Economic MPC of Thermal Storage for Demand Response

American Control Conference, July 1, 2015

Kevin Kircher, kircher.mae.cornell.edu

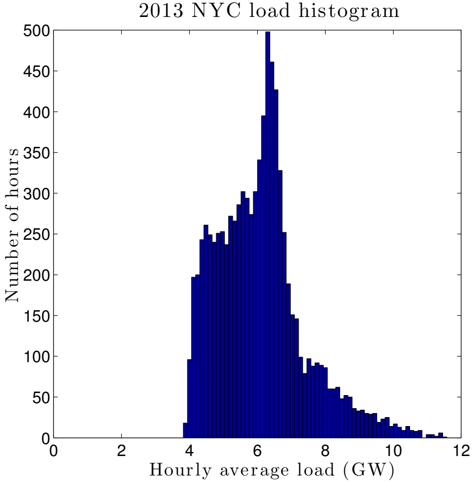
Background

Model

Simulation

Discussion

Power system peaks are expensive



- 95th percentile: 8.5 GW
- maximum: 11.5 GW
- 1 GW of new peaking capacity: $1 billion

Depeaking with thermal storage

- peaks happen on hot summer days, driven by AC
- curtailing cooling on hot days risks bothering occupants
- storage eliminates this risk
- why **thermal** storage?
    - ◇ electrochemical storage:[1] 500-600 \$/kWh
    - ◇ thermal storage:[2] 14-20 \$/kWh$_{\mathrm{th}}$
      (equivalent to 35-60 \$/kWh with chiller COP of 2.5-3)

---

[1] R. Hensley *et al.*, "Battery Technology Charges Ahead." *McKinsey Quarterly* **3** (2012): 5-50.

[2] A. Arteconi *et al.*, "State of the Art of Thermal Storage for Demand-Side Management." *Applied Energy* **93** (2012): 371-389.

Can MPC handle the incentives that real buildings face?

A challenging case study

- ConEd's default rate plan[3] for large commercial buildings
  - ◇ hourly energy prices determined by wholesale market
  - ◇ three-tiered demand charge
- a ConEd demand response program[4]

Main result: yes, but it's important to include true incentives, particularly demand charge, in MPC objective function

---

[3] Rider M - Day-Ahead Hourly Pricing. *General Rule 24: Service Classification Riders.* ConEd, 2014.

[4] Commercial System Relief Program. *Demand Response Program Details*, ConEd, 2014.

Background

Model

Simulation

Discussion

Physics

- DOE "large office" prototype[5] (3 floors, 14,000 m^2)
- quasi-steady model extends seminal work[6] to include
  - ◇ two chillers
  - ◇ temperature-varying COPs
  - ◇ non-ideal tank and heat exchanger efficiencies

---

[5] Commercial Building Prototype Models: "Large Office." *Building Energy Codes Program*, U.S. Department of Energy. (2011)

[6] Henze, G. *et al.* "Development of a Predictive Optimal Controller for Thermal Energy Storage Systems." *HVAC&R Research* **3.3** (1997): 233-264.

Physics (continued)

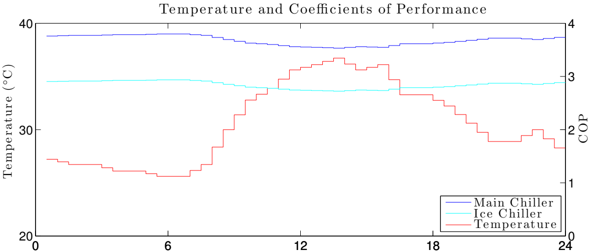
$$\mathbf{x}(k+1) = A\mathbf{x}(k) + B(k)\mathbf{u}(k) + G\mathbf{w}(k)$$

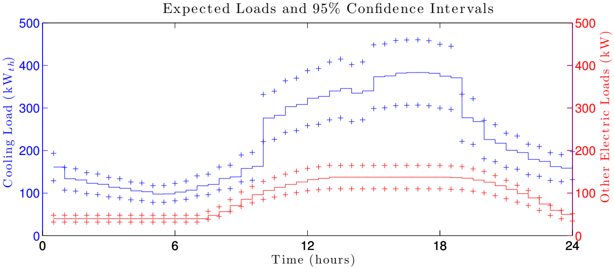
- states
    - ◇ tank charge (x_1, $\mathrm{kWh}_{\mathrm{th}}$)
    - ◇ cooling deficit (x_2, $\mathrm{kWh}_{\mathrm{th}}$)
- controls
    - ◇ ice chiller power (u_1, kW)
    - ◇ cooling from ice (u_2, $\mathrm{kW}_{\mathrm{th}}$)
    - ◇ main chiller power (u_3, kW)
- disturbances (Gaussian, white)
    - ◇ cooling demand (w_1, $\mathrm{kW}_{\mathrm{th}}$)
    - ◇ electrical demand (w_2, kW)

MPC optimization

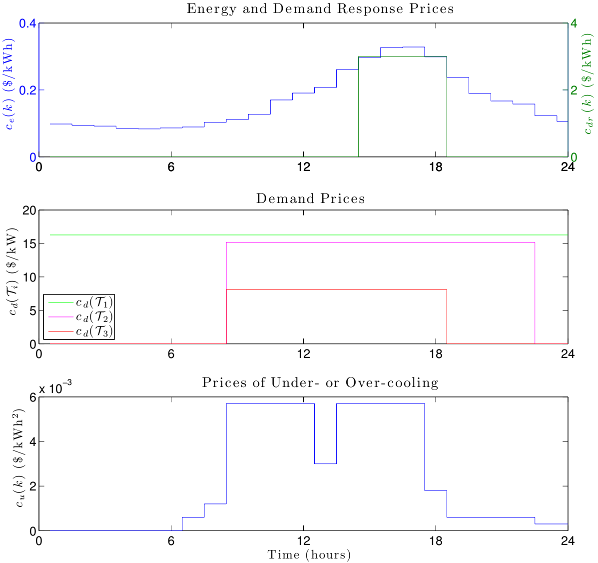
- 24-hour horizon, half-hour time steps
- minimize
  - + energy cost
  - + increase in demand cost
  - + occupant discomfort
  - + terminal cost (tank depletion)
  - − demand response revenue
- subject to
  - ◇ chiller capacity and ramping limits
  - ◇ tank limit
- solved in CVX, driving SDPT3

Simulation day

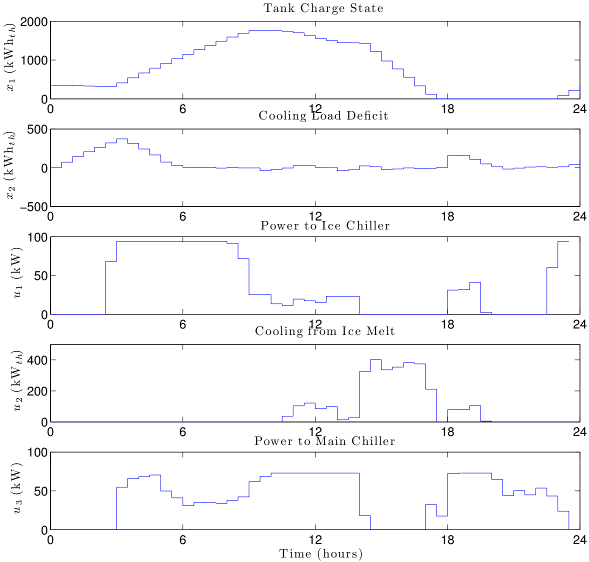




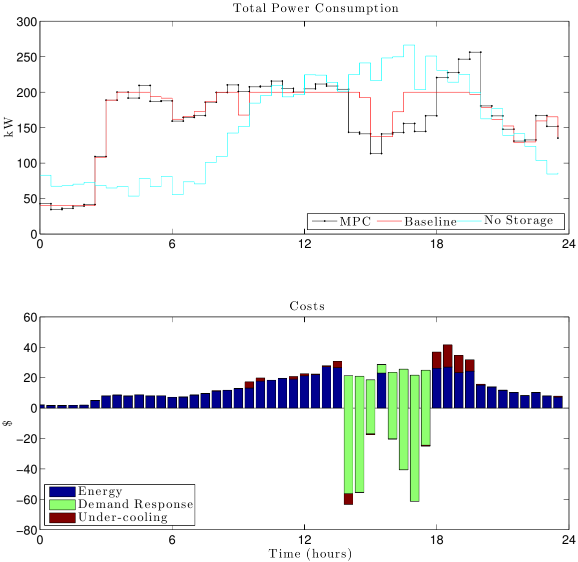
Prices


Energy and Demand Response Prices
$c_e(k)$ (\$/kWh)
$c_{dr}(k)$ (\$/kWh)
0.4
0.2
0
4
2
0
0
6
12
18
24
Demand Prices
$c_d(\mathcal{T}_i)$ (\$/kW)
20
15
10
5
0
$c_d(\mathcal{T}_1)$
$c_d(\mathcal{T}_2)$
$c_d(\mathcal{T}_3)$
0
6
12
18
24
Prices of Under- or Over-cooling
x 10^{-3}
$c_u(k)$ (\$/kWh^2)
6
4
2
0
0
6
12
18
24
Time (hours)

A typical Monte Carlo run



A typical Monte Carlo run (continued)



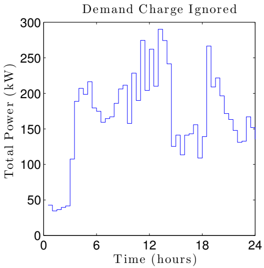
Background

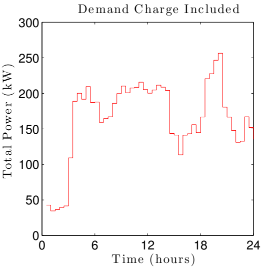
Model

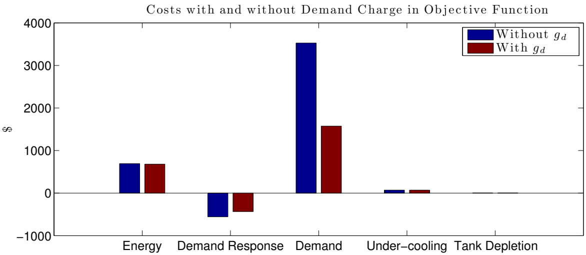
Simulation

Discussion

Important to model demand charge







Lots of extensions

- optimal tank size?
- simulate for a month, study demand charge in depth
- other economic incentives
  - ◇ critical peak pricing
  - ◇ ancillary services
  - ◇ contracts with aggregators

All code is available by email or at kircher.mae.cornell.edu.

Thanks to…

- the Consortium for Electric Reliability Technology Solutions (CERTS) for funding
- Max Zhang for advising
- Santiago Naranjo Palacio, Brandon Hencey, and Eilyan Bitar for ideas and feedback
- **you** for listening!