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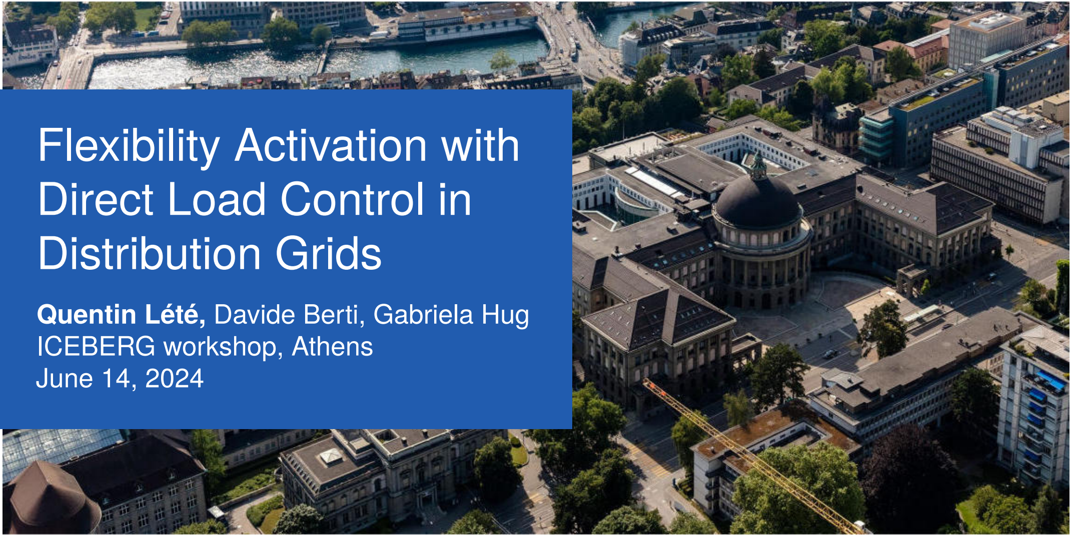


Flexibility Activation with Direct Load Control in Distribution Grids

Quentin Lété, Davide Berti, Gabriela Hug

ICEBERG workshop, Athens

June 14, 2024

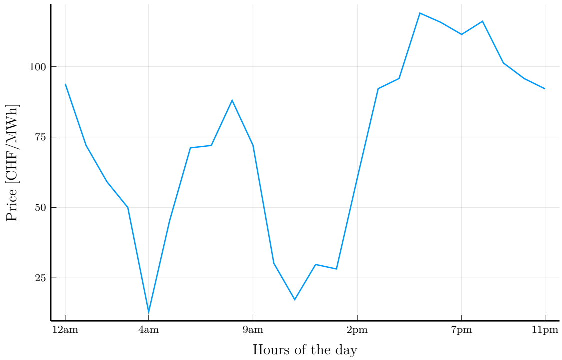
Outline

Flexibility

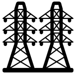
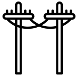
Definition

Ability of the system to react to **variability** in supply and demand.

Variability is increasing



Different types of flexibility

Scope / Time scale	**Expected** (day-ahead)	**Unexpected** (real-time)
Global 		
Local 		

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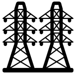
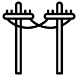
Global 		
Local 		

Different types of flexibility

Time scale / Scope	**Expected** (day-ahead)	**Unexpected** (real-time)
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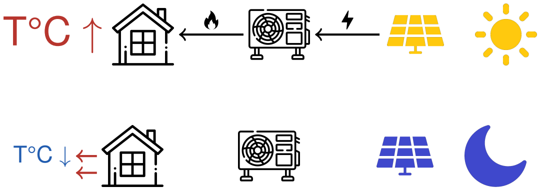
Local		

Controllable load

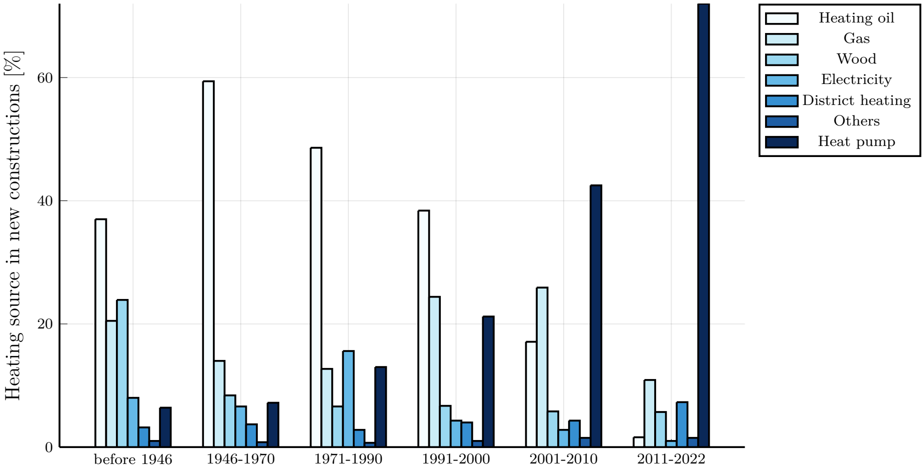
In this talk, focus on:

Heat Pumps

- Flexibility through thermal inertia
- Similar to a battery, without discharging



Increasing installation of heat pumps



Source: FSO – Buildings and dwellings statistics

Demand Response approaches

Smart tariffs

Local markets

Direct load control

In this talk

Smart tariffs | **Local markets** | **Direct load control**

Design

Direct load control

Design

Direct load control

- How to compensate users for controlling them?

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- How to incentivize consumers to reveal their key information to **DSO**?

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Direct load control

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- How to incentivize consumers to participate?

Design

Direct load control

- How to compensate users for controlling them?
- How to incentivize consumers to reveal their key information to **DSO**?
- How to incentivize consumers to participate?

→ Mechanism design

Existing literature

Priority Service Pricing

- Chao & Wilson (1987)

Existing literature

Priority Service Pricing

- Chao & Wilson (1987)

Reliability (%)	Price (€/MWh)
21.6	0.0
94.2	46
98.2	52.8
99.7	57.3
100.0	58.3

Existing literature

Priority Service Pricing

- Chao & Wilson (1987)

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- Gérard & Papavasiliou (2022)

Existing literature

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Assets with intertemporal constraints

- Power **and energy** constraints matter
- E.g. (battery, shiftable load)

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Assets with intertemporal constraints

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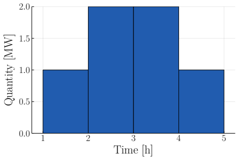
Day-ahead market = combinatorial auction



Existing literature

Multi-Level Demand Subscription

- Chao et al. (1986)

Reliability (%)	Duration (%)	Price (€/MWh)
	33.3	14.9
58.5	66.7	22.9
	100.0	26.4
	33.3	22.1
85.3	66.7	34.1
	100.0	39.3
	33.3	27.3
100	66.7	42.1
	100.0	48.5

- Gérard et al. (2022)

In this work

- Can we do better if we focus on Heat Pumps?

Outline

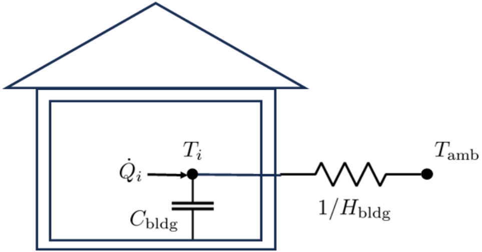
Menu design

Wholesale market

- Multi-part bids
  - Piecewise linear cost curve
  - No-load/Startup offer
  - Ramp rate
  - Min up and down time

Direct control mechanism

- Linear model of HP control (RC dynamics)



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$$C_{\text{bldg}}(T_j - T_{j-1}) = -H_{\text{bldg}}(T_j - T_{\text{amb}}) + q_j$$

Menu design

Wholesale market

- Multi-part bids
  - Piecewise linear cost curve
  - No-load/Startup offer
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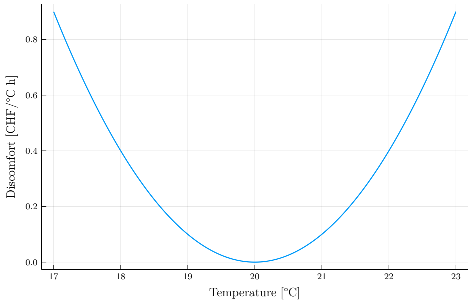
  - Min up and down time

Direct control mechanism

- Quadratic temperature discomfort



$$\text{Discomfort } = V_{\text{discom}}(T - \bar{T})^2$$

Menu design

Wholesale market

- Multi-part bids
  - Piecewise linear cost curve
  - No-load/Startup offer
  - Ramp rate
  - Min up and down time

Direct control mechanism

- Illustrative menu

H_{bldg} [kW/K]	C_{bldg} [kWh/K]	V_{discom} [CHF/K^2]	Compensation [CHF/day]
0.24	31.5	0.1	1.5
1.71	83.8	0.05	3.6
2.14	174.3	0.15	2.2

Menu design

How can user know how they will be activated?
$\rightarrow$ Use **price information**

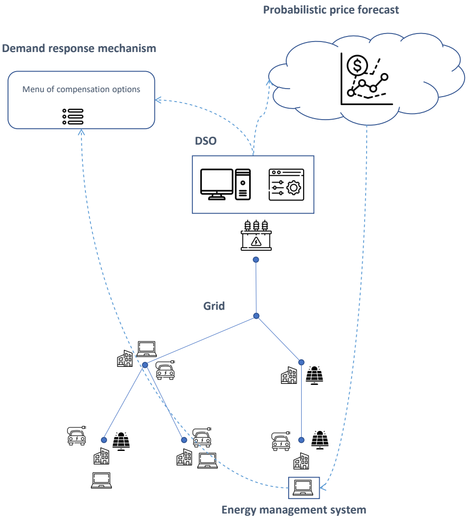
Wholesale market

- Used extensively by traders (Cramton et al. 2006)

Direct control mechanism

- The DSO publishes a forecast available for every participant

Direct load control mechanism



DSO activation problem

Objective

- Minimize procurement cost on wholesale market
- While controlling the heat pumps

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For each consumer who selected option with parameters $H_{\text{bldg}}, C_{\text{bldg}}, V_{\text{discom}}$:

DSO activation problem

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For each consumer who selected option with parameters $H_{\text{bldg}}, C_{\text{bldg}}, V_{\text{discom}}$:

$$\begin{aligned} \min \quad & \text{Procurement cost } + \text{Discomfort cost}(V_{\text{discom}}) \\ \text{s.t.} \quad & \text{Technical constraints of heat pump}(H_{\text{bldg}}, C_{\text{bldg}}) \end{aligned}$$

DSO activation problem

Objective

- Minimize procurement cost on wholesale market
- While controlling the heat pumps

For each consumer who selected option with parameters $H_{\text{bldg}}, C_{\text{bldg}}, V_{\text{discom}}$:

$$\min_{q_j, T_j} \sum_{j \in \mathcal{J}} \rho_j q_j + V_{\text{discom}} (T_j - \bar{T})^2 \tag{1}$$

$$\text{s.t. } C_{\text{bldg}} (T_j - T_{j-1}) = -H_{\text{bldg}} (T_j - T_{\text{amb}}) + q_j \tag{2}$$

Consumer decision problem

Objective

- Select its preferred menu option
- While minimize its cost, facing the **retail price**

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Key idea

Thanks to the price forecast, the consumer knows how they will be activated when selecting a certain option.

Consumer decision problem

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- Select its preferred menu option
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Key idea

Thanks to the price forecast, the consumer knows how they will be activated when selecting a certain option.

$$\min_{H_{\text{bldg}}, C_{\text{bldg}}, V_{\text{discom}}, \gamma \in \mathcal{M}} \mathcal{O}_m(H_{\text{bldg}}, C_{\text{bldg}}, \gamma) \equiv \sum_{j \in \mathcal{J}} \bar{\rho} q_j^*(H_{\text{bldg}}, C_{\text{bldg}}) + V_{\text{discom}}(T_j - \bar{T})^2 - \gamma_i$$

$$\text{s.t. } C_{\text{bldg}}(T_j - T_{j-1}) = -H_{\text{bldg}}(T_j - T_{\text{amb}}) + q_j^*(H_{\text{bldg}}, C_{\text{bldg}})$$

Compensation computation

How to compute optimal compensations γ?

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Objective

- Minimize DSO payement to conusmers, such that:
- Incentive to reveal their true preferences; and
- Incentive to participate.

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Interpretation

- The first constraint is the **incentive compatibility** constraint.
- The second constraint is the **individual rationality** constraint.

Compensation computation

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Interpretation

- The first constraint is the **incentive compatibility** constraint.
- The second constraint is the **individual rationality** constraint.

Key question

Is it always possible?

Counterfactual

We assume that the DSO price at average cost:

$$\bar{\rho} = \frac{\sum_{i \in \mathcal{I}, j \in \mathcal{J}} \rho_j q_{ij}}{\sum_{i \in \mathcal{I}, j \in \mathcal{J}} q_{ij}}$$

This implies that users have a tiny interest in reacting to the price if they do not participate.

Truthful implementation

Theorem

If the retail price is equal to the average price, then the direct control mechanism is truthfully implementable.

Proof.

The social choice function is ex post efficient. □

Outline

Simple example with three consumers

Building characteristics

Building 1:

$$C_{\text{bldg}} = 9.4 \text{ kWh/K}$$
$$H_{\text{bldg}} = 0.1 \text{ kW/K}$$

Building 2:

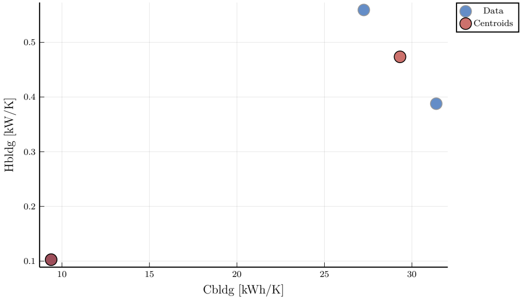
$$C_{\text{bldg}} = 31.4 \text{ kWh/K}$$
$$H_{\text{bldg}} = 0.4 \text{ kW/K}$$

Building 3:

$$C_{\text{bldg}} = 27.2 \text{ kWh/K}$$
$$H_{\text{bldg}} = 0.6 \text{ kW/K}$$

Menu design

Clustering

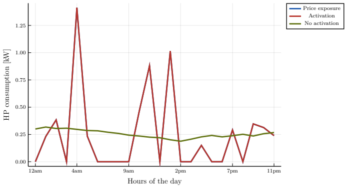


Menu

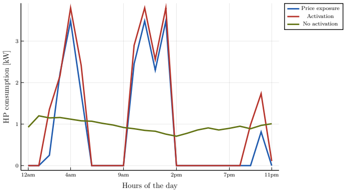
H_{bldg} [kW/K]	C_{bldg} [kWh/K]	V_{discom} [CHF/K^2]	Compensation [CHF/day]
0.47	29.3	0.1	0.0
0.1	9.4	0.1	0.0

Impact of activation

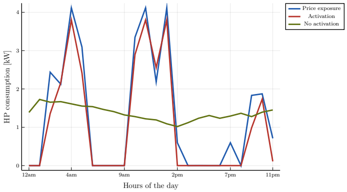
Building 1



Building 2



Building 3



Results

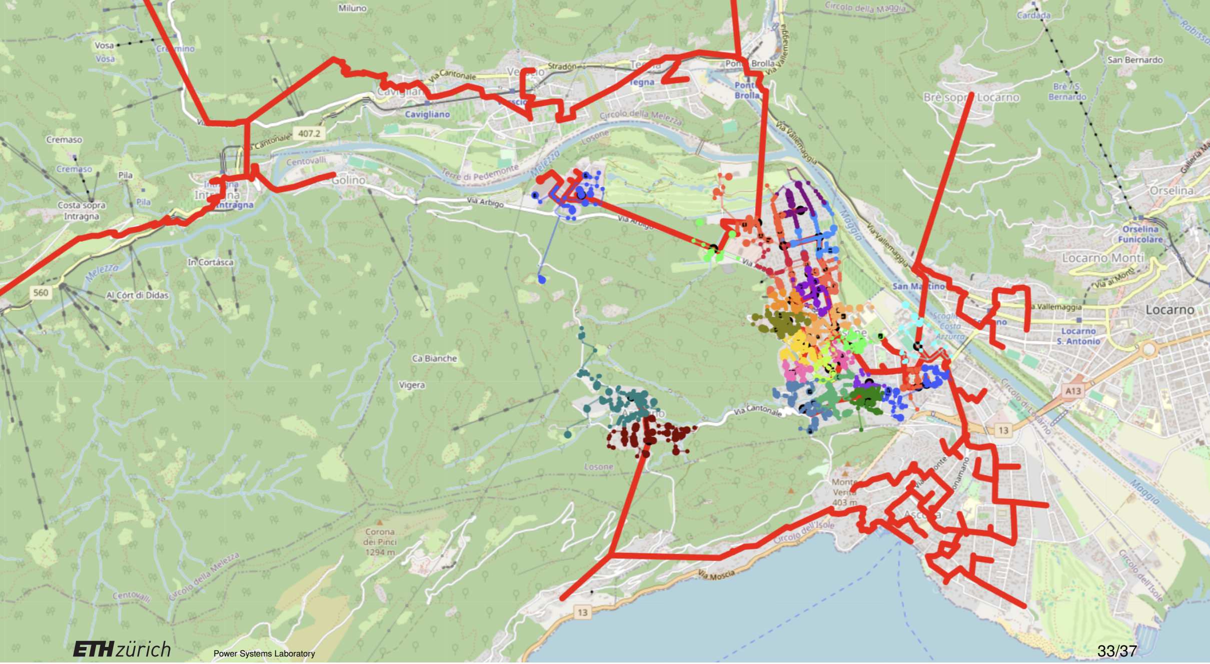
Efficiency

	Bldg 1	Bldg 2	Bldg 3	Total
Min. cost [CHF/day]	0.32	0.84	1.61	2.77
Cost with activation [CHF/day]	0.34	1.58	1.73	3.65
Cost without activation [CHF/day]	0.44	1.64	2.37	4.45
Max. cost reduction [%]				37.8
Cost reduction achieved [%]				18
Payment with activation [CHF/day]	0.3	1.63	1.62	
Payment without activation [CHF/day]	0.44	1.65	2.37	

Outline

Case study overview

- Goal: Apply the mechanism on realastic data from a Swiss municipality (Losone).
- Assumptions and parameters:
  - The DSO has statistical knowledge of the approximate parameters (H,C,V) in its control area.
  - 2409 buildings, 351 with heat pump.
  - 130 MV nodes, 1569 LV nodes
  - 5 selected days across winter with different characteristics (price and temperature).



Miluno
Vosa
Cremaso
Pila
Costa sopra Intragna
Intragna
Cavigliano
Tegna
Ponte Brolla
Circolo della Maggia
Cardada
San Bernardo
Brè sopra Locarno
Orselina
Locarno Monti
Locarno
Locarno S. Antonio
San Martino
Golino
Via Arbigo
Circolo della Melezza
Centovalli
In Cortàsca
Al Cört di Didas
Ca Bianche
Vigera
Losone
Via Cantonale
Monte Verità 403 m
Ascona
Circolo dell'Isole
Via Moscia
Corona dei Pinci 1294 m
Maggia
A13
13
560
407.2

Efficiency

With low congestion

(2023/2024)	Day 1 19.11	Day 2 31.12	Day 3 08.01	Day 4 20.01	Day 5 05.03
Min. Cost [CHF/day]	517.3	177.9	1595.9	1850.9	1161.9
Act. Cost [CHF/day]	622.5	197.5	1632.5	1859.9	1183.2
Base Cost [CHF/day]	904.5	232.0	2074.1	1892.3	1232.0
Max cost reduction [%]	42.8	23.3	23.1	2.2	5.7
Achieved cost reduction [%]	31.2	14.9	21.3	1.7	4.0

Observations

→ The most important driver for efficiency is the price variation, more that the outside temperature.
→ Tends to be less accurate when the temperature is very cold.

Efficiency

With high congestion

(2023/2024)	Day 1 19.11	Day 2 31.12	Day 3 08.01	Day 4 20.01	Day 5 05.03
Min. Cost [CHF/day]	655.1	177.9	1595.9	1974.9	1161.9
Act. Cost [CHF/day]	777.4	197.5	1632.5	3436.1	1188.0
Base Cost [CHF/day]	1195.6	232.0	2074.1	4942.3	1307.9
Max cost reduction [%]	45.2	23.3	60.0	2.2	11.2
Achieved cost reduction [%]	35.0	14.9	30.5	1.7	9.4

Observations

→ Large efficiency increase when the grid is congested in some instances.

Outline

Discussion

Key messages

- Important drivers of efficiency are price variability and network congestion.

$\rightarrow$ Both expected to increase in the future.

- Important challenge is with consumers engagement in view of low consumers benefit.

$\rightarrow$ Participation bonus can easily be integrated endogenously in this setting.

Future research

- Efficiency losses with the nonlinear building dynamics.
- Multi-market participation from DSO.

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Thank you

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