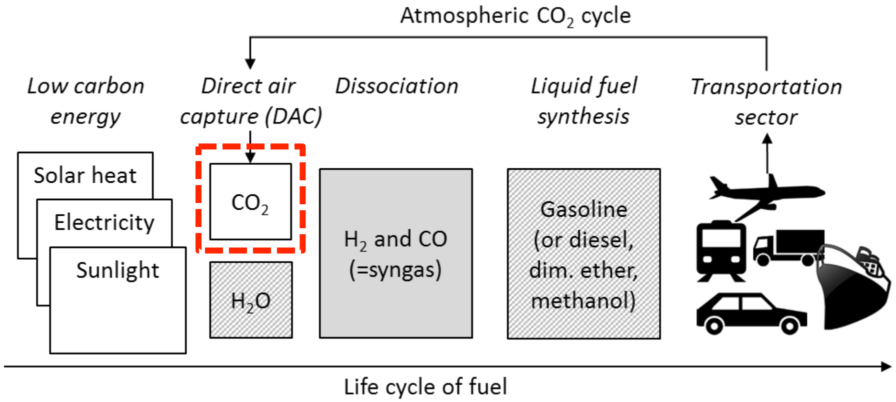
Overview

- Background
- Impacts and challenges
- How we are approaching it
- Poster: #20-B-R

Research projects in our group

Models for techno-economic assessments of low carbon energy systems

- Direct air capture of CO_2 and use in fuels



Atmospheric CO_2 cycle

Low carbon energy

Direct air capture (DAC)

Dissociation

Liquid fuel synthesis

Transportation sector

Solar heat

Electricity

Sunlight

CO_2

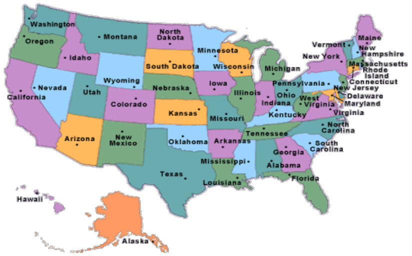
H_2O

H_2 and CO (=syngas)

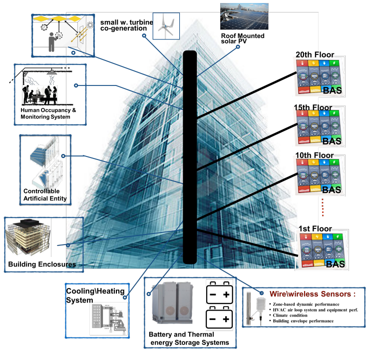
Gasoline (or diesel, dim. ether, methanol)

Life cycle of fuel

- Electric cars and their use in transportation systems



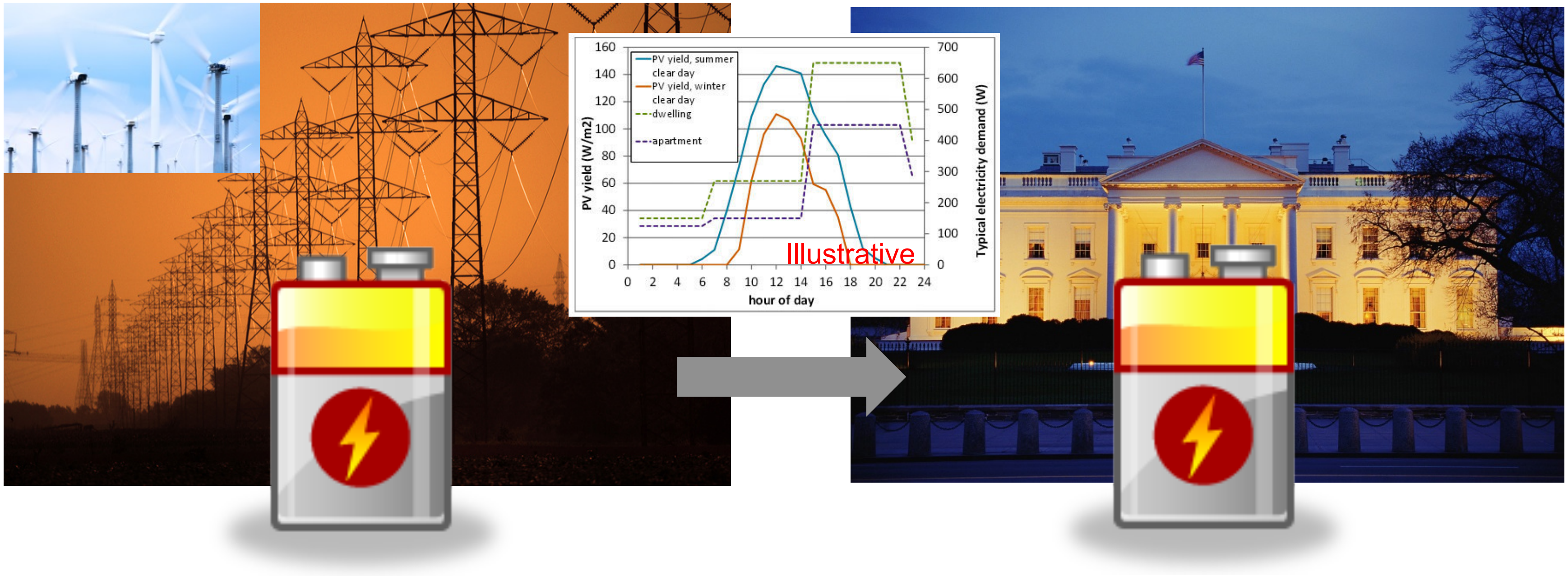
- Smart buildings



Common denominator: Systems' ability to use intermittent electricity

Battery-aided demand response (DR)

Motivation and impacts



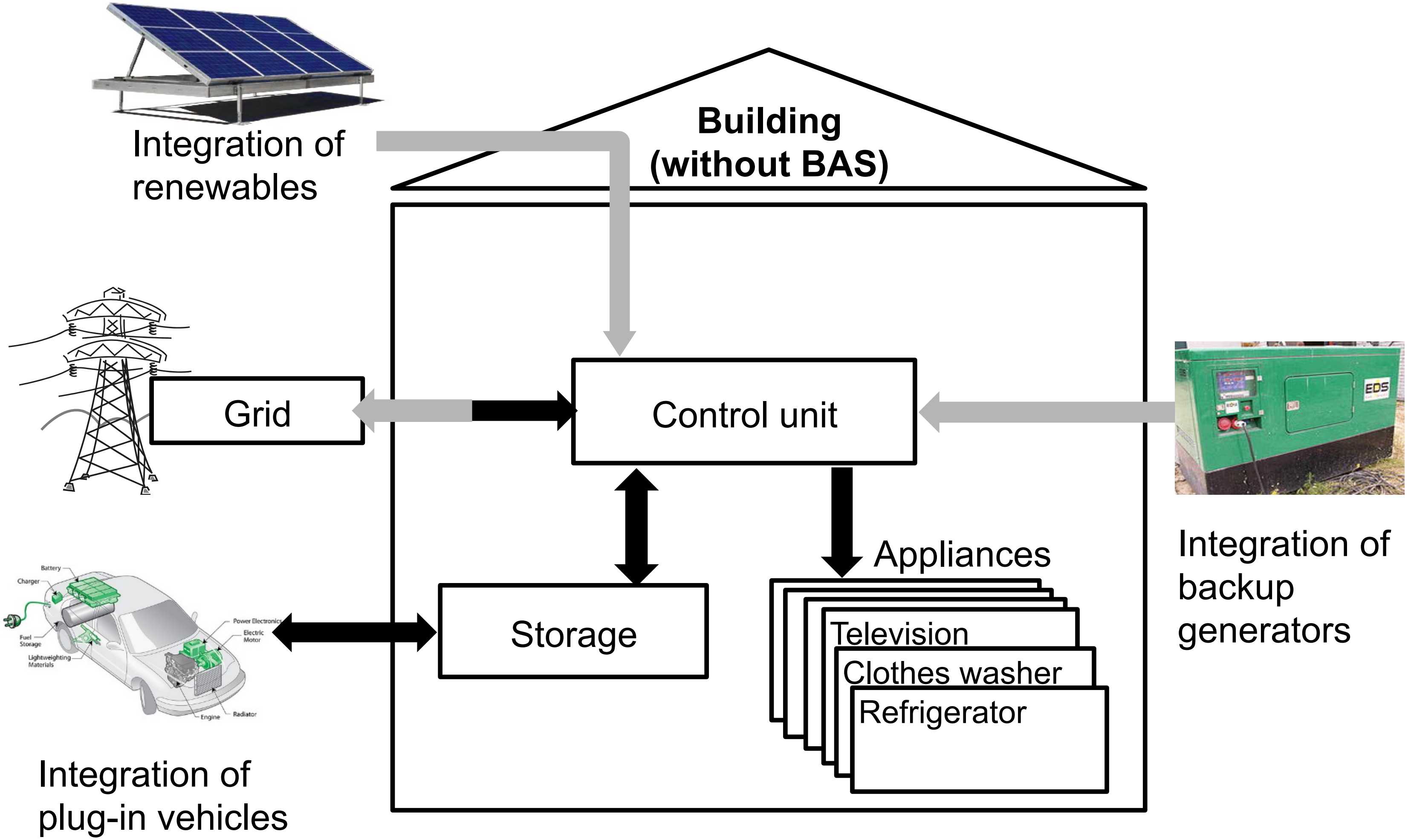
Problems from supply-demand mismatch

- Low capacity utilization → higher kWh cost
- Grid instability - brownouts
- Barriers to higher renewable penetration
- High GHG intensity and pollutants because of more and often older hardware

Benefits of DR → more nimble demand

- Lower kWh cost
- More stable grid
- Higher integration of renewables
- Cleaner generation facilities

Early work (no BAS yet): With current tariffs, storage costs … can battery-aided demand response be economically viable?



Integration of renewables

Building (without BAS)

Grid

Control unit

Storage

Appliances

Television

Clothes washer

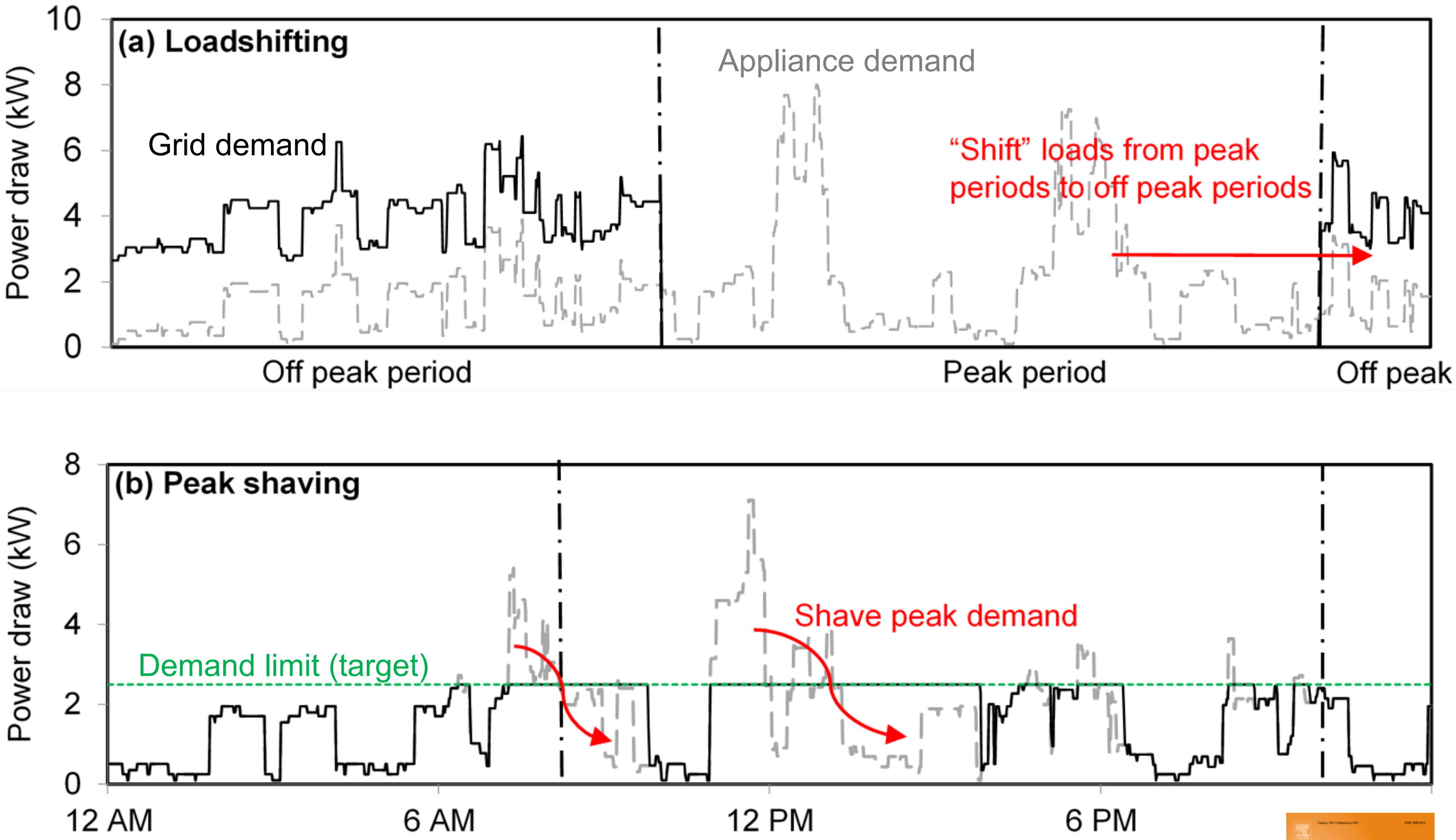
Refrigerator

Integration of backup generators

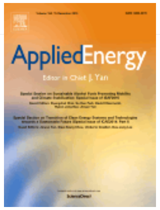
Integration of plug-in vehicles

Agent-based, stochastic demand model to simulate building load profile

Loadshifting and peakshaving to lower electricity bill

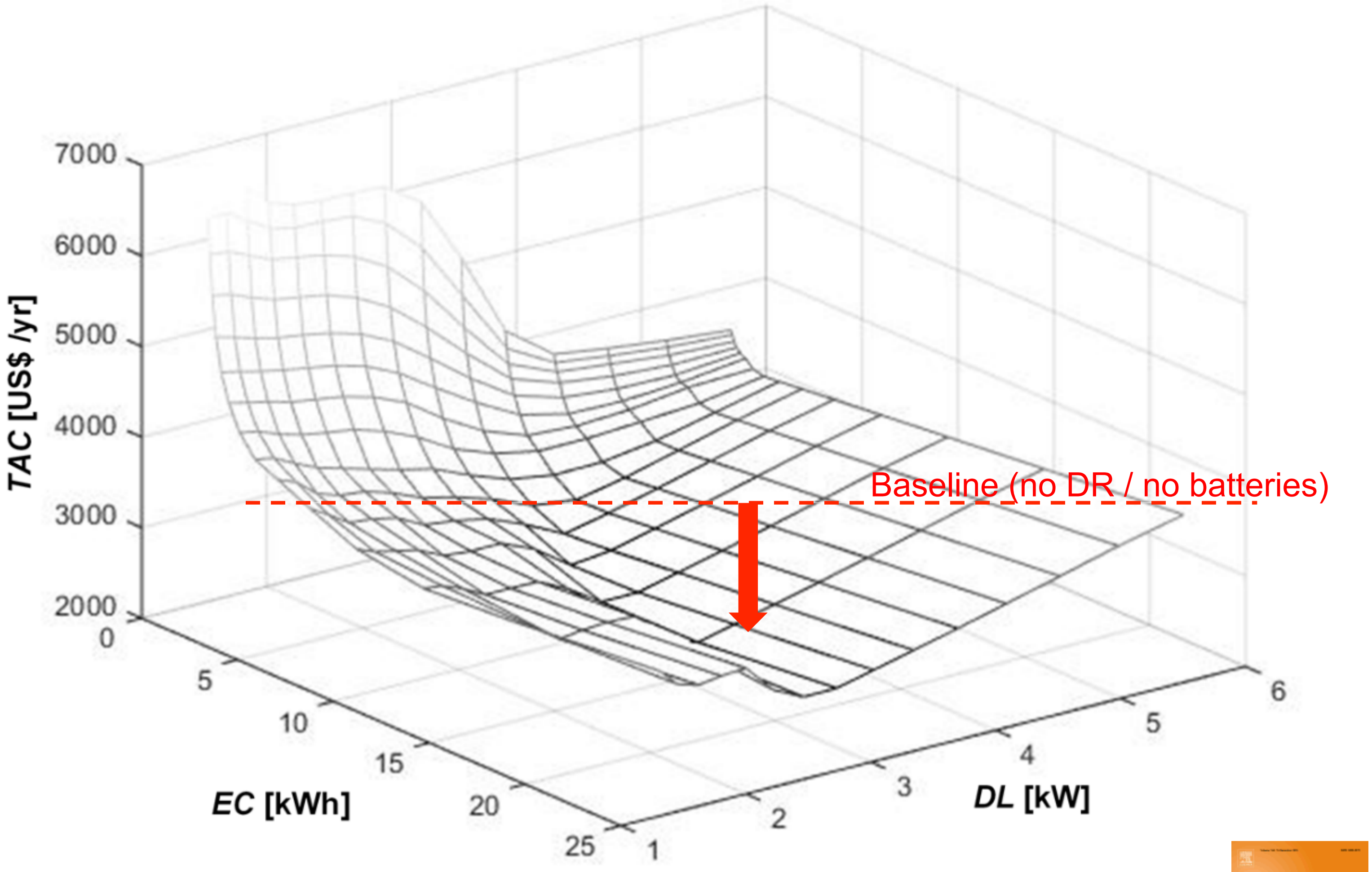


Zheng M, **Meinrenken** CJ, Lackner KS (2015)
Smart households: Dispatch strategies and economic analysis of distributed energy storage for residential peak shaving. Applied Energy 147



Optimize battery size (EC) and demand limit (DL) for lowest cost (TAC)

Tariff arbitrage savings are higher than battery/inverter installation costs



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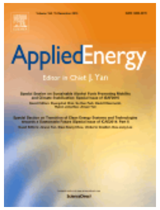
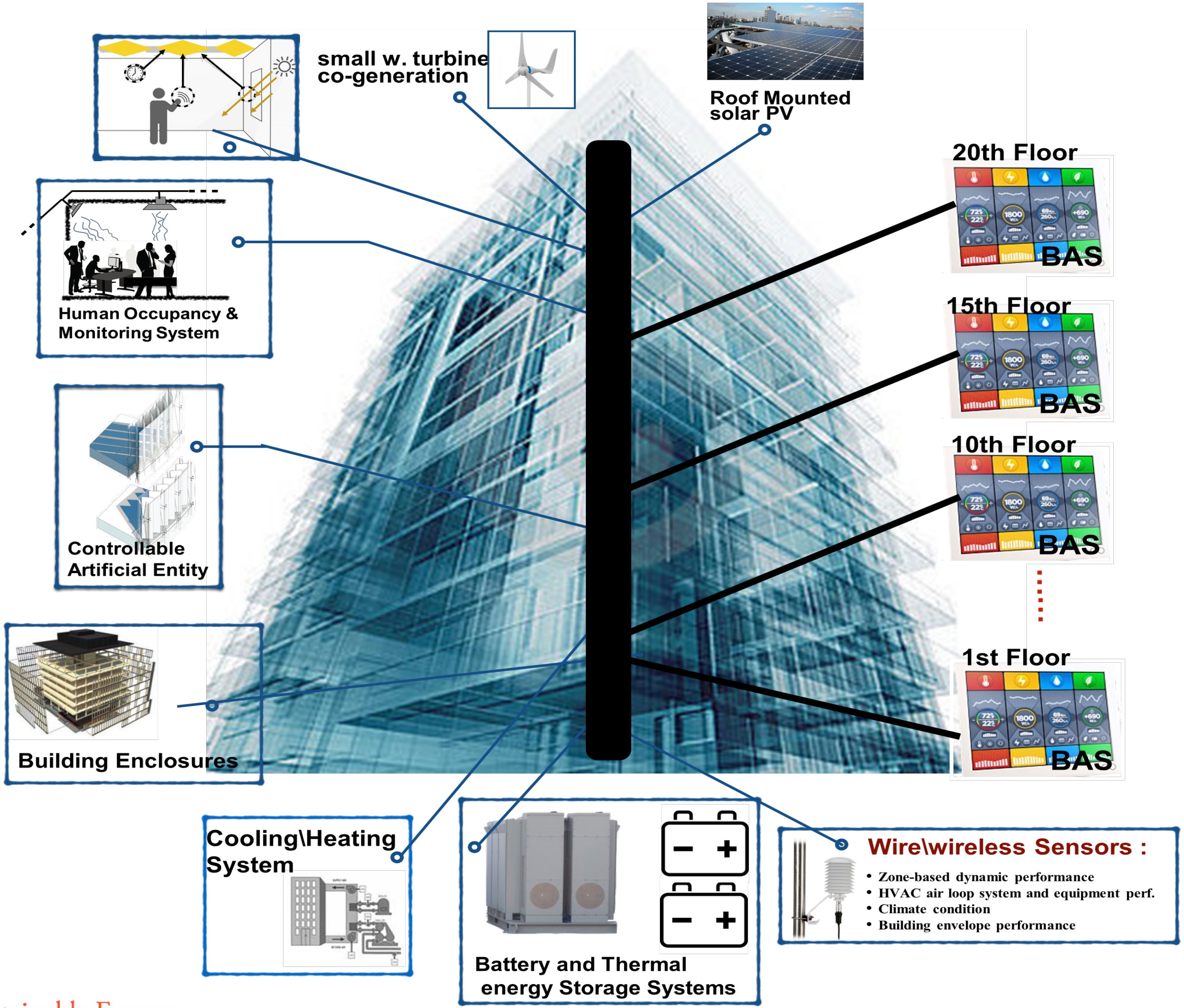


From this early proof-of-concept to complex large scale CPS

Commercial buildings with traditional BAS, batteries, and smart controls



small w. turbine
co-generation

Roof Mounted solar PV

Human Occupancy & Monitoring System

Controllable Artificial Entity

Building Enclosures

Cooling\Heating System

Battery and Thermal energy Storage Systems

20th Floor

15th Floor

10th Floor

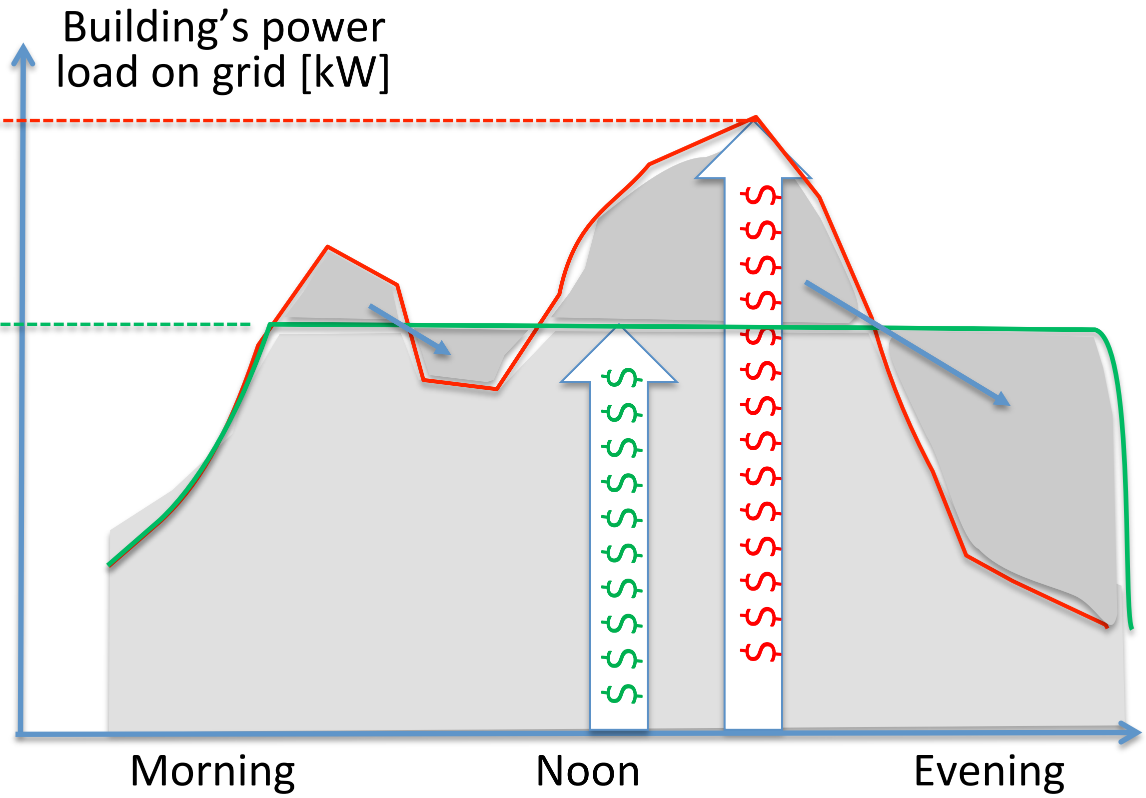
1st Floor

Wire\wireless Sensors :

- Zone-based dynamic performance
- HVAC air loop system and equipment perf.
- Climate condition
- Building envelope performance

Typical tariffs offer high incentives for demand response

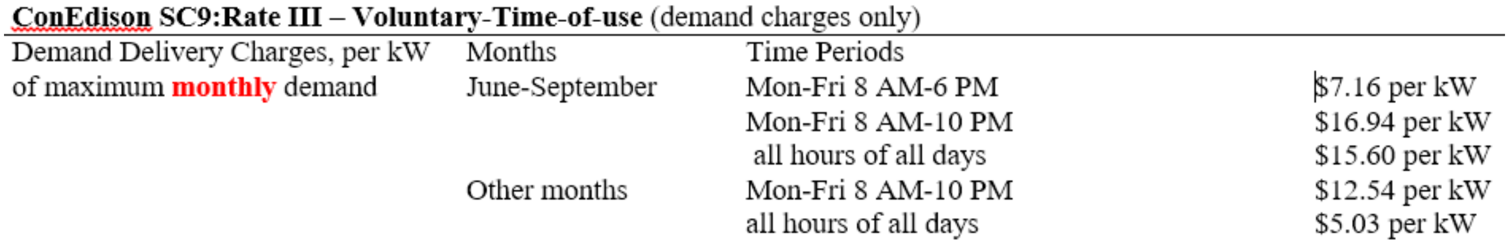
… but rules e.g. "monthly peaks" pose challenges for intelligent controls



Load profile without DR
→ High demand charges

DR profile (“peak shaved”)
→ Lower demand charges

Similar total kWh are consumed in both scenarios → that (usually smaller) portion of the electricity cost remains

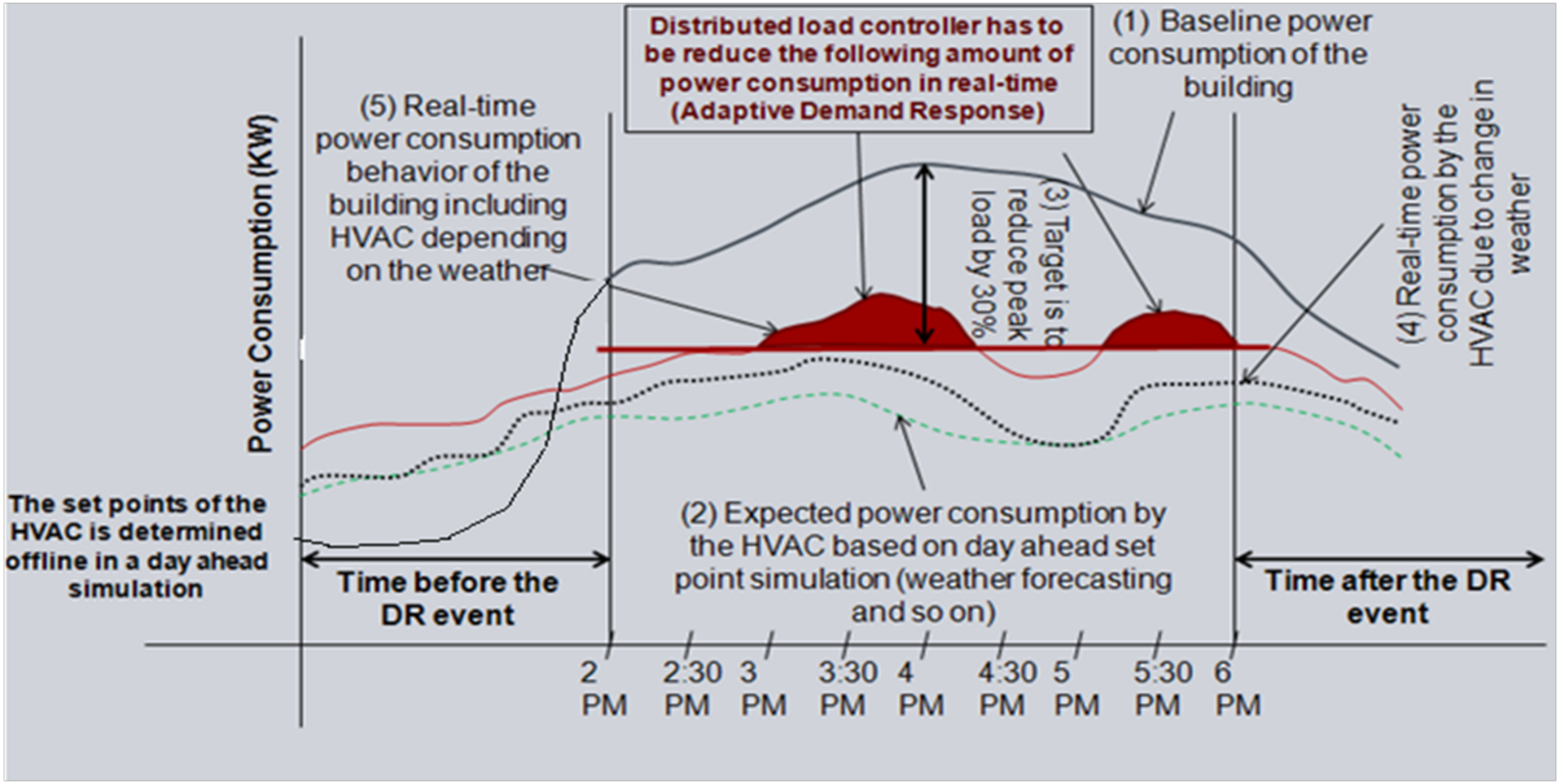


ConEdison SC9:Rate III – Voluntary-Time-of-use (demand charges only)

Demand Delivery Charges, per kW	Months	Time Periods	
of maximum **monthly** demand	June-September	Mon-Fri 8 AM-6 PM	$7.16 per kW
		Mon-Fri 8 AM-10 PM	$16.94 per kW
		all hours of all days	$15.60 per kW
	Other months	Mon-Fri 8 AM-10 PM	$12.54 per kW
		all hours of all days	$5.03 per kW

Existing work on BAS (without batteries)

Demand reductions possible – but limited by occupancy comfort



Source: Siemens and GCTC project team

Our GCTC: **Energy Storage-based Adaptive Demand Response in Smart Commercial Buildings**

Objective:

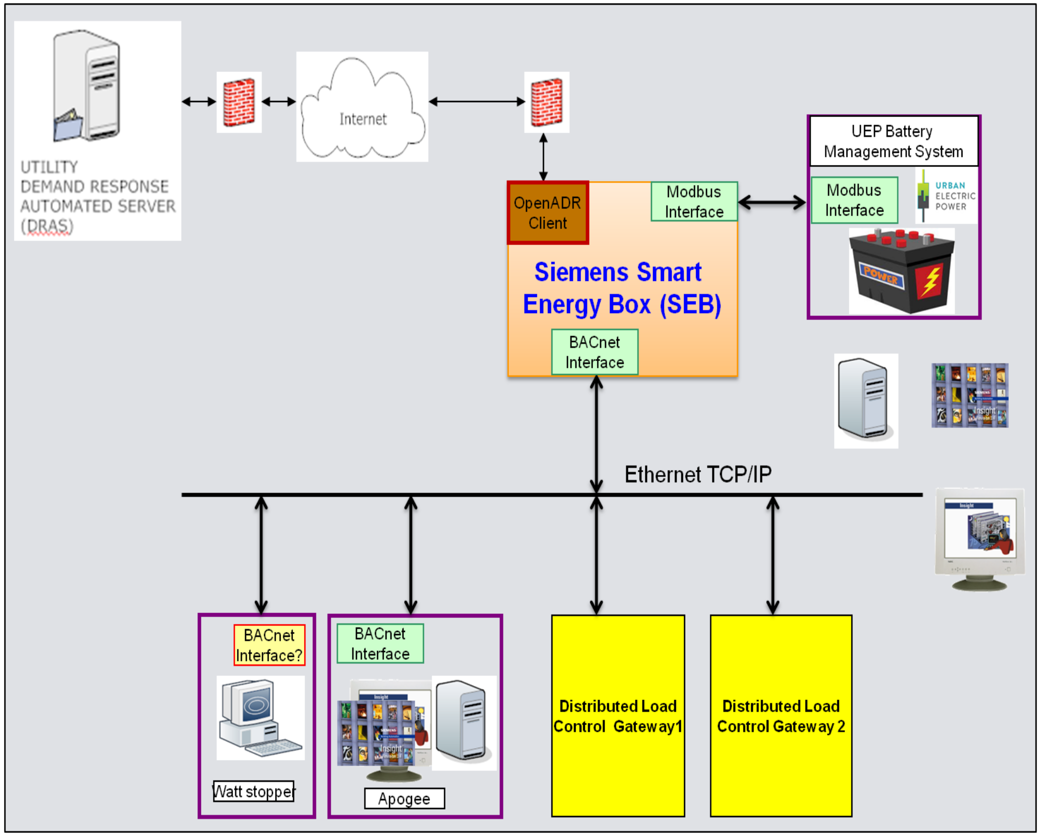
To develop and demonstrate how battery storage can be used synergistically with a commercial building's other DR capabilities.

Impacts:

- Reduce grid stress and rate payer cost
- Spur technology innovation
- Reduce environmental impacts
- Improve grid reliability

Domains/Sectors:

- Advanced battery technology
- Smart grid and smart building systems
- Building-based cyber physical systems and relevant control algorithms



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SIEMENS

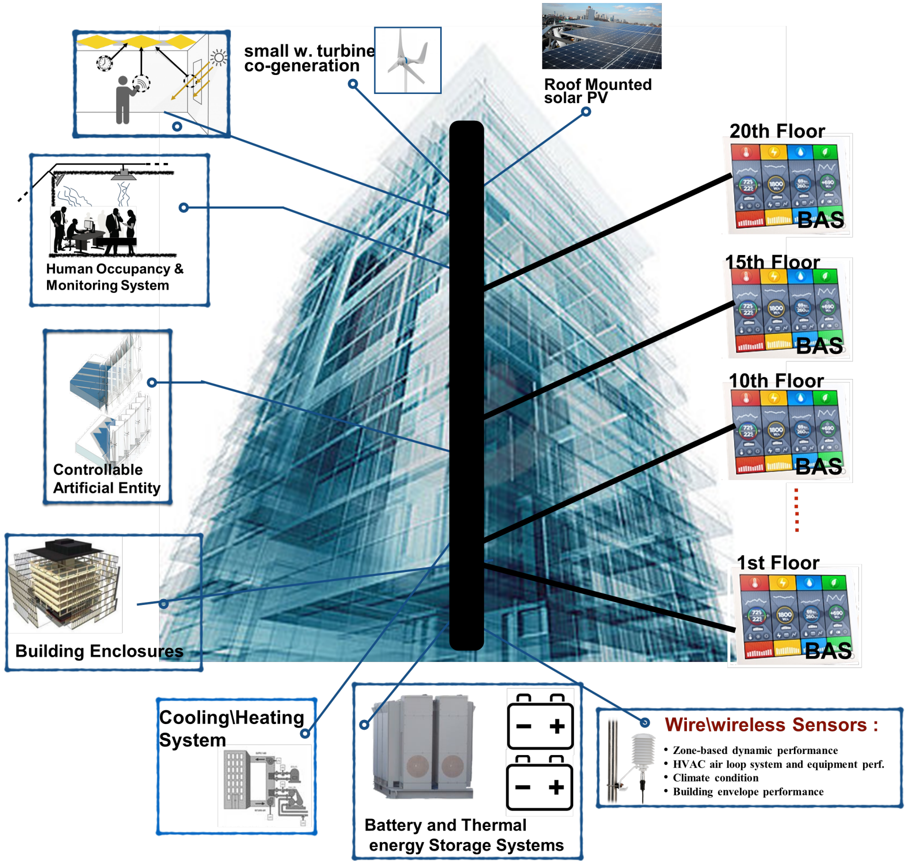
COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

NY BES+ NEW YORK BATTERY AND ENERGY STORAGE TECHNOLOGY CONSORTIUM

CUNY The City University of New York

Lenfest Center for Sustainable Energy
EARTH INSTITUTE | COLUMBIA UNIVERSITY

Core questions of this NSF EAGER project: Can advances in control and optimization theory be applied to CPS such that objectives are met?

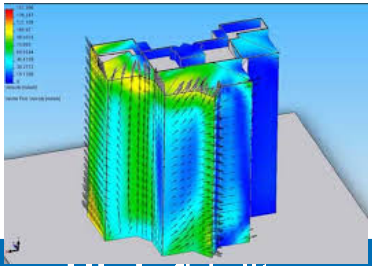


Minimize

- Demand Charge (kW)
- Supply Charge (kW-h)
- Loss of Comfort — THERMAL COMFORT, VISUAL COMFORT
- **Levelized** Equipment Cost

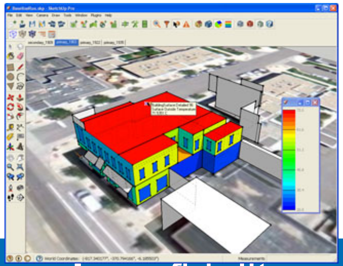
Existing approaches to predicting building's electricity load profile

Pro's and Con's



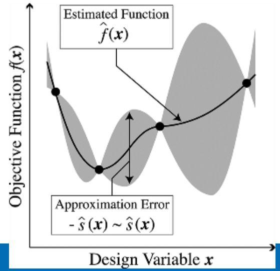
High fidelity physical model

- Full resolution of thermal impedances and fluid dynamics throughout building
- **Slow**
- In-flexible vis-à-vis imperfect building info or faulty hardware



Low fidelity physical model

- Simplified thermal impedances and usually uniform air temperature
- In-flexible vis-à-vis imperfect building info or faulty hardware
- Significant deviations from actual load profiles

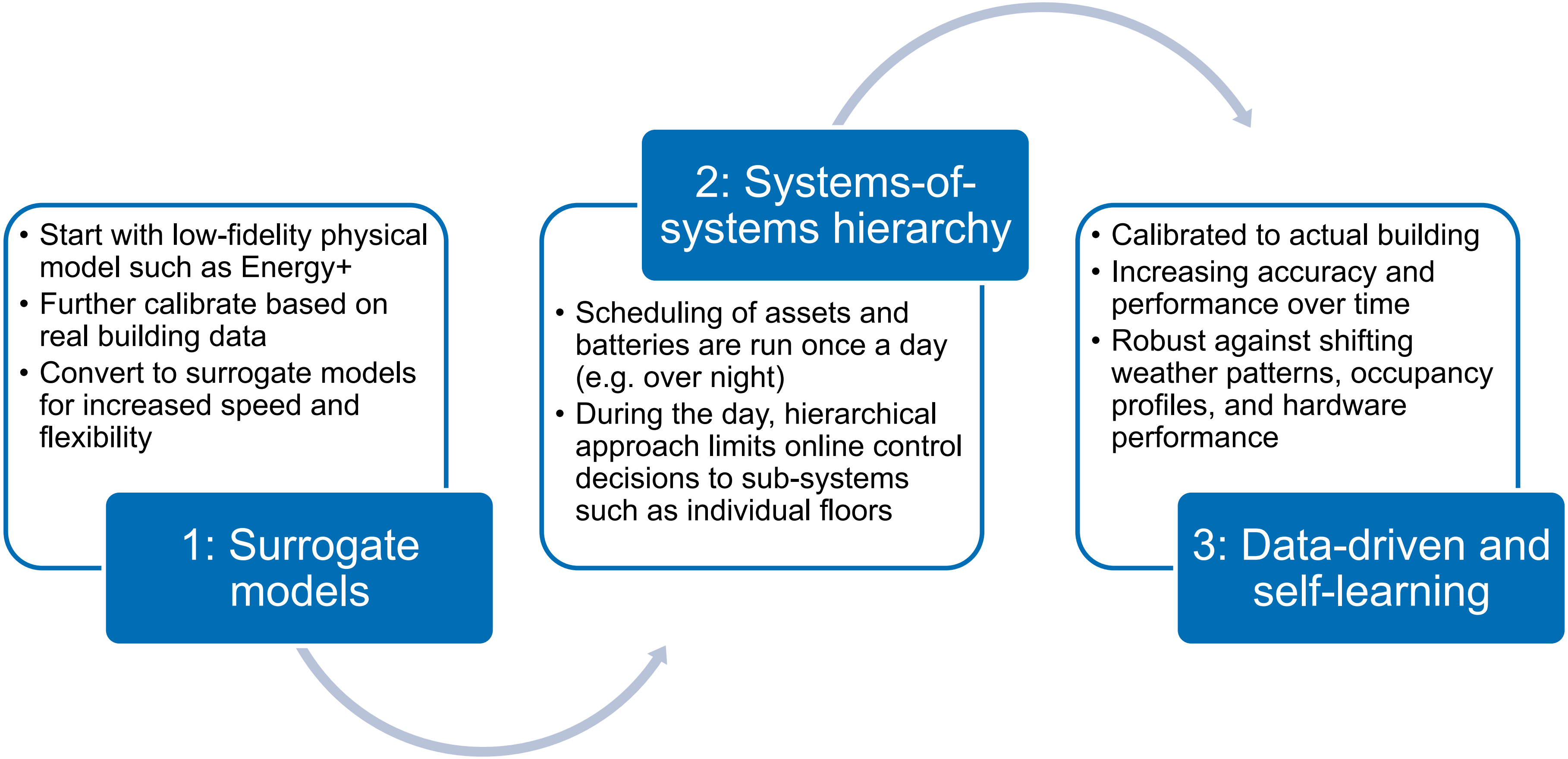


Surrogate model

- Statistical model calibrated to building behavior → can achieve high fidelity
- **Fast enough for online control**
- Self learning and thus flexible to adjust to faulty hardware

Our modeling approach: Experiment with 3 advanced techniques

Asset scheduling in real time subject to multi-objective function



- Start with low-fidelity physical model such as Energy+
- Further calibrate based on real building data
- Convert to surrogate models for increased speed and flexibility

1: Surrogate models

2: Systems-of-systems hierarchy

- Scheduling of assets and batteries are run once a day (e.g. over night)
- During the day, hierarchical approach limits online control decisions to sub-systems such as individual floors

- Calibrated to actual building
- Increasing accuracy and performance over time
- Robust against shifting weather patterns, occupancy profiles, and hardware performance

3: Data-driven and self-learning

Advanced battery-based demand response for building management systems

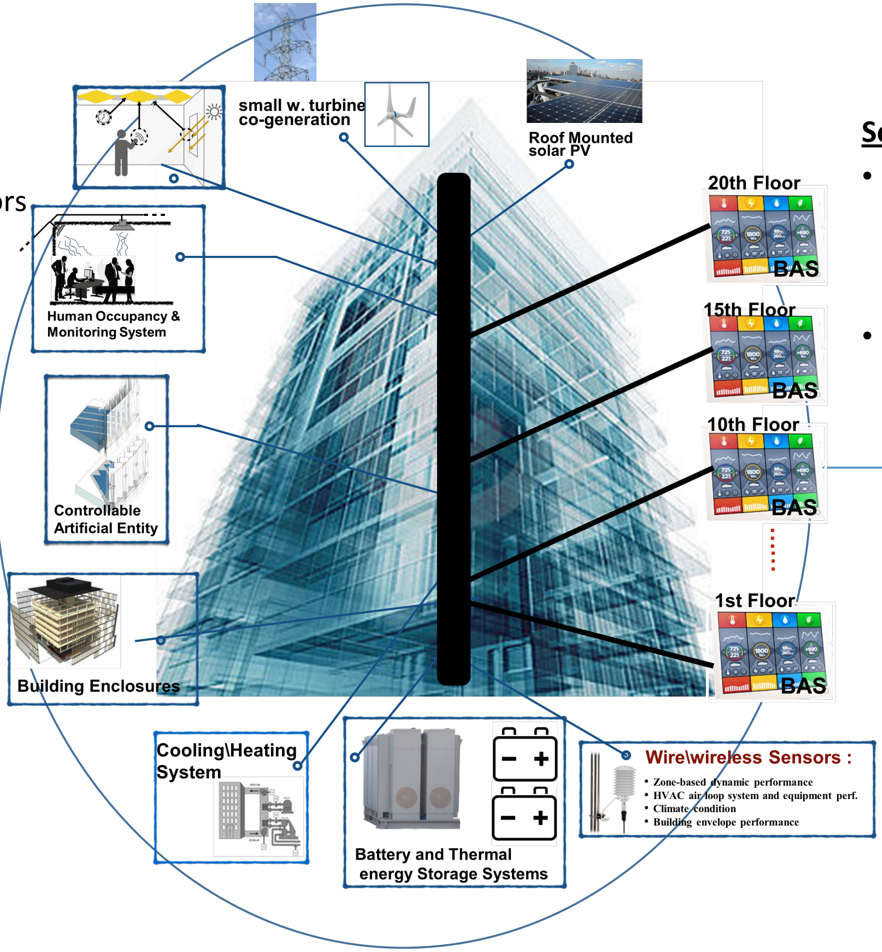
Christoph Meinrenken (PI) Columbia University

Challenge:

- Large commercial buildings are energy hogs and GHG contributors
- Grid congestion
- Expensive, carbon-intensive electricity
- Barriers to entry for more renewables

Solution:

- Battery storage integrated with other BAS features
- Sensor data-driven, self learning CPS to optimize against objective function



Wire\wireless Sensors :

- Zone-based dynamic performance
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Scientific Impact:

- Develop surrogate modeling and machine learning for building applications and novel system-of-systems approach
- Weather and building sensor data provides use and test case for *Internet Of Things*

Broader Impact:

- Energy-efficient yet comfortable and affordable buildings
- Cheaper, cleaner electricity generation
- Pilot in campus building (phase 2) to promote public awareness of CPS

NSF EAGER 1524628
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