Predictive Dispatch and Demand Response for Commercial Buildings

Colin Jones

Laboratoire d'Automatique

Altug Bitlislioglu, Luca Fabietti, Tomasz Goreki, Ali Ahmadi Khatir, Ioannis Lymperopoulos, Truong Nghiem, Faran Qureshi

Distributed Energy Systems Lab

Mario Paolone, Fabrizio Sossan, Emil Namor

Laboratoire d'Automatique

BuildNet

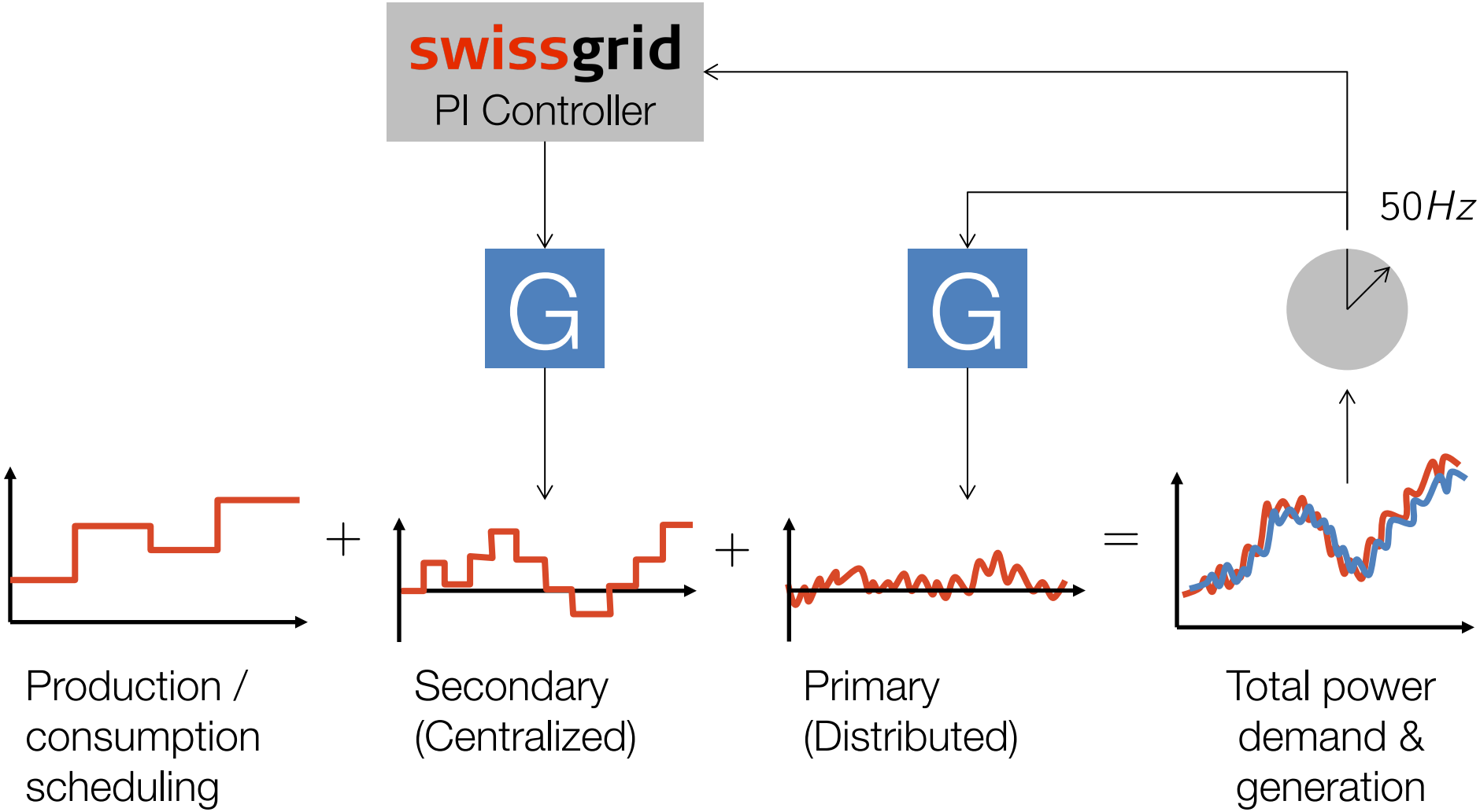
SEVENTH FRAMEWORK PROGRAMME

erc

FNSNF

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Balancing Generation with Loads : Ancillary services

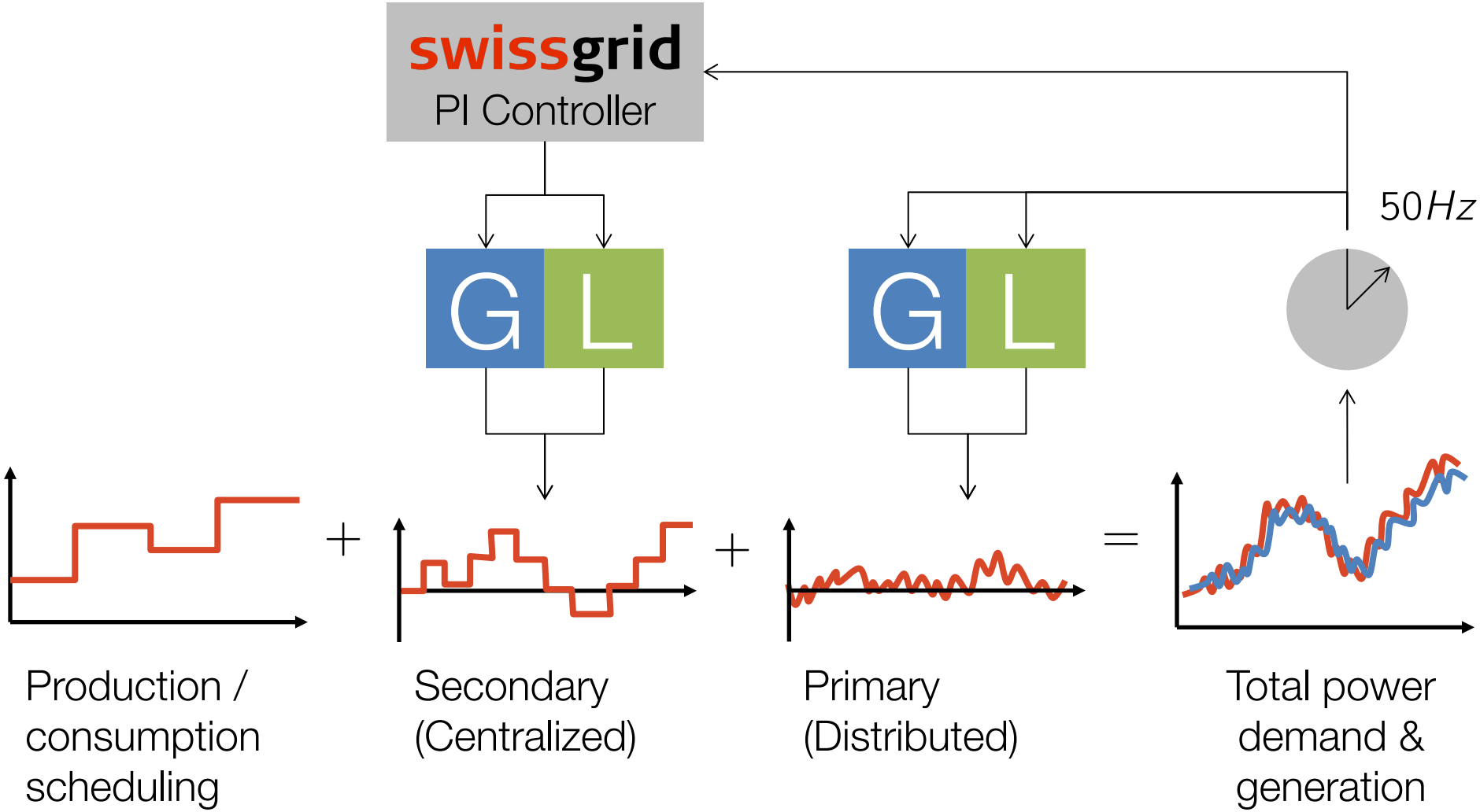


Energy Markets **Planning** | Balancing Markets **Feedback**

G Generators

L Loads

Balancing Generation with Loads : Ancillary services



Energy Markets **Planning** | Balancing Markets **Feedback**

G Generators

L Loads

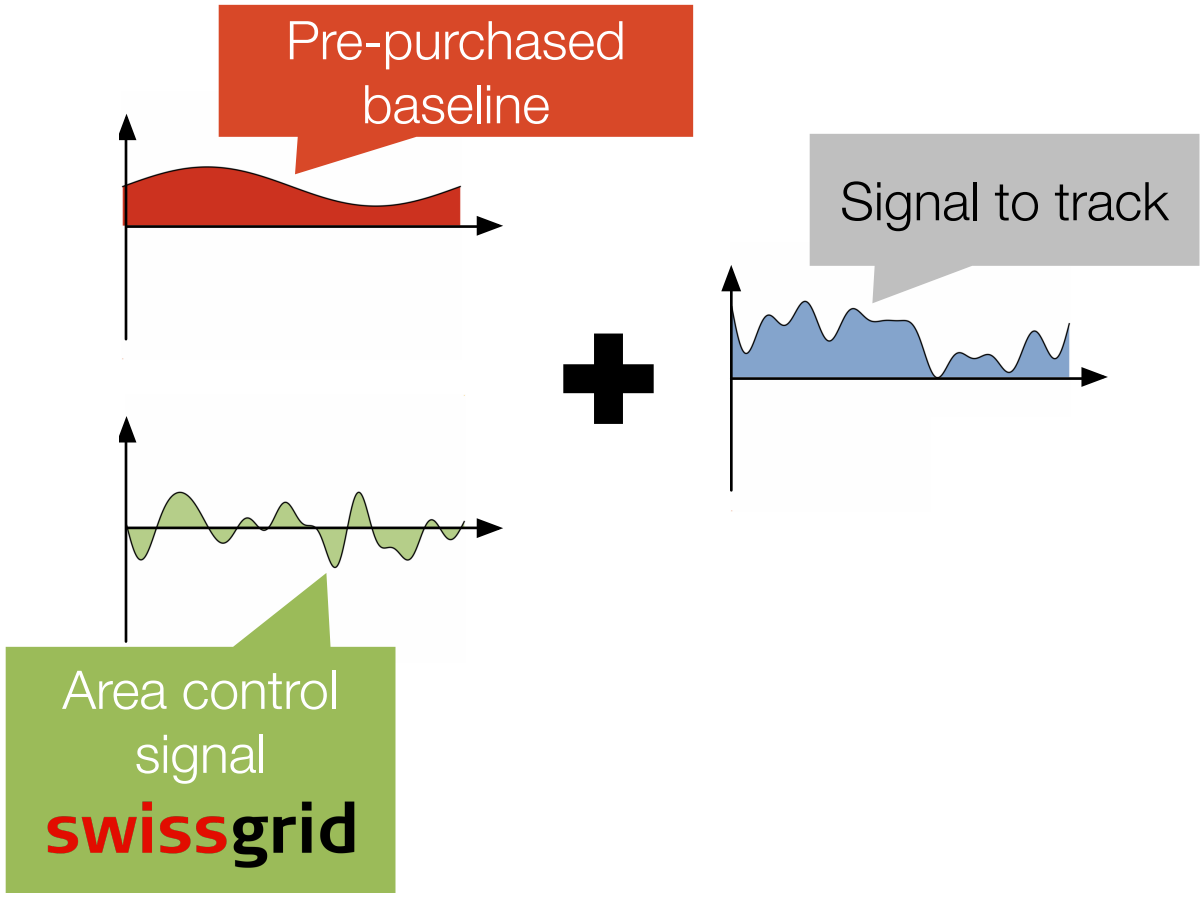
Swiss Ancillary Market for Loads

Phase 1 : Bidding

	Period	Payment
Bid flexible capacity α *MW*	Weekly	$\alpha \cdot$ bid
Purchase baseline energy		
Day-ahead market	1 day	Open market
Energy exchange	90 min	

Swiss Ancillary Market for Loads

Phase 2 : Tracking

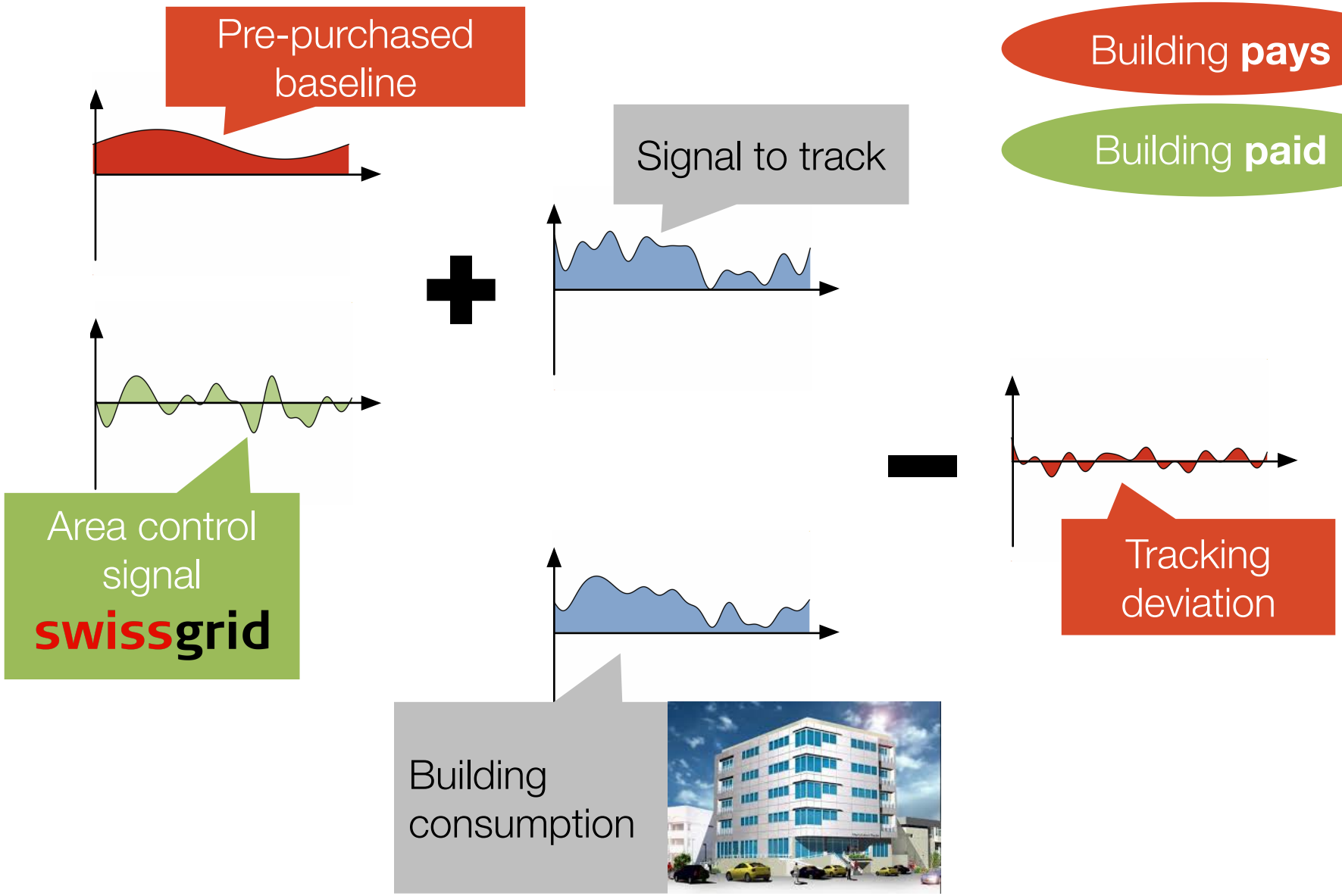


Building **pays**

Building **paid**

Swiss Ancillary Market for Loads

Phase 2 : Tracking



Outline

Bidding	What is a bid? How flexible can a building be? Convex solution to the bidding problem
Experiments	Can a demand-response solution be practically deployed?
Economics	Does demand response add value in the current market?

A Bid is a Tracking Set

A bid of α MW is hypercube

$$\alpha S \triangleq \{(p_0, \dots, p_N) \mid -\alpha \leq p_i \leq \alpha\}$$

… fine for generators, but demand-response is a ***virtual storage system***

→ A bid of 1MW requires a battery of 48 MWh!

Impossible!

~225 kCHF / year

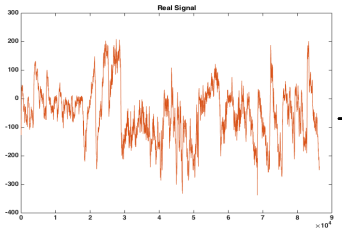
~24 mCHF

Components of a possible solution:

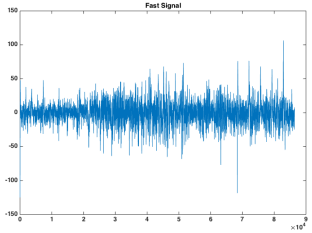
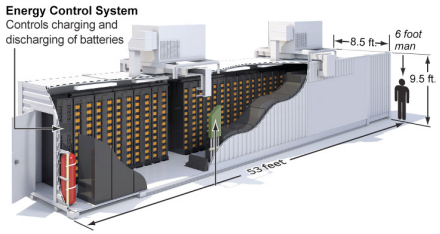
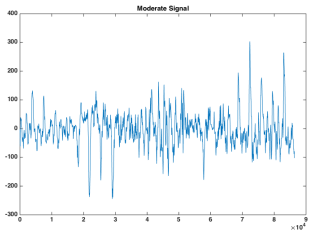
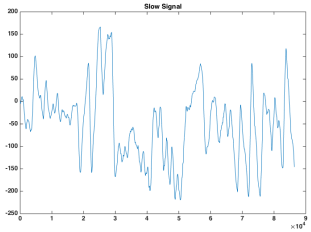
1. Use multiple complementary devices
2. Provide the service that is requested, not the legally required one

Hybrid Storage Scheme Increases Available Capacity

swissgrid

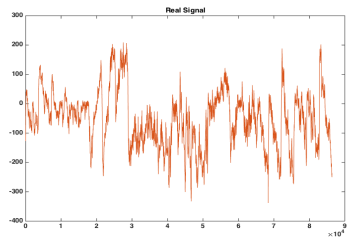


Spectral Split

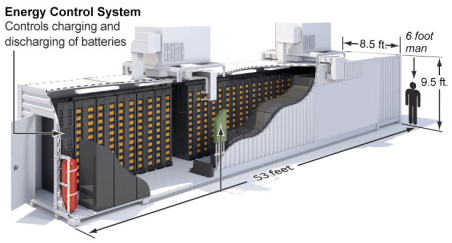
		Power	Energy	Time
		High ✓	Low ✗	Fast ✓
		?	?	Med
	EPEXSPOT		High ✓	Slow ✗

Battery Control

Key : Energy storage is very expensive



a_i



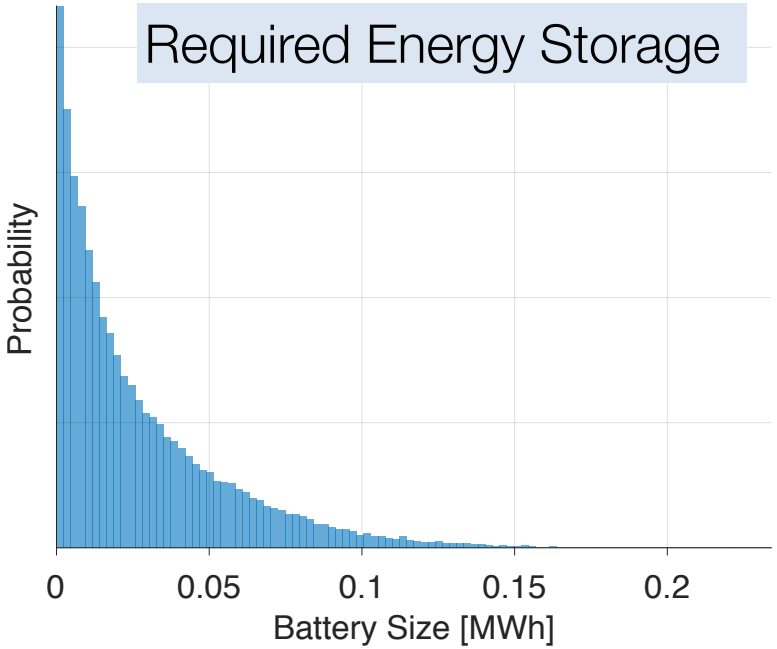
$\sum a_i$

15 min

Area Generation Control

Energy Storage

Clear Energy to Building



150kWh battery per 1MW capacity

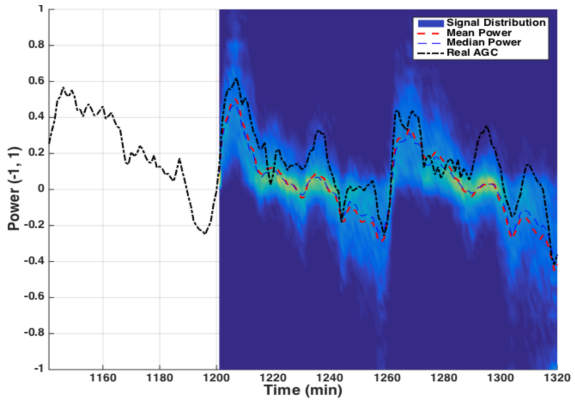
~65k CHF

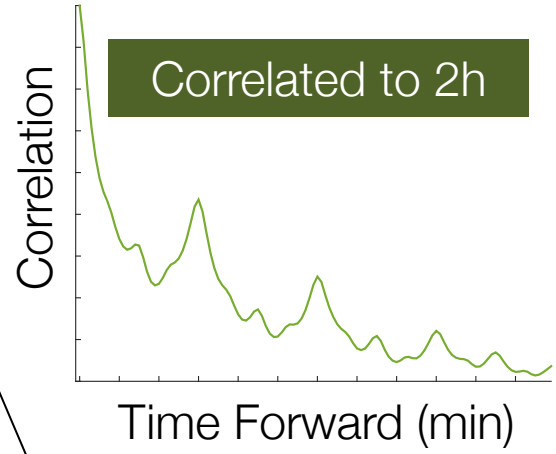
~225k CHF / year

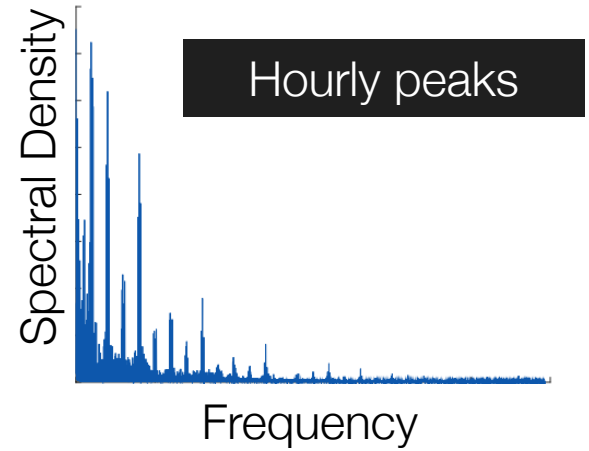
Optimal Participation in the Intraday Market

Goal : Minimize energy stored in the building.

Forecast distribution (Gaussian Process)







$$\min \sum \mathbb{E}[r_i]$$

$$\text{s.t. } r_{i+1} = r_i + \sum a_j + \pi(r_{i-d})$$

$$\mathbb{E}\left[\sum a_j + \pi(r_{i-d})\right] \in U$$

Goal : Minimize energy stored in building

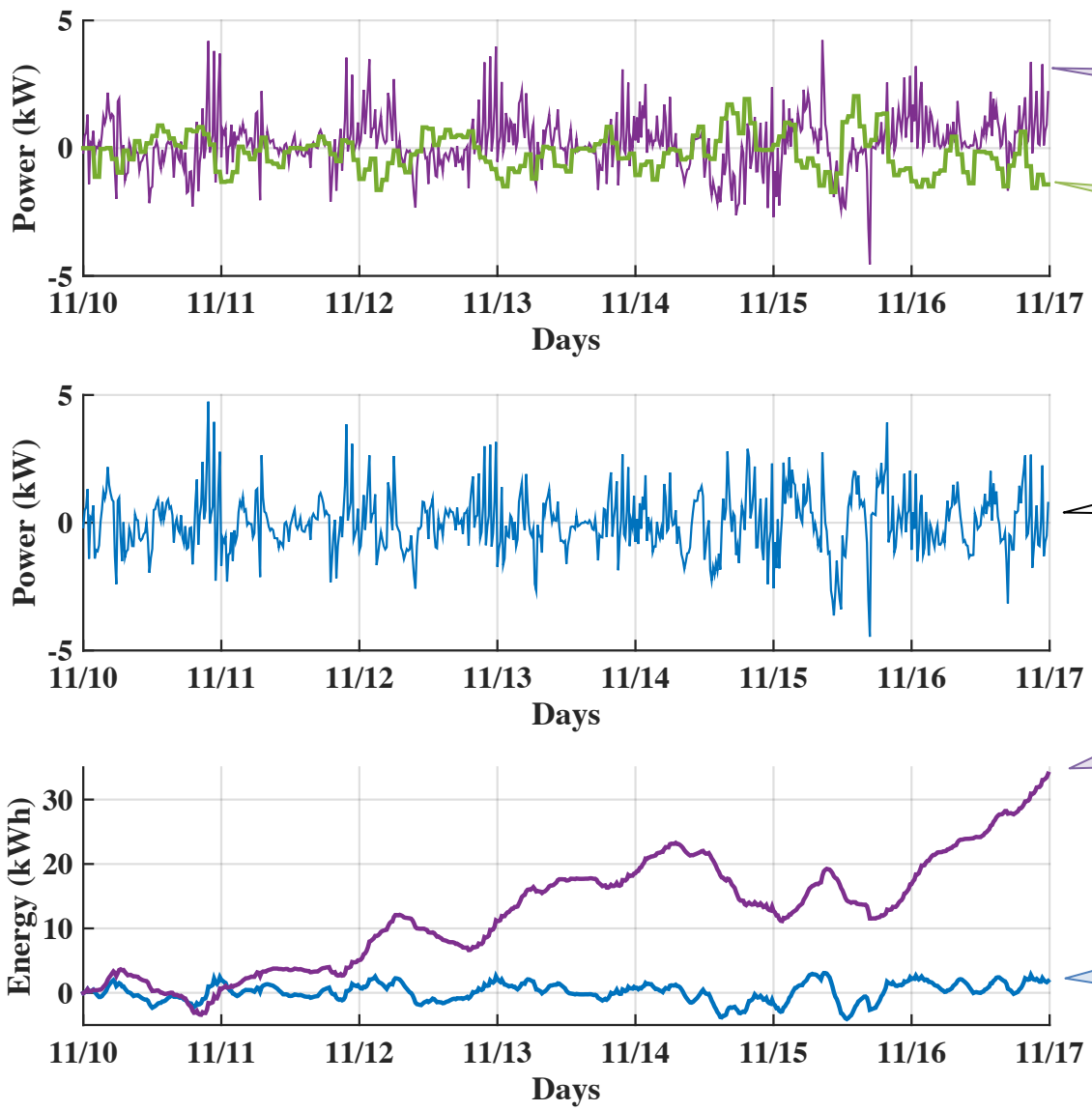
Challenges

- Market delay
- Uncertain constraints

Area Generation Control

Control action : Purchase / sell

Remove the Mean via Intraday Trading



AGC Signal

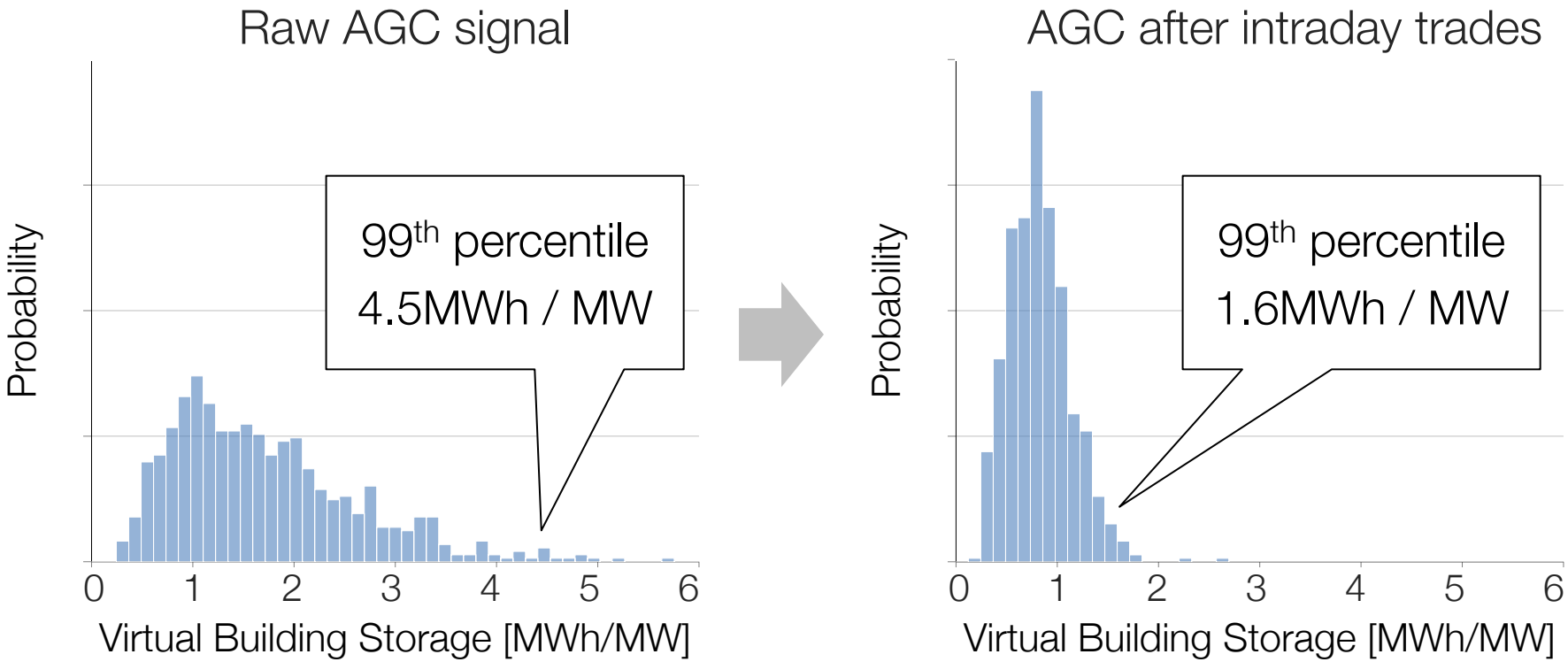
Intraday Transactions

Residual tracking signal

Required energy storage without intraday market

Required energy storage with intraday market

Reduced Energy Requirements from Intraday Trading

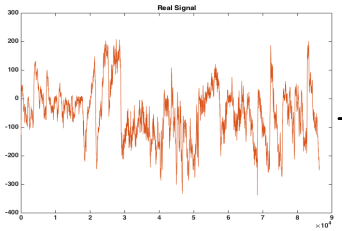


Required virtual energy storage in buildings:

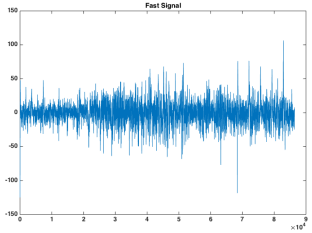
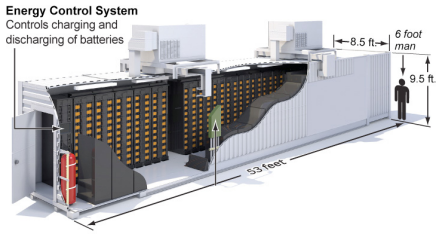
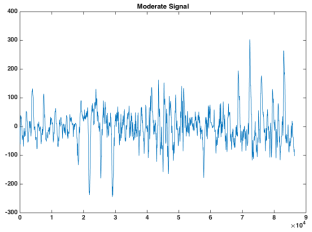
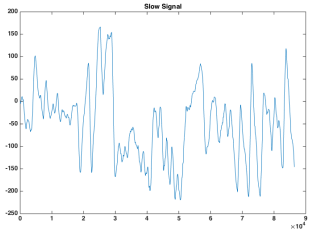
4.5 MWh / MW offered → 1.6 MWh / MW offered

Hybrid Storage Scheme Increases Available Capacity

swissgrid



Spectral Split

		Power	Energy	Time
		High ✓	Low ✗	Fast ✓
		?	?	Med
	EPEXSPOT		High ✓	Slow ✗

Bidding Problem – Convex Robust Optimization

Maximize capacity payment α

$$\max \alpha - \sum \text{cost}_i \cdot e_i$$

Minimize energy costs e

$$\text{s.t. } \alpha B + e \subset C(x)$$

Every battery trajectory feasible for building

Comfortable building power trajectories

All energy trajectories up to 1.6 MWh / MW

$$B \triangleq \left\{ (p_0, \dots, p_N) \;\middle|\; \begin{aligned} s_{i+1} &= s_i + p_i \\ s_0 &= 0 \\ |s_i| &\leq 1.6 \\ |p_i| &\leq 1 \end{aligned} \right\}$$

$$C(x_0) \triangleq \left\{ (p_0, \dots, p_{N-1}) \;\middle|\; \begin{aligned} \|u_i\|_1 &= p_i \\ x_{i+1} &= A_i x_i + B_i u_i + b_i \\ (x_i, u_i) &\in \mathbb{X}_i \times \mathbb{U}_i \\ x_N &\in \mathcal{X}_N \end{aligned} \right\}$$

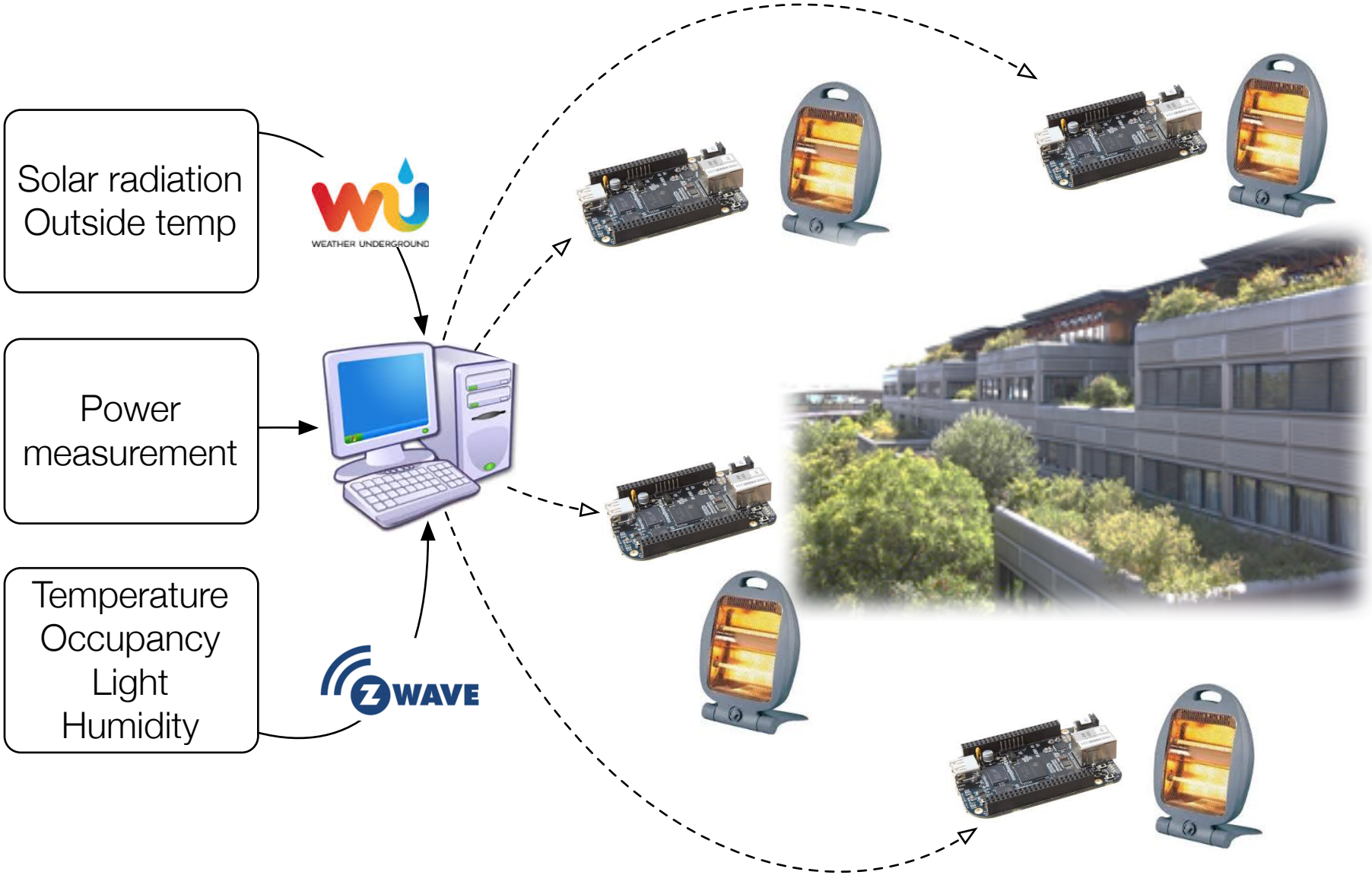
Reach-set of building defines all *comfortable* trajectories

openBuild toolbox extracts time-varying linear model from E+ model

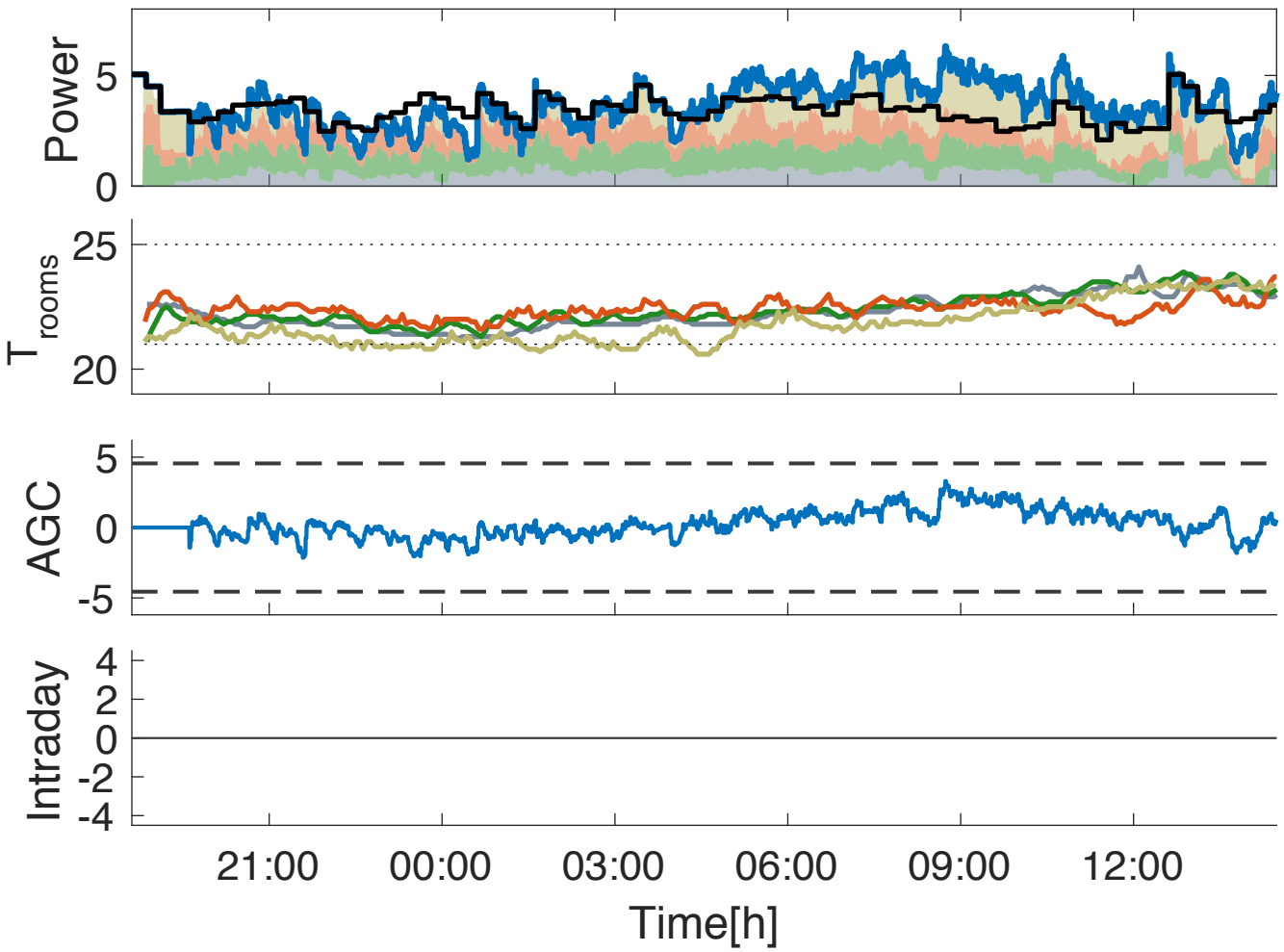
Outline

Bidding	What is a bid? How flexible can a building be? Convex solution to the bidding problem
Experiments	Can a demand-response solution be practically deployed?
Economics	Does demand response add value in the current market?

Laboratoire d'Automatique Demand Response



Single Building Can Track AGC – No Intraday Trading

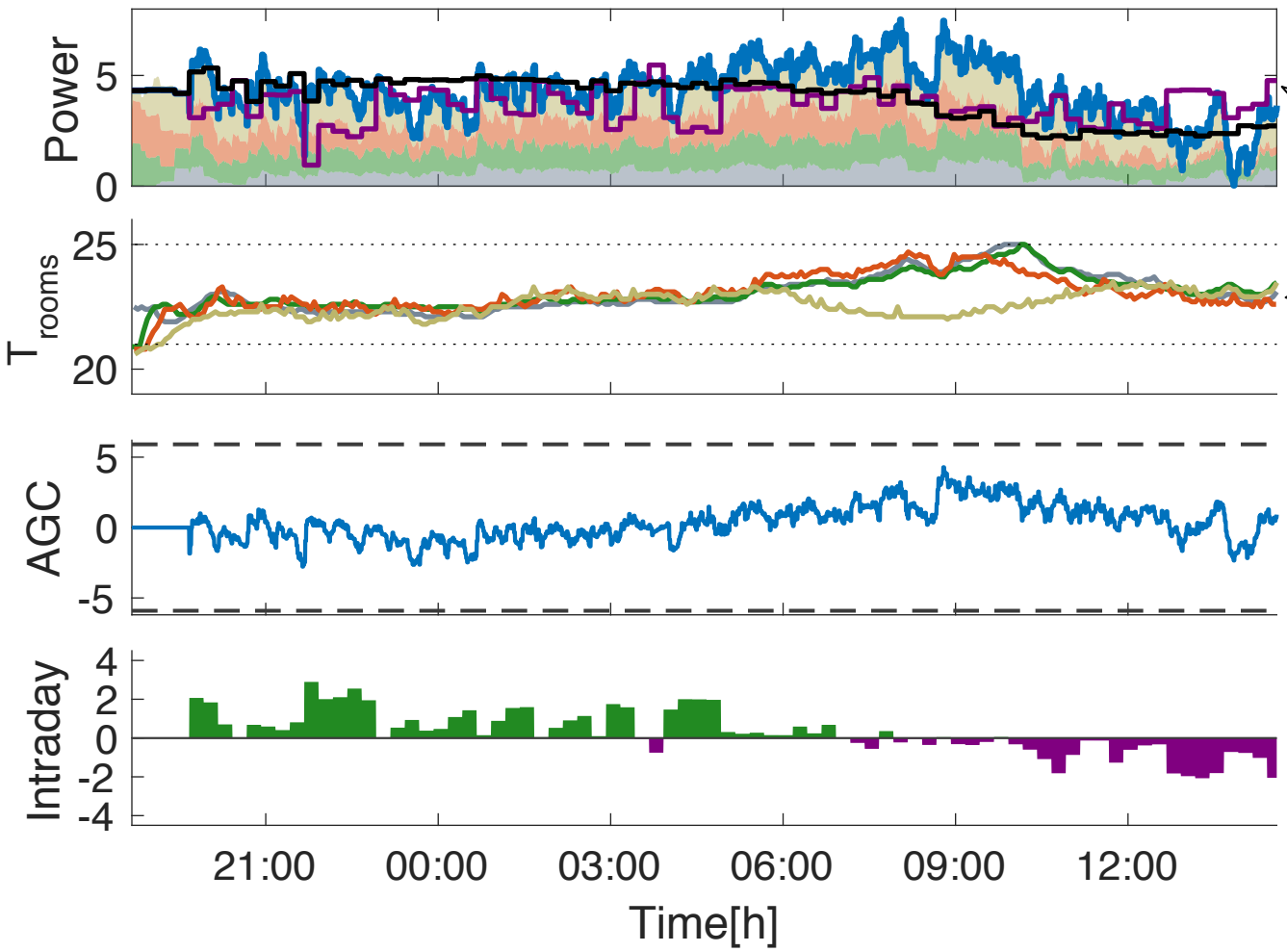


Purchased baseline energy (black)

Occupant comfort is maintained, but tends to be at the limits

Offered capacity : 45% of peak building power consumption

Intraday Trading Improves Comfort and Capacity



Baseline (black)
+
Intraday (purple)

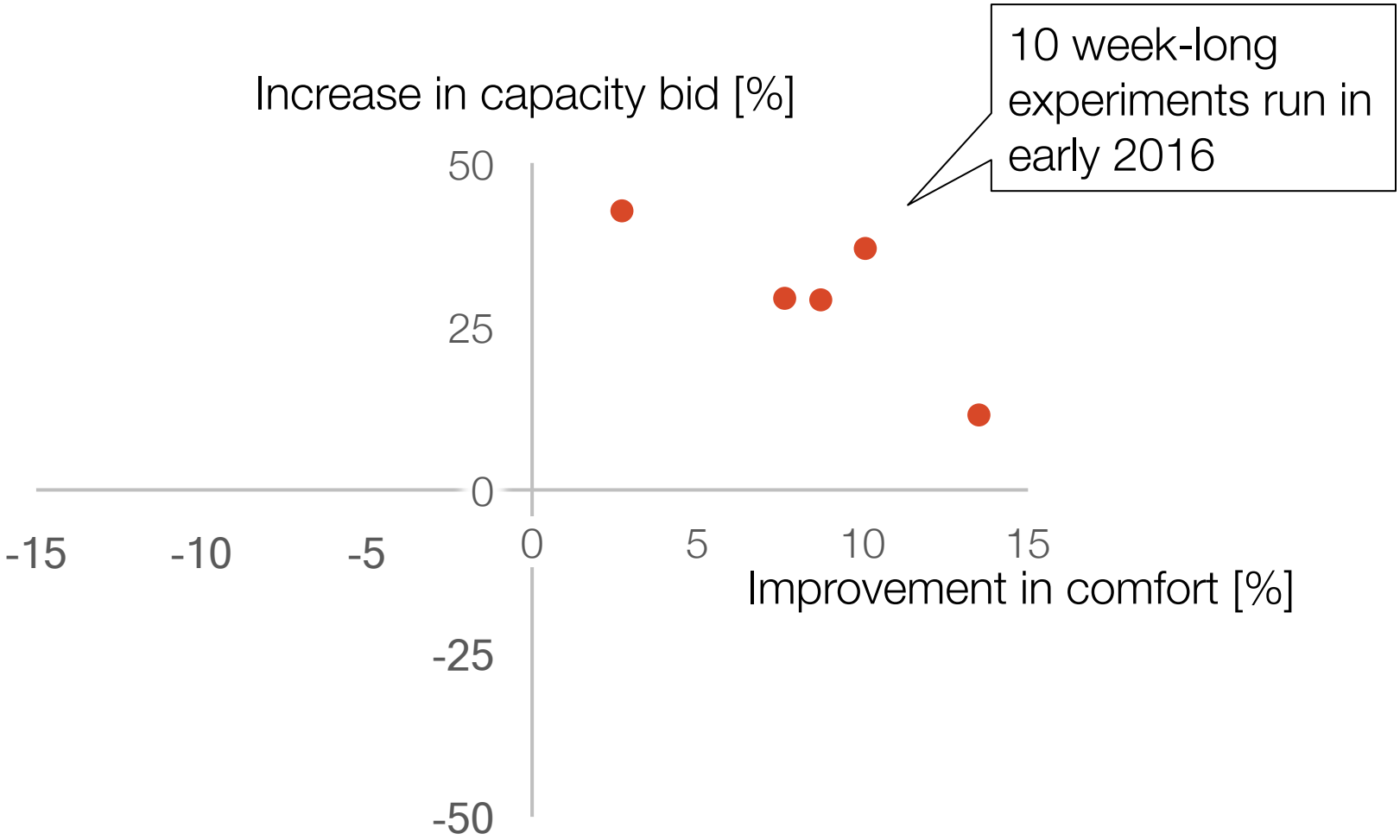
Excellent occupant comfort

Trades average approximately to zero

Intraday trading results in a 30% increase in capacity

LADR : Intraday Trading Increases Capacity

Week-by-week comparison with and without intraday trading.



Result Intraday scheme increases comfort ***and*** capacity income

Campus Scale Experiments

Controllable

LADR

12% total load

Leclanché battery

550 kWh / 720 kW

Uncontrollable

EE Buildings

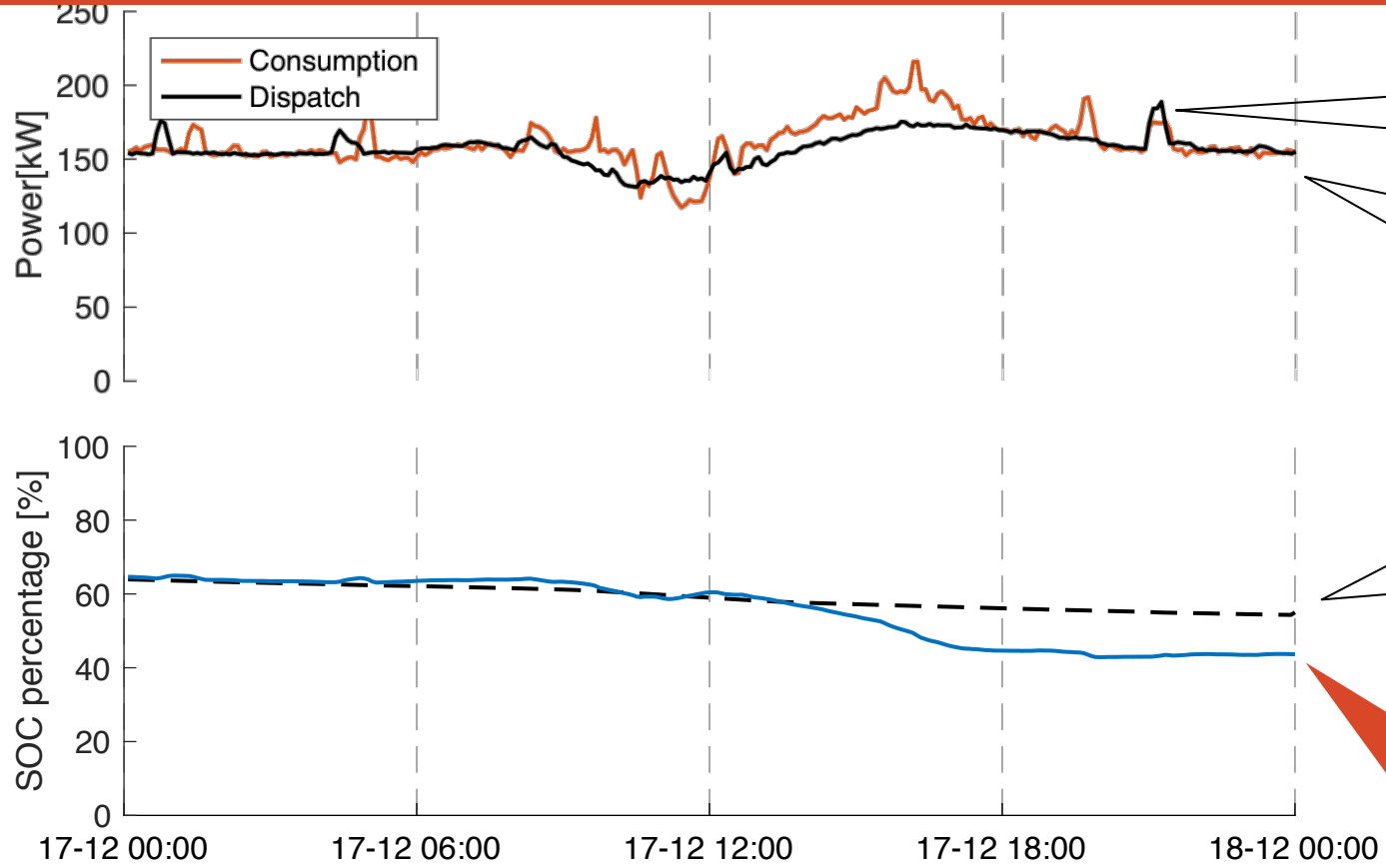
350 kW

PV Panels

Collaboration with DESL

[Fabietti, Gorecki, Namor, Sossan, Paolone & Jones IEEE CCTA, 2017]

Good Prediction Day – Battery Only



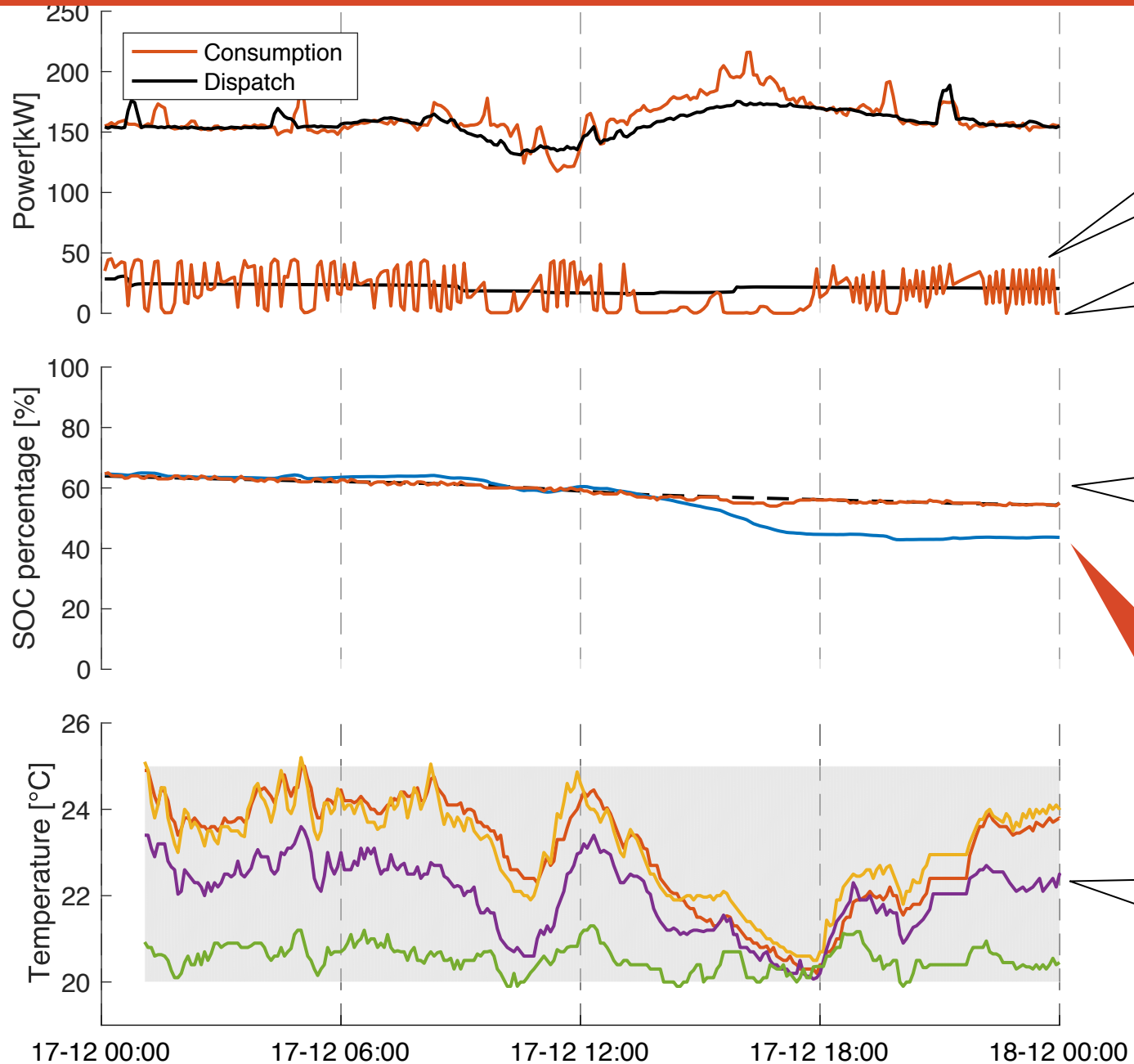
Dispatch plan (black)

Prosumer consumption (red)

SOC reference

Battery easily compensates for prediction errors (SOC)

Good Prediction Day – Battery & LADR



Building dispatch plan (black)

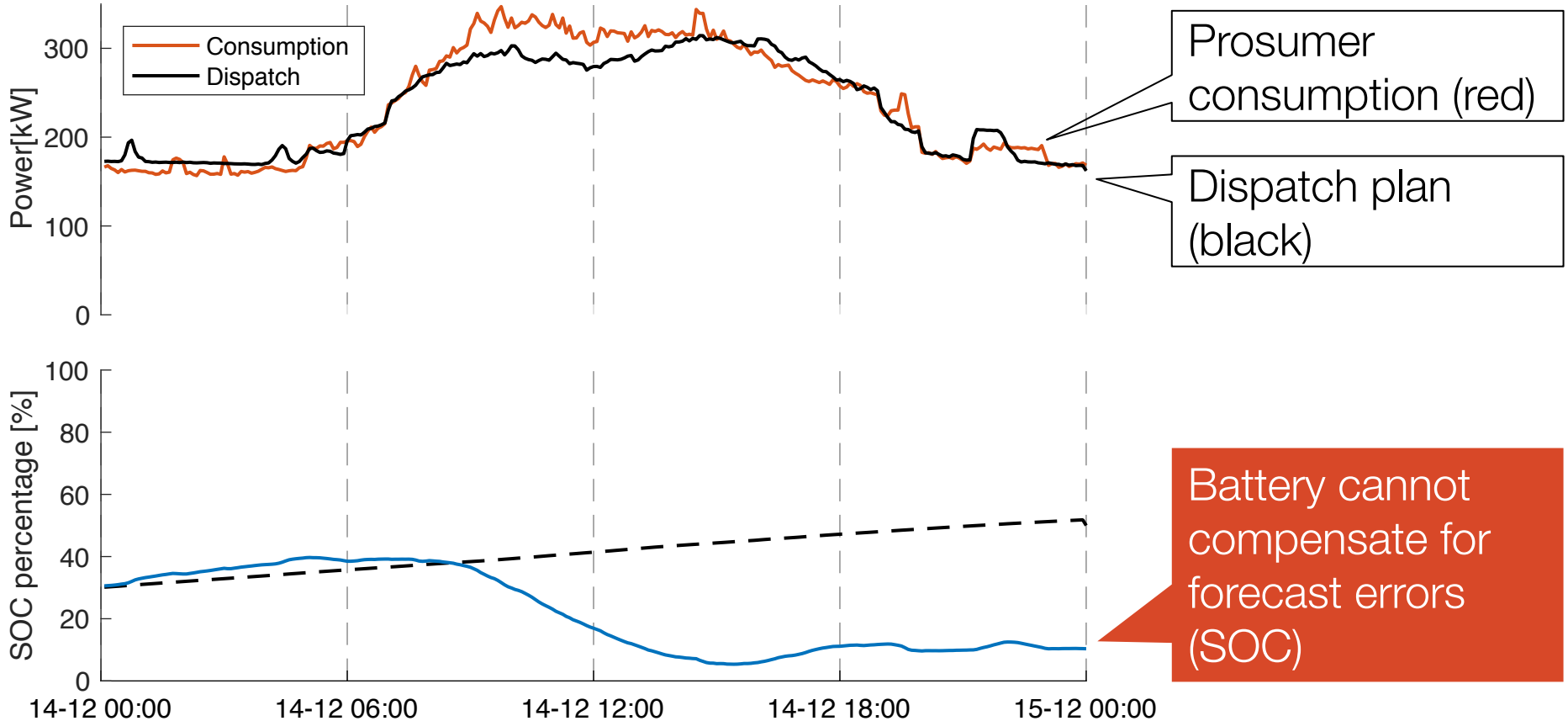
Building consumption (red)

SOC with battery (red)

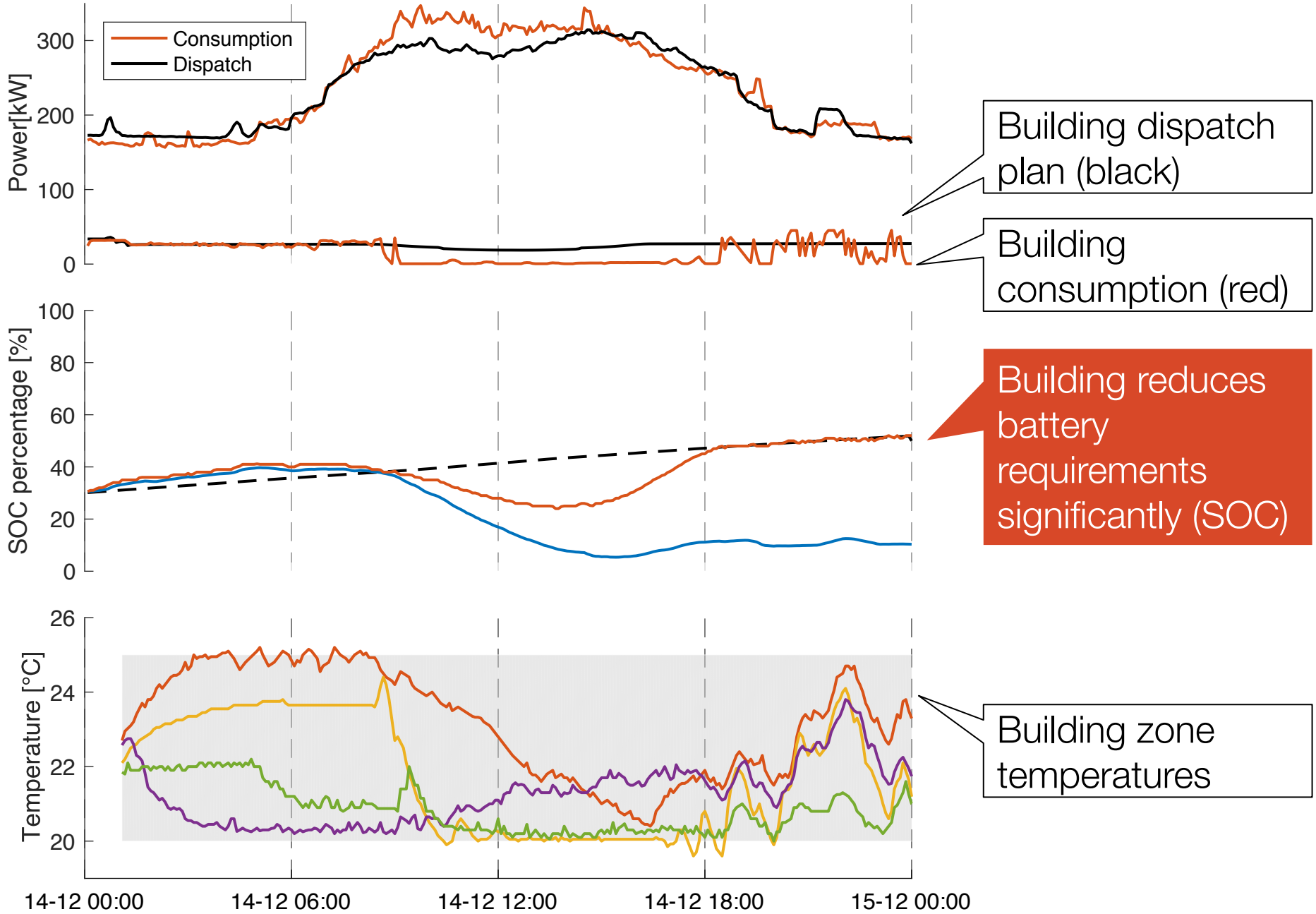
Building reduces battery requirements significantly

Building zone temperatures

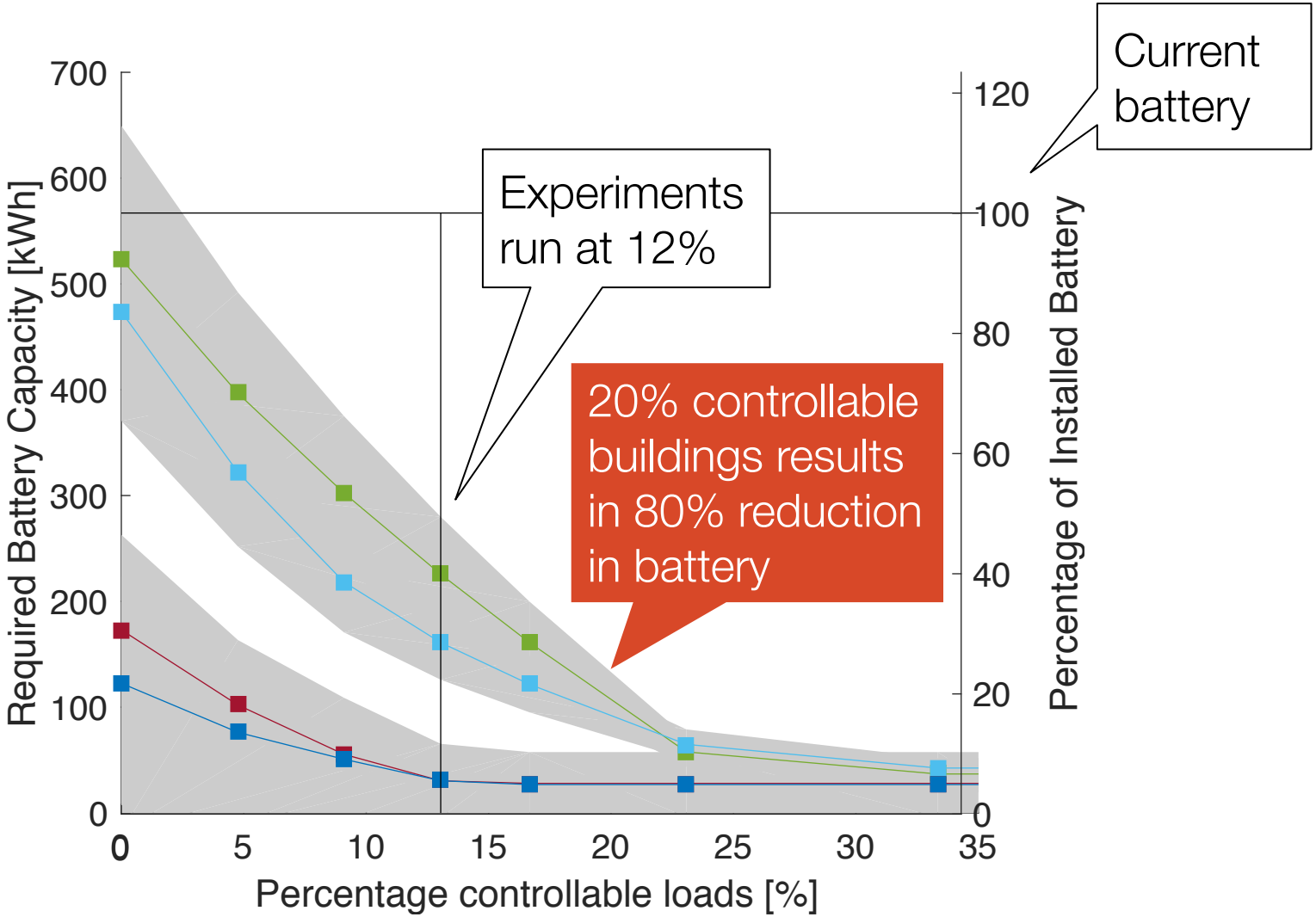
Poor Prediction Day – Battery Only



Poor Prediction Day – Battery & LADR



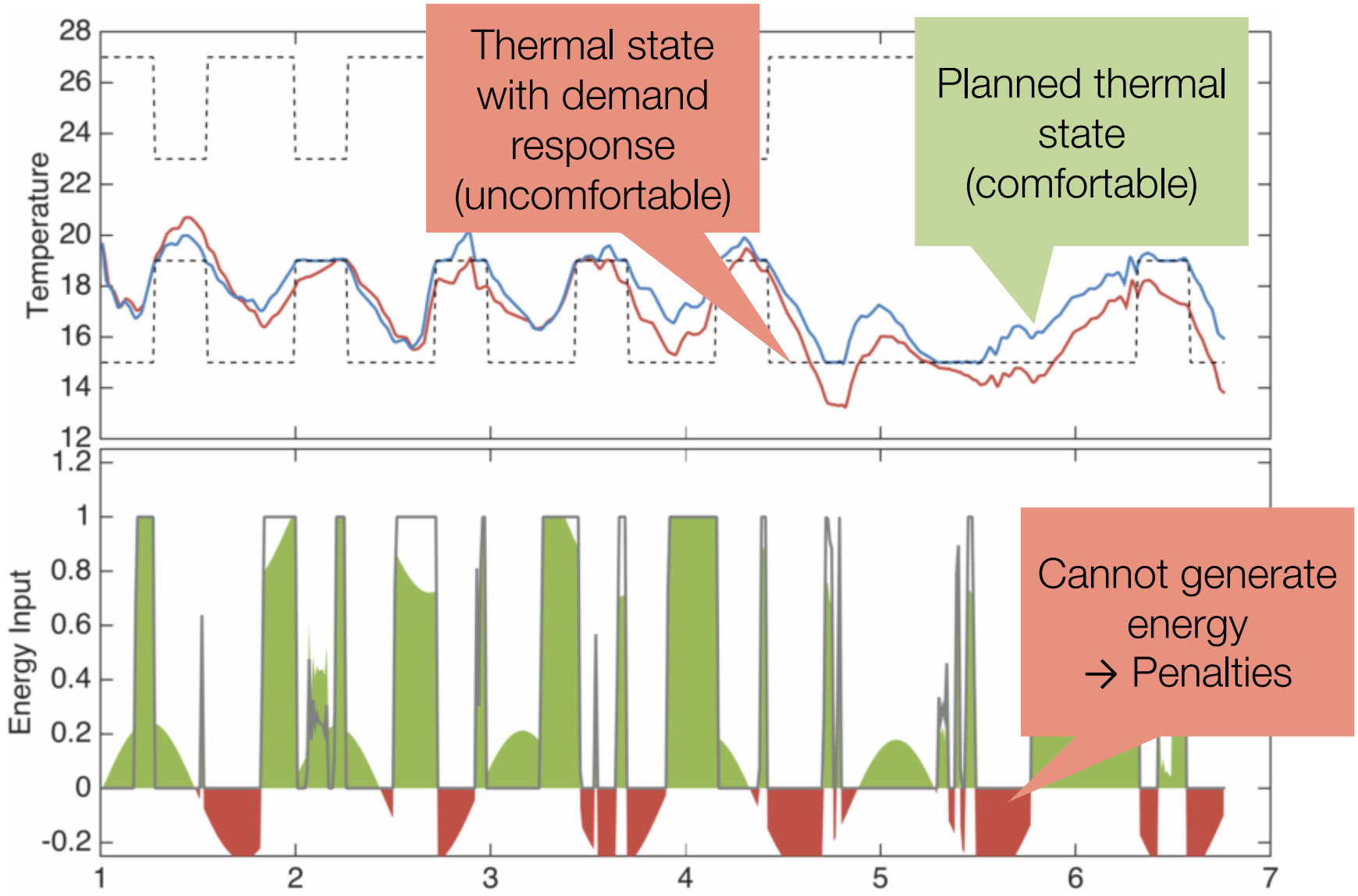
Impact of Building Size – Preliminary Conclusion



Outline

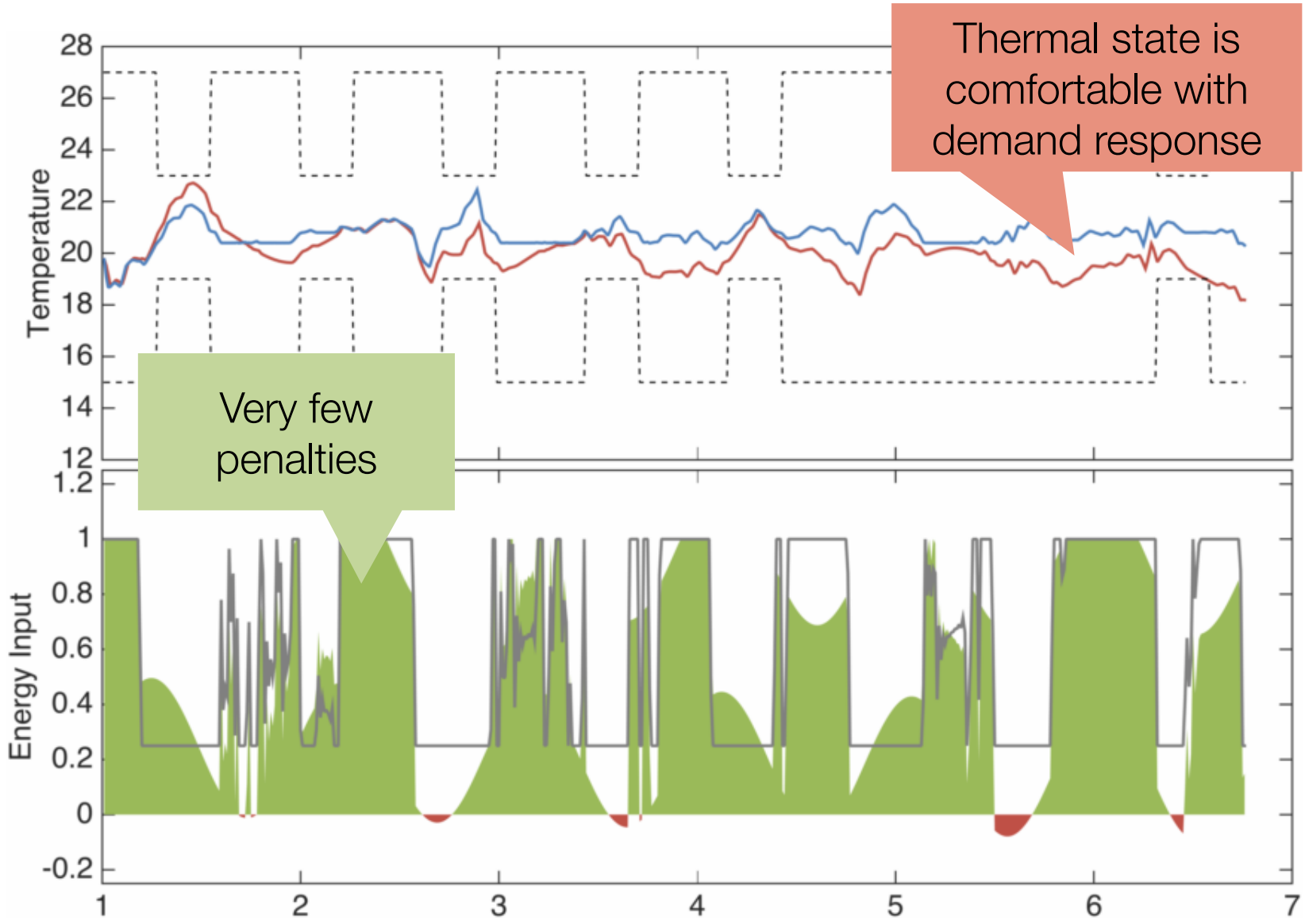
Bidding	What is a bid? How flexible can a building be? Convex solution to the bidding problem
Experiments	Can a demand-response solution be practically deployed?
Economics	Does demand response add value in the current market?

Minimum Cost Control is Bad for Demand Response



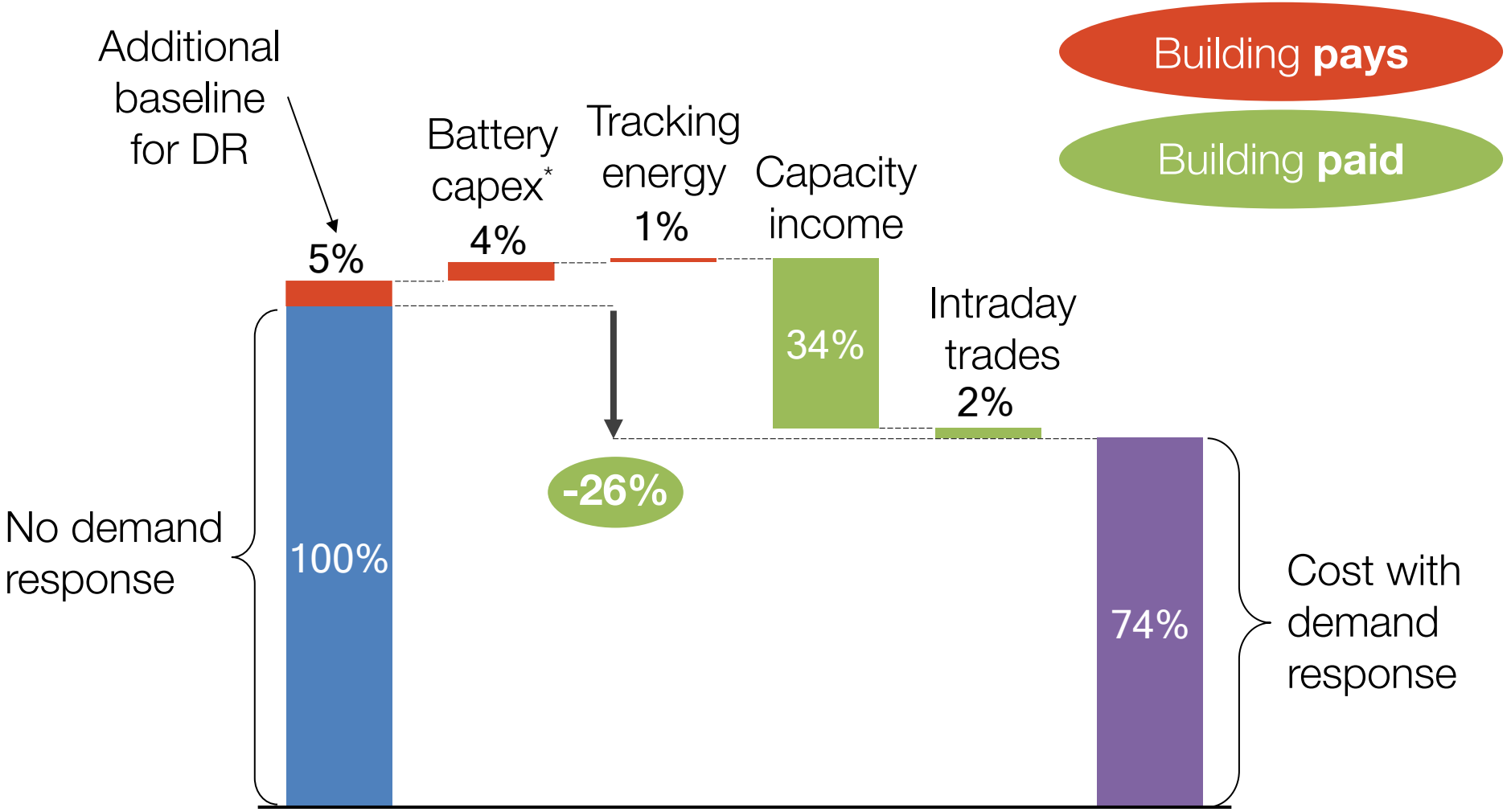
Implication : Demand-response + optimal control = discomfort + penalties

Loads Must Pay to Participate



Implication : A building ***has to pay*** to participate in DR

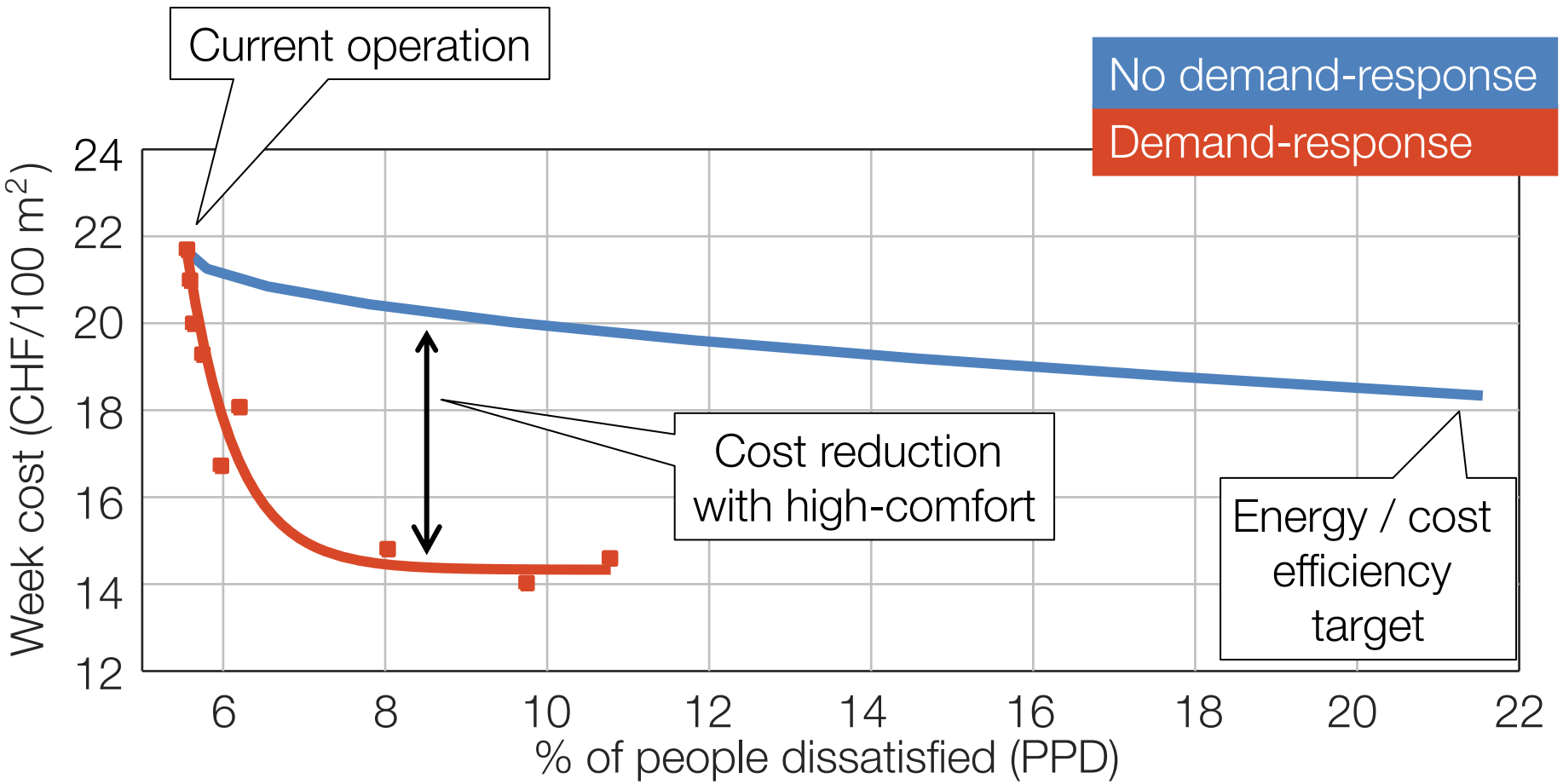
Annual Cost of Building Operation



Result Demand response results in 26% reduction in operating costs

**Assumption : Battery lasts for 5 years*

Demand Response has Strong Comfort Benefits



Result Demand response results in a more comfortable building from increased baselines ***and*** a reduced cost from capacity payments

Conclusion

How can buildings provide fast regulation services?

Requires a mix of devices

	Power	Energy	Speed
Battery	High	Low	Fast
Building	Mid	High	Mid
Intraday	High	High	Slow

Is there a business case in the current Swiss market?

Yes, but comfort considerations play an important role in measuring economic value