Breaking Boundaries of Advanced Controls in the Real Building Market: Demonstration, Demonstration, and Demonstration

Guest Lecture: Occupant Centric Grid Interactive Buildings, University of Texas at Austin

Donghun Kim

Computational Research Scientist

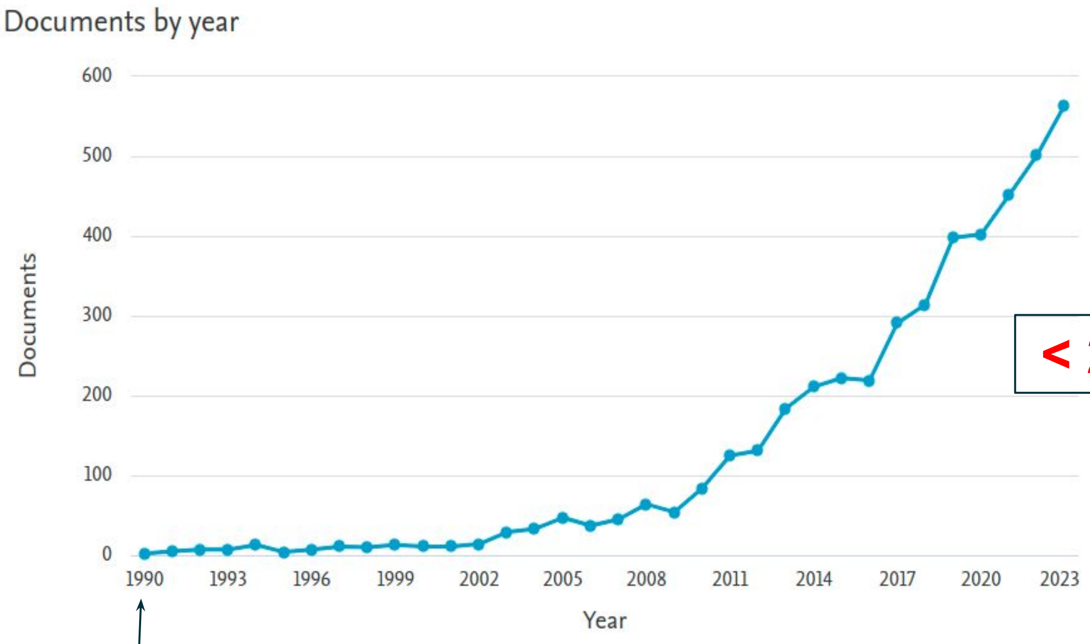
Building Technology & Urban Systems Division, Energy Technologies Area, LBNL

March 27, 2024

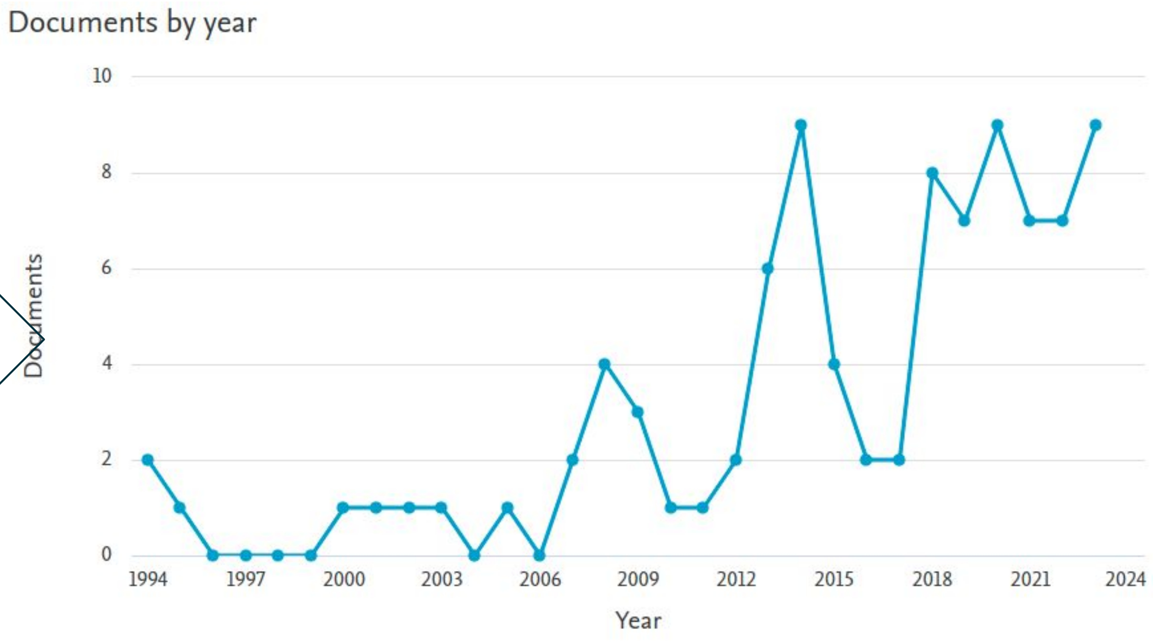
0.00001% of buildings have employed advanced controls, despite enormous amount of research

4,665 papers in Scopus
(keyword: Model Predictive Control & Buildings)

<< 100 papers in Scopus
(keyword: + **Demonstration or Field Test**)

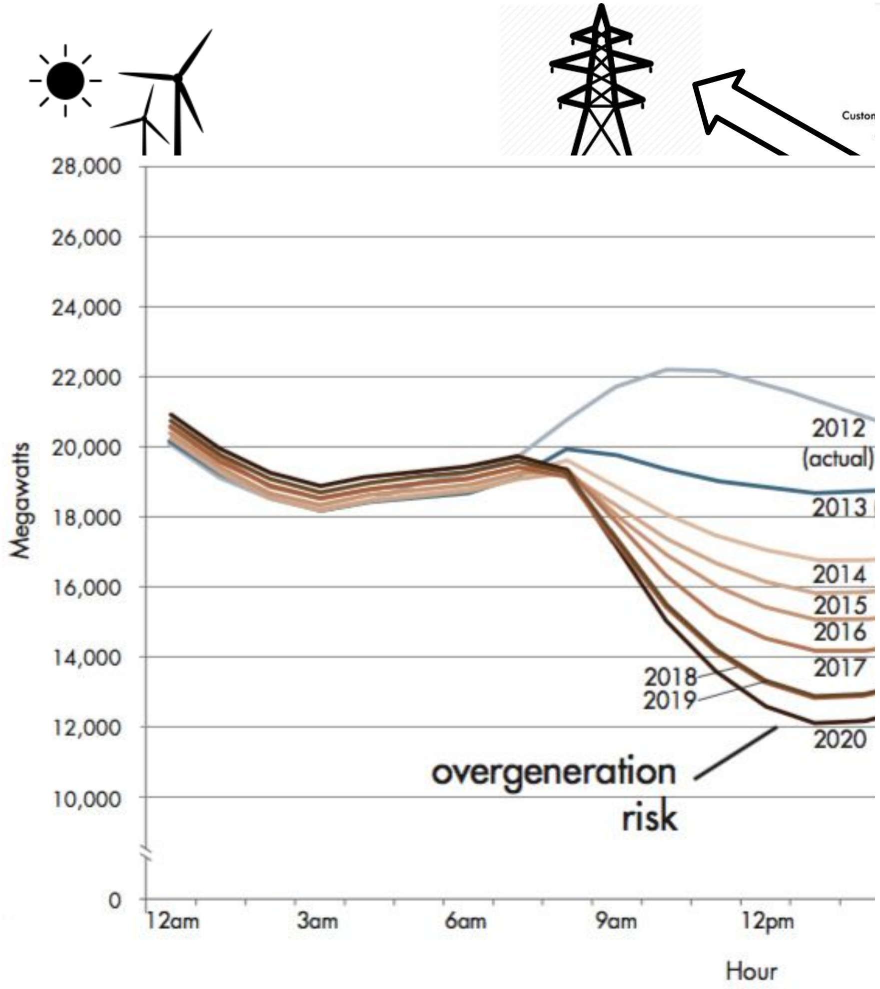


< 2%



Braun J.E. A comparison of chiller-priority, storage-priority, and optimal control of an ice-storage system, ASHRAE Trans, 98 (1992), pp. 893-902

Why is the wide adoption of advanced controls in the real-world market urge



panel the planet
SOLAR SOLUTIONS

Commercial Solar | Residential Solar | About Us

California's 7 GW load shift goal is 'starting gun' for dramatic expansion in flexible demand

The California Energy Commission last week approved a state load shift goal of 7,000 MW by 2030, which is double current levels of demand flexibility and could power up to 7 million homes by the end of the decade without new power plants, according to the agency.

The goal, which comes from a requirement in state Senate Bill 846, passed last year, includes a series of measures including demand response programs and time-of-use rates that incentivize the use of electricity when it makes the most sense for customers and the grid.

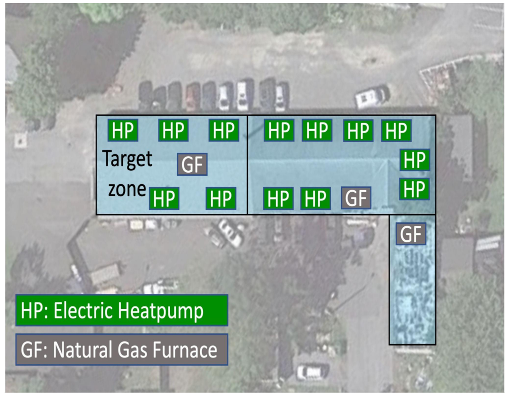
How can we address this urgent issue? Through extensive demonstration, compelling savings, proved scalability and commercialization of advanced controls across various real building HVAC systems, moving beyond algorithm development




Each building sector has unique opportunities, technical challenges and non-technical challenges!

FLEXLAB, LBN

tail Stores


Convenience Store

K-12 Schools

Small Office

Large Office Building

Campus

Sample sites where MPC has been demonstrated

Small & Medium-sized Commercial Buildings (SMCBs)

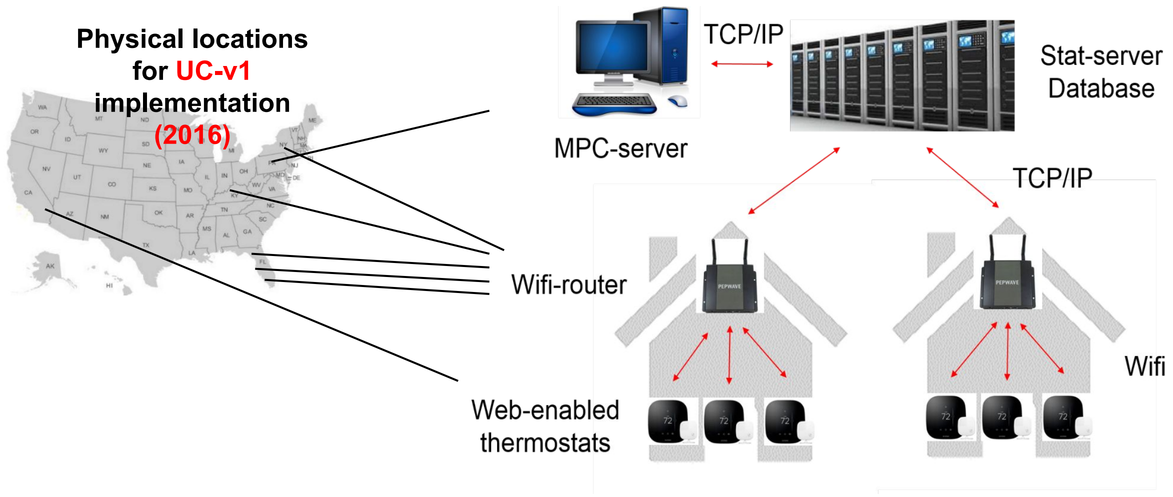
Opportunities and Challenges, along with MPC Demonstration Activities and Savings Results

Opportunities & Challenges

- Opportunities:
  - SMCBs are tremendous demand response resources
    - ~ 50% of the total commercial indoor floor space
    - ~ 50% of energy usage in the commercial buildings sector
  - Unlike large commercial buildings, SMCBs have a high potential for **a universally applicable control solution for automated load flexibility** due to the consistent HVAC configuration (multiple ON/OFF packaged units)

- Challenges:
  - Lack of sensors
  - Discontinuous nature of controllable inputs
  - Economics
    - e.g., for a building paying $1,500/month, 20% utility cost savings, upfront cost of $5,000, $200/month service fee → payback period > **4 years!**

A low-cost advanced control for automated demand reduction and load shifting was developed



Summary of Advanced Control Developments for SMCBs

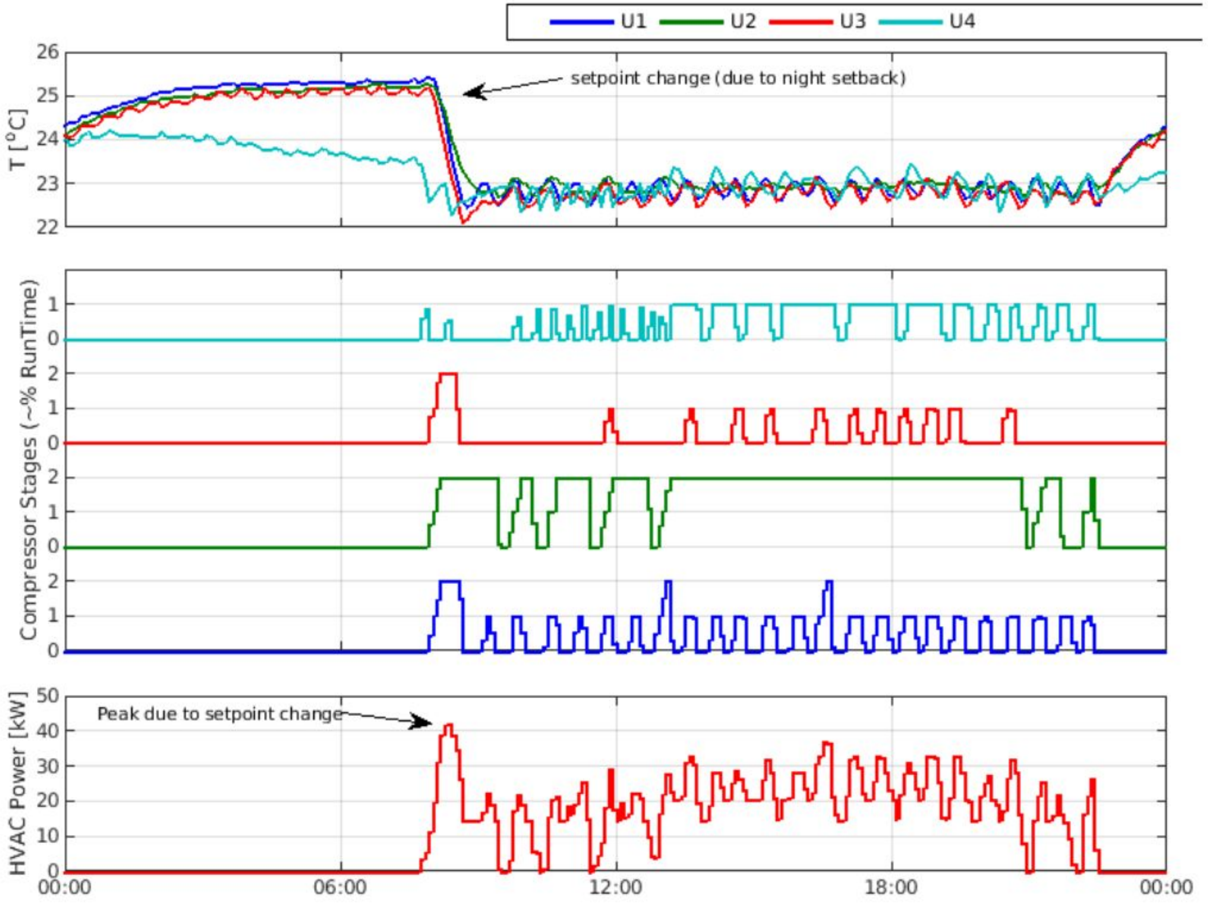
- Target: Buildings served by multiple packaged units
- Capabilities
  - Demand reduction by coordination of unit stages (Unit Coordinator V1)
  - Optimal response to dynamic price signals (Unit Coordinator V2)
- Main features: **Low-cost** (only utilizing Wifi-enabled thermostats)
- **Scalability and reliability**
  - Demonstrated by field demonstrations at multiple sites (since 2016)
  - **UC1 was commercialized** (2017)

References:

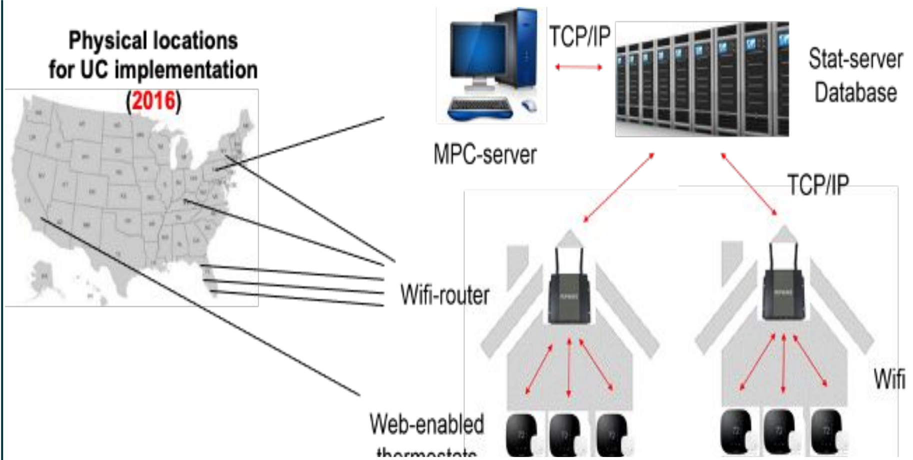
Kim, D., Braun, J. E., Cai, J., & Fugate, D. L. (2015). Development and experimental demonstration of a plug-and-play multiple RTU coordination control algorithm for small/medium commercial buildings. *Energy and Buildings*, *107*, 279-293. https://doi.org/10.1016/j.enbuild.2015.08.025

Kim, D., & Braun, J. E. (2022). MPC solution for optimal load shifting for buildings with ON/OFF staged packaged units: Experimental demonstration, and lessons learned. *Energy and Buildings*, *266*, 112118. https://doi.org/10.1016/j.enbuild.2022.112118

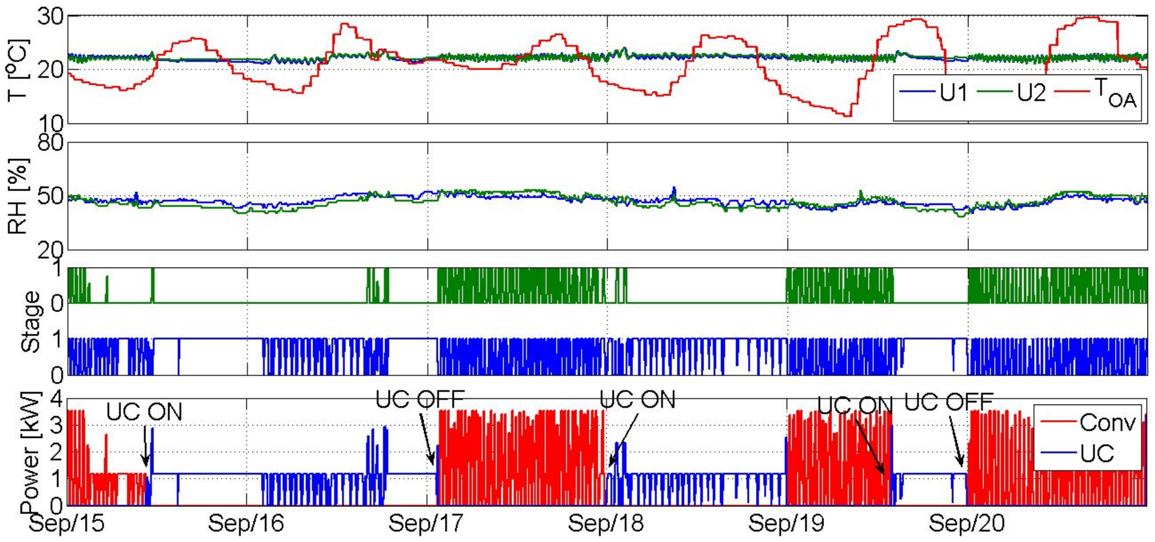
Field Performance of MPC: Demand Reduction (UC_V1)



Typical challenges of SMCBs caused by night setup and a decentralized control of multiple ON/OFF staged units



Sites	# RTUs	DS (%)
Retail	3	20
Retail	4	18
Office	3	29
Lab	2	27
Gym	4	24



Sample experimental results for a building with 2 RTUs

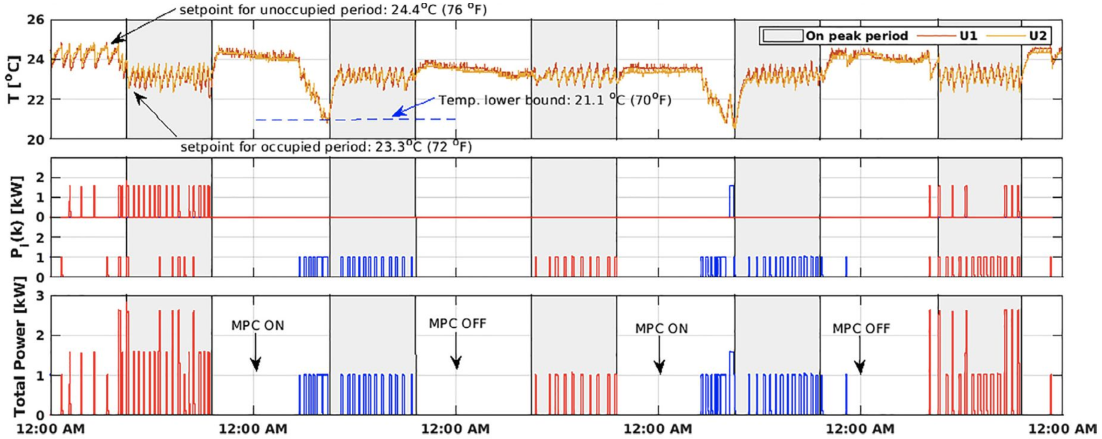
Reference: https://doi.org/10.1016/j.enbuild.2018.08.019

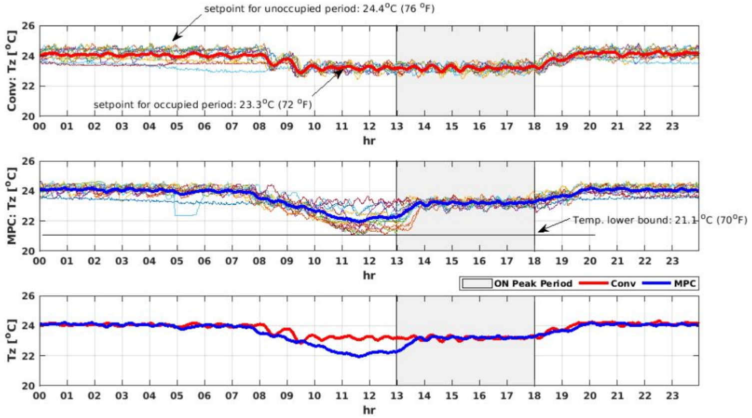
Field Performance of MPC: Demand Reduction + Load Shifting for SMCBs (UC_V2)

With a TOU (ON-OFF peak price ratio of 2,

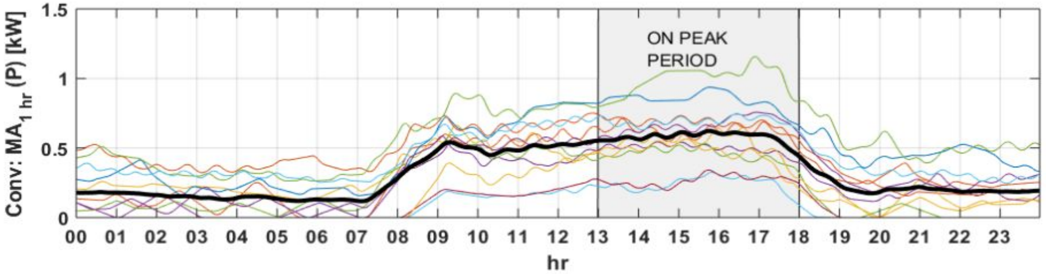
- **> 30% demand** reduction
- **~ 5% energy cost** reduction
- **~ 15% load shifting**

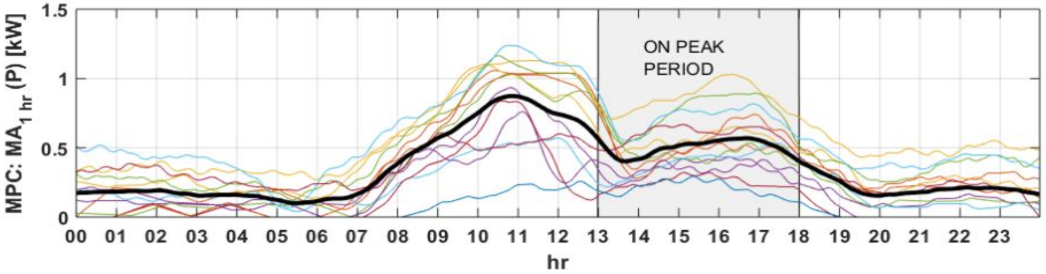
Sample experimental results for 2 RTUs

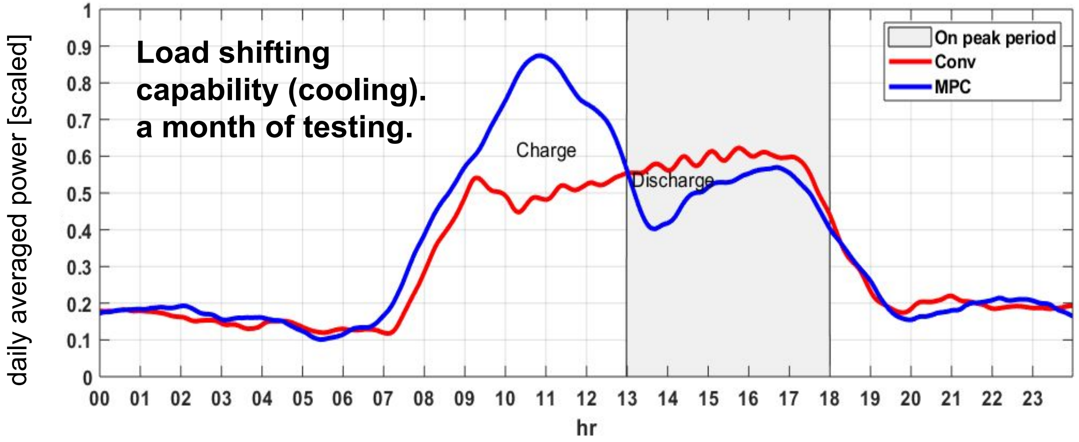




Distributions of daily temperature profiles between the conventional control and MPC. For each figure, different colors represent thermostat temperature measurements for different days, and the thick black line indicates the mean trajectory

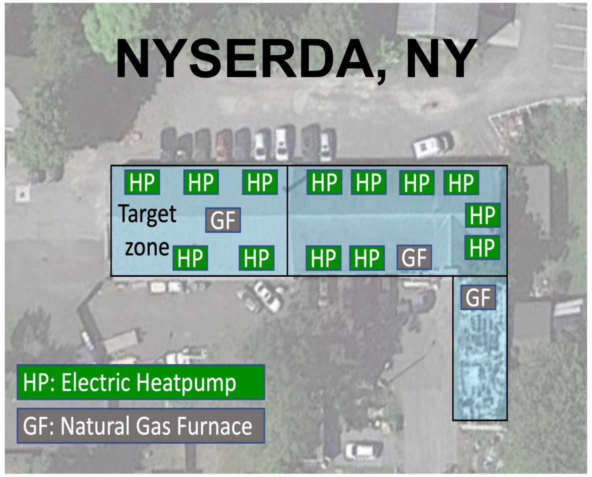




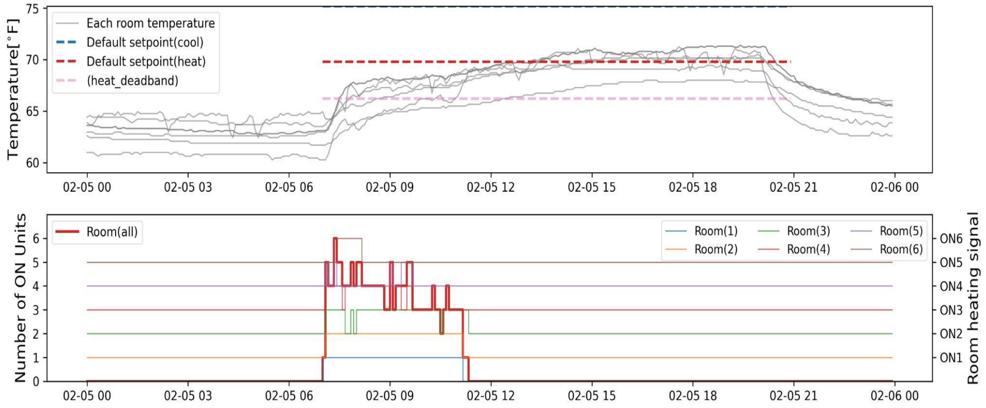


Reference: https://doi.org/10.1016/j.enbuild.2022.112118

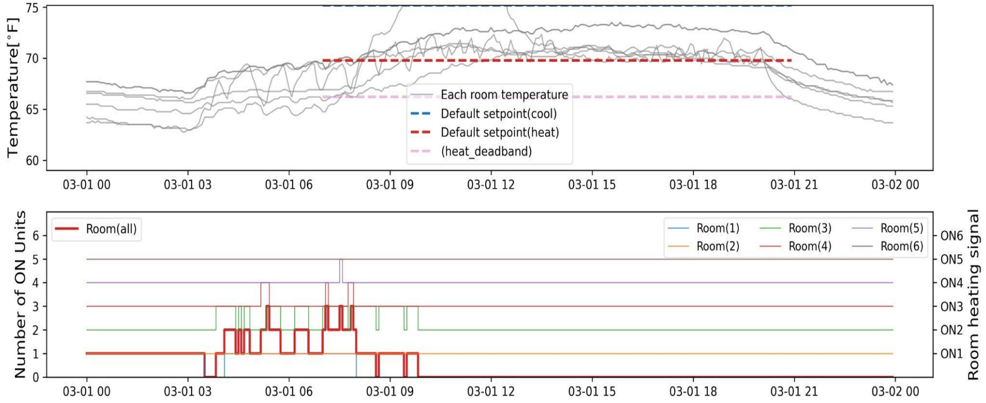
Field Performance of MPC: Carbon Reduction + Demand Reduction (MPC for dual-fuel heat pumps)



	Site details
Building information	- Small business building - Retail + physical work + office
Device	- **Five heat pumps** (Mitsubishi, Cooling: 4.4kW, Heating: 5.2 kW) - **One gas furnace** (York/Luxaire, Heating: 30.4kW)
Tariff	Electricity tariff (conEdison ToU small business) - 08:00-22:00: On-peak (**18.62**$/kWh) - Other time: off-peak (**1.38**$/kWh)

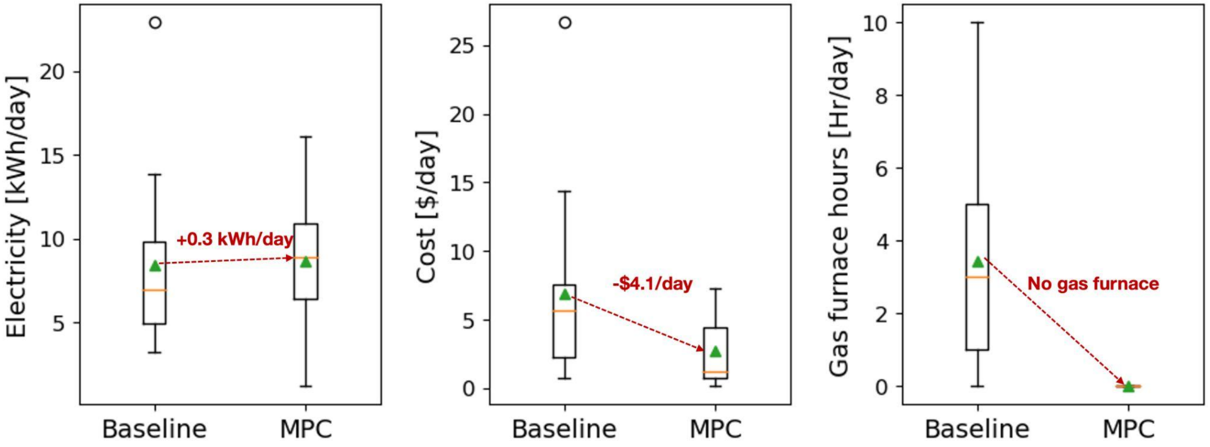


(a) Baseline operation



(b) MPC operation

Savings summary.
A few weeks of testing.



- **37% demand** reduction
- **20% utility energy** cost reduction
- **Completely eliminated the use of gas**

Reference: https://doi.org/10.1016/j.apenergy.2024.122935

The scalability of the MPC was proven through multiple site deployments

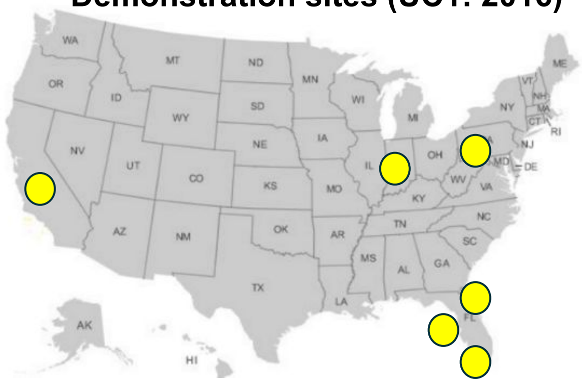
Herrick Lab, Purdue Univ.

Church

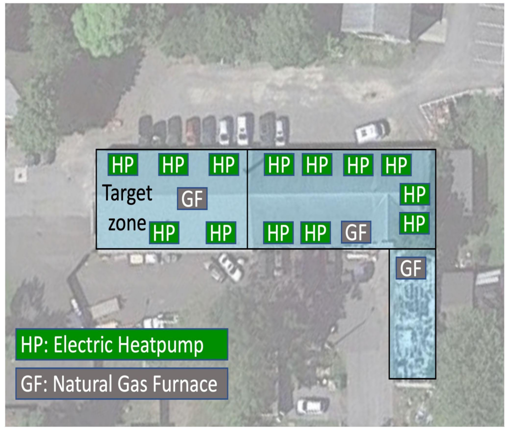
Restaurant

Retail Stores

Demonstration sites (UC1: 2016)



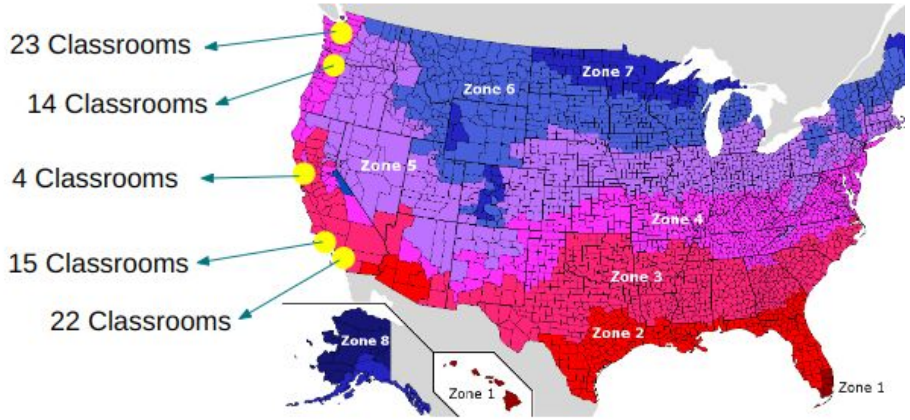
FLEXLAB, LBNL



Small Office

Multiple K-12 Schools

On-going site deployments (UC1+UC2: 2024)



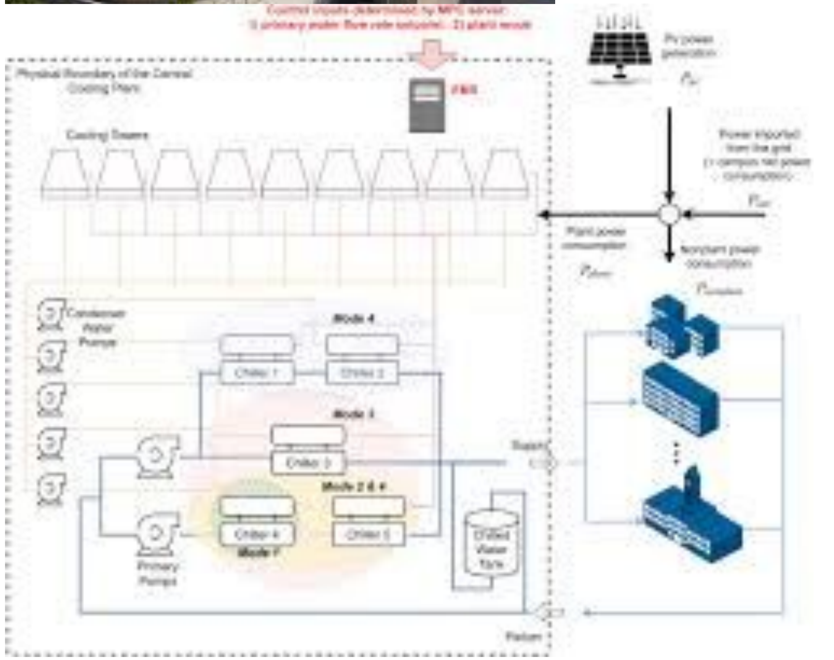
Sample sites where the MPC has been deployed and demonstrated

Large Commercial & District Energy Systems

Opportunities and Challenges, along with MPC Demonstration Activities and Savings Results

Opportunities & Challenges

- Opportunities:
  - Significantly greater effectiveness ($ savings or load shifting per building) for large commercial buildings and district energy systems compared to SMCBs, if MPC is successfully deployed
  - For example, for a district energy system, a single control deployment could achieve **MW-hr scale load shifting** and **saves $10,000 per month**
- Challenges:
  - Diverse HVAC systems
  - Legacy control systems
  - Complex and customized internal control logics (due to safety and energy efficiency operation) that prevents taking supervisory level control commands
  - BMS modification is not easy
  - Lack of or unreliable water flow measurements
  - Interoperability issues between subsystems
  - Many stakeholders
  - Safety issues
  - liability issues
  - …

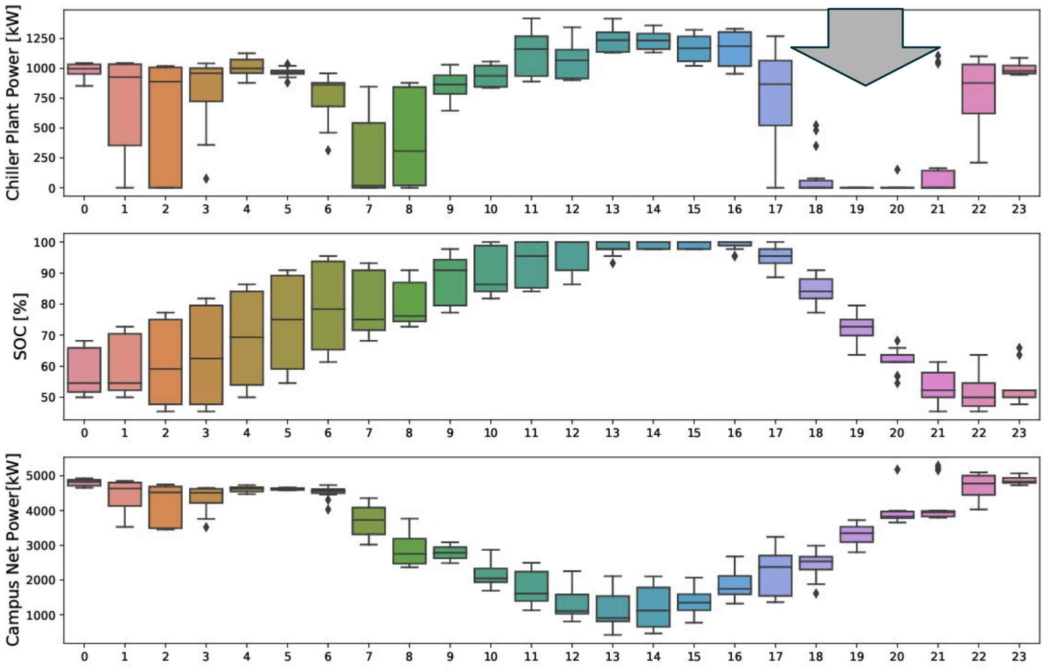


Reference: https://doi.org/10.1016/j.apenergy.2022.119343

Field Performance of MPC: Pead Demand Reduction + Load Shift + Self-Consumption of On-site PV

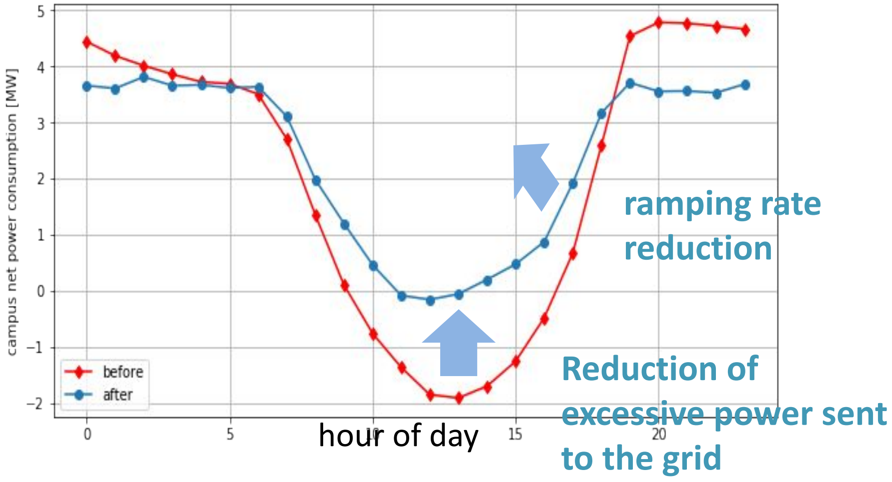
UC-Merced central cooling plant

High peak price period



Chiller plant power, state of charge, and campus net power consumption

Experimental data: daily-averaged net power consumption profiles*
(one week MPC test period in May)



Control	On-site Solar Self-Consumption [%]	Carbon Emission Savings [%]	Peak Demand Reduction [%]
Baseline	72	-	-
MPC	**99**	**10**	**10 ~ 15**

CO_2 savings ~ 1mTonCO2/day

Reference: https://doi.org/10.1016/j.apenergy.2022.119343

Lessons-Learned and Conclusion

Lessons Learned

- There are numerous unexpected problems in real buildings that are not captured in simulations.
  - Do not assume that we have all sensors available
  - Unmeasured disturbances in buildings are never white noise gaussian process
  - Do not assume that everything is controllable

Conclusion

- The tangible real-world performance of advanced controls in buildings, along with their proven scalability, is essential for decarbonizing the grid and maximizing clean energy use.

Thank you!

Donghun Kim

donghunkim@lbl.gov

- I am seeking multiple postdoctoral researchers with a strong background in HVAC systems and advanced controls. Contact me if interested.