• Careful model formulation (zoning and HVAC)
Data • Useful data points missing • Data quality and gaps	• Data filtering and cleaning algorithms
BMS Integration and IT • Failure of MPC should not lead to failure of BMS • MPC should not affect control of High Performance Computer • Cybersecurity	• MPC suggests new setpoints for BMS, not directly control HVAC actuators • MPC on separate server from BMS • Ensure separation of control between office and HPC HVAC • Work with LBNL IT on cybersecurity
Occupant Comfort • Optimization of room air temperature setpoint within an acceptable range (ASHRAE Std 55)	• Report discomfort to facility manager or via a short survey

Progress

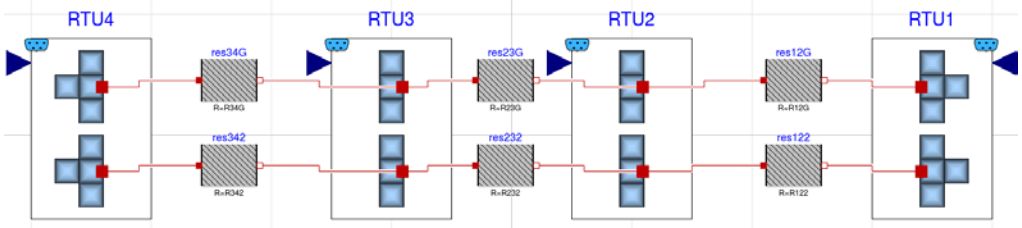
Field Test of MPC at Room and Building Levels at LBNL Building 59

Modeling

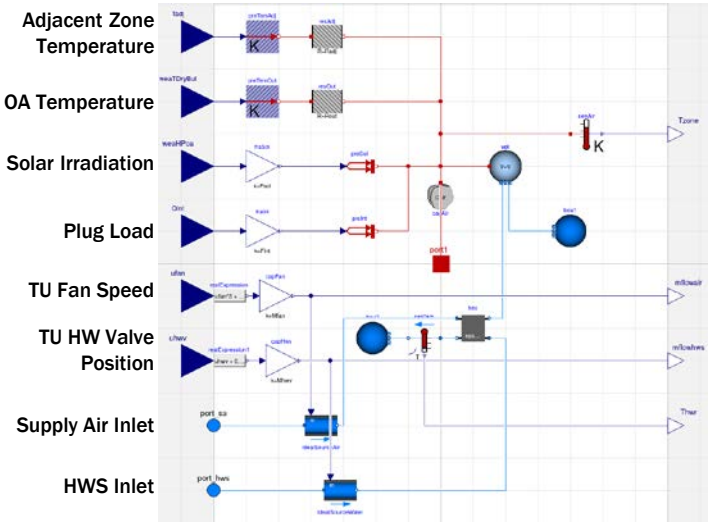
Zone Grouping
(similar on each floor)

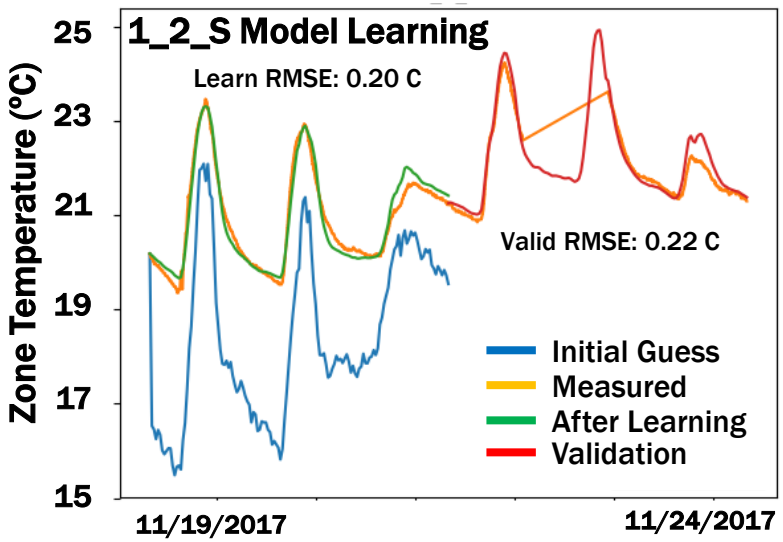


Building Level Model
for Control Optimization



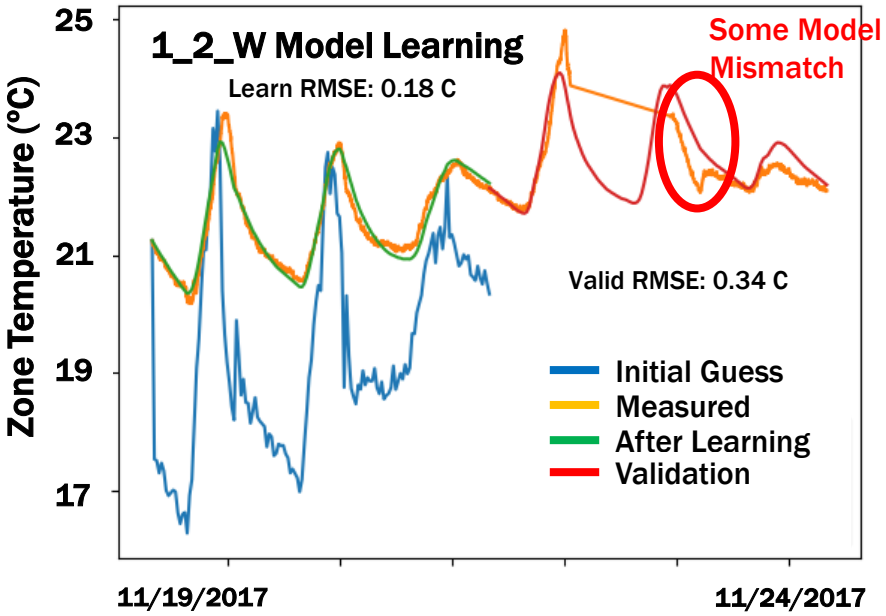
Zone Level Model
and Adaptive
Learning

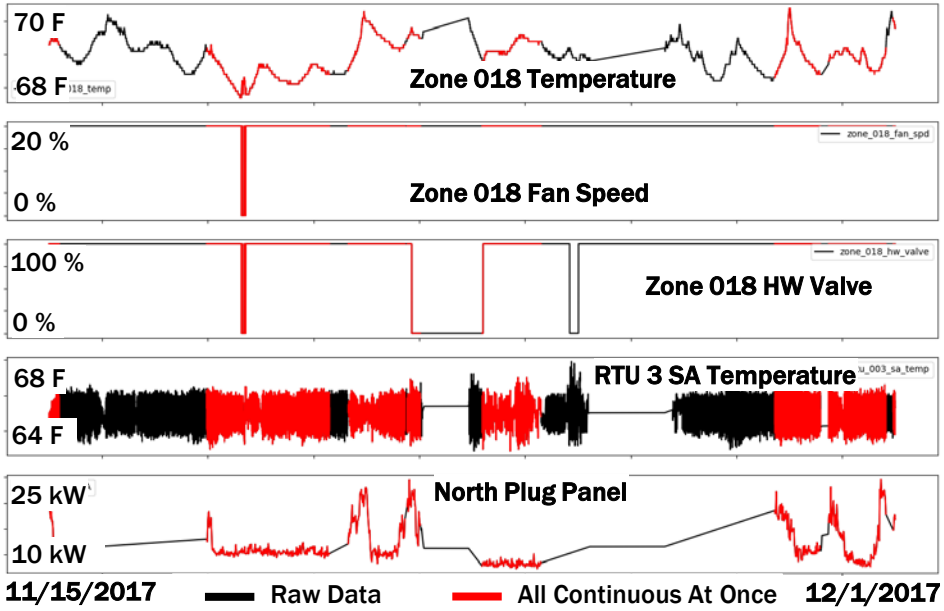




Progress

Field Test of MPC at the Room and Building Levels at LBNL B59





Findings

- Modeling and model training approach is promising, needs further testing on all zones
- Continuity of data is a challenge for model training and will be for control

Collaboration and Coordination

- Johnson Controls
  - Opened its LEED, EDGE and Three-Star certified Shanghai HQ building in June, 2017.
  - Building will deploy model-based commissioning and M&V of MPC benefit.
- Disney
  - Engaged in discussions for campus site demonstration
- LBNL
  - Develop commercialization plan through collaboration with industry partners and LBNL IPO office
  - Actively engage LBNL CSO, IT staff, B59 managers and occupants on the field tests and occupant surveys
- Research community / public
  - Conduct public webinars to announce and demonstrate MPCpy software
  - Present at conferences (e.g. ASHRAE, ACEEE and IBPSA) and publish journal articles

Collaboration and Coordination

- Collaboration with China team
  - Jointly developed the research plan
  - Joint activities on model-based commissioning and occupant module
  - Parallel MPC field tests
  - 1 joint technical workshop and three meetings in 2017 and 2018
  - Tsinghua researchers/students exchanged to LBNL
  - Joint research and planned joint IP on building electric load prediction

Remaining Project Work

Task 3 – Field Test Building-Level MPC and Prepare for Campus-Level MPC

- Integration of occupant module into MPC at building level
- Finish modeling and develop control optimization
- Field test the building-level MPC
- Development of campus-level MPC
- Occupant module development at the campus level
- Campus-level MPC field test preparation

Task 4 - Demonstration of the MPC at the campus level

- Integrate occupant module and MPC at campus level
- Test through simulation
- Verify through full-scale field test at a Disney campus

Remaining Project Work

Task 5 - Commissioning of MPC technology and the CERC demonstration buildings

- Develop MPC commissioning guide to detail data, procedures, and tools used to commission MPC at room, building, and campus levels.

Task 6 - Commercialization and dissemination

- Develop commercialization plan through collaboration with industry partners and LBNL IPO office
- (2) workshops to market the occupancy responsive MPC technology to industry leaders for technology transfer and adoption,
- (5) presentations in national conferences, e.g. ASHRAE, ACEEE and IBPSA and (5) publication of peer-review journal articles
- Dedicated project web site to detail MPC technology, potential energy savings and other benefits, and
- 1 or several open-source software repositories on github.com to host open-source code.

Thank You

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REFERENCE SLIDES

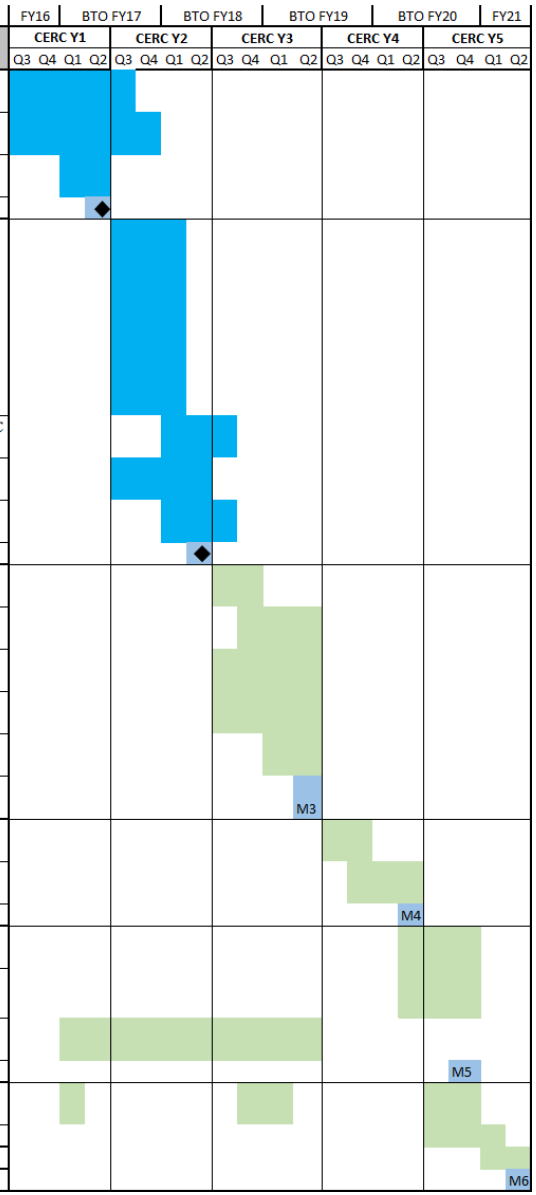
Project Budget

Project Budget: $430k (Year 1), $460k (Year 2)
Variances: Site for building-level field test changed to LBNL Building 59
Cost to Date: $460k (Year 2)
Additional Funding: NA

Budget History					
4/1/2016 – FY 2017 (past)		FY 2018 (current)		FY 2019 – 3/31/2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$430k	$1,531k	$460k	$1,531k	$460k	$660k

Project Plan and Schedule

Tasks	Subtasks	Deliverables
Task 1: Occupant module development at the room-level, MPC algorithm development at the building level	Subtask 1.1: Occupant module development at the room level	Deliverable 1.1: Room level occupant module
	Subtask 1.2: Development of building-level MPC	Deliverable 1.2: Building level MPC
	Subtask 1.3: Room level MPC demonstration preparation	Deliverable 1.3: Room level demonstration plan
	Milestone 1: Room level occupant module and building level MPC	
Task 2: Field test of the MPC at the room level; occupant module development at the building level	Subtask 2.1: Integration of the occupant module into MPC at the room level	Deliverable 2.1: Technical report- Room level module implementation into MPC
	Subtask 2.2: Demonstration of room-level MPC	Deliverable 2.2: Technical report- Room level MPC demonstration
	Subtask 2.3 Occupant module development at the building level	Deliverable 2.3: Building level occupant module
	Subtask 2.4: Building level MPC demonstration preparation	Deliverable 2.4: Building level demonstration plan
	Milestone 2: Successfully demonstrate the room level MPC through emulation	
Task 3: Field test of the MPC at the building level; occupant module and MPC algorithm development at the campus level	Subtask 3.1: Integration of the occupant module into MPC at the building level	Deliverable 3.1: Technical report- Building level module implementation into MPC
	Subtask 3.2: Field test the building-level MPC	Deliverable 3.2: Technical report- Building level MPC field study
	Subtask 3.3: Development of campus-level MPC	Deliverable 3.3: Campus level MPC
	Subtask 3.4: Occupant module development at the campus level	Deliverable 3.4: Campus level occupant module
	Subtask 3.5: Campus level MPC field test preparation	Deliverable 3.5: Campus level field study plan
	Milestone 3: Successfully field test the building level MPC	
Task 4: Field test of the MPC at the campus level	Subtask 4.1: Integration of the occupant module into MPC at the campus level	Deliverable 4.1: Technical report- Campus level module implementation into MPC
	Subtask 4.2: Field test of campus-level MPC	Deliverable 4.2: Technical report- Campus level MPC field study
	Milestone 4: Successfully field test the campus level MPC	
Task 5: Commissioning of MPC technology and the CERC demonstration buildings	Subtask 5.1 Development of MPC commissioning guide	Deliverable 5.1: Commissioning guidebook
	Subtask 5.2 Evaluation of MPC to support continuous commissioning	Deliverable 5.2: A memo report
	Subtask 5.3 Retro-commissioning of China CERC demonstration buildings	Deliverable 5.3: Report on the retro-commissioning results
	Milestones 5: Publish the commissioning guides	
Task 6: Commercialization and dissemination	Subtask 6.1: Development of a commercialization plan	Deliverable 6.1: Commercialization plan
	Subtask 6.2: Dissemination of results	Deliverable 6.2: Dissemination results
	Subtask 6.3: Final technical report	Deliverable 6.3: Final technical report
	Milestone 6: Deliver the final report	



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