Grid-Interactive Efficient Building R&D Opportunities

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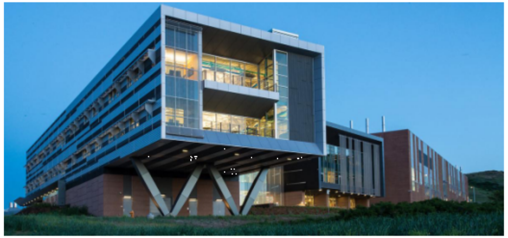
Grid-Interactive Efficient Building Definition

Interactive Buildings

Information

Energy

Waste



Urban District

Distributed Energy Systems

Ambient Loops

Resource Sharing

Aggregation

Infrastructure

Electricity Grid

- ✓ TCL
- ✓ Storage (TES, EES)
- ✓ Lighting and Plug Loads

Water Network

- ✓ Waste Water Heat Recovery

Transportation Network

- ✓ PV Charging Station

Environment

Façade

Integrated Design

Seasonal Storage

Sensing, Control, and

Forecasting

Zero Energy Districts (ZED)

Zero Energy Building (ZEB)

Source:
Fallahi, Z., & Henze, G. P. (2019). Interactive Buildings: A Review. Sustainability, 11(14), 3988.

Opportunities

Interactions with counterparts (urban district, infrastructure, and environment) provide opportunities for:

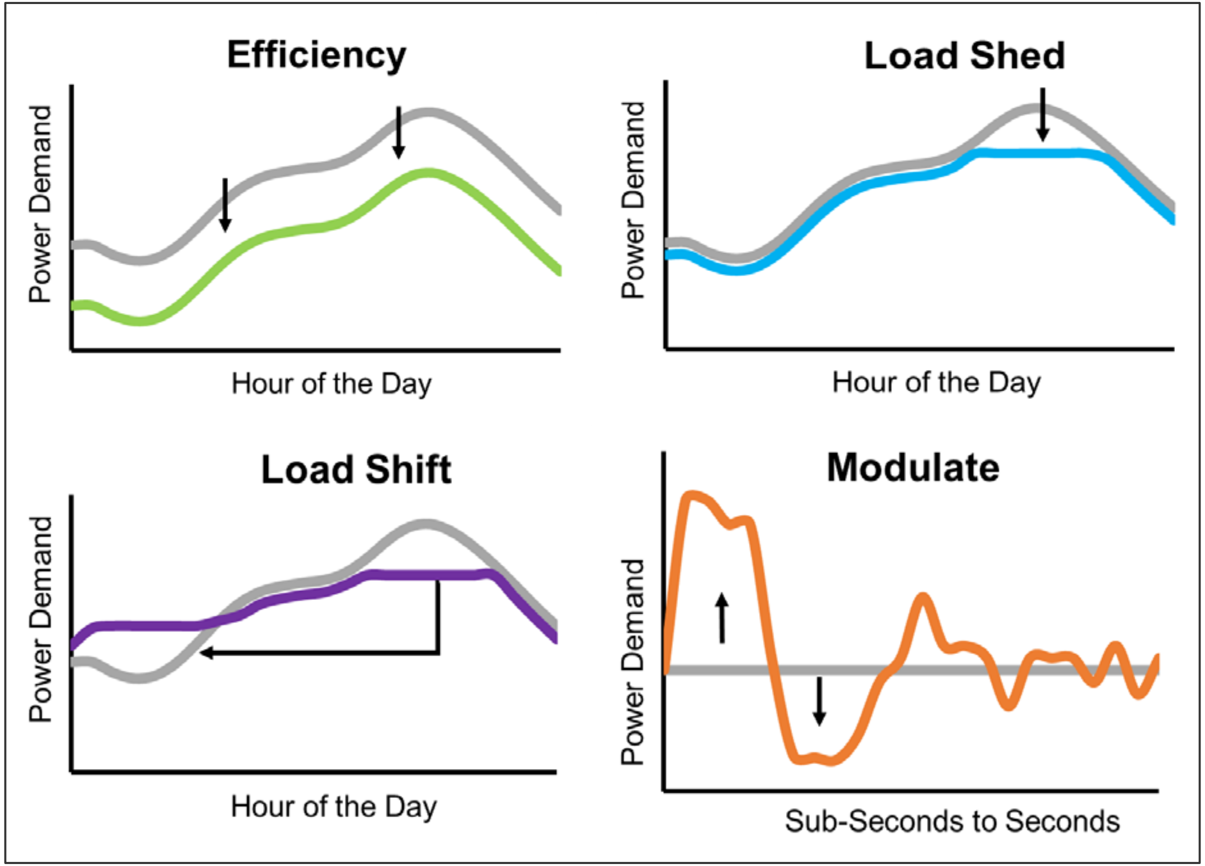
- Improvements of **building performance** such as net energy use, emissions, occupant comfort, and operational cost.
- Support **infrastructure planning** such as transportation system, water systems and the electric power grid
- Shaping the future structure of **smart cities**
  - Buildings more than shelters – connected and adaptable
  - District level resource sharing to reduce waste
  - Facilitate multi-modal and autonomous transportation
  - Real-time tracking of energy use, water use, and emissions

Challenges

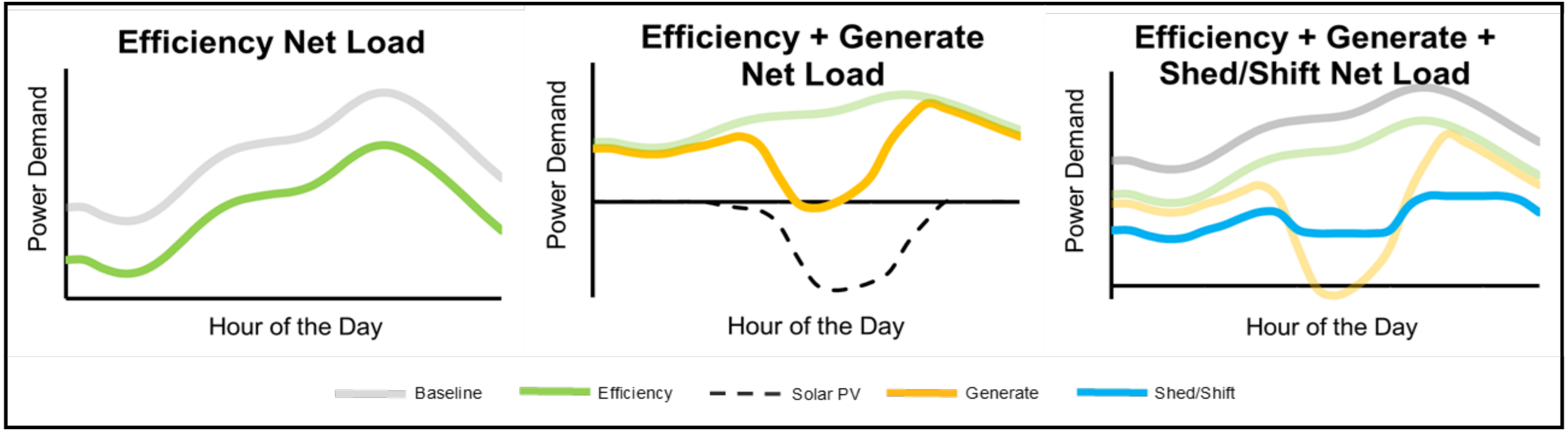
- Validation of **degree and characteristics** of load flexibility given participating technologies
- Assessing **monetary value** of load flexibility and reward mechanism by building type
- Control and characterization of **aggregated flexibility**
- Evaluation of interaction between building **energy use and occupant comfort** along different time scales

Demand Flexibility Building Load Curves

Source: https://www.energy.gov/sites/prod/files/2019/04/f61/bto-geb_overview-4.15.19.pdf

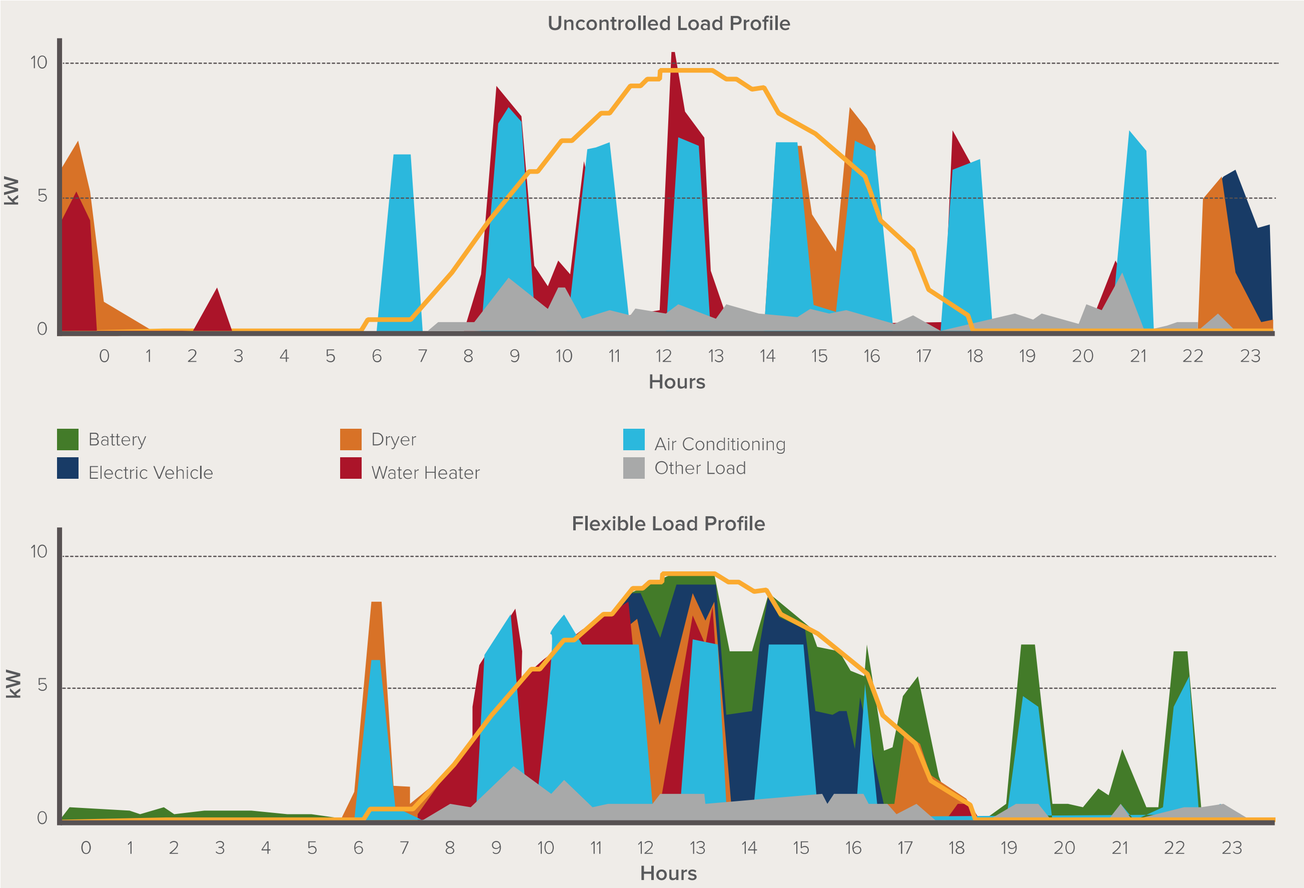


Grid Interactive Efficient Building Load Curves



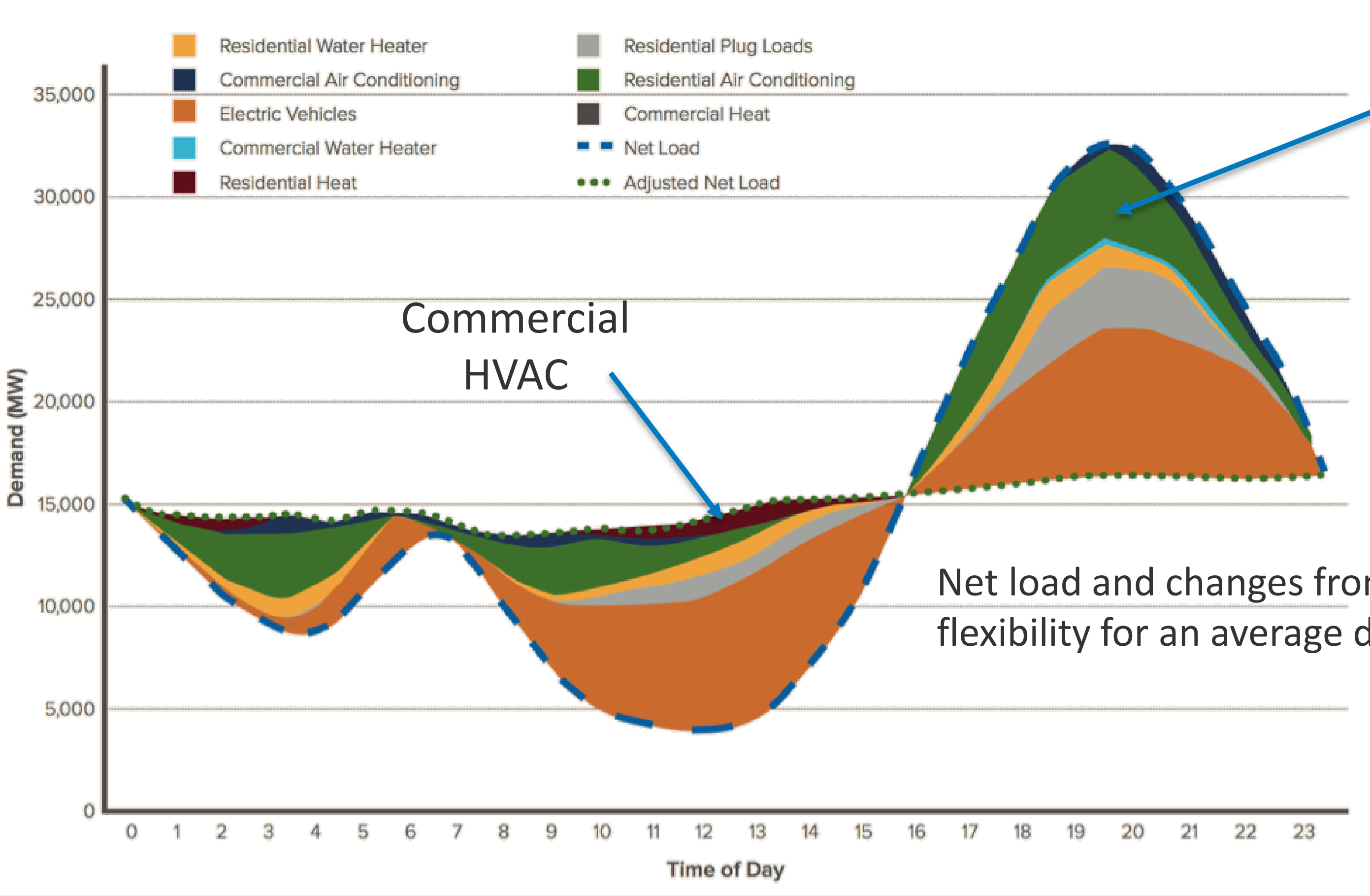
Source:
https://www.energy.gov/sites/prod/files/2019/04/f61/bto-geb_overview-4.15.19.pdf

RMI: Residential Demand Flexibility



Source:
RMI report 2018. https://rmi.org/demand-flexibility-can-grow-market-renewable-energy/

RMI: Aggregate Flexibility Impact



Net load and changes from demand flexibility for an average day

Source:
RMI report 2018. https://rmi.org/demand-flexibility-can-grow-market-renewable-energy/

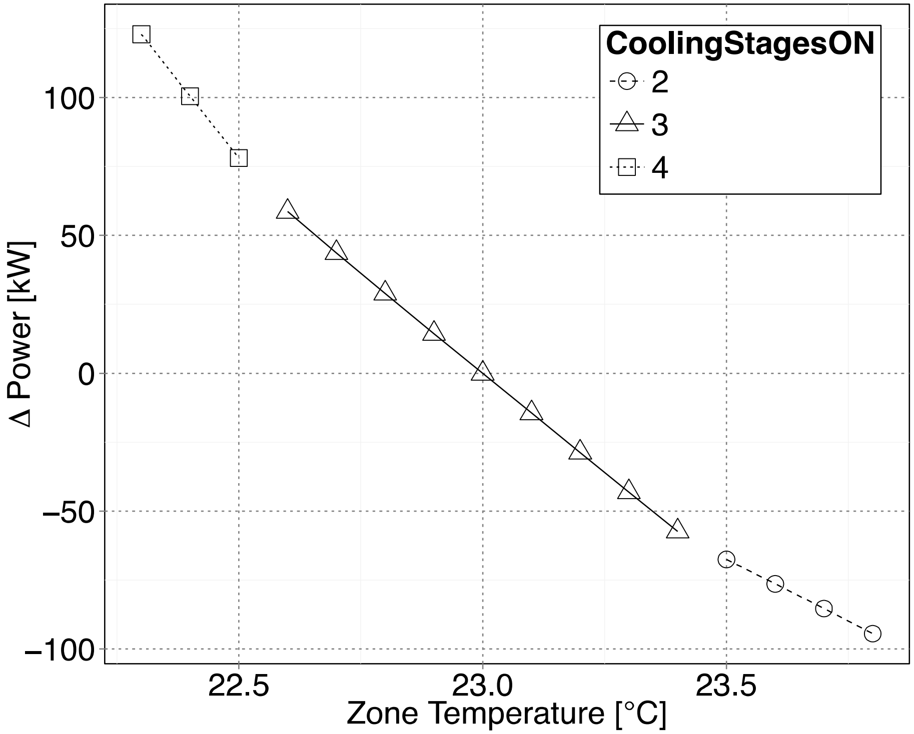
Commercial Building Participation in Energy and FR Markets

Greg Pavlak (CU) & Gregor Henze (CU/NREL)

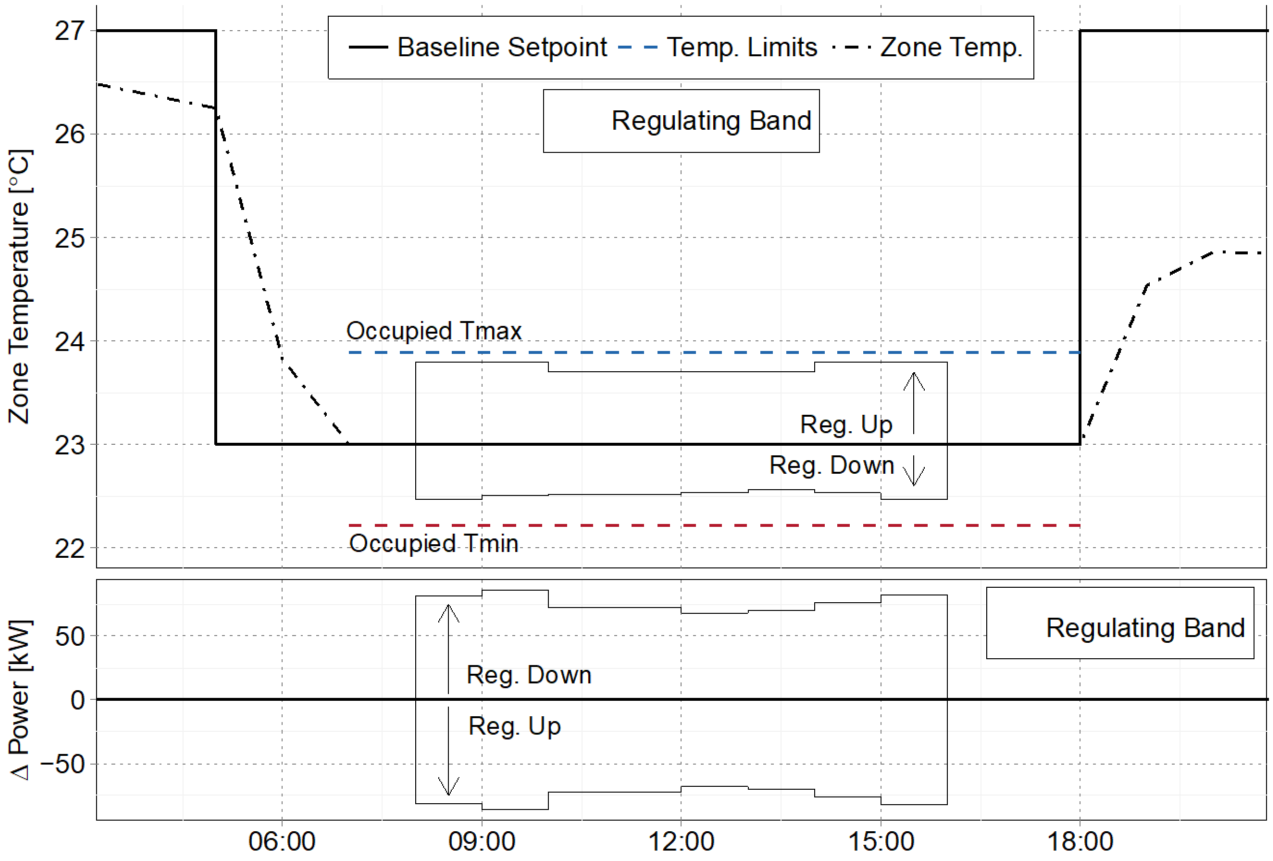
Frequency Regulation Estimation

An illustrative example: How much FR at 13:00?

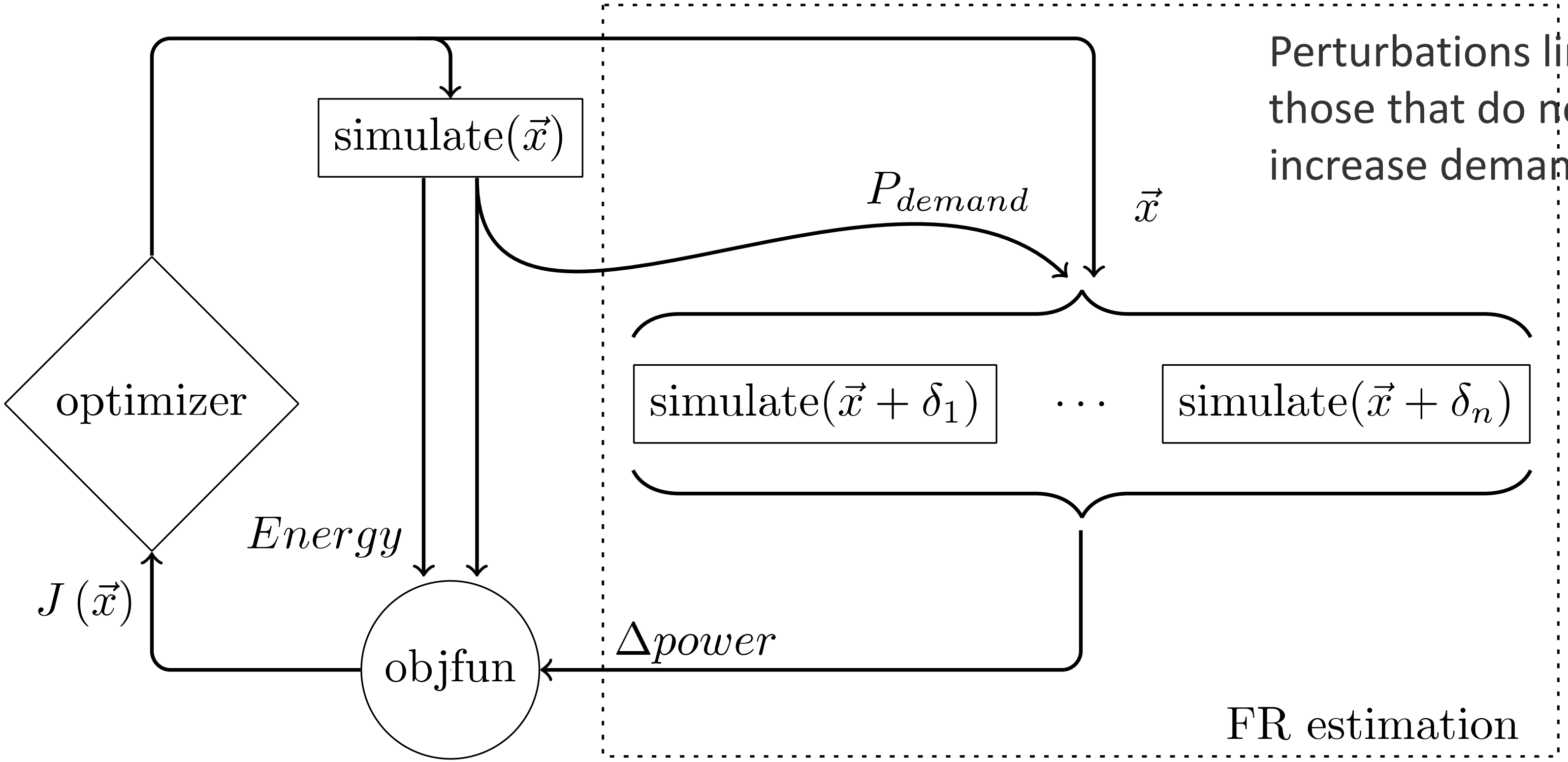
- Baseline setpoint of 23°C
- Fans 50%, DX Coil: On-On-Cyc-Off, 85% Occupied



FR Estimation: Repeat from 9:00-16:00



Multi-Market Optimization Overview

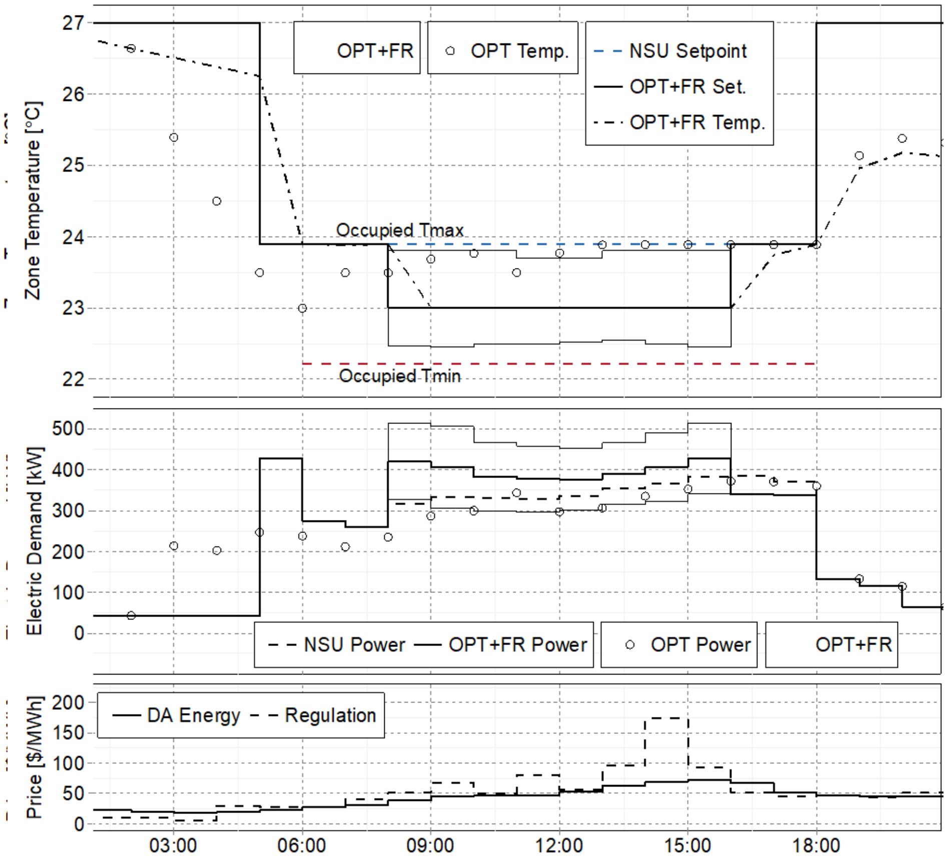


Perturbations limited to those that do not increase demand penalty.

Medium Office Results: Impact of Target Limit

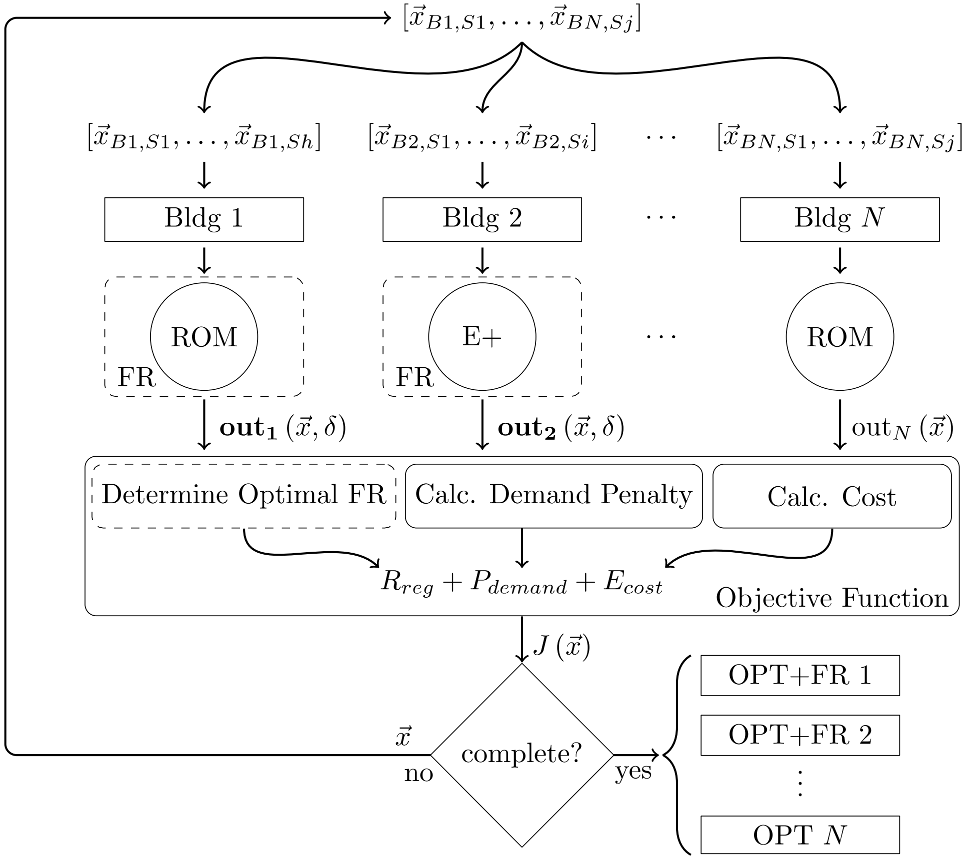
Low Target Limit:
Available 5/9 hours
±8 kW to ±60 kW
$12 reg. revenue
38% → 39.5%

High Target Limit:
Available 8/9 hours
277 kWh > OPT
$23 > energy expense
±85 kW on average
$56 reg. revenue
2.3% → 15.7%



Source:
Pavlak, G. S., Henze, G. P., & Cushing, V. J. (2014). Optimizing commercial building participation in energy and ancillary service markets. Energy and Buildings, 81, 115-126.

Portfolio Multi-Market Optimization



Source:
Pavlak, G. S., Henze, G. P., & Cushing, V. J. (2015). Evaluating synergistic effect of optimally controlling commercial building thermal mass portfolios. Energy, 84, 161-176.

Residential Directed Thermal Mass Optimization

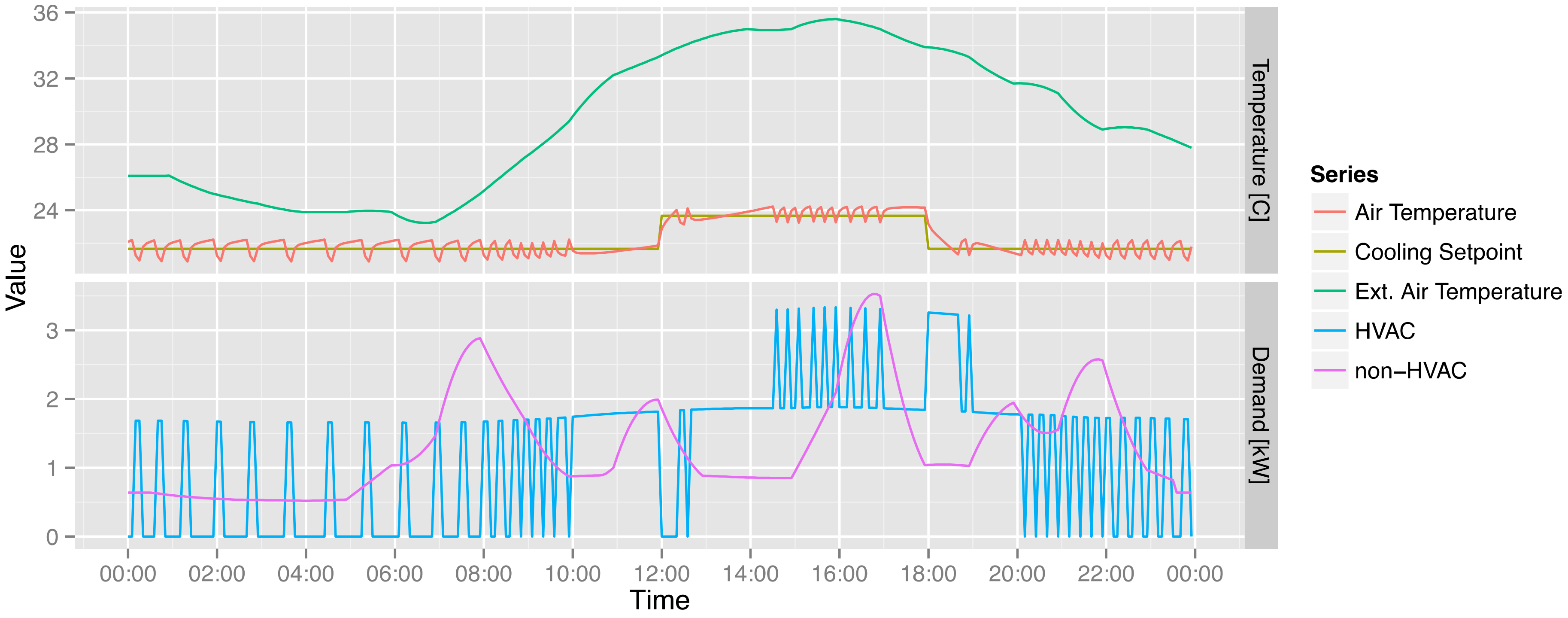
Charles Corbin (CU) & Gregor Henze (CU/NREL)

Grid Model Description

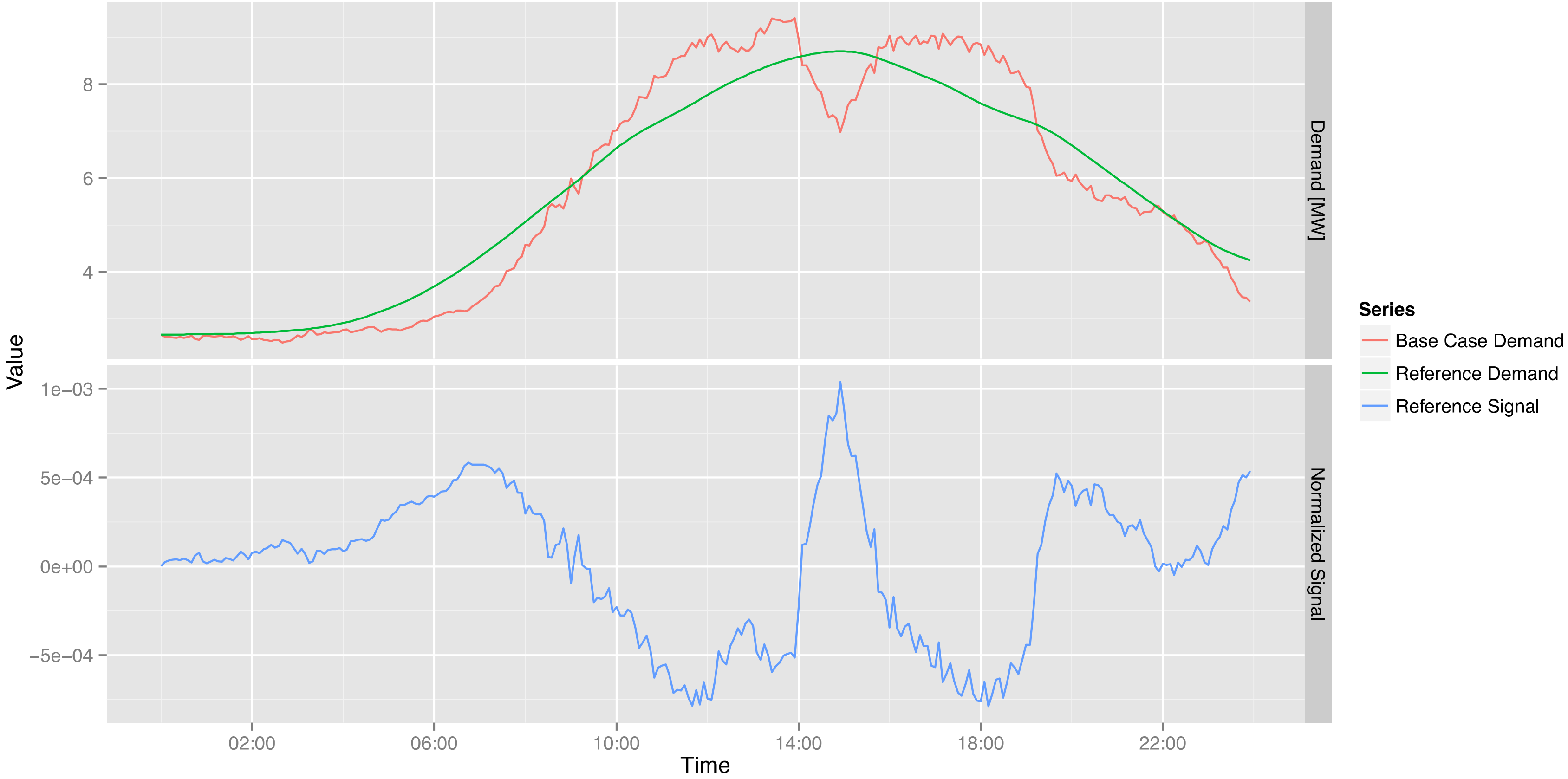
	Houston	Los Angeles	New York
Cooling Degree Days base 50	4043	2674	1911
Cooling Degree Days base 65	1667	343	543
Nominal voltage (kV)	22.9	12.47	12.47
Nominal load (MW)	12	7.8	7.4
Commercial transformers	14	0	6
Industrial transformers	0	0	0
Agricultural transformers	0	107	0
Residential transformers	284	1491	396
Number of residences	2146	1326	1506
Percent of residential consumption	80%	78%	86%
Air conditioning penetration	98%	54%	79%

Building Model Description

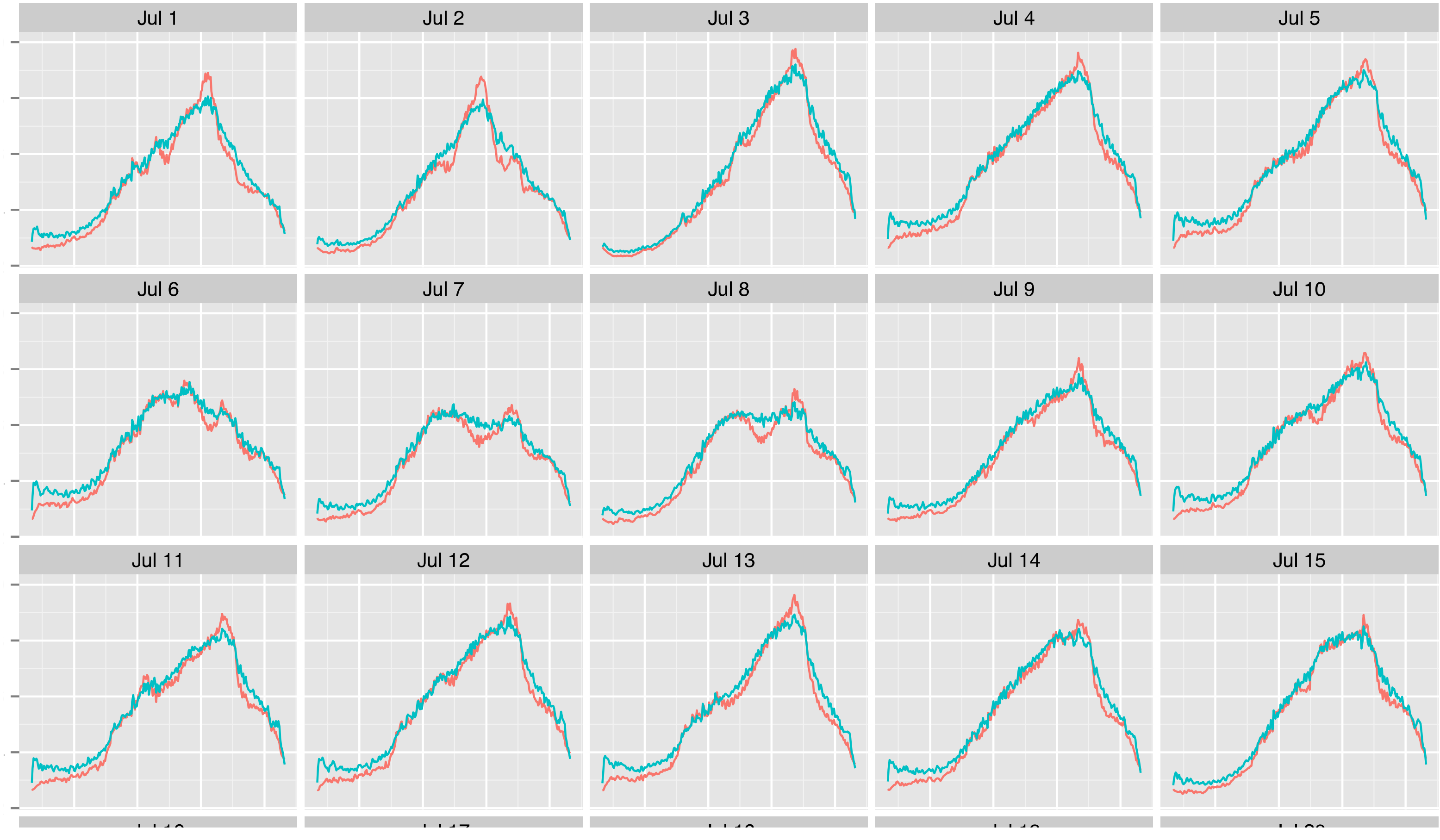
Source: Corbin, C. D., & Henze, G. P. (2017). Predictive control of residential HVAC and its impact on the grid. Part I: simulation framework and models. *Journal of Building Performance Simulation*, *10*(3), 294-312.



Directed Optimization: Load Shaping

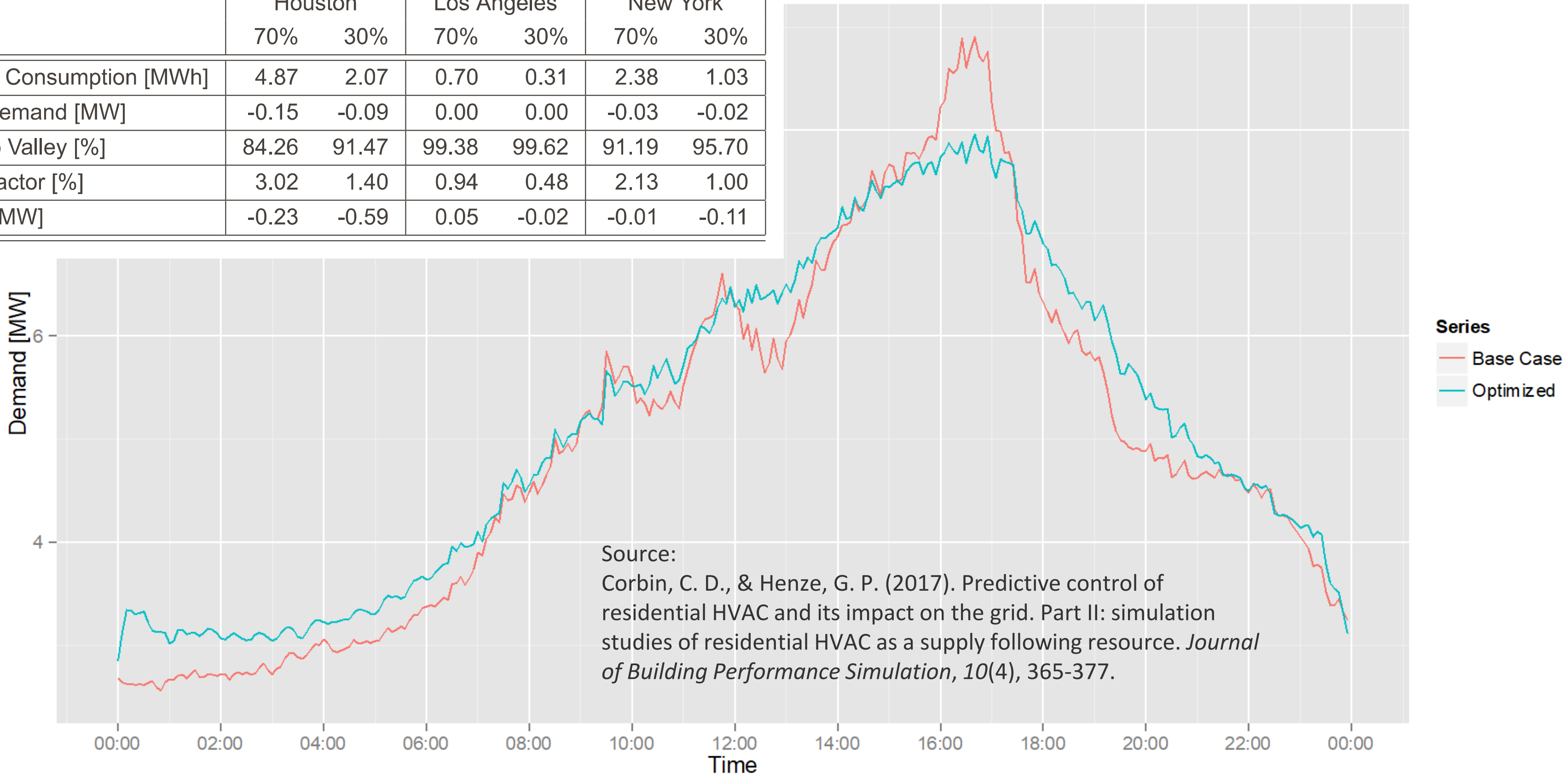


Houston 70% High Solar Penetration



Houston 70% High Solar Penetration July 1

	Houston		Los Angeles		New York	
	70%	30%	70%	30%	70%	30%
Electric Consumption [MWh]	4.87	2.07	0.70	0.31	2.38	1.03
Peak Demand [MW]	-0.15	-0.09	0.00	0.00	-0.03	-0.02
Peak to Valley [%]	84.26	91.47	99.38	99.62	91.19	95.70
Load Factor [%]	3.02	1.40	0.94	0.48	2.13	1.00
Ramp [MW]	-0.23	-0.59	0.05	-0.02	-0.01	-0.11



Source:
Corbin, C. D., & Henze, G. P. (2017). Predictive control of residential HVAC and its impact on the grid. Part II: simulation studies of residential HVAC as a supply following resource. *Journal of Building Performance Simulation*, *10*(4), 365-377.

Directed MPC Summary

- Models fast and light weight to allow for PCT deployment
- Residential HVAC Directed MPC
  – Most effective at short term variations in demand
  – Methodology can be extended to other loads
  – Distributed but directed MPC can be implemented
  – More controlled and predicable than price-based optimization
  – Improvements in all metrics except consumption
- Limited by
  – Flexible cooling demand
  – Storage efficiency
  – Model accuracy

Valuation of Demand Flexibility

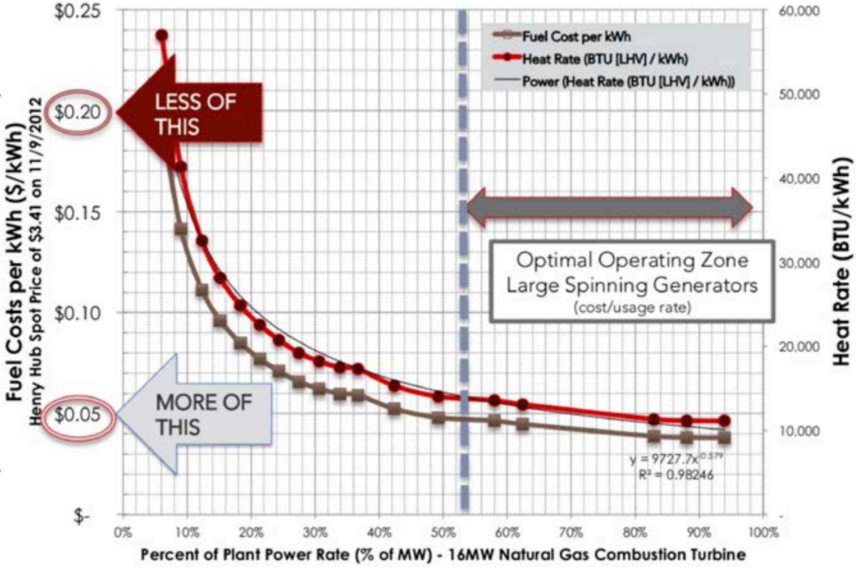
Robert Cruickshank (CU/NREL), Anthony Florita (NREL), Gregor Henze (CU/NREL)

Does Residential Load Shaping Provide $ Savings?

↑ Low-cost RES penetration and
↓ RES curtailment by
- Shaping load ↑ or ↓ to follow supply

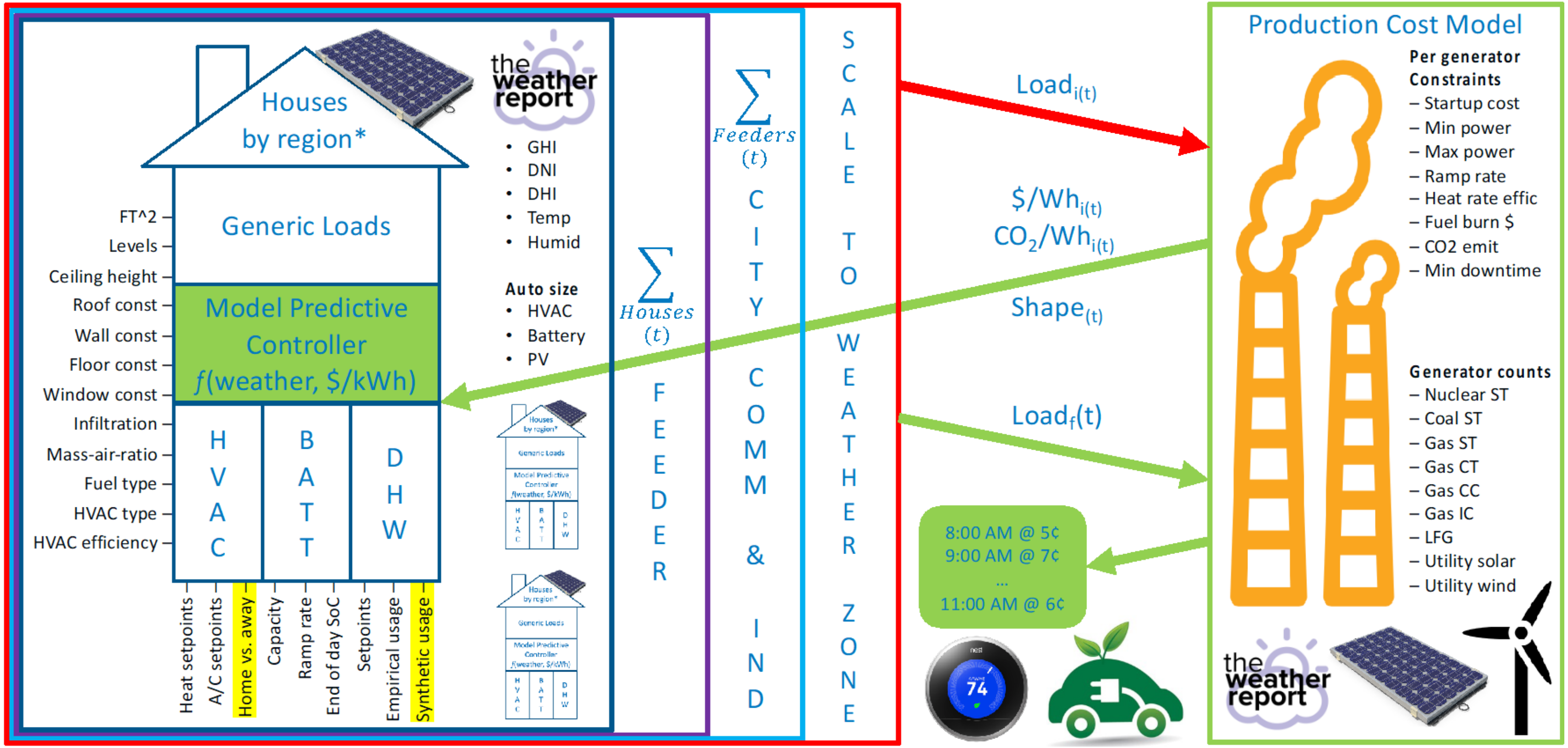
↓ Generation contingency reserve requirements with
- Interruptible loads
- Distributed thermo-electric storage

↑ Thermal plant efficiency by
- ↓Partial-load operation
- ↑Full-load operation

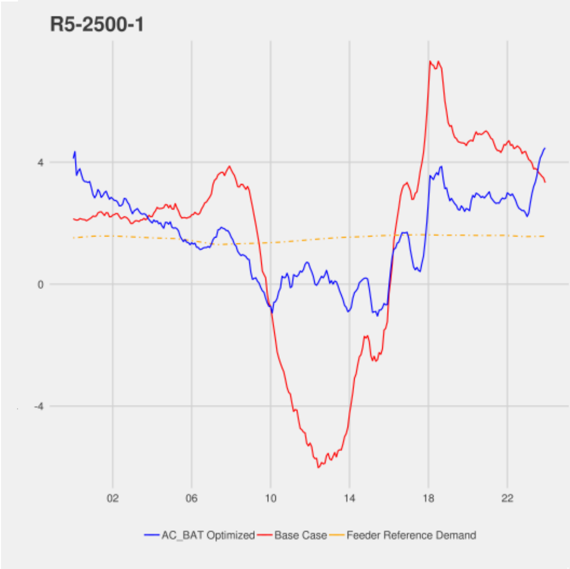


Source: USC - John Bryan Energy Storage v2

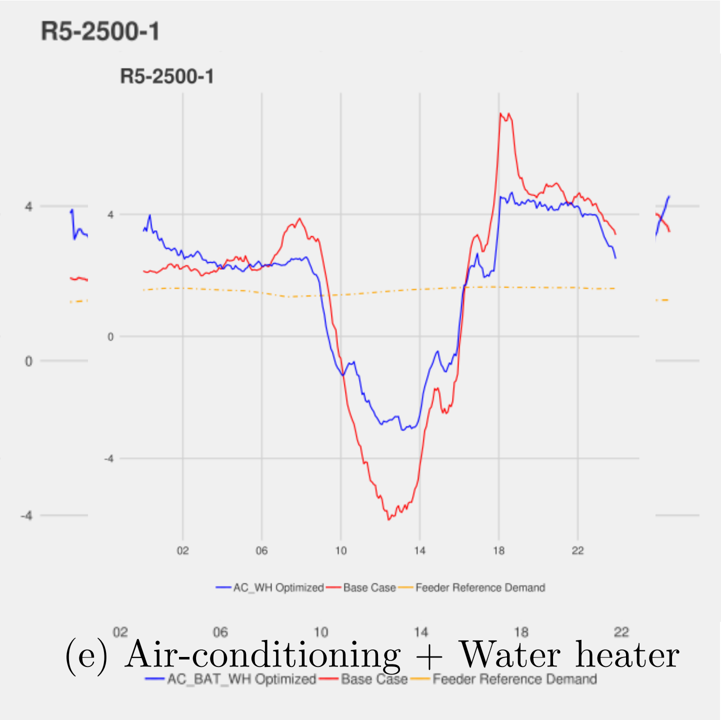
Value of Demand Flexibility



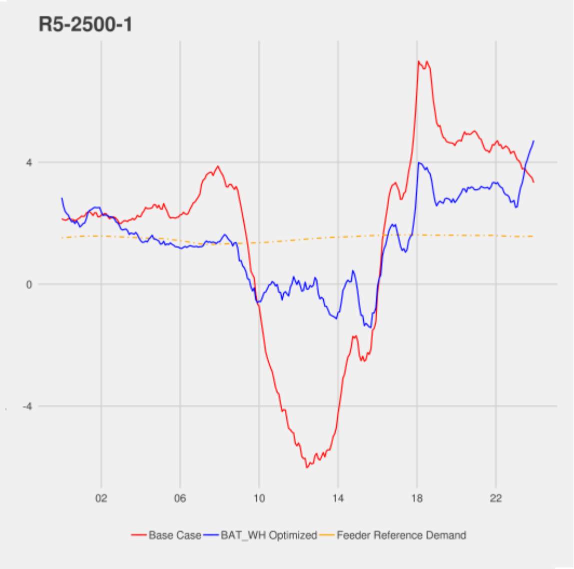
Houston 50% PV: ARLS A/C, Battery, DHW Heater



(d) Air-conditioning + Battery



(e) Air-conditioning + Water heater



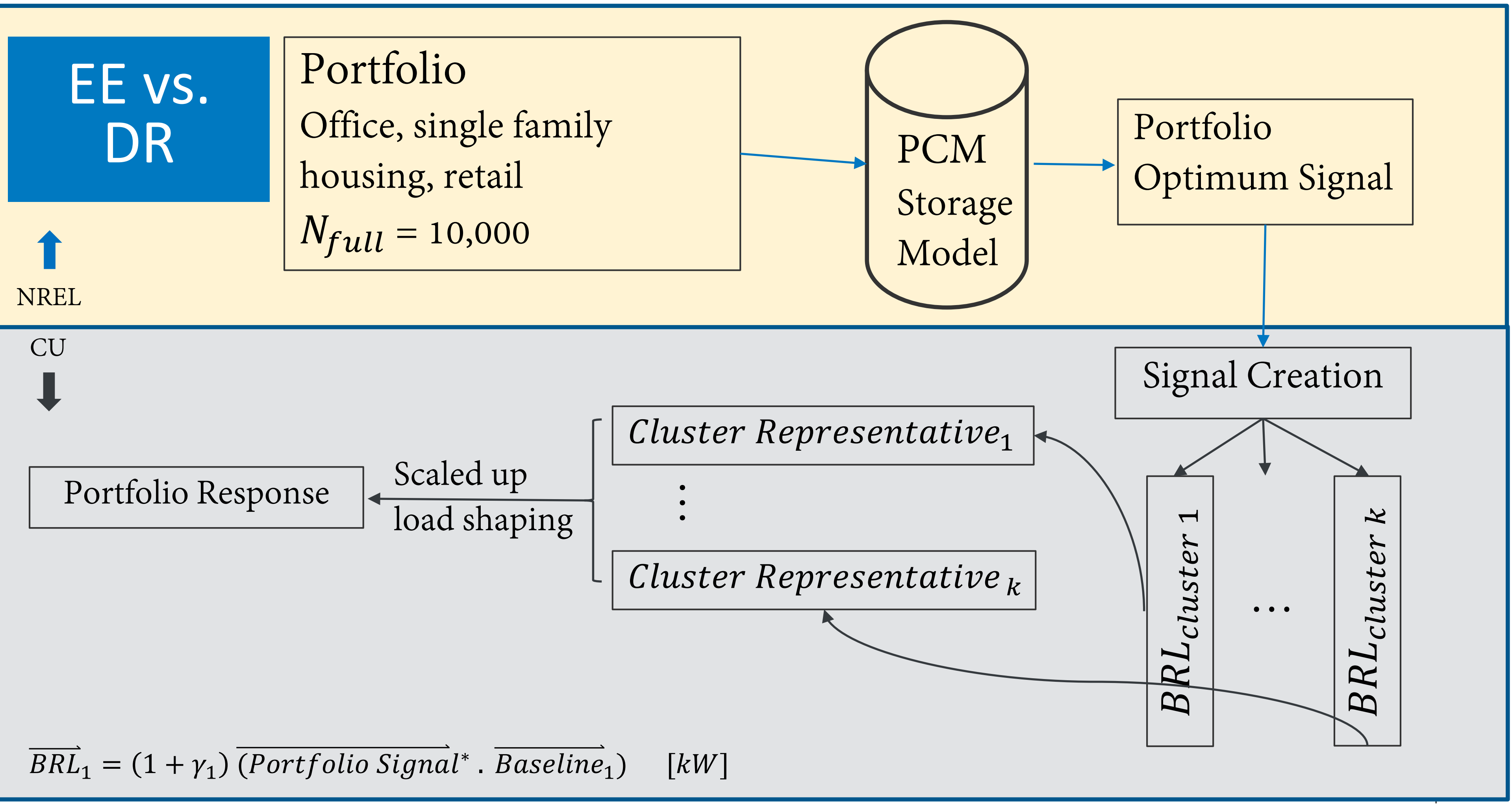
(f) Battery + Water heater

(g) Air-conditioning + Battery + Water heater

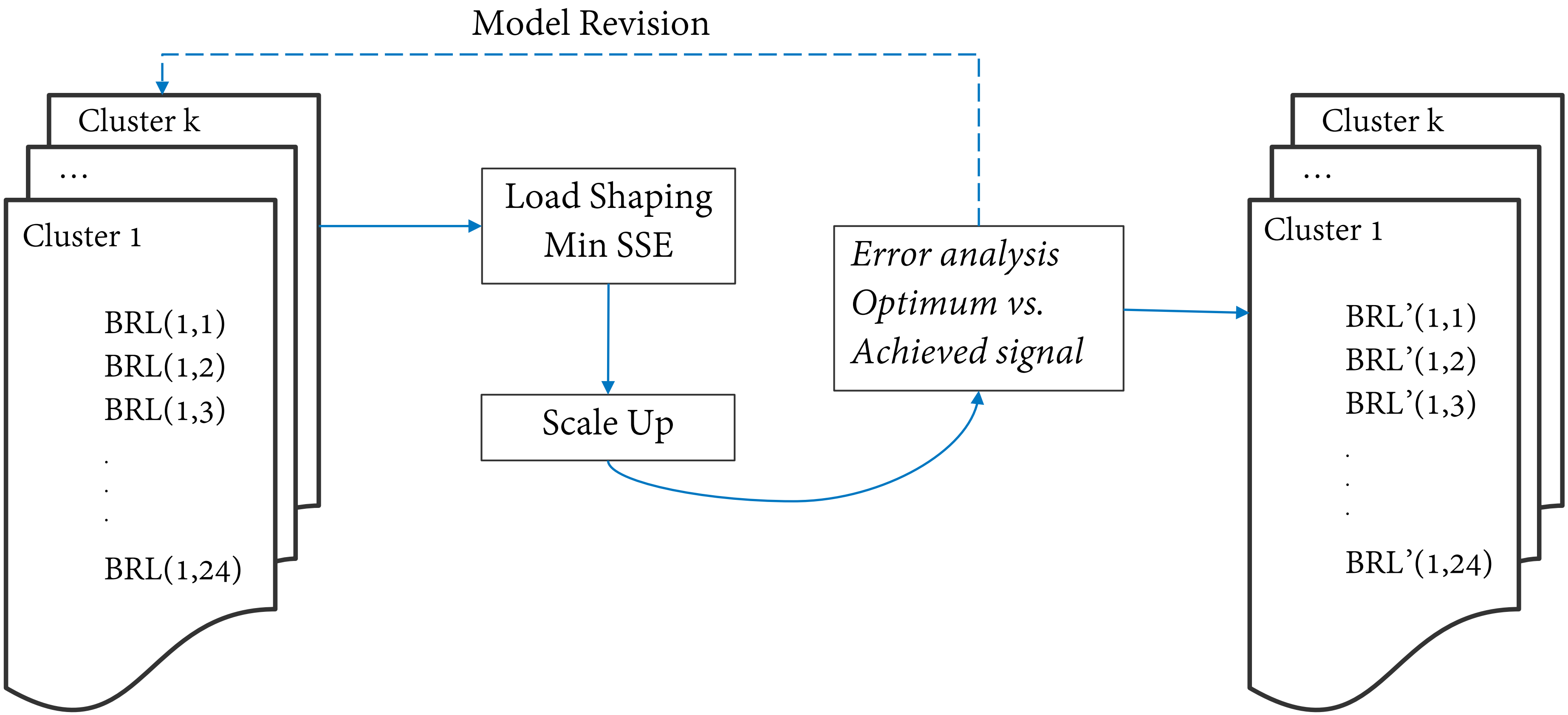
Source: R.F. Cruickshank Estimating the Value of Jointly Optimized Electric Power Generation and Residential Electrical Use (2019), Ph.D. Dissertation, University of Colorado.

Relationship b/w Energy Efficiency and DR

Zahra Fallahi (CU), Gregor Henze (CU/NREL), Elaine Hale (NREL), Matt Leach (NREL)


EE vs. DR
NREL
CU
Portfolio
Office, single family housing, retail
$N_{full} = 10,000$
PCM Storage Model
Portfolio Optimum Signal
Signal Creation
$Cluster\ Representative_1$
$Cluster\ Representative_k$
Scaled up load shaping
Portfolio Response
$BRL_{cluster\ 1}$
$BRL_{cluster\ k}$
$\overrightarrow{BRL_1} = (1+\gamma_1)\ (\overrightarrow{Portfolio\ Signal^*}\ .\ \overrightarrow{Baseline_1})\quad [kW]$

Bayesian Calibration of GEB Flexibility

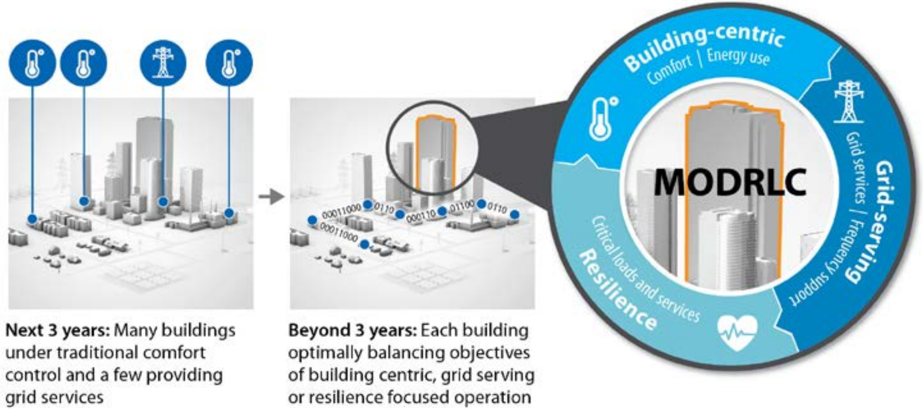


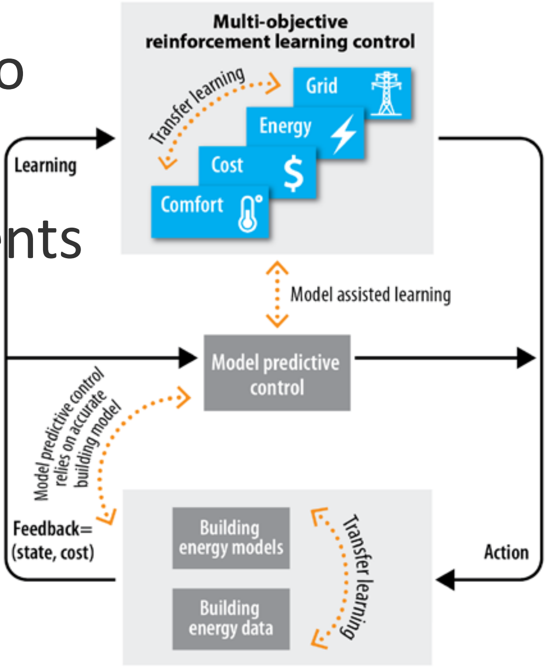
Deep Reinforcement Learning Control for GEB

Andrey Bernstein (NREL), Gregor Henze (CU/NREL), Emiliano Dall'Anese (CU), Peter Graf (NREL), Xin Jin (NREL)

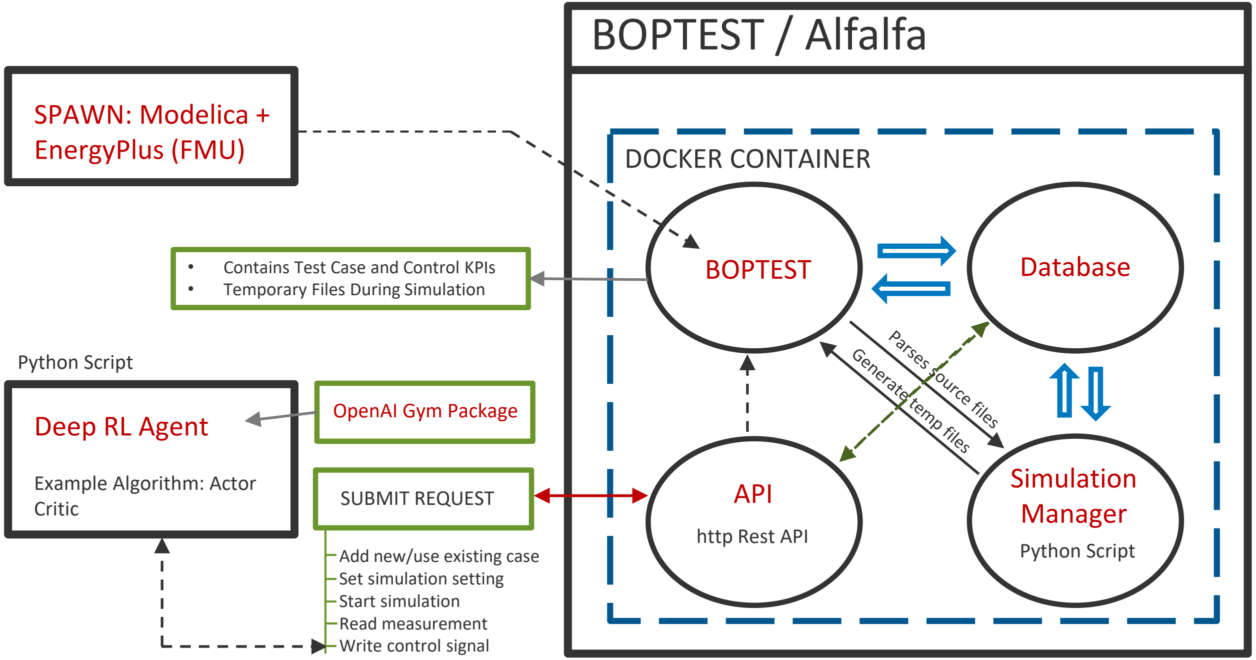
Multiobjective Deep RLC for GEB

- DOE BENEFIT 2018 award
- Balance learning and domain knowledge to enable GEBs with fast T2M path
- Three NREL Centers and two CU departments





Planned RLC Testbed Architecture



NREL CU RASEI Joint Professional MS in NGPES

NEW DEGREE OPTION

Professional Master's Program in Next Generation Power and Energy Systems

CU Boulder – conveniently located in Colorado's renewable energy industry hub – offers a new opportunity to learn about cutting-edge technology developed to make our world more sustainable through emerging, interconnected power and energy systems.

With rapid energy sector transformation bringing new opportunities for power and energy systems engineers, the Department of Electrical, Computer and Energy Engineering (ECEE) expands its professional course offerings to include a new Master of Science (MS) degree—starting in fall 2020—for students with bachelor's degrees in electrical engineering or related engineering or scientif c backgrounds.

Instructors from CU Boulder's faculty and National Renewable Energy Laboratory research programs offer f ve core courses and numerous electives for the 30-credit hour program to prepare students with the specialized knowledge required to practice grid integration of renewable energy.

What's the Next Generation?

Renewable energy sources, such as wind and solar, are increasingly being integrated into the electric power grid, while the power system becomes more tightly intertwined with other systems, such as buildings, natural gas pipelines, and the transportation sector.

Today's rapid changes create industry demand for professionals who understand new power electronic interfaces, improved modeling and simulation capabilities, and knowledge of advances in communication, control, and optimization to mitigate the impacts of variability and uncertainty in power systems generation.

CU's new master's program helps engineers and decision makers prepare for this next generation—with deep foundational knowledge, modern technical skillsets, and the ability to effectively participate in multidisciplinary teams to solve new challenges.

Applications are due by December 1 for full-time, part-time, and online course options.
For more information, visit colorado.edu/ecee/nextgen-power-systems

Electrical, Computer & Energy Engineering

Be Boulder.

Program Features

Future-focused Research

Adjoint professors from NREL teach program courses with CU faculty to bring practical industry knowledge to classroom discussions. Students have opportunities to explore energy systems integration themes from the Renewable and Sustainable Energy Institute (RASEI), a joint program between CU Boulder and NREL that addresses important, complex problems in energy to expedite solutions that transform energy by advancing renewable energy science, engineering, and analysis through research, education, and industry partnerships.

NREL Transforming ENERGY

Colorado's Renewable Energy Hub

The CU Boulder campus offers students opportunities to live an outdoor, active lifestyle while learning in Colorado's growing hub for renewable energy. Sunshine, wind, and new opportunities are abundant—with research taking place in nearby organizations and industry applications powering systems all along the Rocky Mountain Front Range.

Study Online

Many of the Next-Generation Power and Energy Systems courses offer distance-learning options through CU Boulder's Graduate School.

For more information visit, colorado.edu/connect.

Instructors from CU's faculty and NREL prepare students for new opportunities in power and energy systems engineering.

Curriculum

Five core courses (15 credits) required
Renewable Energy and the Future Power Grid
Introduction to Power Electronics
Power System Analysis
Distribution System Analysis
Power System Operations and Planning

Five electives (15 credits)
Building Electrical Systems
Building Energy System Modeling and Control
The Business of Sustainable Energy
Decision Making for Modern Power and Energy Systems
Cybersecurity Policy OR other relevant cybersecurity courses
Distributed Electrical Generation
Energy Policy in the 21st Century
Grid-Connected Systems
Modeling and Control of Power Electronics Systems
Modeling of Urban Energy Systems
Optimization of Energy Systems
Power System Communications
Power System Dynamics and Control
Photovoltaic Power Electronics Laboratory
Power Electronics for Electric Drive Vehicles

Electrical, Computer & Energy Engineering
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Thank you!

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