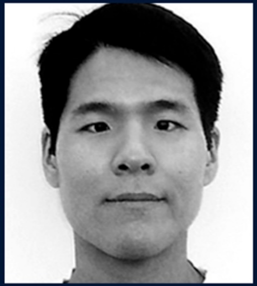
CALFLEXHUB SYMPOSIUM

NOVEMBER 3 | 8am-4pm PT

CATON MANDE

ETTORE ZANETTI

DONGHUN KIM



SANG WOO HAM

MARCO PRITONI

PROJECT SHOWCASE: **MODEL-PREDICTIVE CONTROLS**

SPEAKERS: Caton Mande, R&D Engineer, UC Davis; **Ettore Zanetti,** Post-doctoral Researcher, Berkeley Lab; **Donghun Kim**, Computational Research Scientist, Berkeley Lab; **Sang woo Ham,** Post-doctoral Researcher, Berkeley Lab; **Marco Pritoni,** Research Scientist, Berkeley Lab.

2023

CalFlexHub

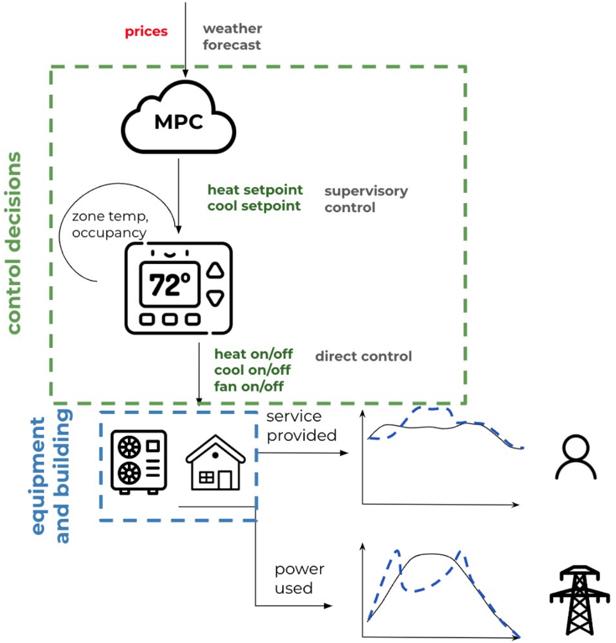
BERKELEY LAB

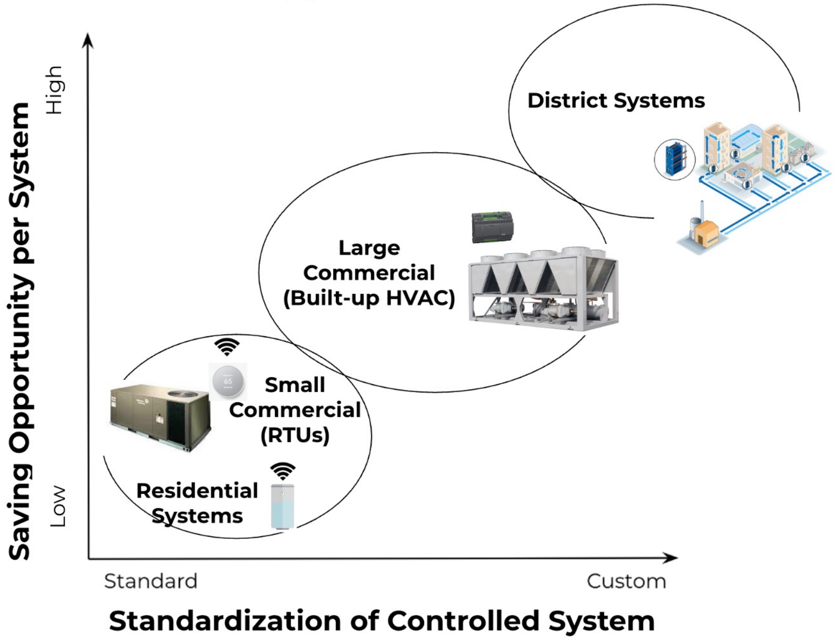
STATE OF CALIFORNIA ENERGY COMMISSION

MOMENTUM

CalFlexHub Applied Research and Development Projects

- Model Predictive Control (MPC)
- Model -> uses model of the controlled building and HVAC/DHW system
- Predictive -> anticipates future events and plans a sequence of actions to respond
- Supervisory Control -> defines the setpoints or modes on top of local controls





Dynamic Heat Pump for Residential Space Heat and DHW

UC DAVIS Western Cooling Efficiency Center

- Supervisory MPC control system for residential heat pumps (multi-splits and water heaters)
- Multi-objective Optimization
- Modularity: can be used with a variety of systems

Test Site(s): Woodland, CA
San Jose, CA

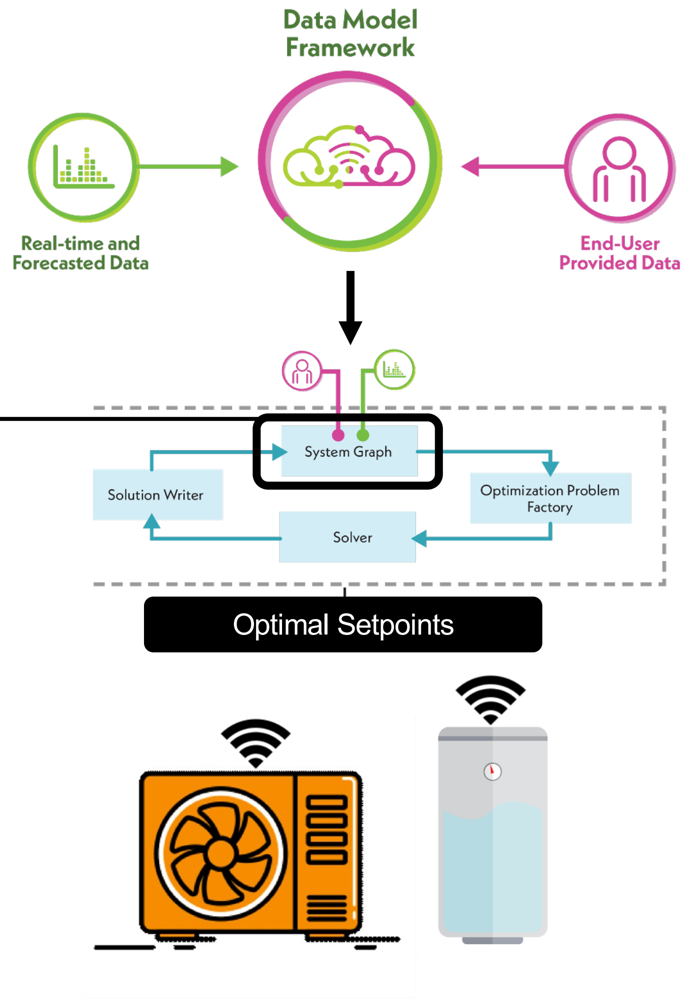
Sector/Building Type	Multi-Family
Technology & End Use	Heat pumps, domestic hot water and space conditioning
Communications Pathway	Research Cloud -> OEM Cloud -> Equipment (via Cellular)
Expected Grid Benefit	Automated load shifting based on price and GHG
Testing Status (Timeline)	Collecting baseline data, testing expected Q2 2024

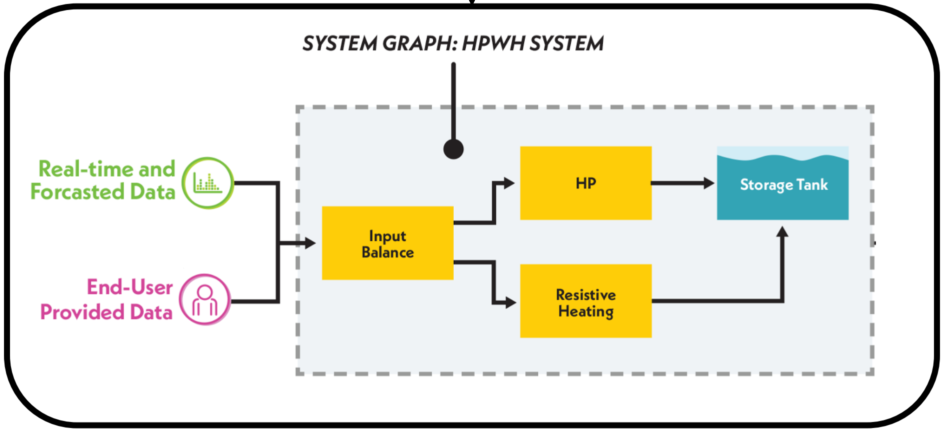
Woodland, CA
Climate Zone 12

San Jose, CA
Climate Zone 4

Communication Architecture

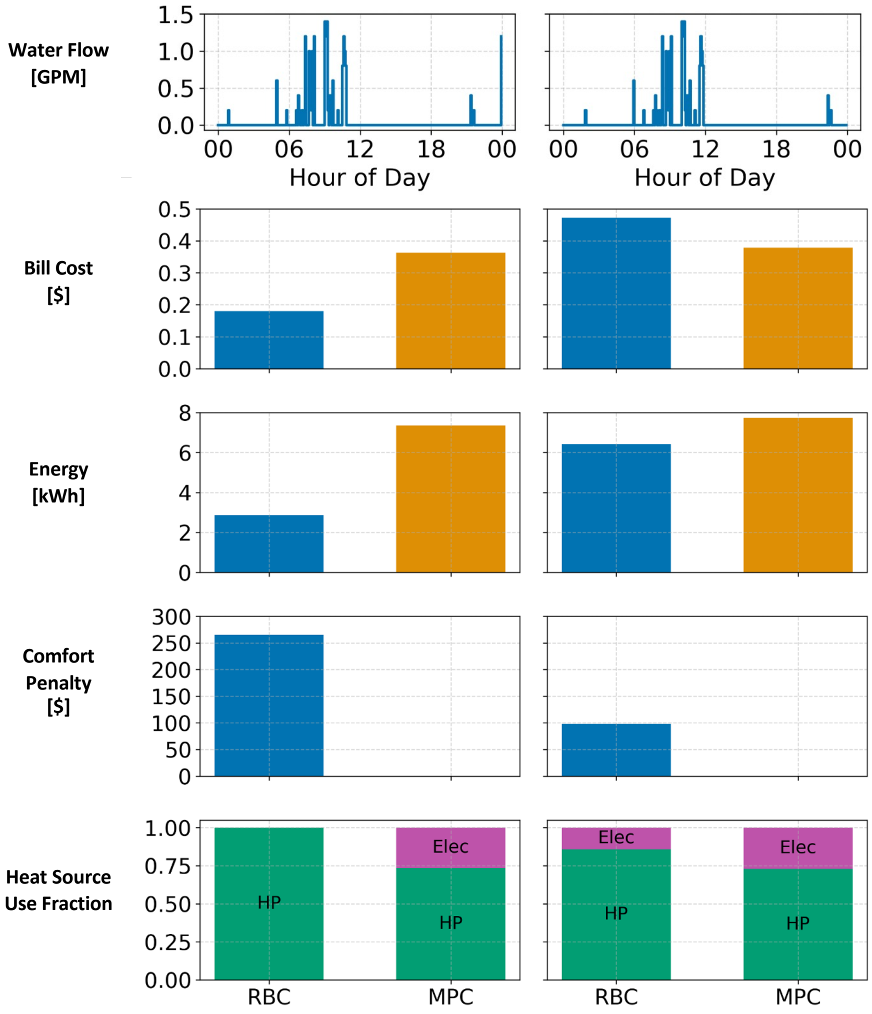
- Can use signal from CalFlexHub, MIDAS or WattTime
- Software polls price signal every 5-minutes
- Price signal currently used in simulation and lab testing





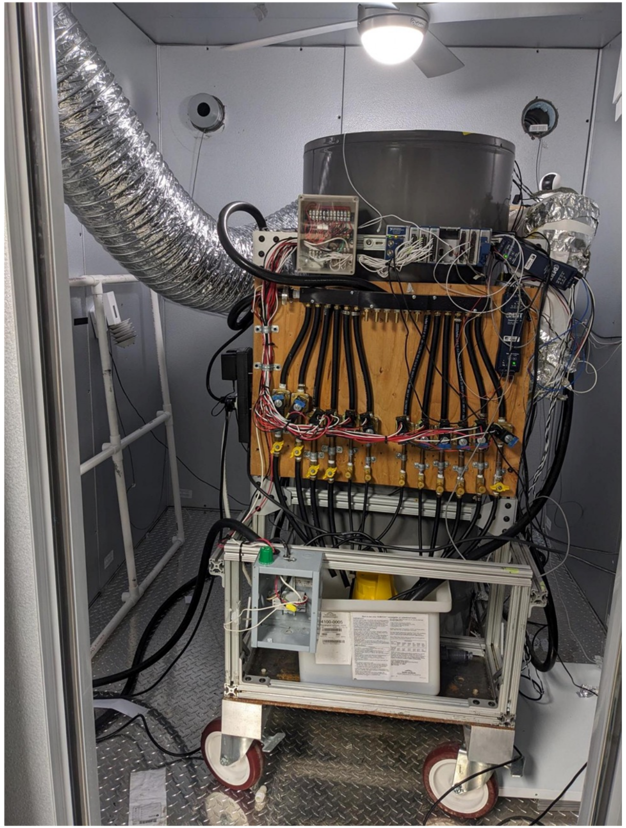
Test Results

- Simulation of 65-gallon HPWH, SummerHDP tariff, and perfect forecasts to investigate interplay between:
  - Amount of hot water use
  - Timing of hot water use
  - Capacity of HPWH tank
- Flow profile measured at field site
  - Daily volume held constant and flow profile was shifted in 1-hour increments
- Comfort penalty means <u>no hot water available</u>, calculated using \$2/°C below deadband every 5-minutes.
- MPC had similar performance with both profiles, unlike RBC
- For the first profile, the water temperature never drops enough activate electric resistance heat.



Key Learnings

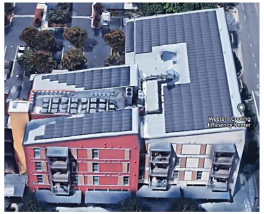
- Hot water use behavior can have a big impact on load flexibility potential.
    - The storage capability of HPWHs enables load shifting on the timescale of hours,
    - But that might not be enough to satisfy comfort if no peak power usage is the goal.
- APIs and internet connections are not perfect.
    - MPC should balance operation with incomplete information with confidence in its state estimation.
- Loss of comfort not captured in bill cost comparison
    - MPC can help automate the balance of cost and comfort, based on the relative importance for the user.

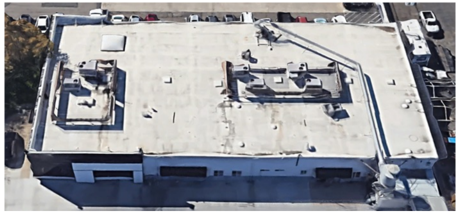


UCD HPWH Lab Testing

Dynamic Heat Pump Design and Control for Small Commercial HVAC

- Supervisory MPC control system for small commercial systems w/ rooftop units or other small systems
- Can coordinate operation of multiple units
- Can optimize for cost, energy, CO_2 emissions
- Can optimize active thermal storage
- Can communicate with local or cloud software





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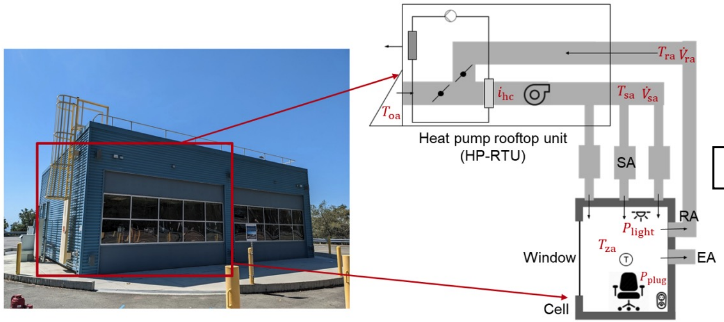
Test Site(s)

- FLEXLAB
- 6 field sites in CA
- 1 site in NY (related project)

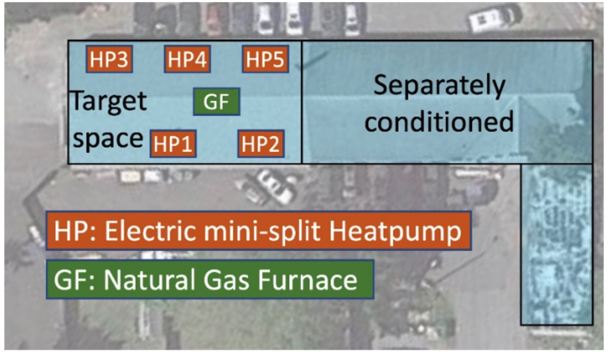
Sector/Building Type	Small Commercial
Technology & End Use	Rooftop units & thermal storage for space and water heating
Communications Pathway	Research Cloud-> OEM Cloud -> Thermostat via Cellular & Wi-Fi LAN
Expected Grid Benefit	Reduce peak demand, reduce carbon emissions, reduce natural gas use (NY)
Testing Status (Timeline)	In progress (2023-25)

Communication Architecture

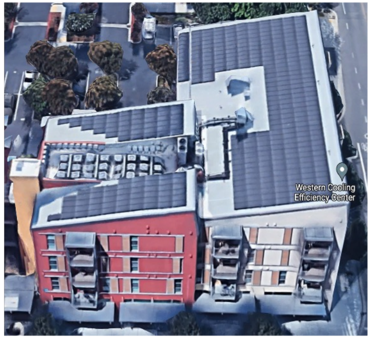
FLEXLAB

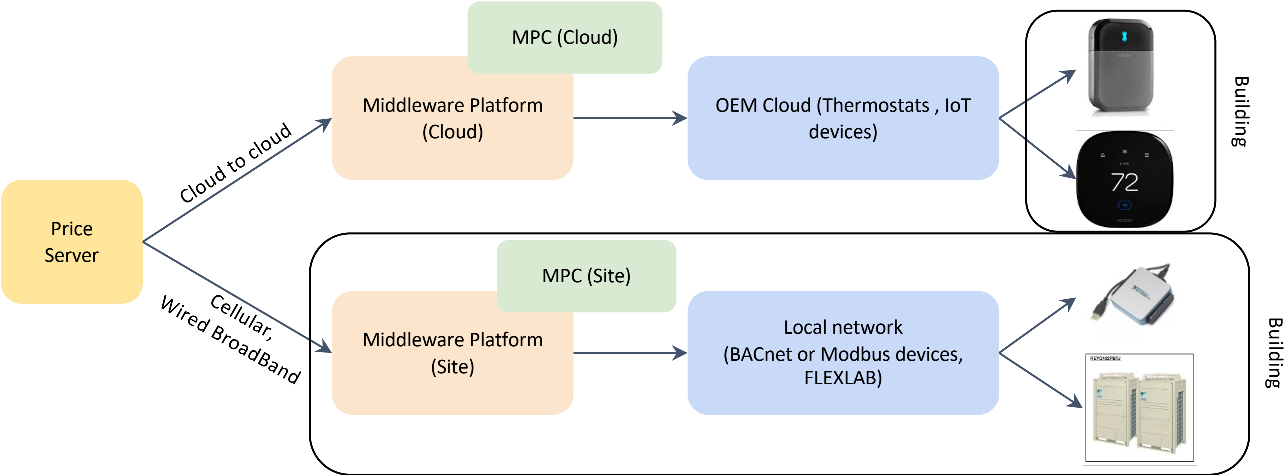


Site in NY



UC Davis

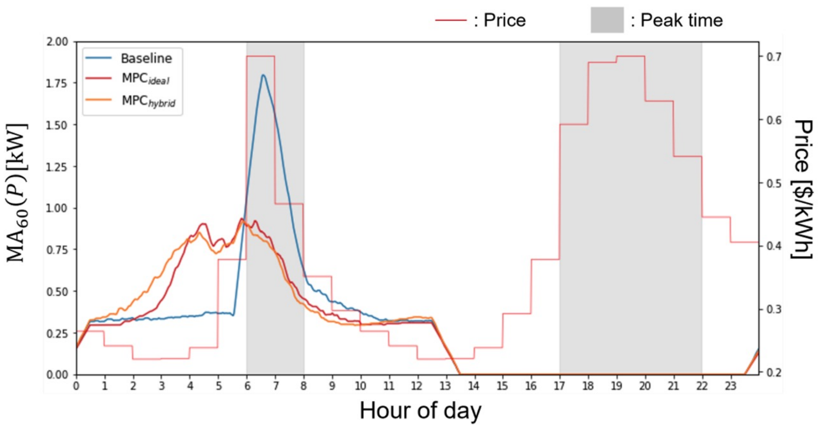




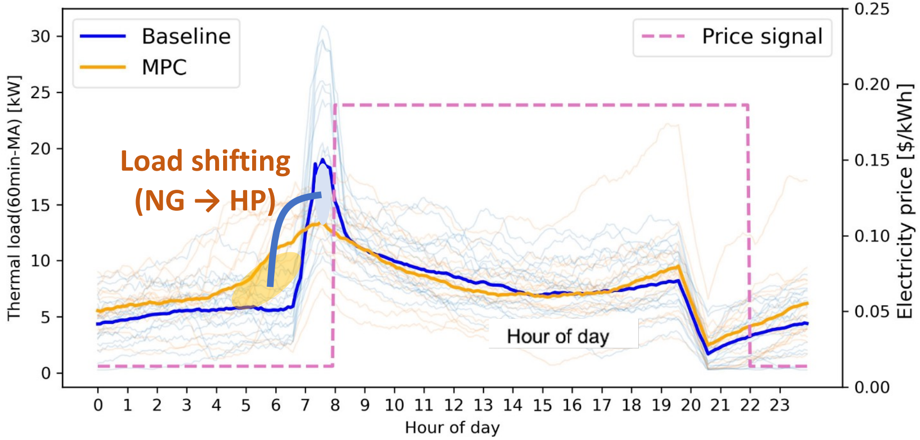
Test Results

- MPC$_{ideal}$
  - HVAC Cost Savings 24%
  - HVAC Peak Reduction 33%
- MPC$_{hybrid}$
  - HVAC Cost Savings 18%
  - HVAC Peak Reduction 27%

FLEXLAB

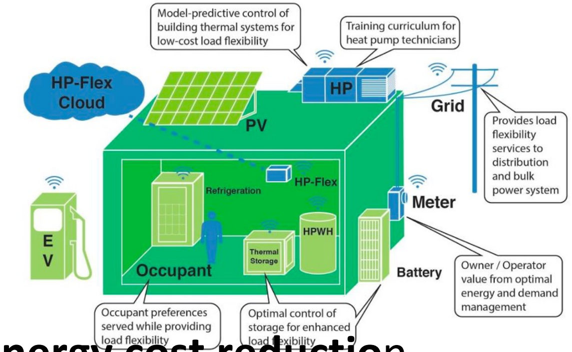


Small building in NY



- Dual-fuel MPC for 3 months
- Morning NG heating peak shifted to early morning
- of HVAC load shifted 23%
- HVAC cost saving 27%
- Completely eliminated NG usage.

Key Learnings



FLEXLAB

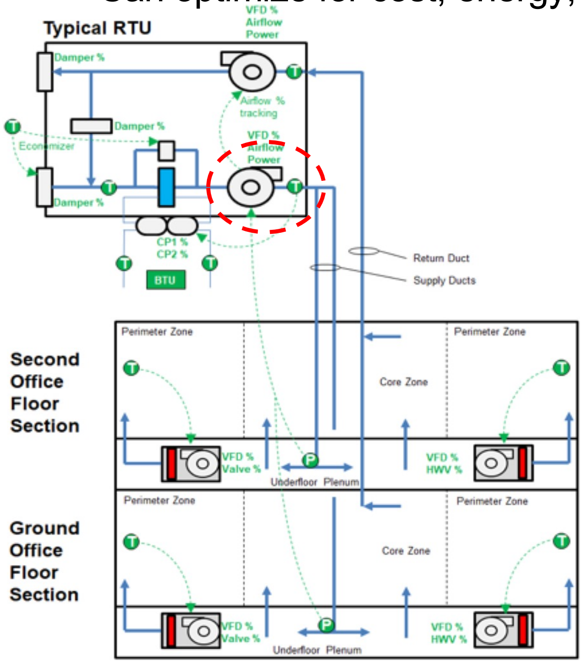
- **MPC** w/ no additional sensors provides **peak demand** and **energy cost reduction** in a **packaged RTU** system.
- **MPC** w/ no additional sensors shows **similar performances** to the **MPC** w/ more sensors

NY SITE

- **MPC** provides further **NG reductions** and **energy savings** in a dual-fuel system.
- **MPC** is scalable, but **interoperability** between devices of **different vendors** still problematic (labor intensive, unreliable)

Large Commercial Building Dynamic HVAC Predictive Controls

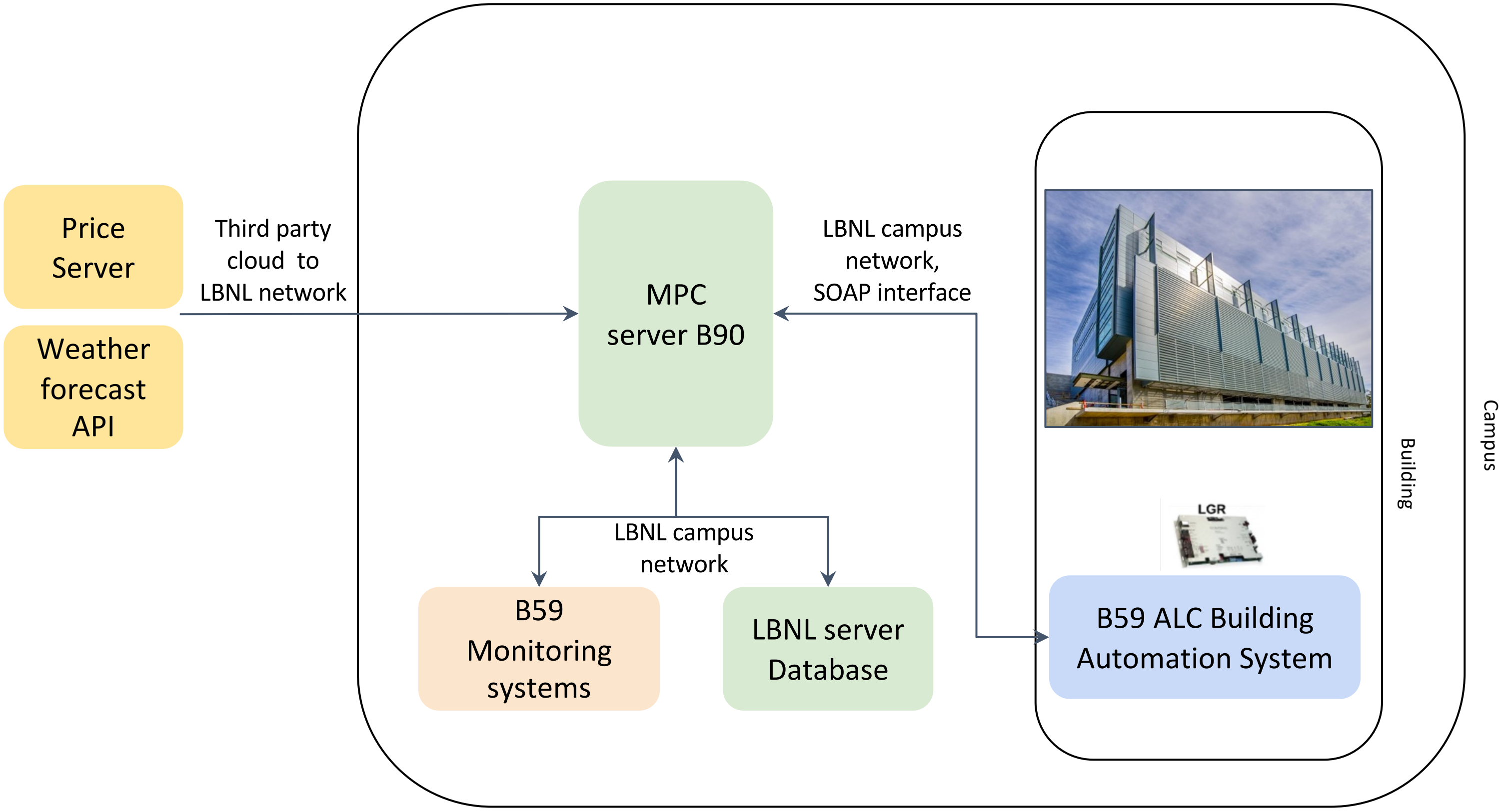
- Supervisory MPC control system
- Coordinates with Building Automation System
- Can optimize for cost, energy, CO_2 emissions



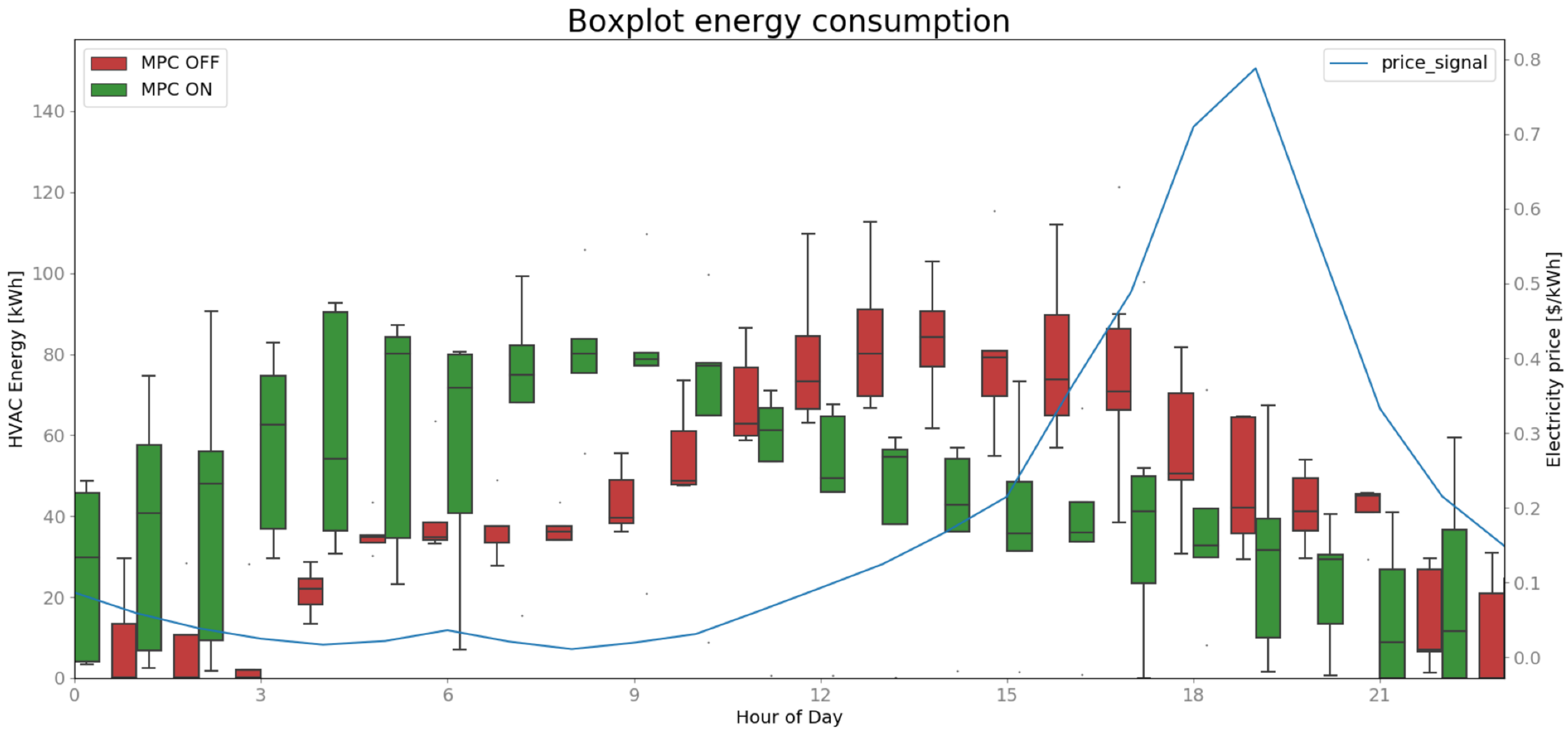
Test Site: LBNL, Building 59

Sector/Building Type	Large Commercial
Technology & End Use	Underfloor Air Distribution (UFAD) w/ Reheat from AWHP, 4 Water-Cooled DX RTUs
Communications Pathway	3rd party cloud -> LBNL cloud <-> B59 ALC <-> HVAC
Expected Grid Benefit	Shift summer daily peak based on price and future winter peak
Testing Status (Timeline)	One field test in August and one in September/October

Communication Architecture

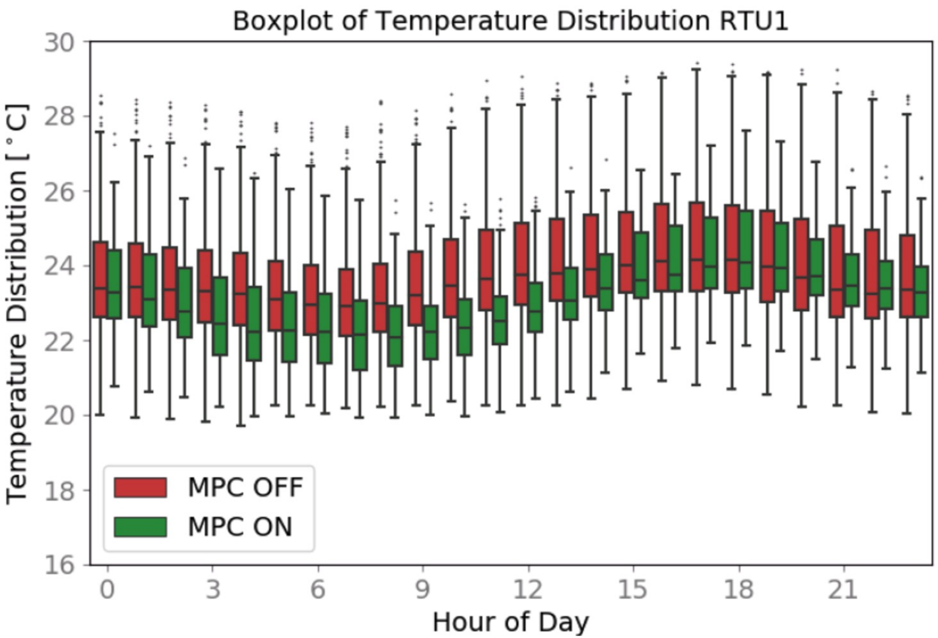


Test Results: MPC Shifts Load During Summer Test

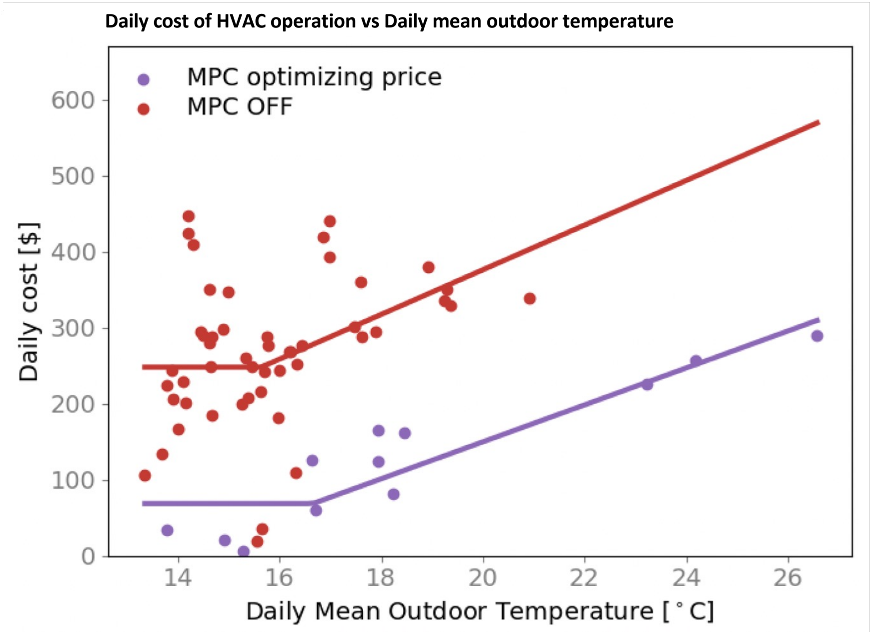


Testing Period (7/3 to 8/26), MPC ON from (8/21 to 8/26), excluding weekends

Test Results: MPC leads to cost savings and keeps comfort



Testing Period (7/3 to 8/26), MPC ON from (8/21 to 8/26), excluding weekends



Testing Period (7/3 to 10/19), MPC ON from (8/21 to 8/26 and 9/27 to 10/6), excluding weekends

Key Learnings

- **MPC can shift load but makes data management more critical**
- MPC can respond to **two** different **dynamic** price profiles **using the same code**
- **Thermal comfort was not compromised**: temperature range in zones was tighter & no complaints by occupants
- MPC maintenance **required significant continuous effort** (data stream interruptions, server restarts, and software updates)
- MPC should have basic understanding of underlying control logic: e.g. “Smoke Mode” imposed by operators to constrain outside air intake when wildfires active, or BMS logic to allow MPC to turn on RTUs during unoccupied times.

Campus-scale Thermal Storage for Load Shift Using Predictive Controls

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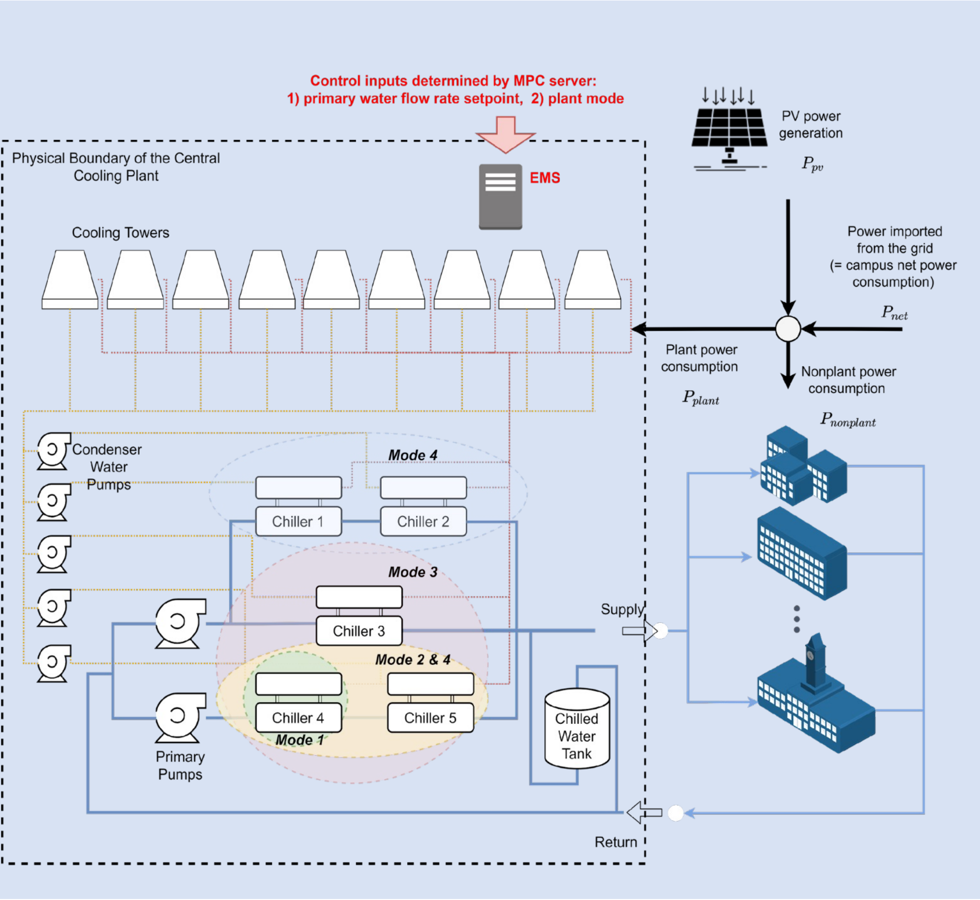
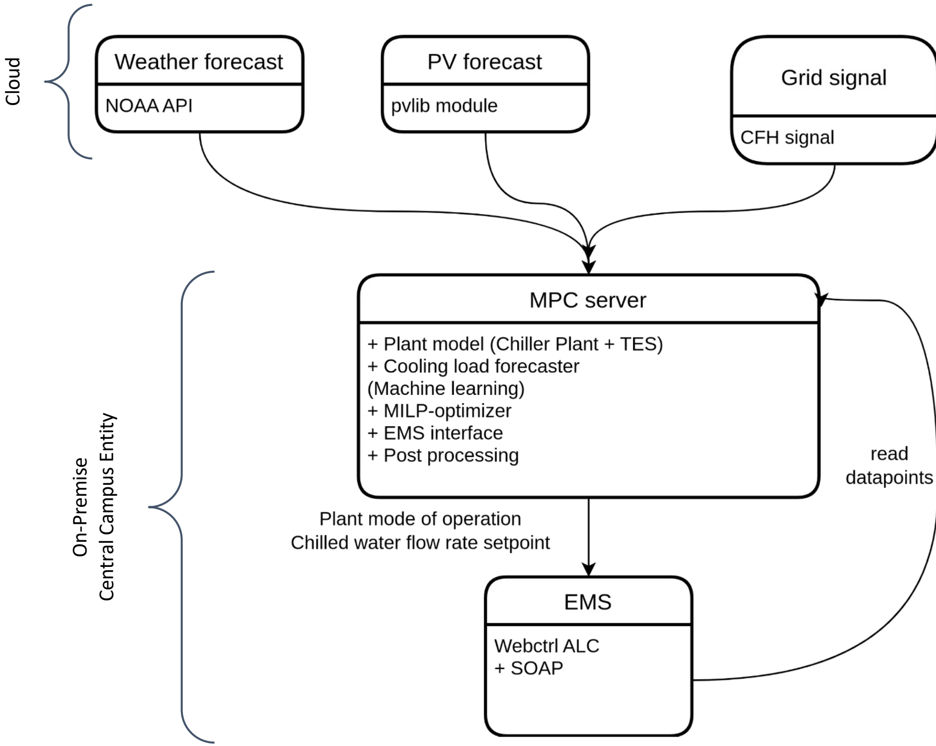
Sector/Building Type	District Energy Systems
Technology & End Use	Chiller plants, Chilled water tank, PVs
Communications Pathway	CFH signal or other signals -> MPC server <-> ALC <-> HVAC
Expected Grid Benefit	- Automated load shifting in response to grid signals - Peak demand reduction - Better on-site renewable integration (more use of self generation)
Testing Status (Timeline)	Test performed in summer and winter 2023, continuing in 2024.

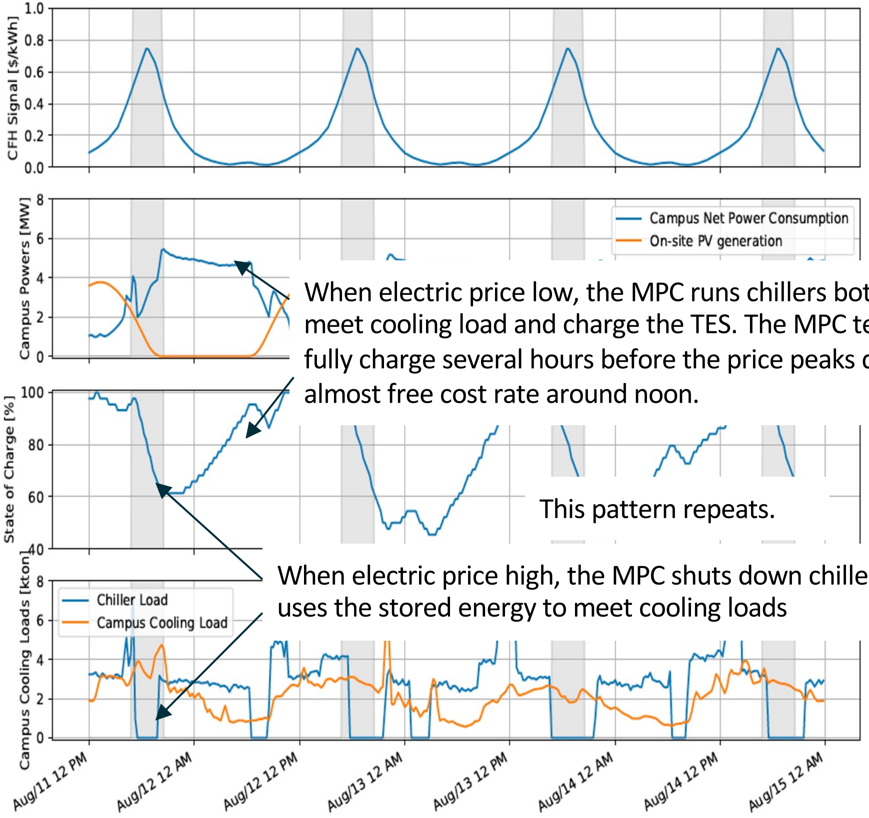
Control and Communication Architecture





Test Results

Grey areas represent high peak price periods

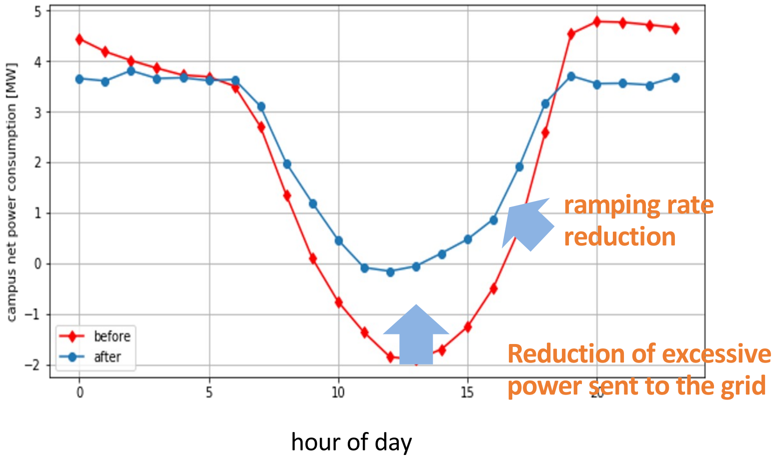


When electric price low, the MPC runs chillers both to meet cooling load and charge the TES. The MPC tends to fully charge several hours before the price peaks due to almost free cost rate around noon.

This pattern repeats.

When electric price high, the MPC shuts down chillers but uses the stored energy to meet cooling loads

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



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

* Kim, D., Wang, Z., Brugger, J., Blum, D., Wetter, M., Hong, T., & Piette, M. A. (2022). Site demonstration and performance evaluation of MPC for a large chiller plant with TES for renewable energy integration and grid decarbonization. *Applied Energy*, *321*, 119343.

Key Learnings: Challenges Identified

Category	Challenge
Operation restriction	Potential **conflicts** between MPC decisions and EMS logic
Operation restriction & Safety	**Revising EMS logic** is practically difficult and it requires identifying potential conflicts after updates, convincing facility manager and operators to accept necessary changes of the EMS, and ensuring operational safety during the MPC demonstration
Safety	**Lack of liability** by MPC implementer for a potential operation failure during MPC implementation
Others	There are **many stakeholders** for a large plant operation including logic programmers, IT personnel, facility operators, and facility managers
Customer adoption	Facility operators are **not familiar** with an advanced control concept since it is not intuitive compared with rule-based control
Customer adoption	**Unclear value proposition** and/or **not enough incentives**