Energy flexibility in residential buildings:

Thermal mass and PV + battery systems

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Oct 12, 2018

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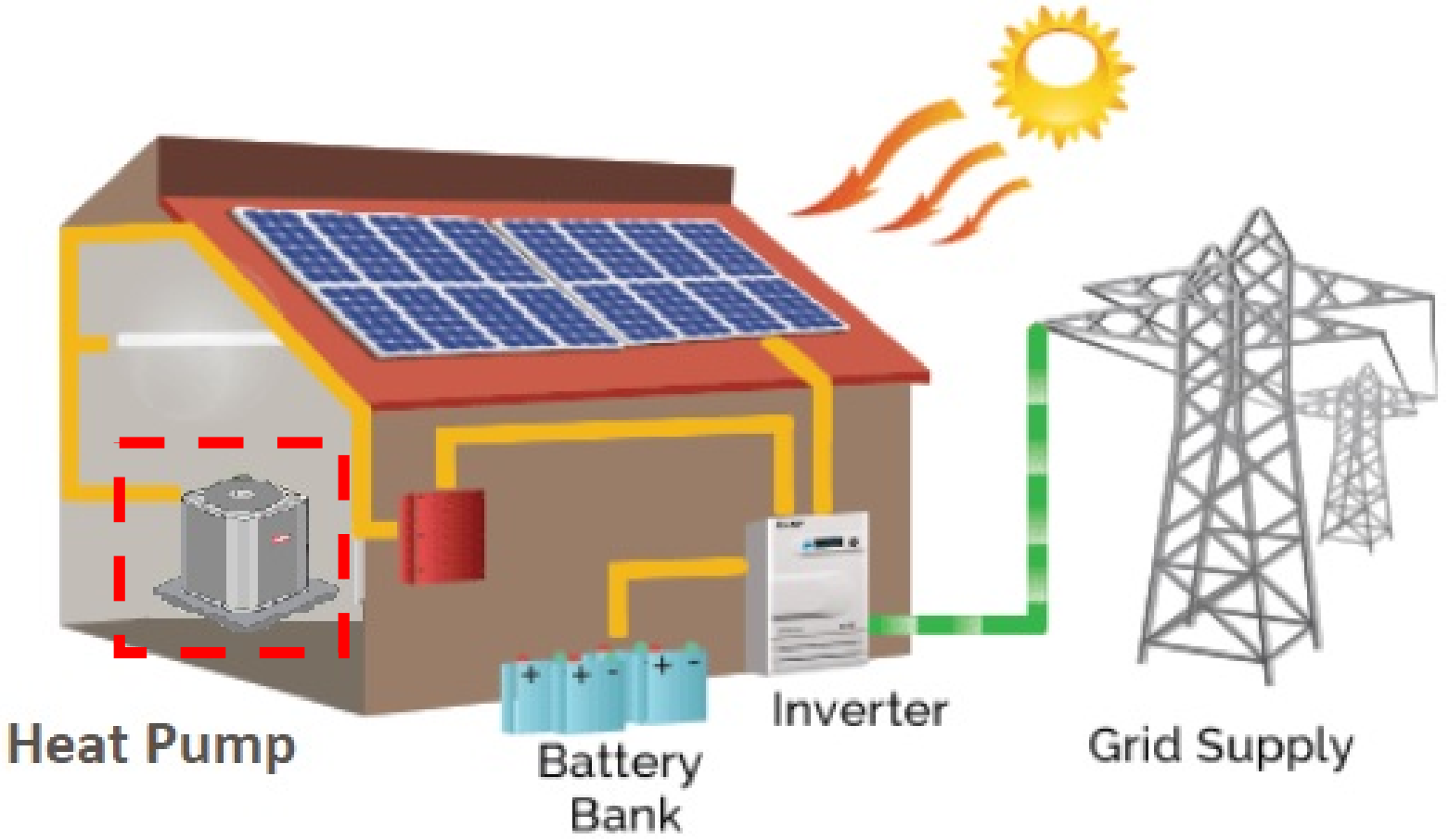
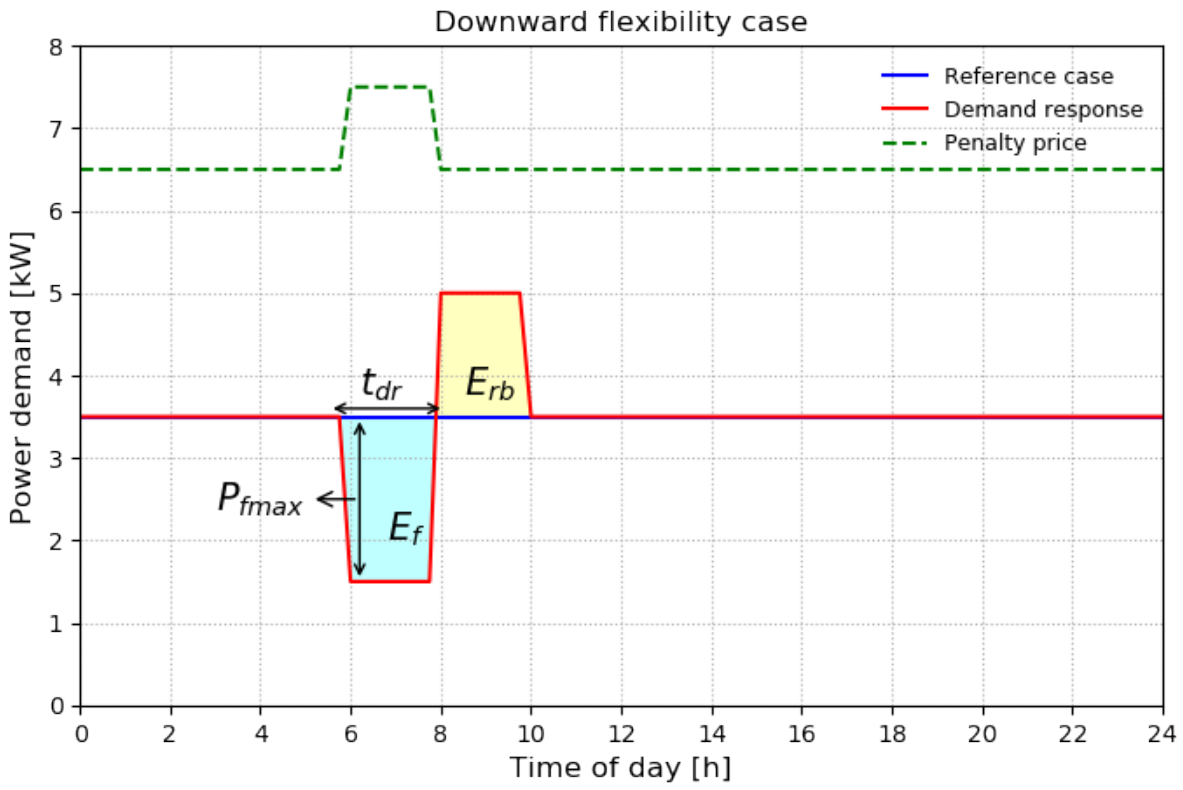
Context: building energy flexibility

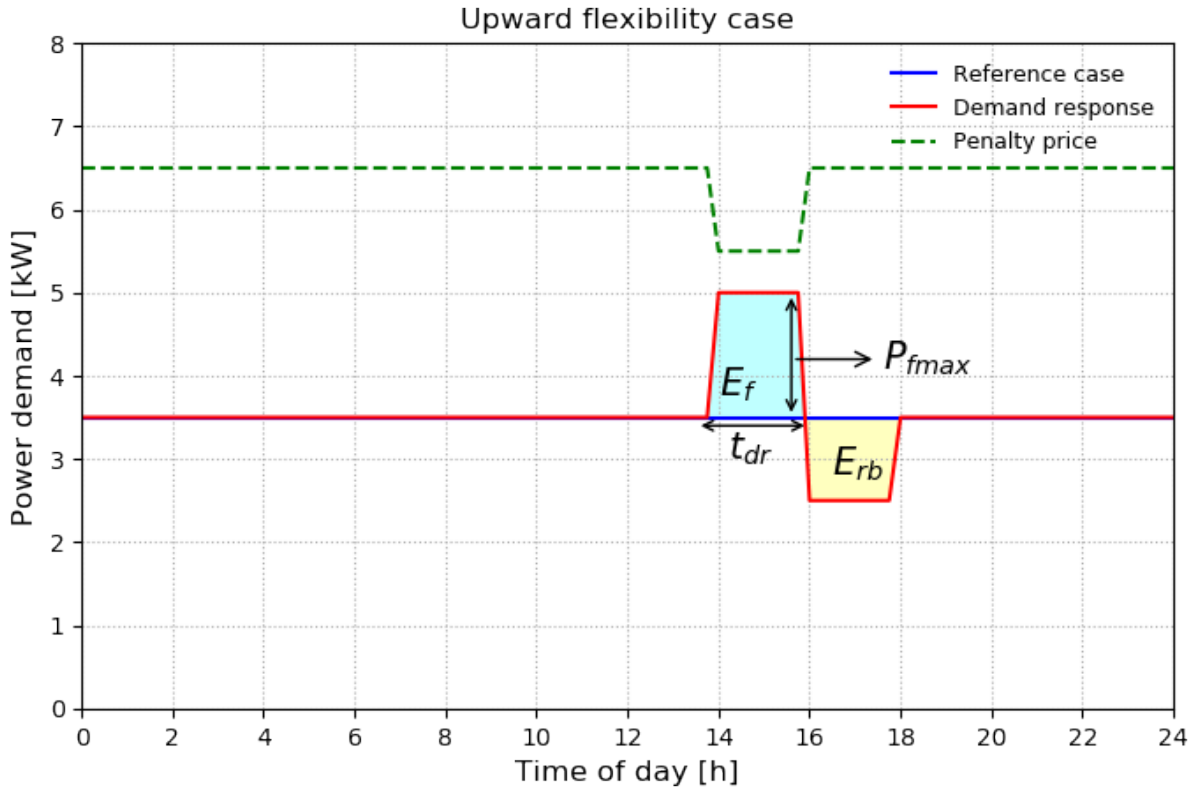


Energy flexibility cases

- Downward flexibility



- Upward flexibility



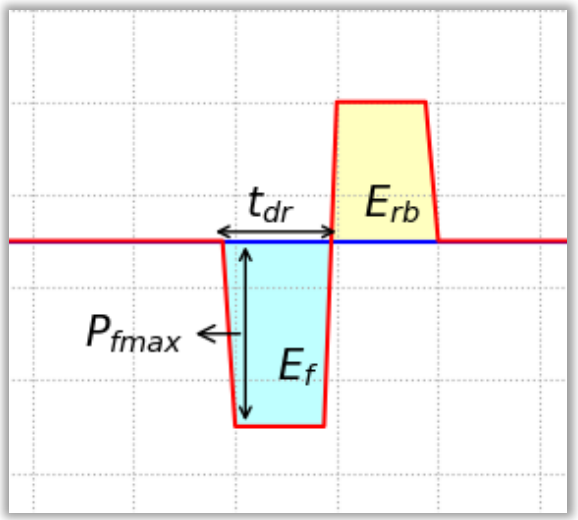
Energy flexibility: Key Performance Indicators (KPIs)

- Flexible energy $\boldsymbol{E_f}$

$$E_f = \int_0^{t_{dr}} (P_{dr} - P_{ref})dt$$

- Rebound energy $\boldsymbol{E_{rb}}$

$$E_{rb} = \int_{t_{dr}}^{t_\infty} (P_{dr} - P_{ref})dt$$



- Flexible energy efficiency $\boldsymbol{\eta}$

$$\eta = \left|\frac{E_f}{E_{rb}}\right|$$

- Maximum flexible power $\boldsymbol{P_{fmax}}$

$$P_{fmax} = \begin{cases} \max\limits_{t_{dr}} (P_{ref} - P_{dr}) \\ \max\limits_{t_{dr}} (P_{dr} - P_{ref}) \end{cases} \text{ for } \begin{matrix} \text{downward} \\ \text{upward} \end{matrix}$$

Case study: typical Canadian home

- Canadian Centre for Housing Technologies (CCHT) houses
  - Twin houses
  - 3 stories (basement, main and sleeping floor)
  - Wood frame structure with brick facing

- Space heating system
  - Electric resistance heating

The CCHT twin houses

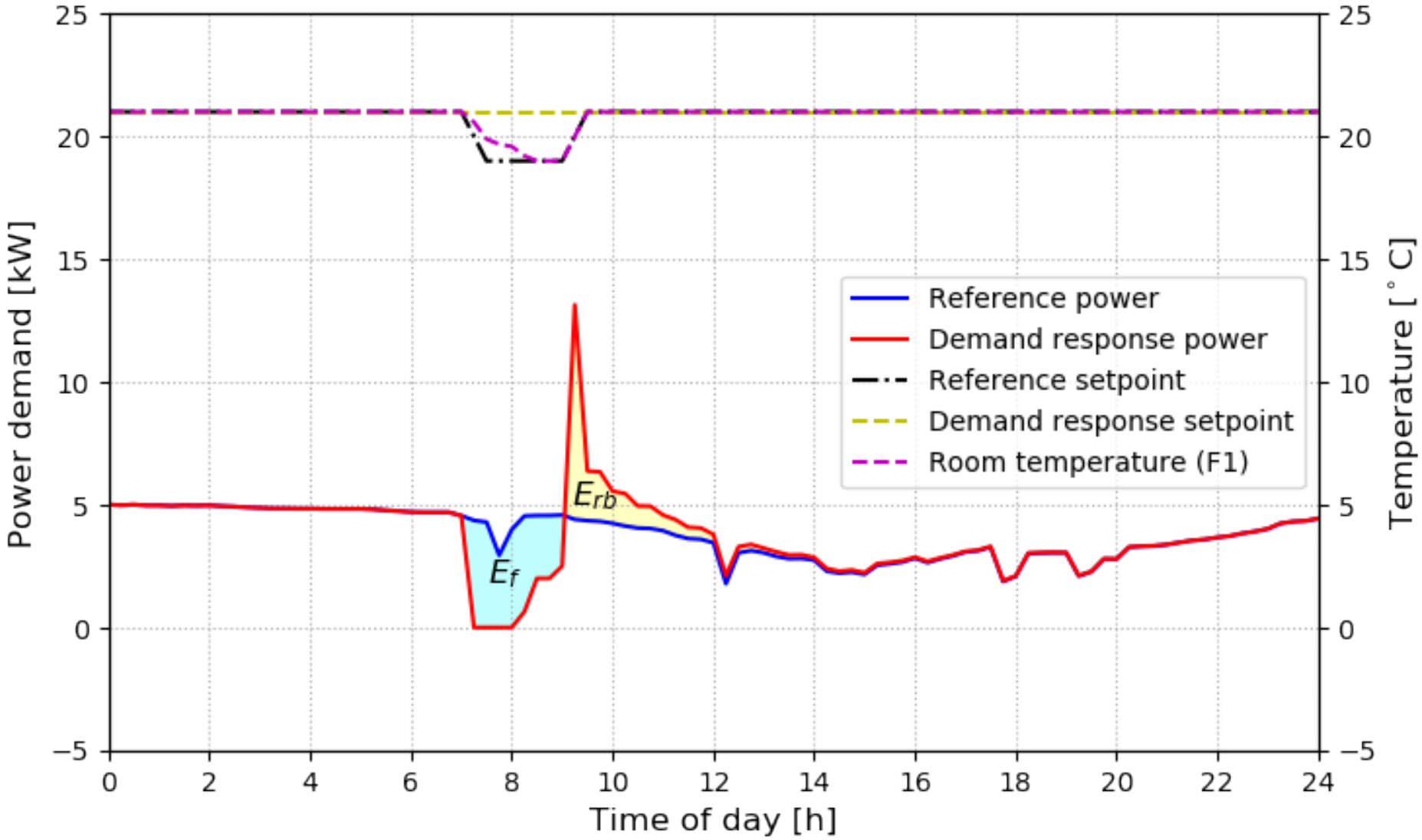
Application: space heating system

- Reference operation: constant setpoint 21 °C

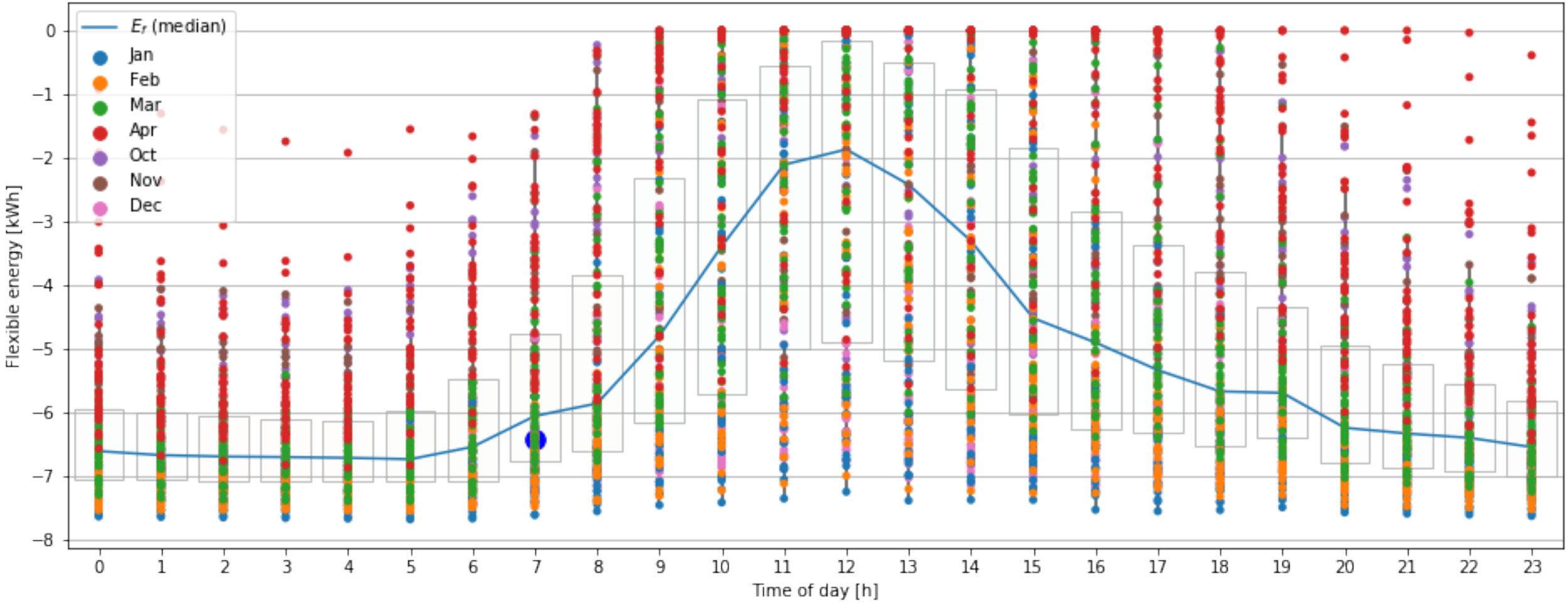
- Reactive control
  - Penalty aware thermostat: $\pm$ 2°C
  - Demand Response (DR) duration t_{dr} = 2 hours
  - DR event: every hour
    - Heating season: October 15th ~ April 29th (4704 hours)
    - 4704 simulations for each case

- Predictive control

Reactive control: one downward event

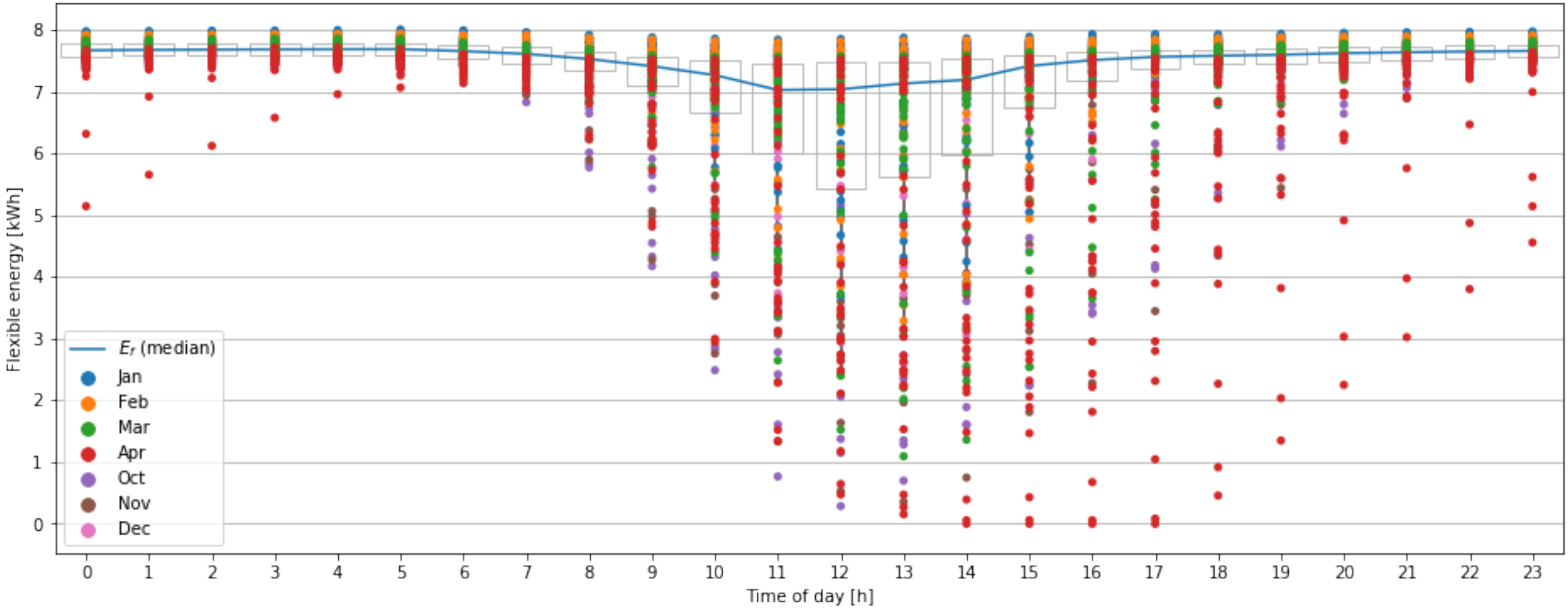


Reactive control: whole heating season



Downward flexibility

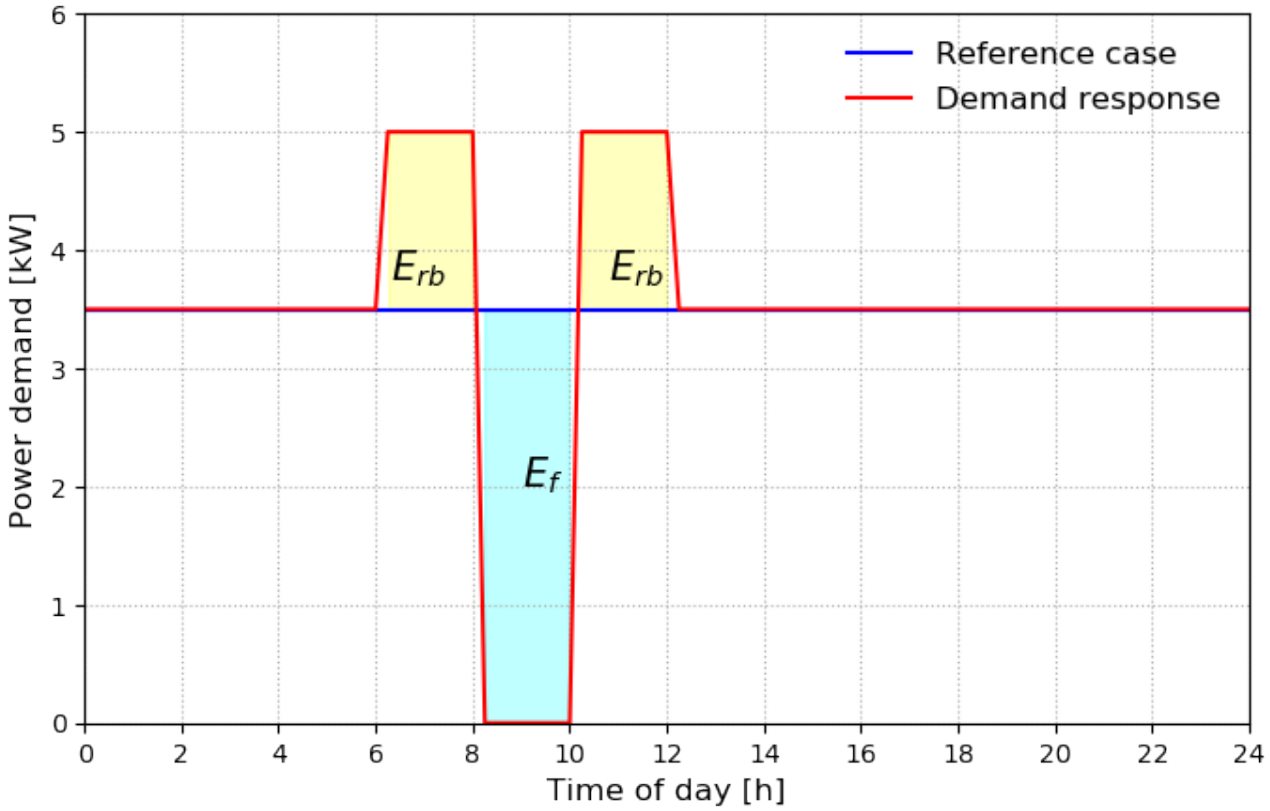
Reactive control: upward flexibility



Upward flexibility

Predictive control: KPI adaptation

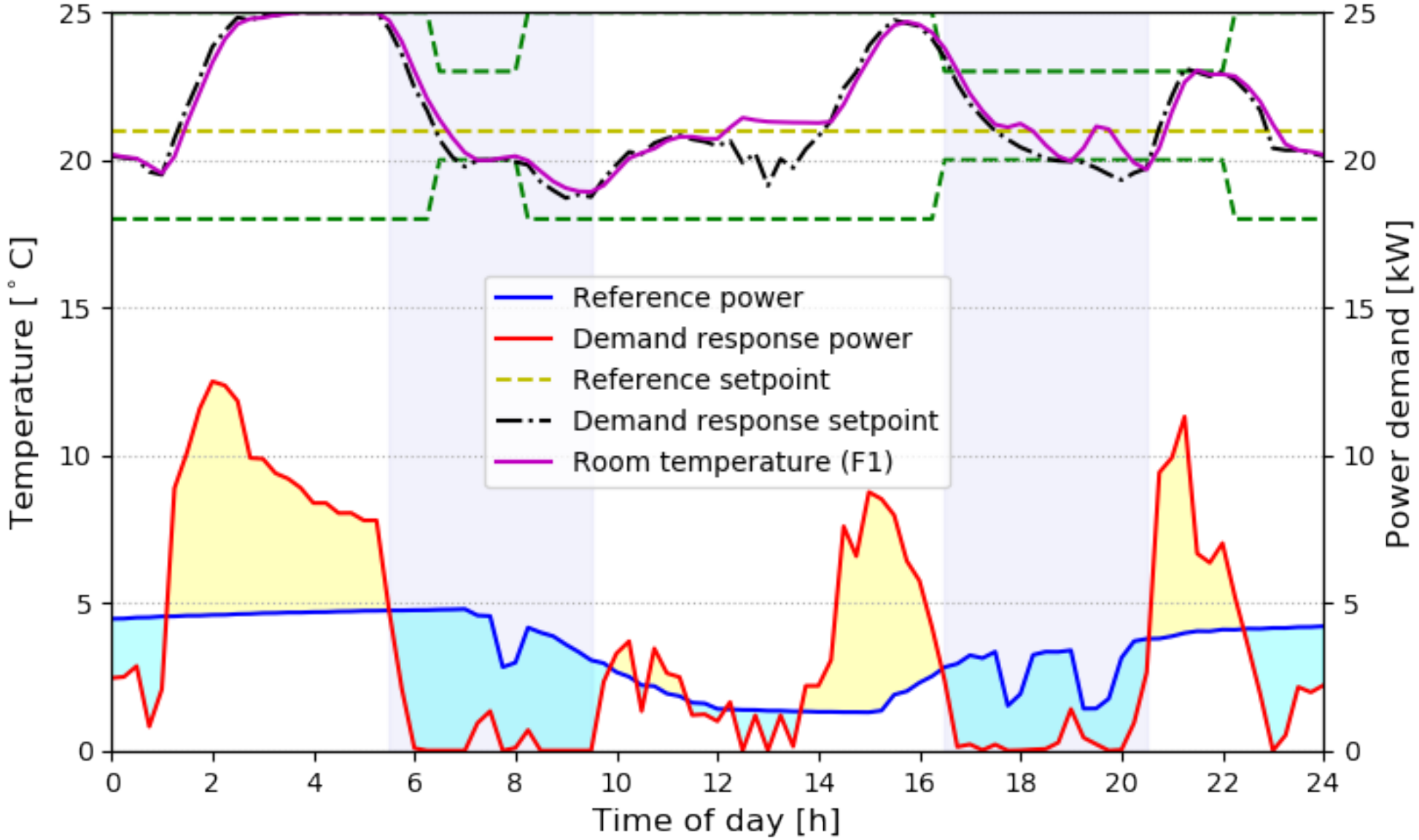
- Anticipation effect



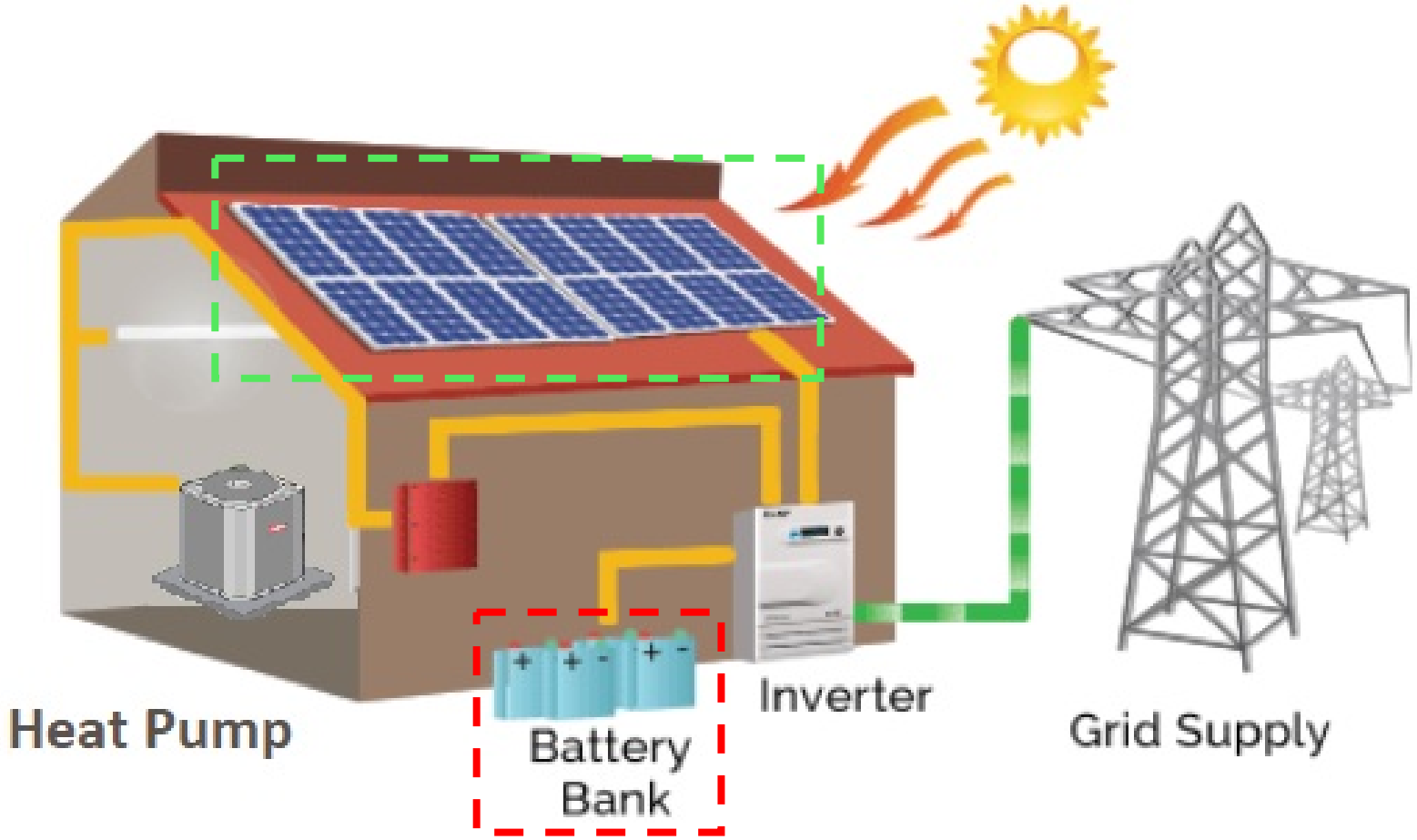
Downward flexibility

$$E_{rb} = \int_{t_{dr}}^{t_\infty} (P_{dr} - P_{ref})dt + \int_{t_{-\infty}}^{t_{dr}} (\boldsymbol{P_{dr}} - \boldsymbol{P_{ref}})\boldsymbol{dt}$$

Predictive control: two consecutive events (downward)

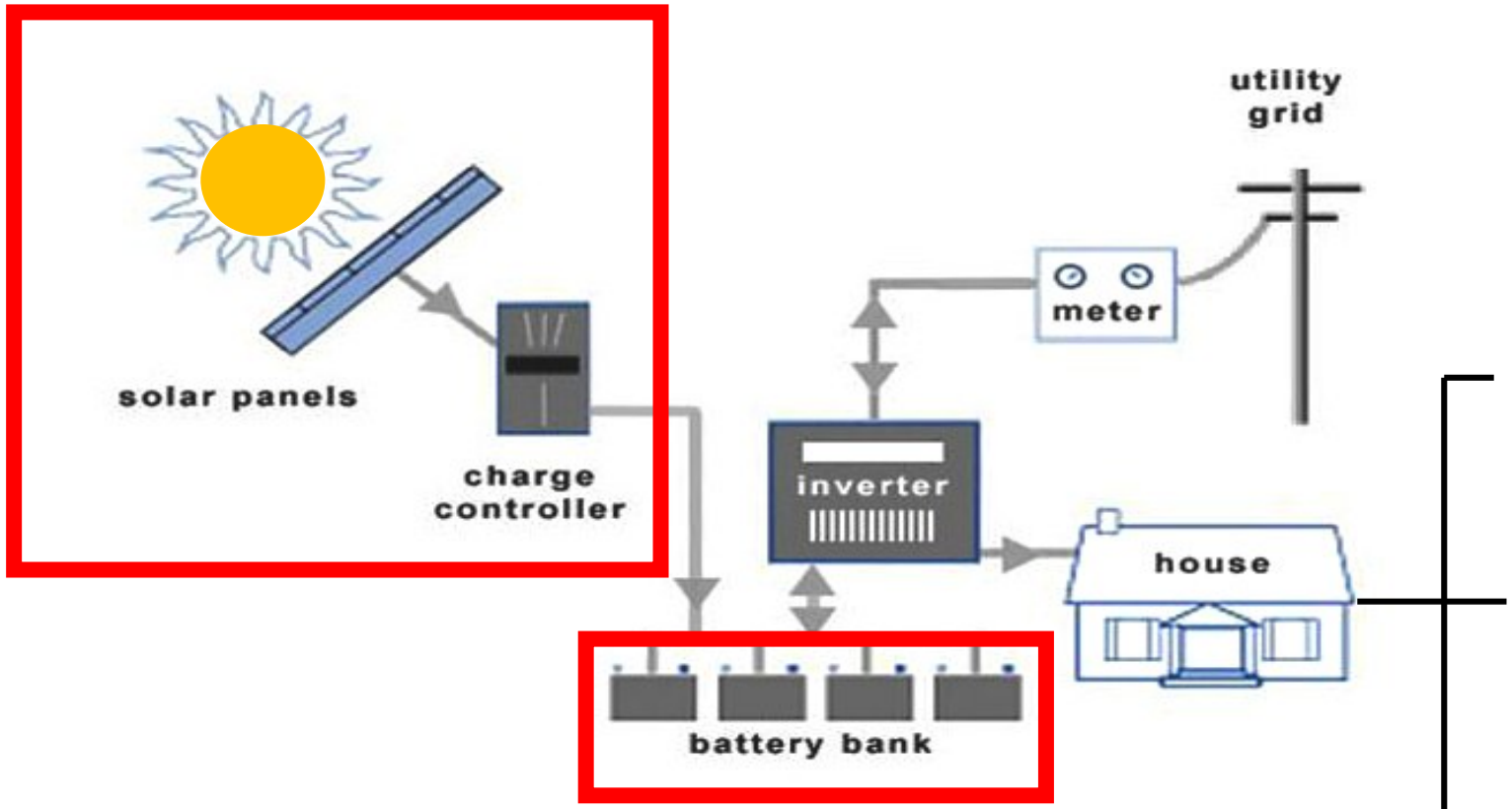


PV + battery for energy flexibility



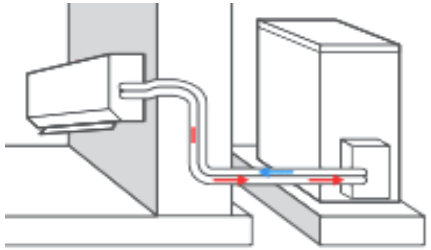
Icons from Noun Project

Grid-tied Solar Power System



Non-HVAC

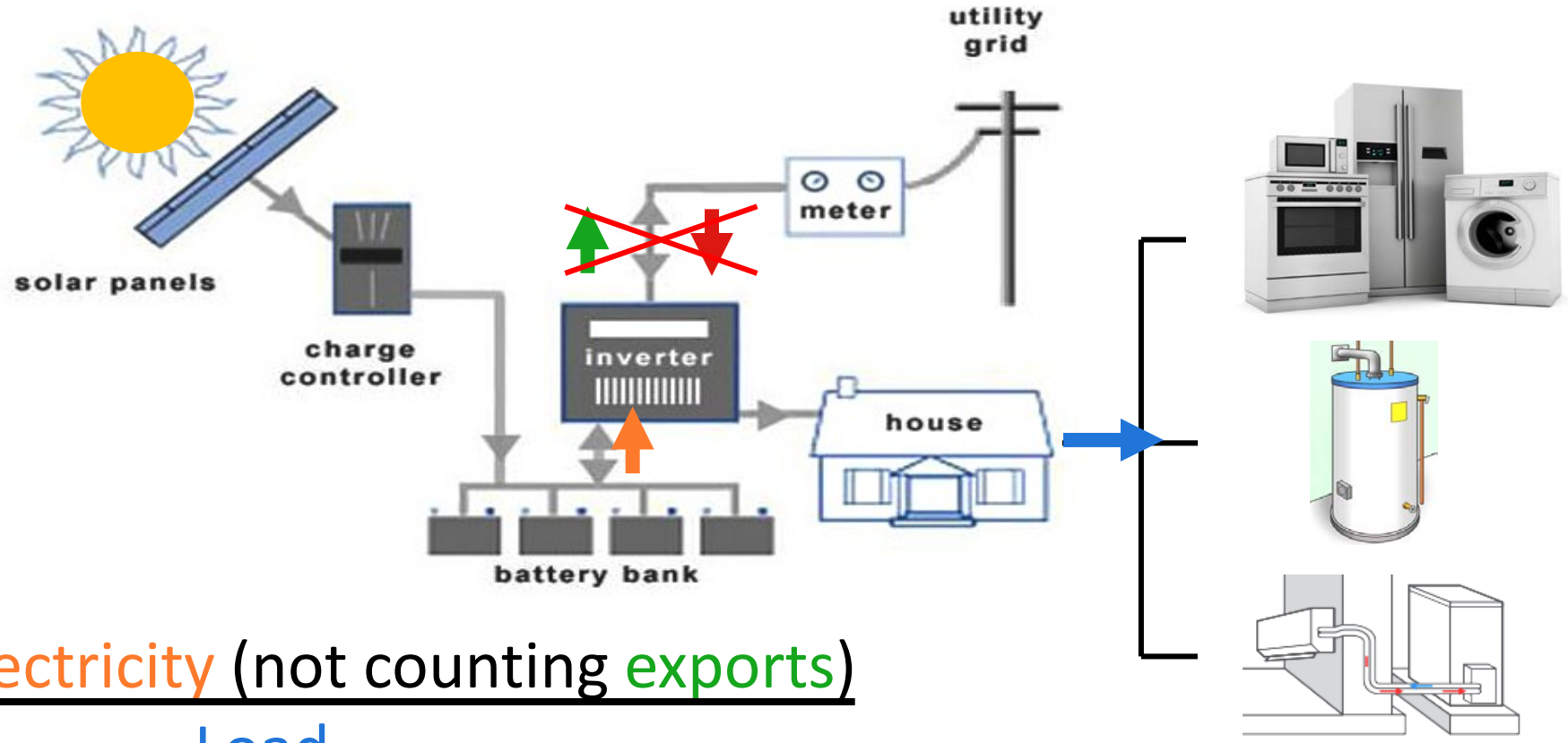
Hot water



HVAC

Yearly KPIs

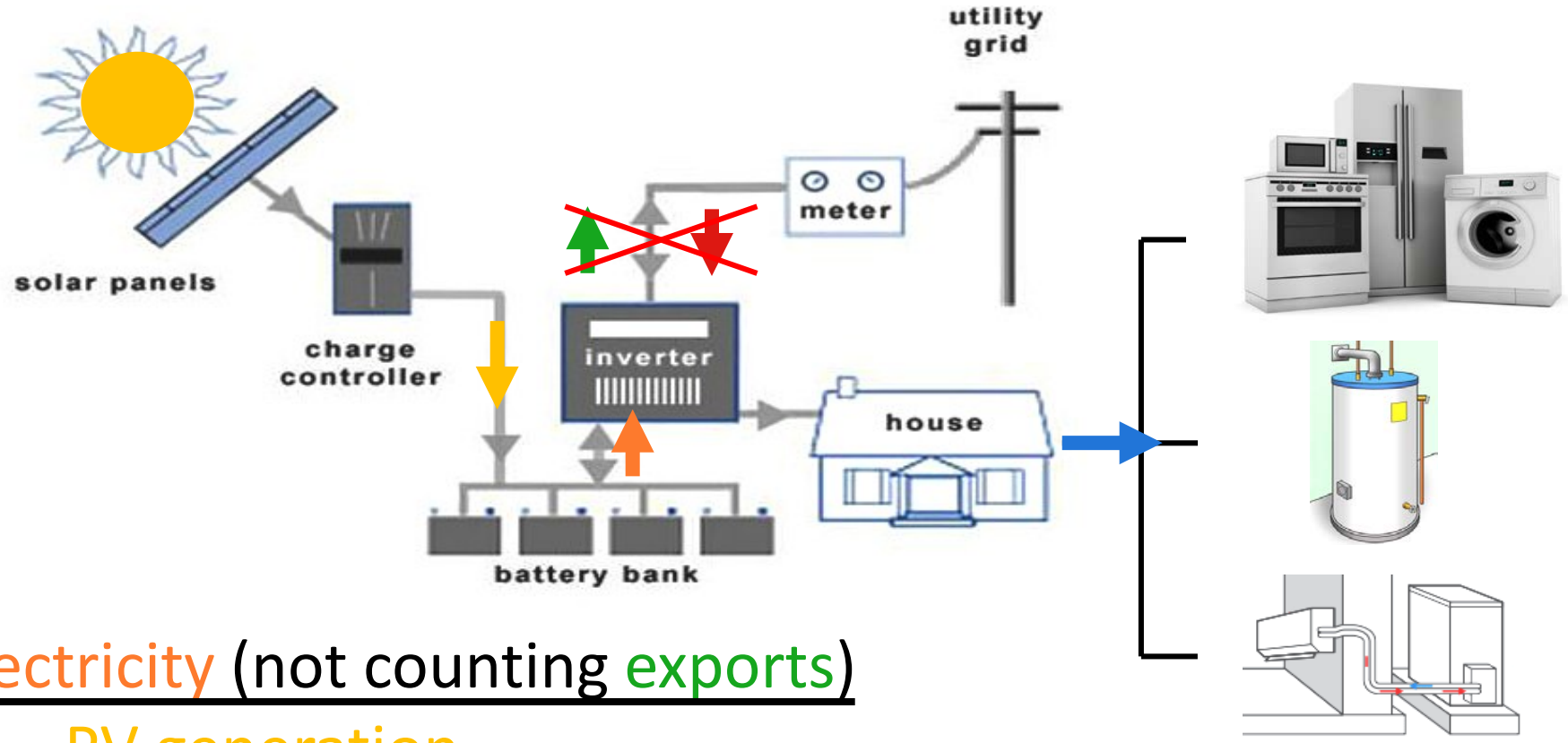
Self-generation = Share of the load met by PV + battery system



$$\frac{\text{Net solar electricity (not counting exports)}}{\text{Load}}$$

Yearly KPIs

Self-consumption = Share of PV system output for accommodating the load



$$\frac{\text{Net solar electricity (not counting exports)}}{\text{PV generation}}$$

Case study

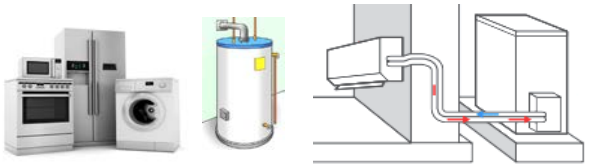
PV size :

- 8.1 kW
- 12.2 kW
- 16.2 kW

Battery capacity:

- 30.1 kWh
- 61.2 kWh
- 122.4 kWh

Electrical load:

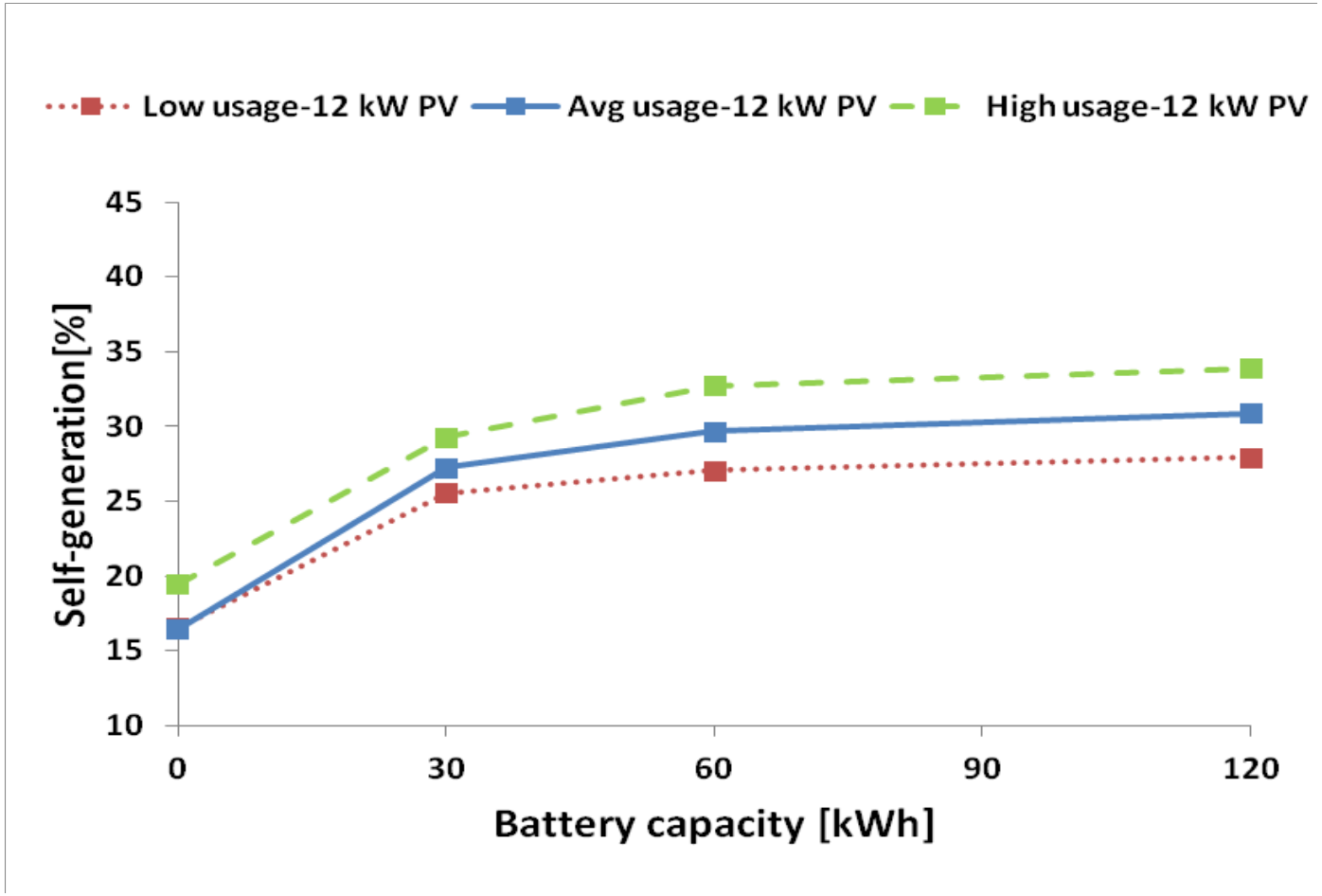


- 70-90 kWh/Day

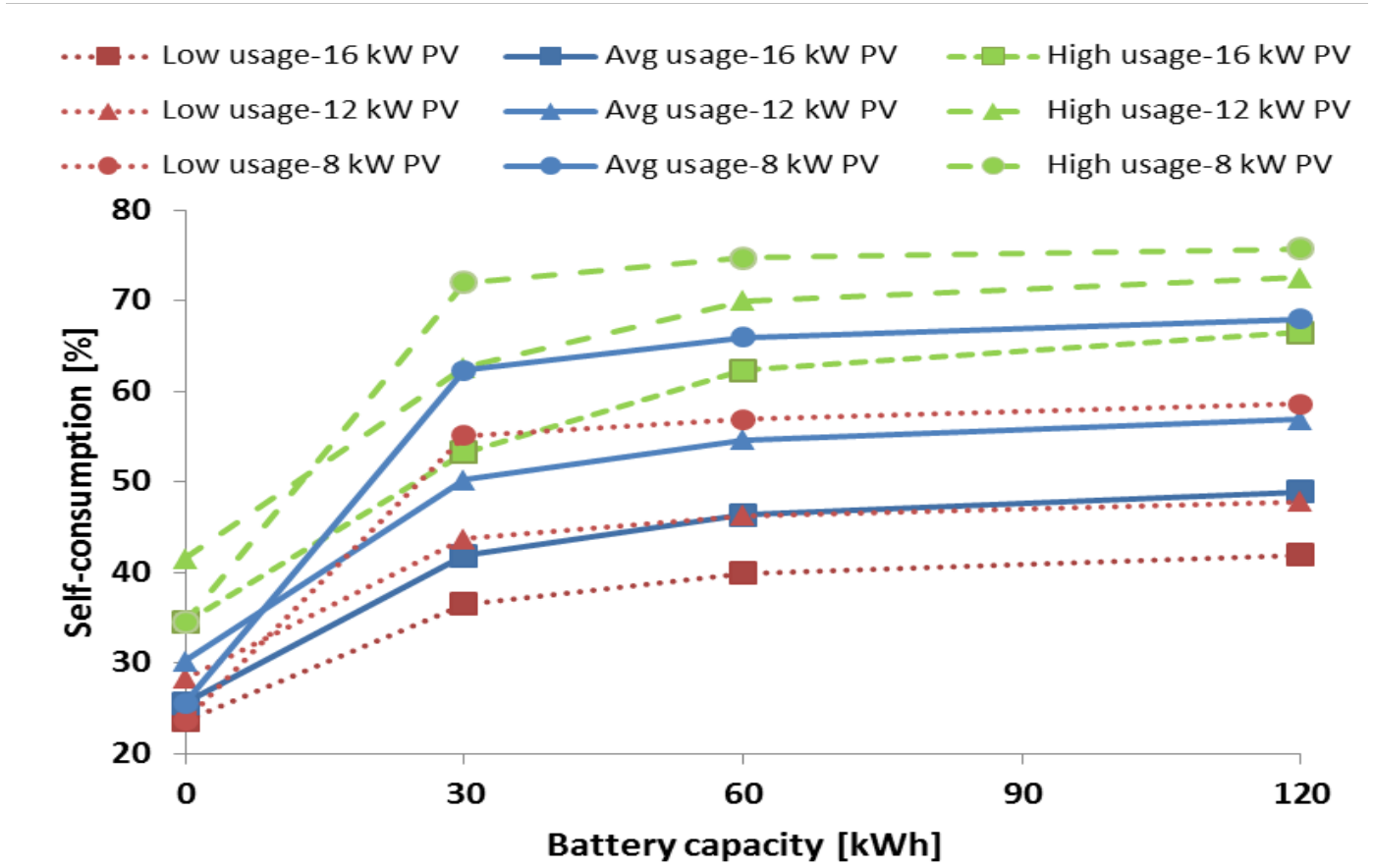
Load management method:

- Grid support
- Uninterrupted Power System (UPS)

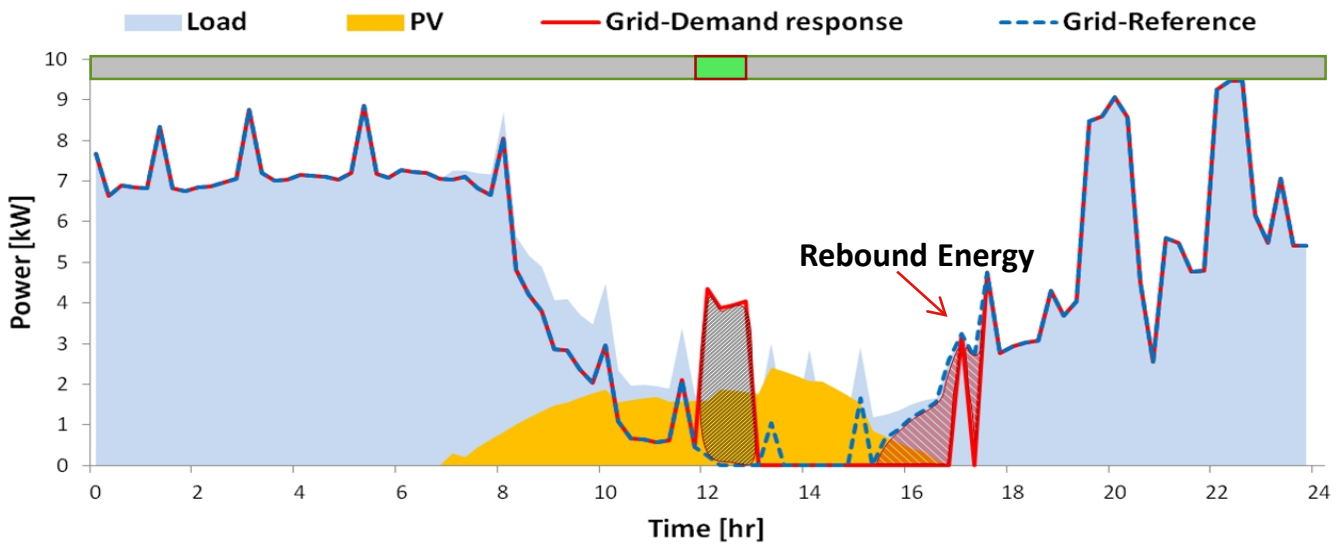
Yearly KPIs: self-generation

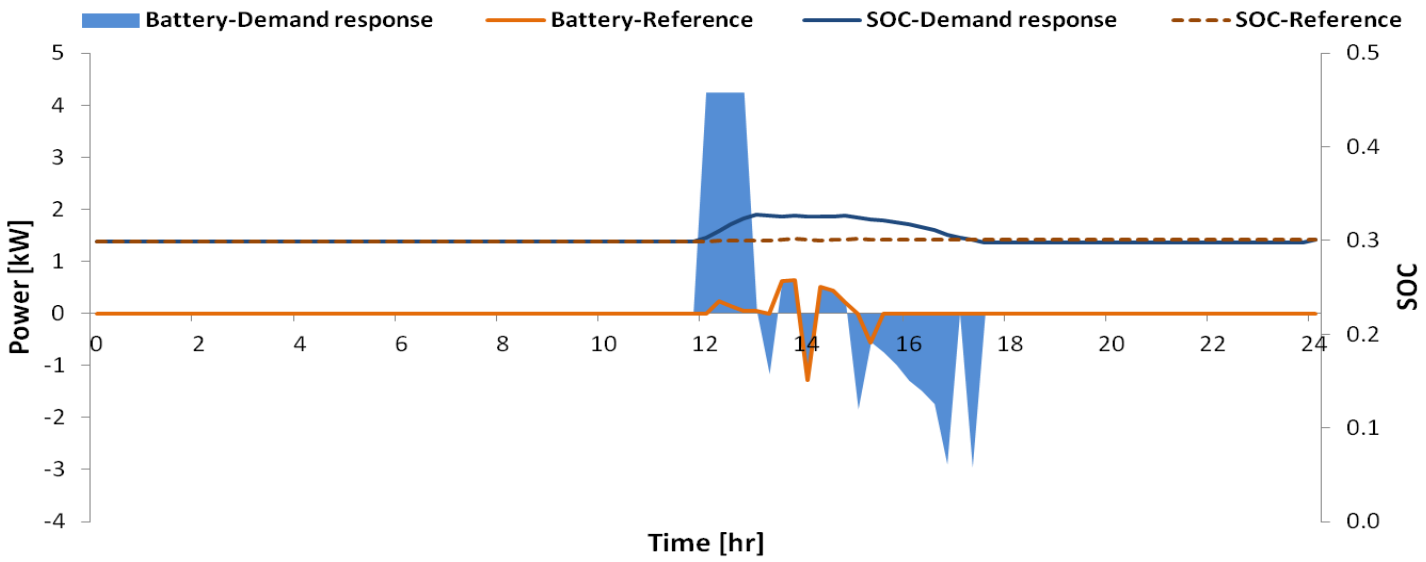


Yearly KPIs: self-consumption

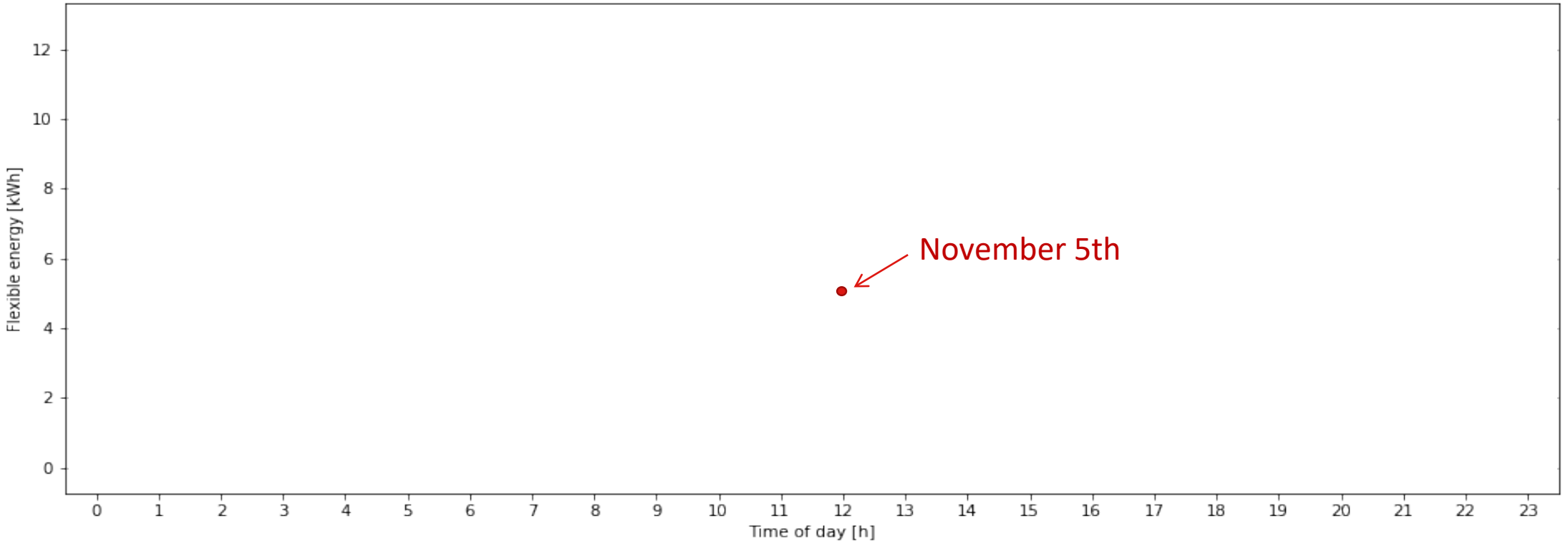


Flexible/Rebound Energy During the Event

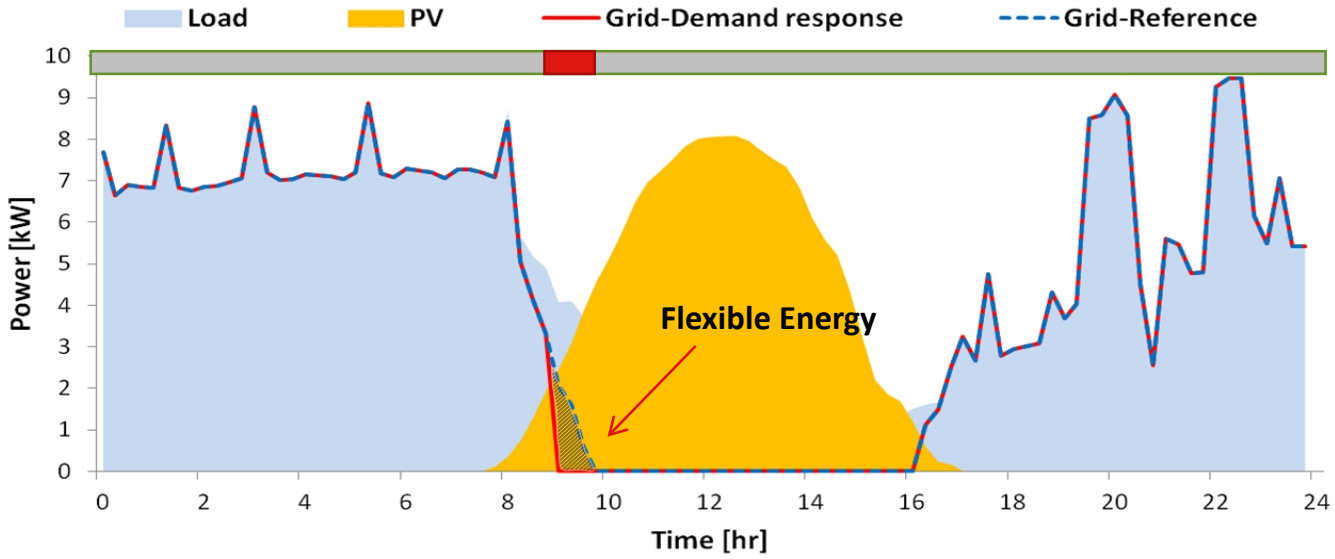


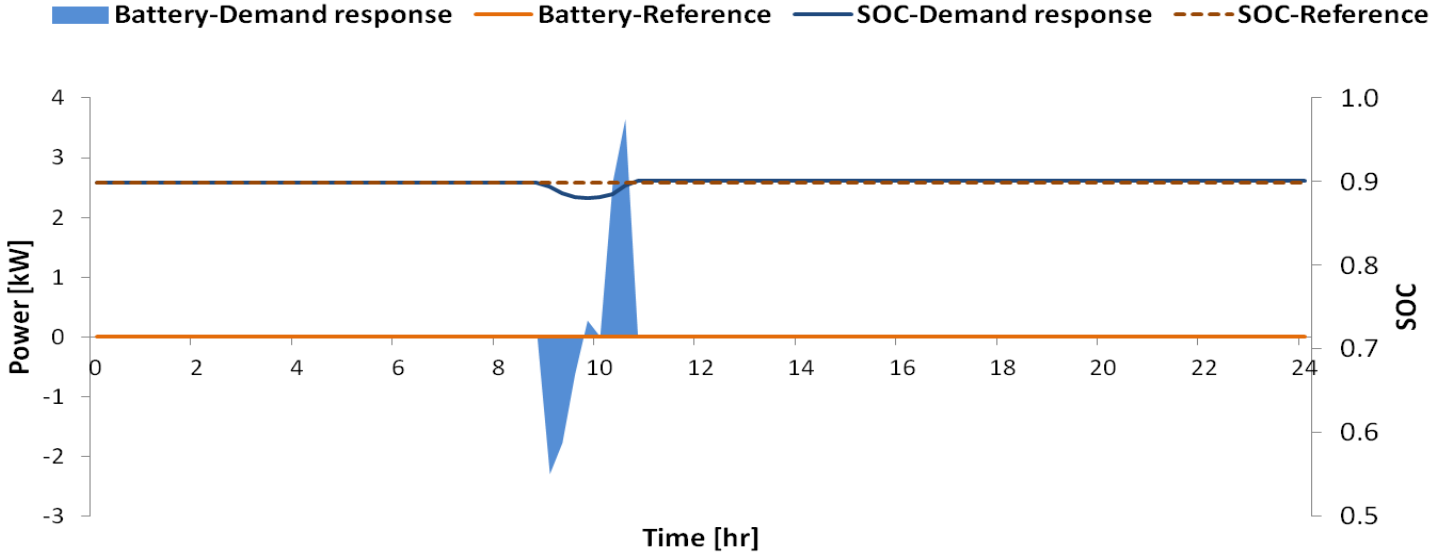


Upward Flexibility (Grid Support Mode)

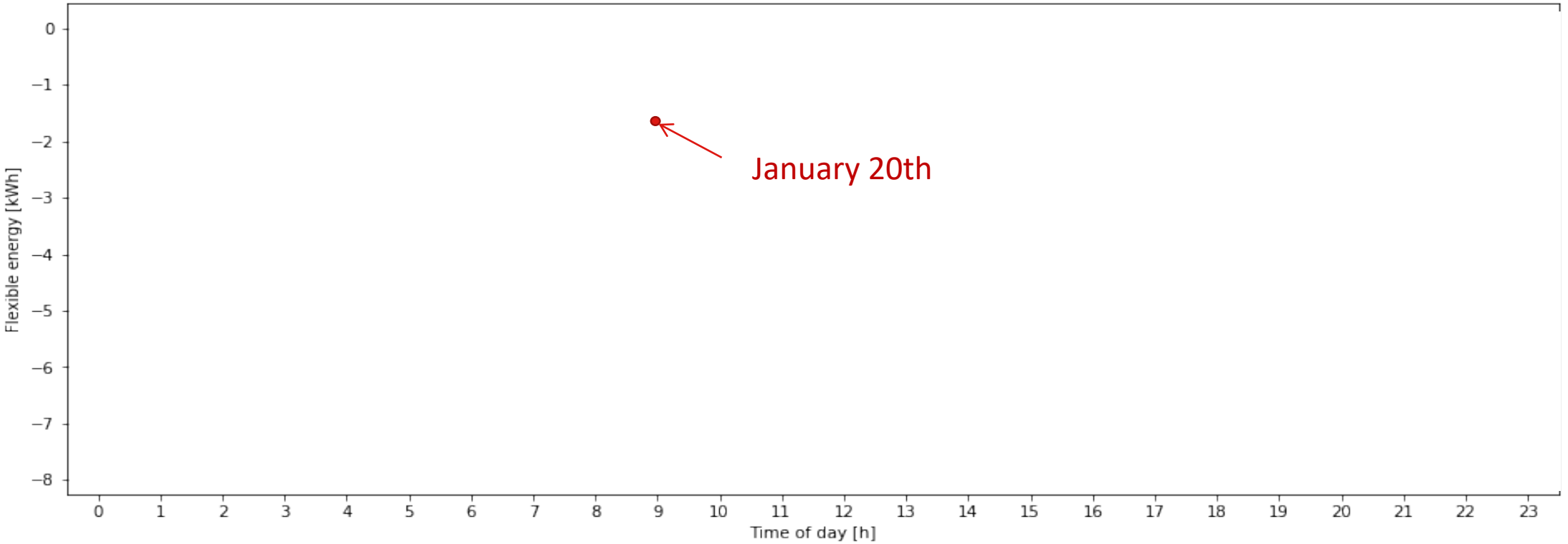


Flexible/Rebound Energy During the Event

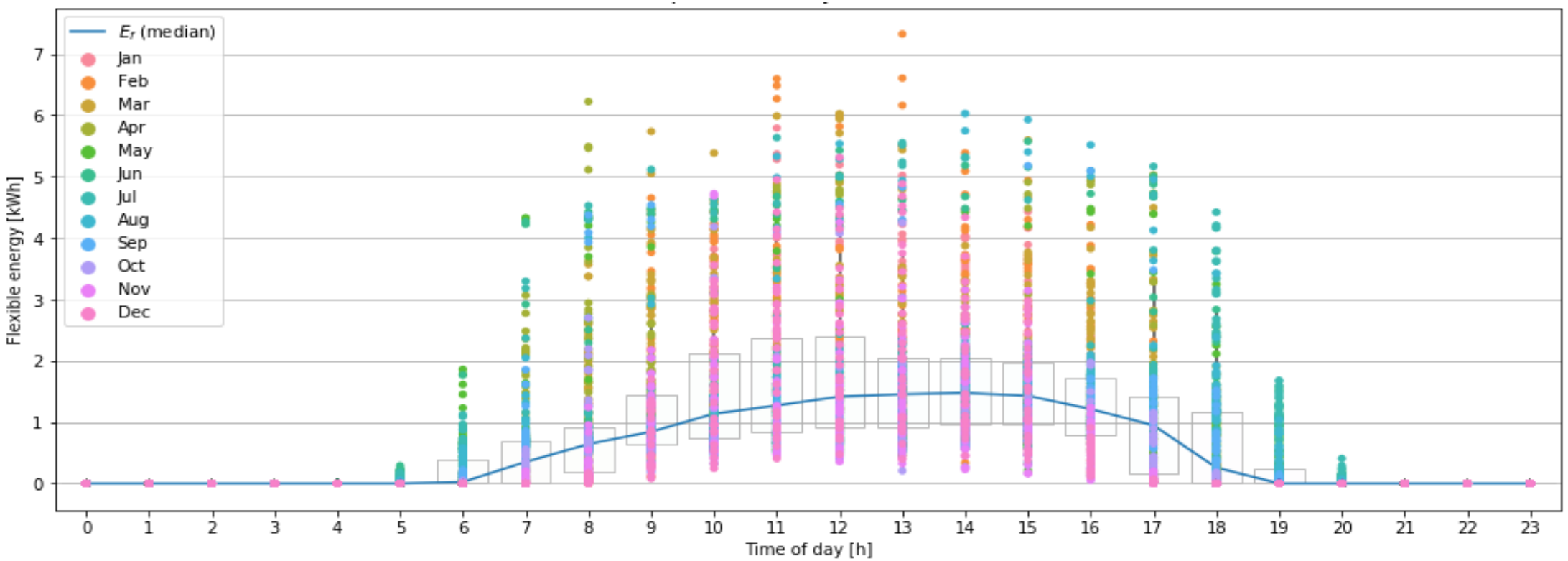




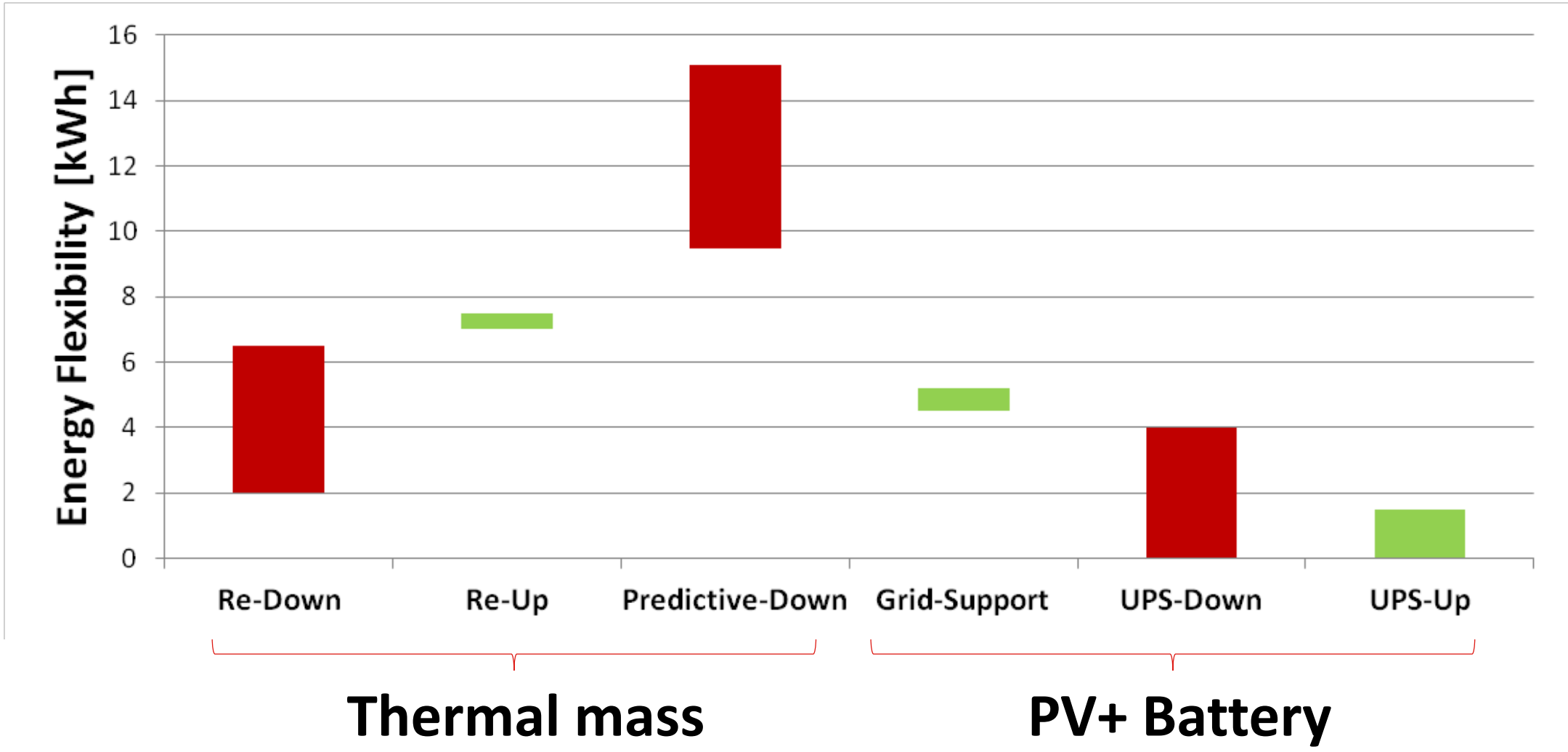
Downward Flexibility (UPS Mode)



Upward Flexibility (UPS Mode)



Conclusion


Energy Flexibility [kWh]
16
14
12
10
8
6
4
2
0
Re-Down
Re-Up
Predictive-Down
Grid-Support
UPS-Down
UPS-Up
Thermal mass
PV+ Battery


תודה
Dankie
Gracias
شكراً
Спасибо
Merci
Takk
Köszönjük
Terima kasih
Grazie
Dziękujemy
Dėkojame
Ďakujeme
Vielen Dank
Paldies
Kiitos
Täname teid
谢谢
Thank You
Tak
感謝您
Obrigado
Teşekkür Ederiz
감사합니다
Σας ευχαριστούμε
ขอบคุณ
Bedankt
Děkujeme vám
ありがとうございます
Tack

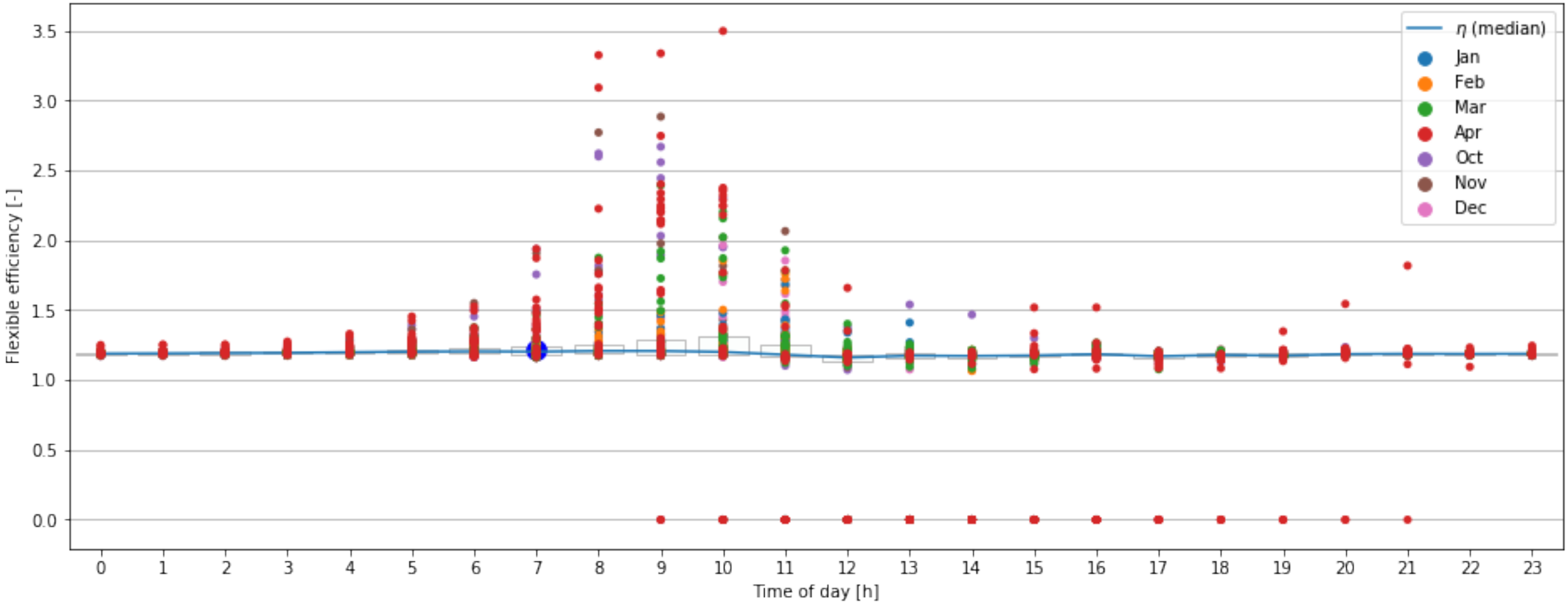
Conclusion

- Thermal mass
  - Reactive control delivers potential for energy flexibility
  - Predictive control can improve the potential

- PV + battery system
  - Coupling the battery improves the yearly self-generation and self-consumption
  - Variable upward flexibility with grid support mode
  - Downward flexibility

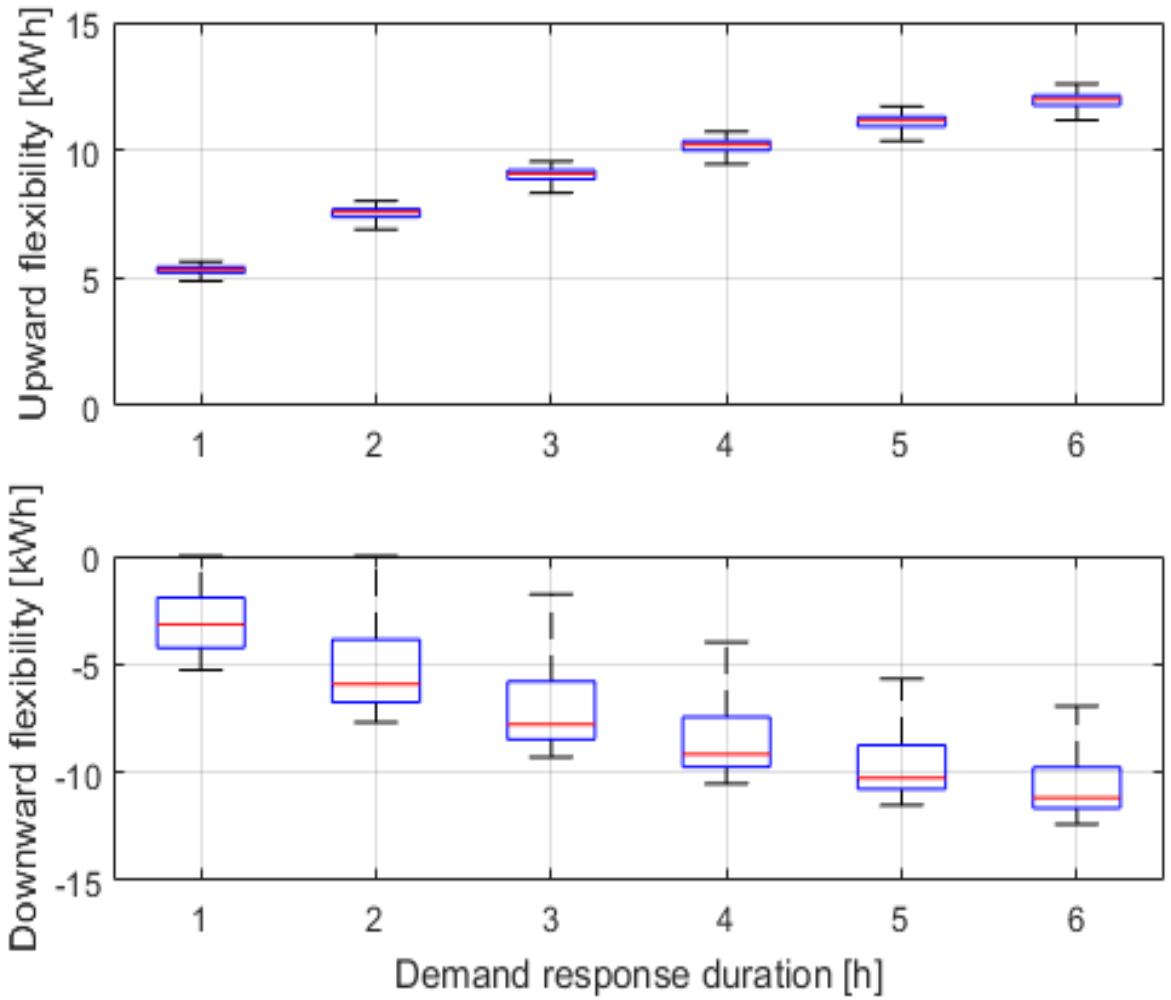
- Future work
  - Improve key performance indicators for energy flexibility
  - Test the methodology on different systems

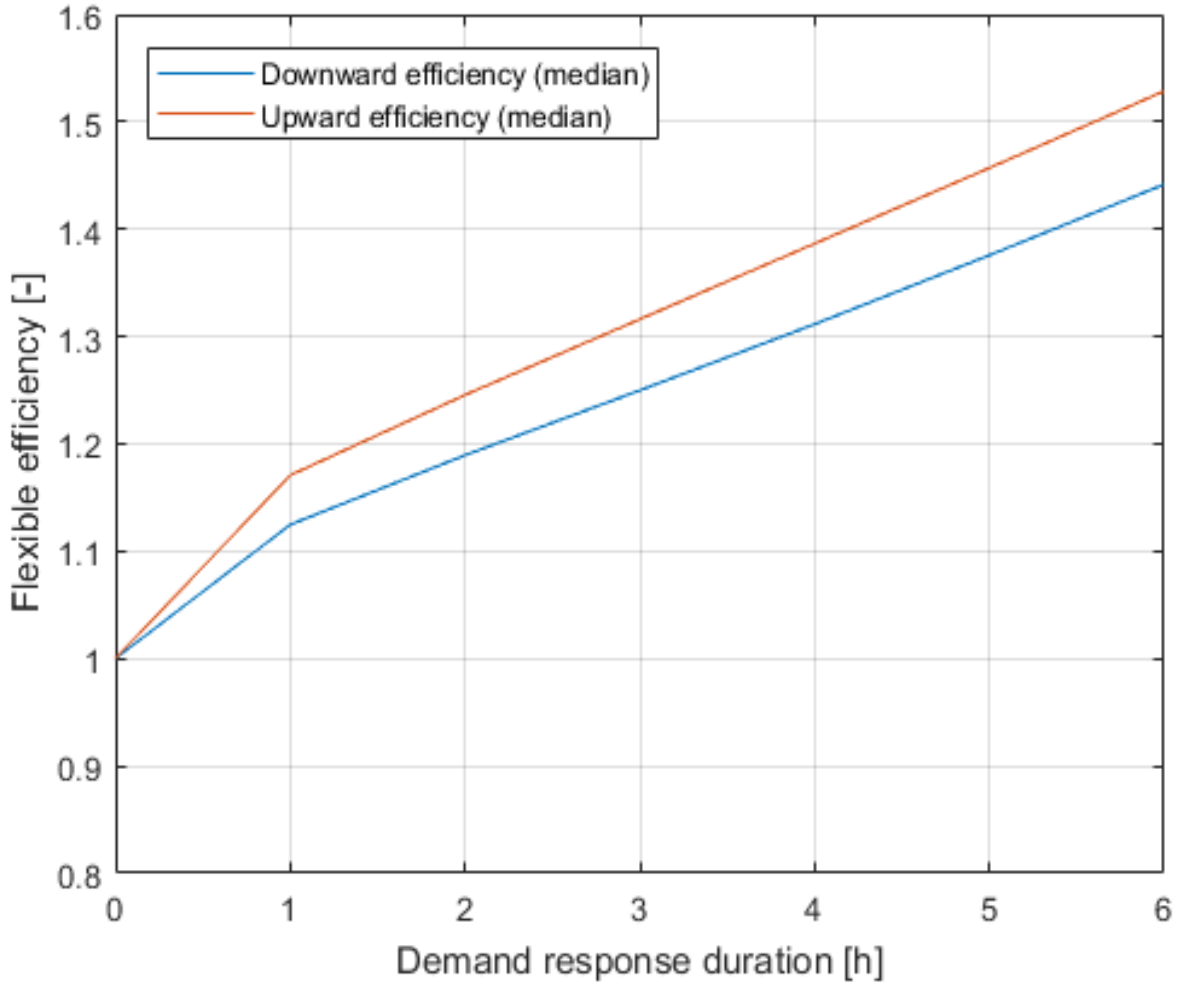
Results: flexible efficiency



Downward flexibility

Results: DR duration impact on flexible energy and efficiency





Results: DR duration impact on maximum flexible power