Demand response in the residential sector
Results from field tests

Ana Soares

Contents

1 What is Vito?

2 What is EnergyVille?

3 What is Demand Response?

4 Demand Response in the Residential Sector

5 Results from Field Tests

6 Other Projects

7 Conclusion

8 Quick Sneak Peek into our Home Lab

1. What is Vito?

VITO is an independent Flemish research organization in the area of cleantech and sustainable development.

At VITO, we develop innovative technologies, methodologies and tools related to several topics (Sustainable Chemistry, Sustainable Land Use, Sustainable Materials, Sustainable Health, Sustainable Energy).

Within the context of **Sustainable Energy**, Vito is focused on:

- Interfaces for electrical storage
- Optimization of thermal energy systems
- Buildings and districts (energy districts design / building technology assessment)
- Energy markets and strategies

Main Goal: to accelerate the transition to a sustainable world

2. What is EnergyVille?

EnergyVille is a collaboration between the Flemish research partners KU Leuven, VITO, imec and UHasselt in the field of sustainable energy and intelligent energy systems.

Researchers involved collaborate in several projects and provide expertise to industry and public authorities on **energy-efficient buildings** and **intelligent networks** for a **sustainable urban environment**. This includes, for example, smart grids and advanced district heating and cooling.

KU LEUVEN

- Power Electronics
- Smart Grids (AC/DC)
- Building Physics
- Energy Conversion & Thermal Fluid Engineering

vito

- Strategies and Markets
- Buildings and Districts
- Thermal Systems
- Electrical Storage

imec

- Photovoltaic Research
- Solid-state Batteries
- Power Devices
- Energy Yield Prediction

UHASSELT

- Materials for Photovoltaic Systems and Batteries
- Thin Film Photovoltaic Research and Reliability Testing
- Battery Research

3. What is Demand Response?

Context

- For **2030** Member States have committed to:
  - **reduce emissions by 40%** (compared to 1990 levels);
  - **increase** the **share** of **renewables** in the EU's energy mix to at least 27%;
  - achieve at least **27% improvement** in **energy efficiency**.
- By **2050** the EU sets the target to **reduce** greenhouse gas **emissions** to **80% below 1990 levels** → **share** of **renewables** should strongly **increase**

Demand Response (DR) programs can:

- be used to match demand and supply in the electric power system;
- help improving the stability of the distribution grid;
- contribute to a more efficient integration of renewables.

In the context of DR the end-user is endowed with the possibility to participate in the operation of power systems by adapting electricity usage during a given period of time in response to external signals (e.g., incentive-based, price-based).

3. What is Demand Response?

Overview of different DR *programs*, *benefits* and *costs*

Demand Response Programs

- Incentive Based Programs (IBP)
  - Classical
    - Direct Control
    - Interruptible/Curtailable Programs
  - Market Based
    - Demand Bidding
    - Emergency DR
    - Capacity Market
    - Ancillary services market
- Price Based Programs (PBP)
  - Time of Use (TOU)
  - Critical Peak Pricing (CPP)
  - Extreme Day CPP (ED-CPP)
  - Extreme Day Pricing (EDP)
  - Real Time Pricing (RTP)

- **Time-of-use pricing (TOU).** This rate design features prices that vary by time period, and are higher in peak periods and lower in off-peak periods. The simplest rate involves just two pricing seasons, with prices being higher during the peaking season. A time-of-day rate is slightly more complex and involves two pricing periods within a day, a peak period and an off-peak period. More complex rates have one or more shoulder periods and seasonal variation.
- **Critical peak pricing (CPP).** This rate design layers a very high price during a few critical hours of the year. It can also be combined with a TOU rate. Typically, a CPP rate is only used on 12-15 days a year. These days are called the day before or the day of the critical peak price.
- **Extreme day pricing (EDP).** This rate design is similar to CPP, except that the higher price is in effect for all 24 h for a maximum number of critical days, the timing of which is unknown until a day ahead.
- **Extreme day CPP (ED-CPP).** This rate design is a variation of CPP in which the critical peak price applies to the critical peak hours on extreme days but there is no TOU pricing on other days.
- **Real time pricing (RTP).** This rate design features prices that vary hourly or sub-hourly all year long, for some or all of a customer's load. Customers are notified of the rates on a day-ahead or hour-ahead basis.

Source: M. H. Albadi and E. F. El-Saadany, "Demand Response in Electricity Markets: An Overview," in *2007 IEEE Power Engineering Society General Meeting*, 2007, pp. 1–5.

3. What is Demand Response?

Overview of different DR *programs*, *benefits* and *costs*

Demand Response Programs

- Incentive Based Programs (IBP)
  - Classical
    - Direct Control
    - Interruptible/Curtailable Programs
  - Market Based
    - Demand Bidding
    - Emergency DR
    - Capacity Market
    - Ancillary services market
- Price Based Programs (PBP)
  - Time of Use (TOU)
  - Critical Peak Pricing (CPP)
  - Extreme Day CPP (ED-CPP)
  - Extreme Day Pricing (EDP)
  - Real Time Pricing (RTP)

Demand Response Benefits

- Participant
  - Incentive payments
  - Bill savings
- Market-Wide
  - Price reduction
  - Capacity increase
  - Avoided/deferred infrastructure costs
- Reliability
  - Reduced outages
  - Customer participation
  - Diversified resources
- Market performance
  - Reduces market power
  - Options to customers
  - Reduces price volatility

Demand Response Costs

- Participant
  - Initial
    - Enabling technology
    - Response plan
  - Running
    - Inconvenience
    - Lost business
    - Rescheduling
    - Onsite
- Program owner
  - Initial
    - Metering & Communication
    - Billing system
    - Customer education
  - Running
    - Administration
    - Marketing
    - Incentive payments
    - Evaluation

Source: M. H. Albadi and E. F. El-Saadany, “Demand Response in Electricity Markets: An Overview,” in *2007 IEEE Power Engineering Society General Meeting*, 2007, pp. 1–5.

3. What is Demand Response?

Active *vs.* passive demand control

- Passive demand control
  - **aim**: measure and inform end-users
  - use of energy or capacity-based tariffs to raise awareness
  - no direct control
- Active demand control
  - done centrally (e.g., in case of grid issues)
  - in an automated way through the use of energy management systems
  - imposed control

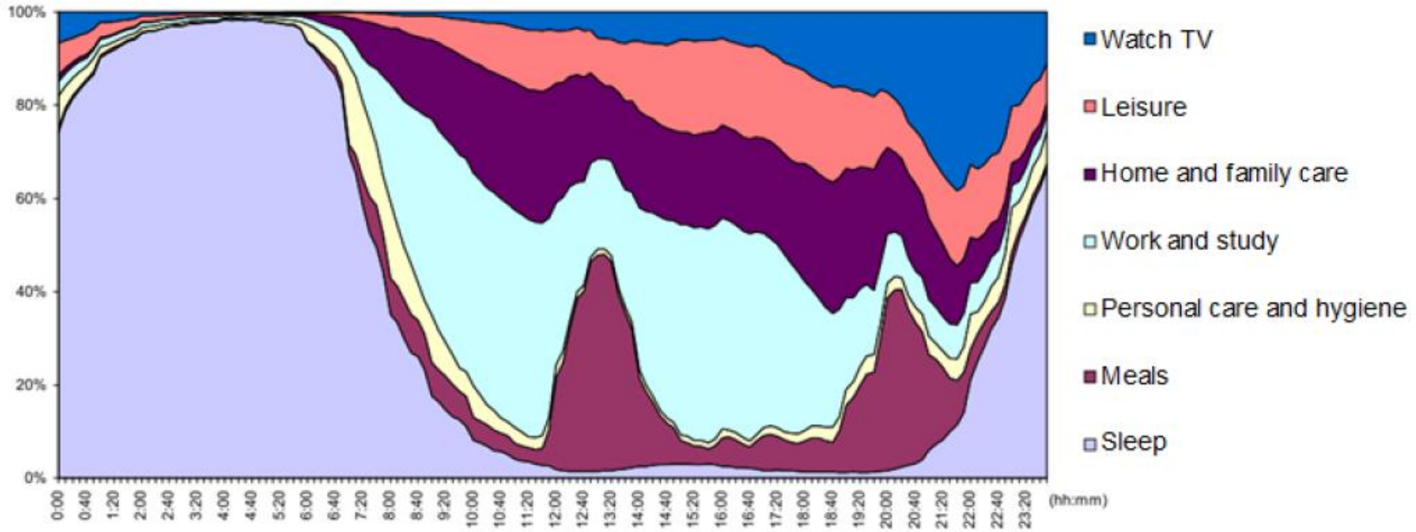
→ new actors are expected to appear

"Member States shall **promote access to and participation of Demand Response in balancing, reserves and other system services markets**, inter alia by requiring national regulatory authorities […] **in close cooperation with demand service providers and consumers**, to define technical modalities for participation in these markets on the basis of the technical requirements of these markets and the capabilities of Demand Response. Such specifications shall include the participation of **aggregators**."

Art. 15.8 of the Energy Efficiency Directive (2012/27/EU) establishes consumer access to energy markets, either individually or through aggregation.

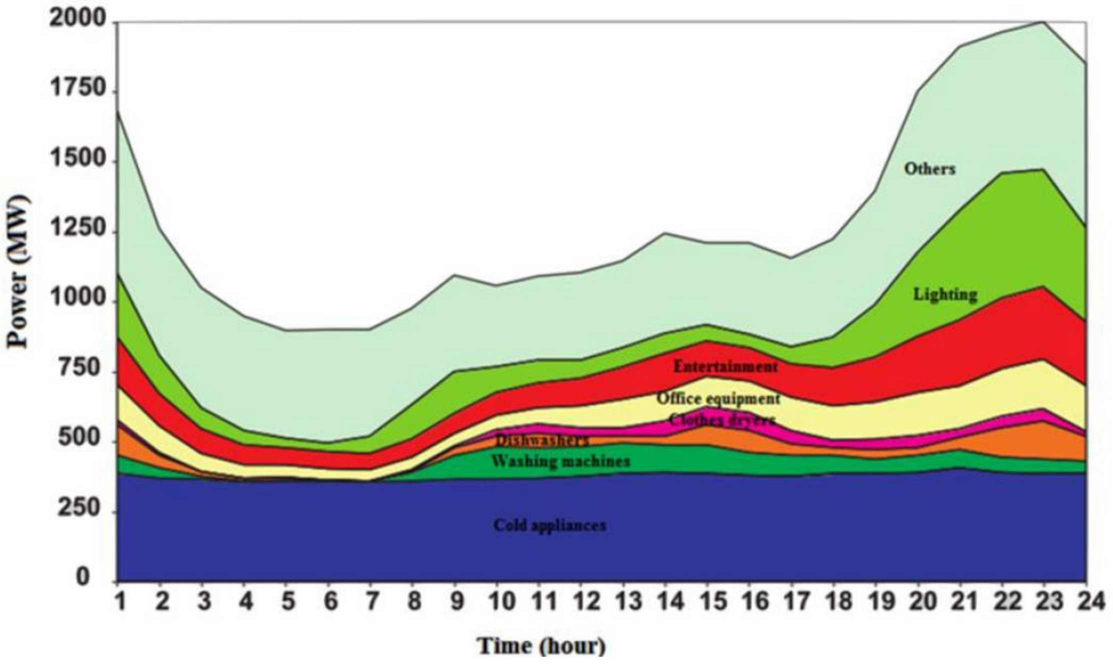
4. Demand Response in the Residential Sector

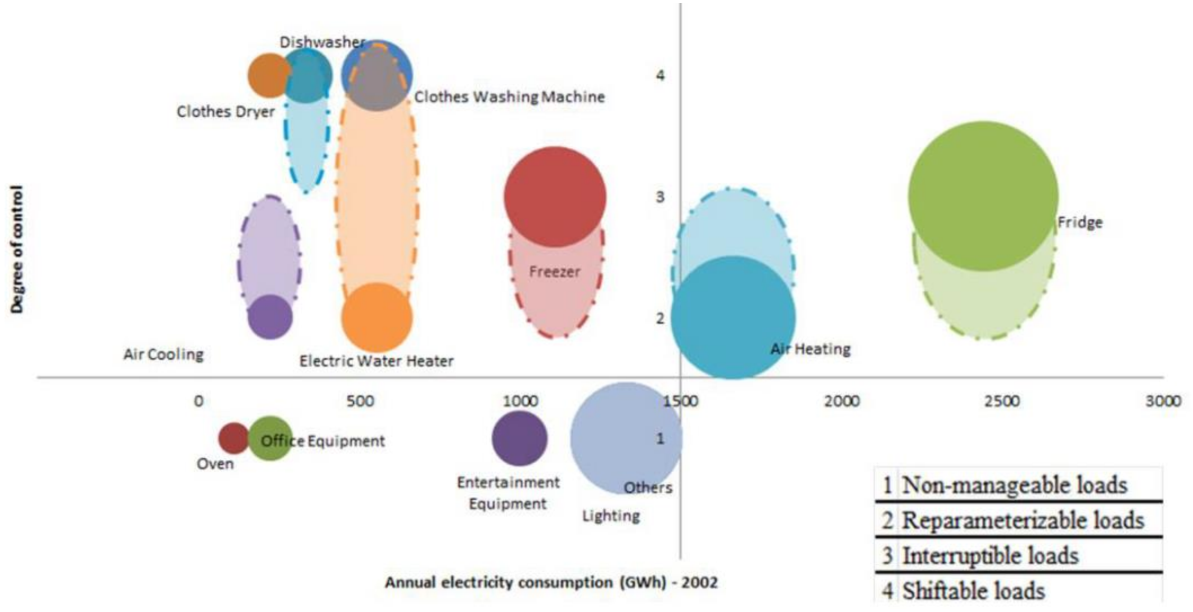
DR at my place? Why? How?



4. Demand Response in the Residential Sector

DR at my place? Why? How?

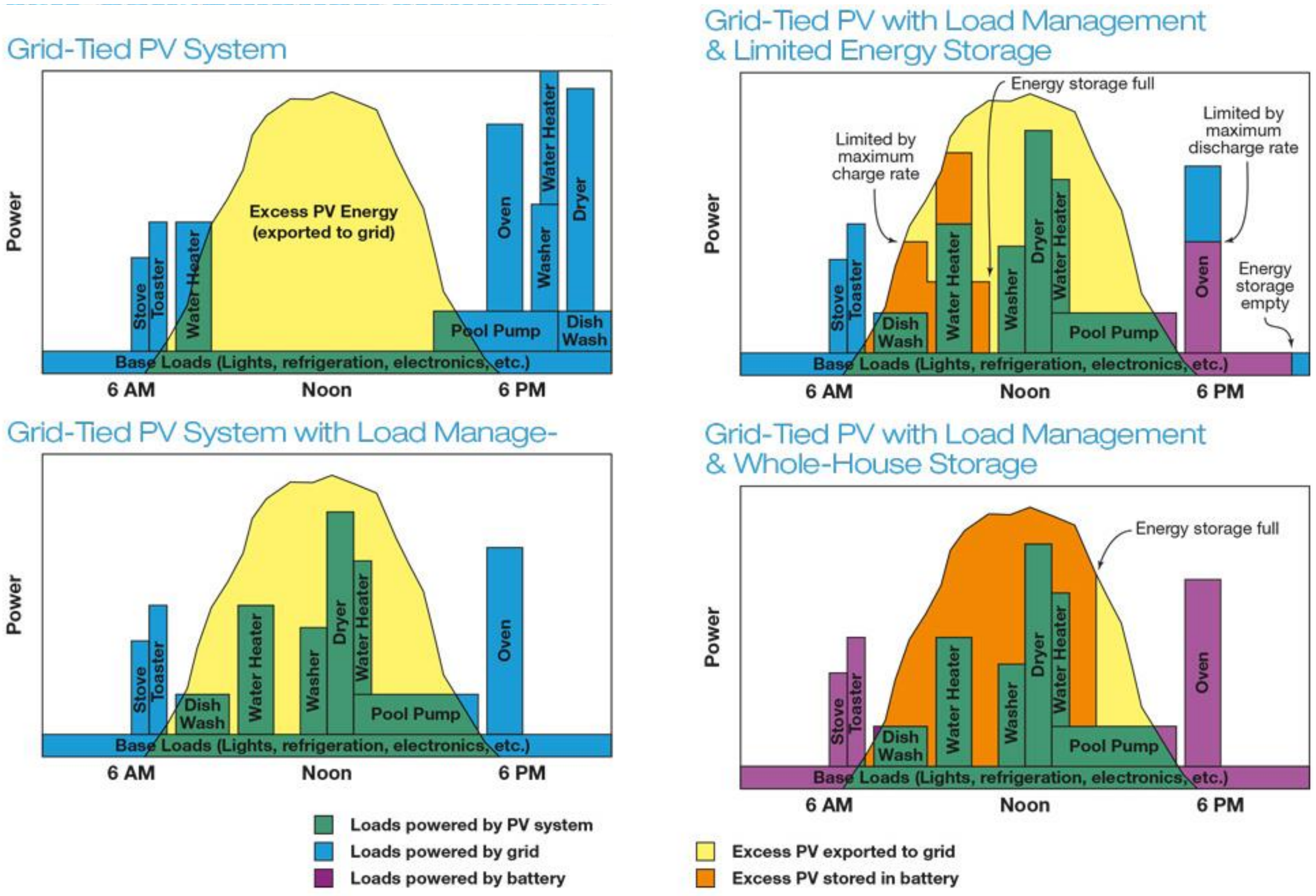




Source: A. Soares, "Integrated Management of Residential Energy Resources: Models, Algorithms and Application," Univ. Coimbra, 2016

4. Demand Response in the Residential Sector

DR at my place? Why? How?



- Via Energy Management Systems (EMS)
  - in an automated way;
    - considering end-users' preferences and habits;
    - incorporating external variables (solar production if existent), temperature, …
  - triggered by prices;
  - without jeopardizing the quality of the energy services provided;
  - without the end-user perceiving any discomfort;
  - without impacting the correct functioning of the loads being controlled.

Advantages:

- lower peaks;
- more local use of renewable energy;
- less external energy (from grid);
- less local energy injected in the grid.

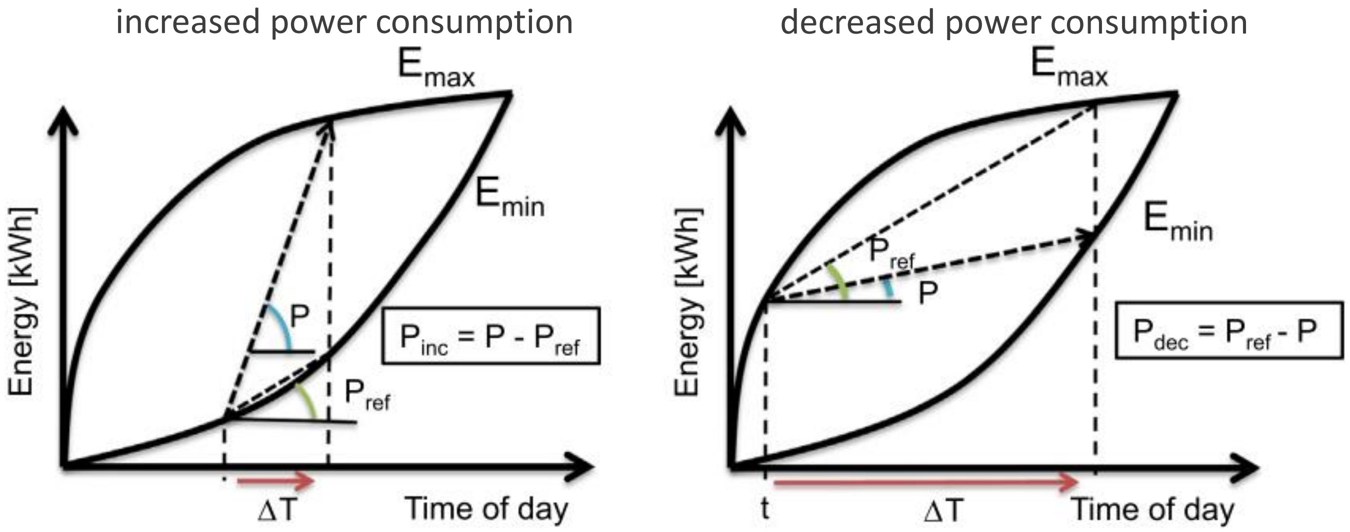
Source: https://www.homepower.com/sites/default/files/articles/14559/docs/178p46-17-SelfConGraphs.jpg

4. Demand Response in the Residential Sector

How much flexibility is there in the residential sector?

Flexibility: the power increase or decrease that are possible within the functional limits of the appliances and comfort limits of the end-user, combined with how long these changes can be sustained.

Schematic illustration of the flexibility potential calculation for:



Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

- E_{max} and E_{min} represent the power consumption when consumption is as early as possible, and as late as possible respectively;
- P_{ref} is the reference power consumption;
- P is the power consumption when a consumption increase or decrease would be realized.

5. Results from field tests

LINEAR Project

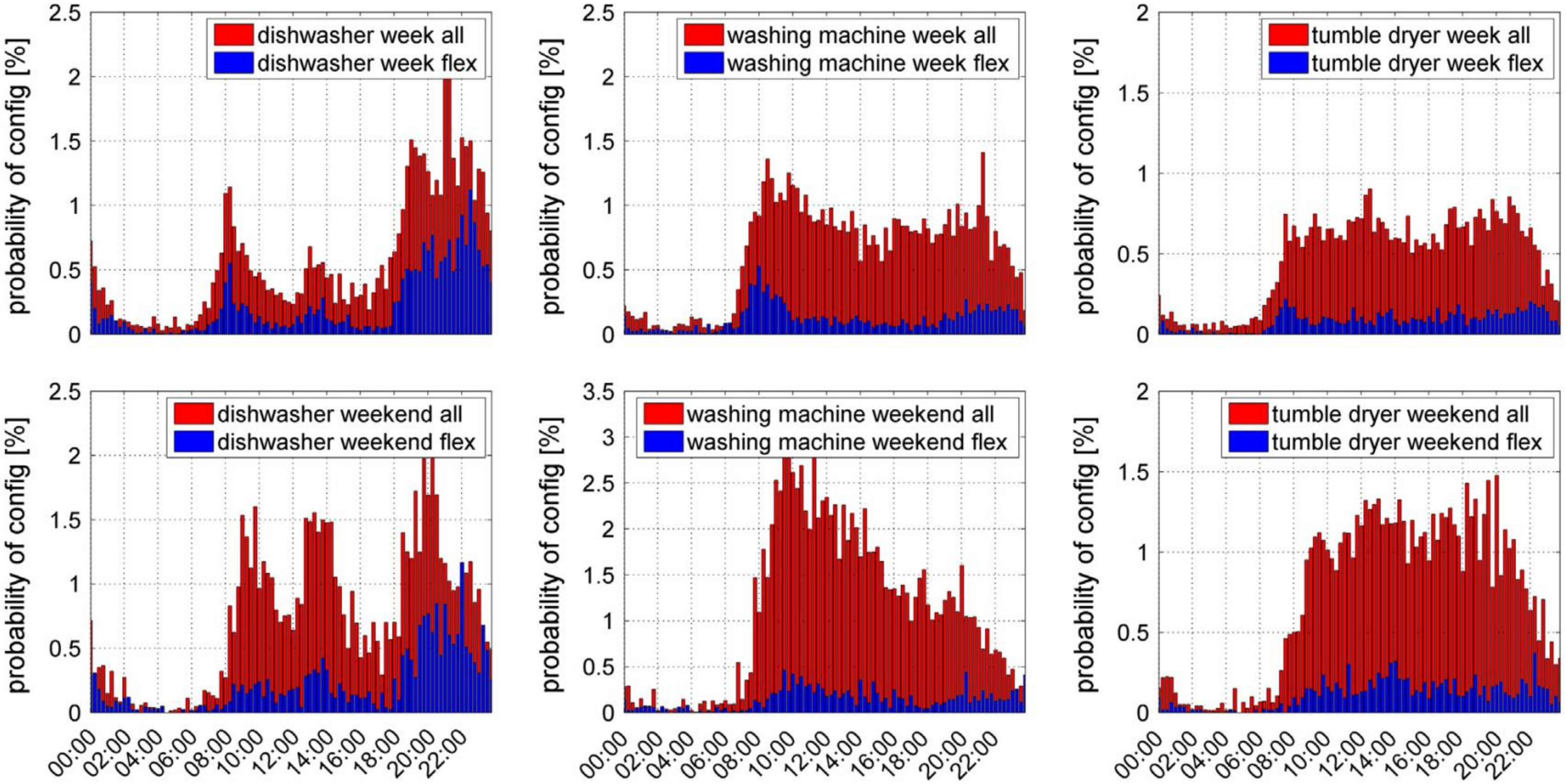
Project ran from 2009 until 2014

- Smart appliances installed in 239 households
  - Dishwashers, washing machines, tumble dryers, heat pumps (and EVs)
    - wet appliances: user interface in which end-users have to configure a deadline for the end of the appliance’s program (no power interruption allowed)
    - heat pumps: no action required from the end-user side
    - EV: portal site where end-users should set the departure deadline + expected charging time (power interruption allowed)
- End-users rewarded using a capacity fee associated with the flexibility offered
    - the flexibility potential for power consumption increase can be calculated, based on the principle that the potential for demanding extra power at any moment is maximized when the reference consumption is maximal postponement.
    - the flexibility potential for power consumption decrease can then be calculated based on the principle that the potential for decreasing power consumption at any moment is maximized when the reference consumption is consumption as early as possible.

5. Results from field tests

LINEAR Project

Probability of configuration (both smart and non- smart, in red) and smart configuration (blue) according to starting time during an average weekday and weekend day, for every wet appliance

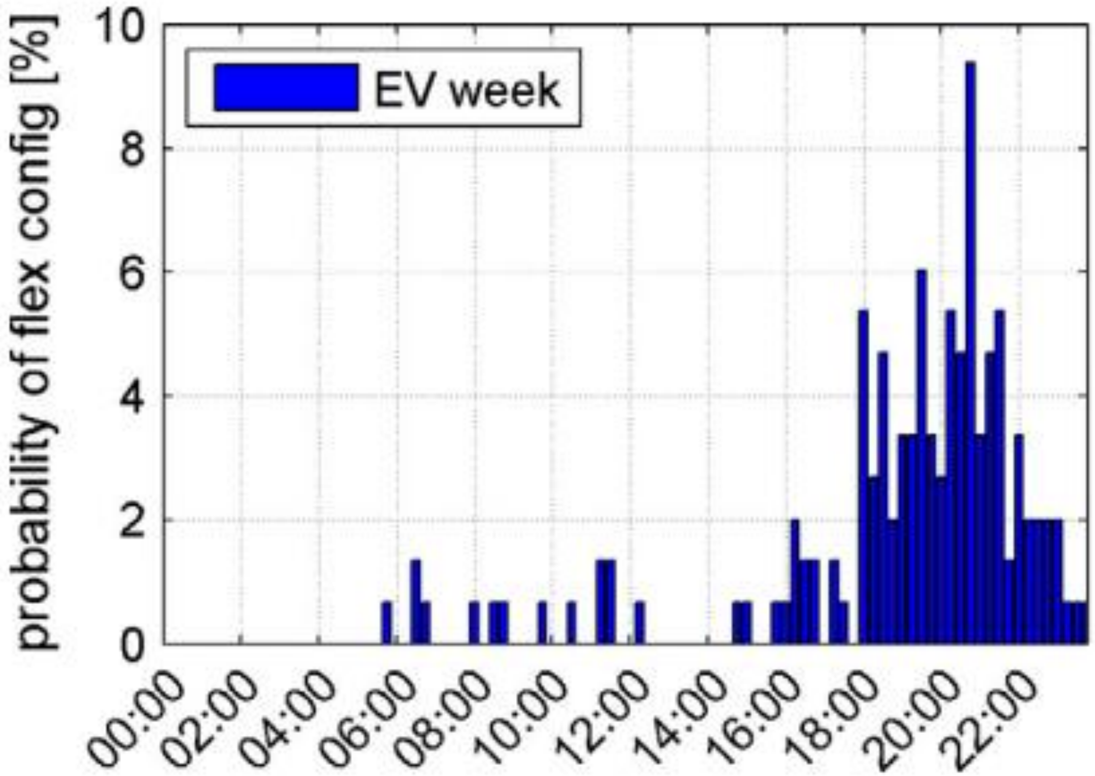


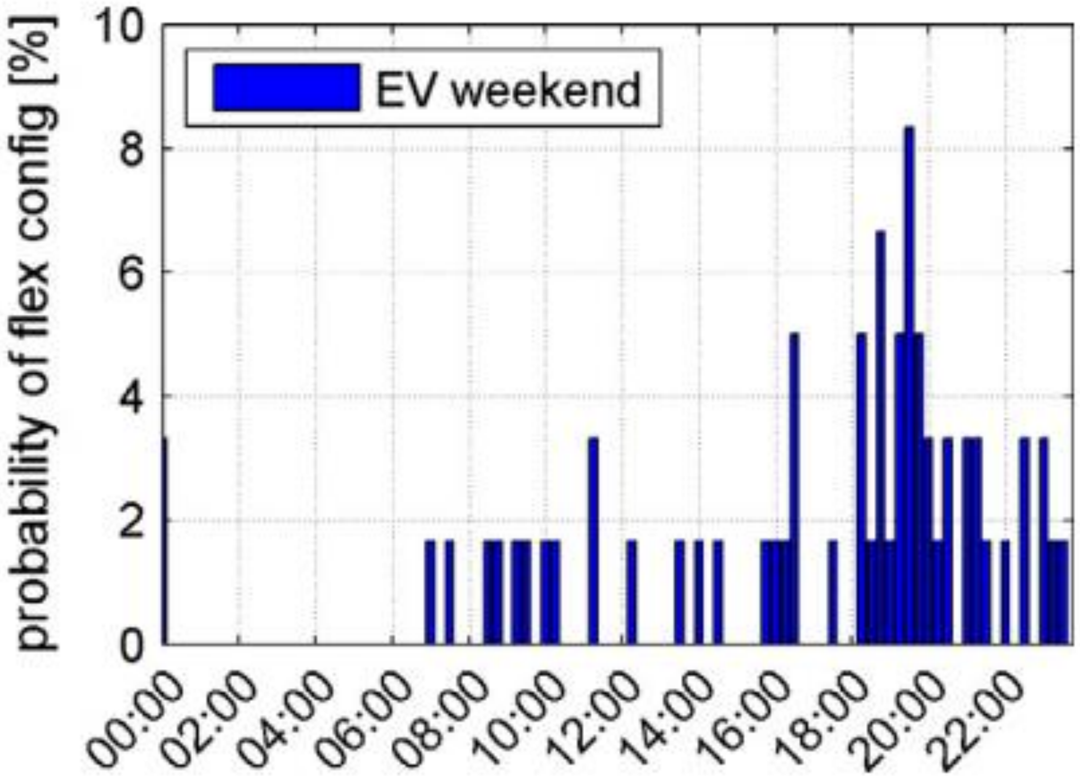
Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

5. Results from field tests

LINEAR Project

Probability of smart configuration of an EV throughout an average weekday and weekend day



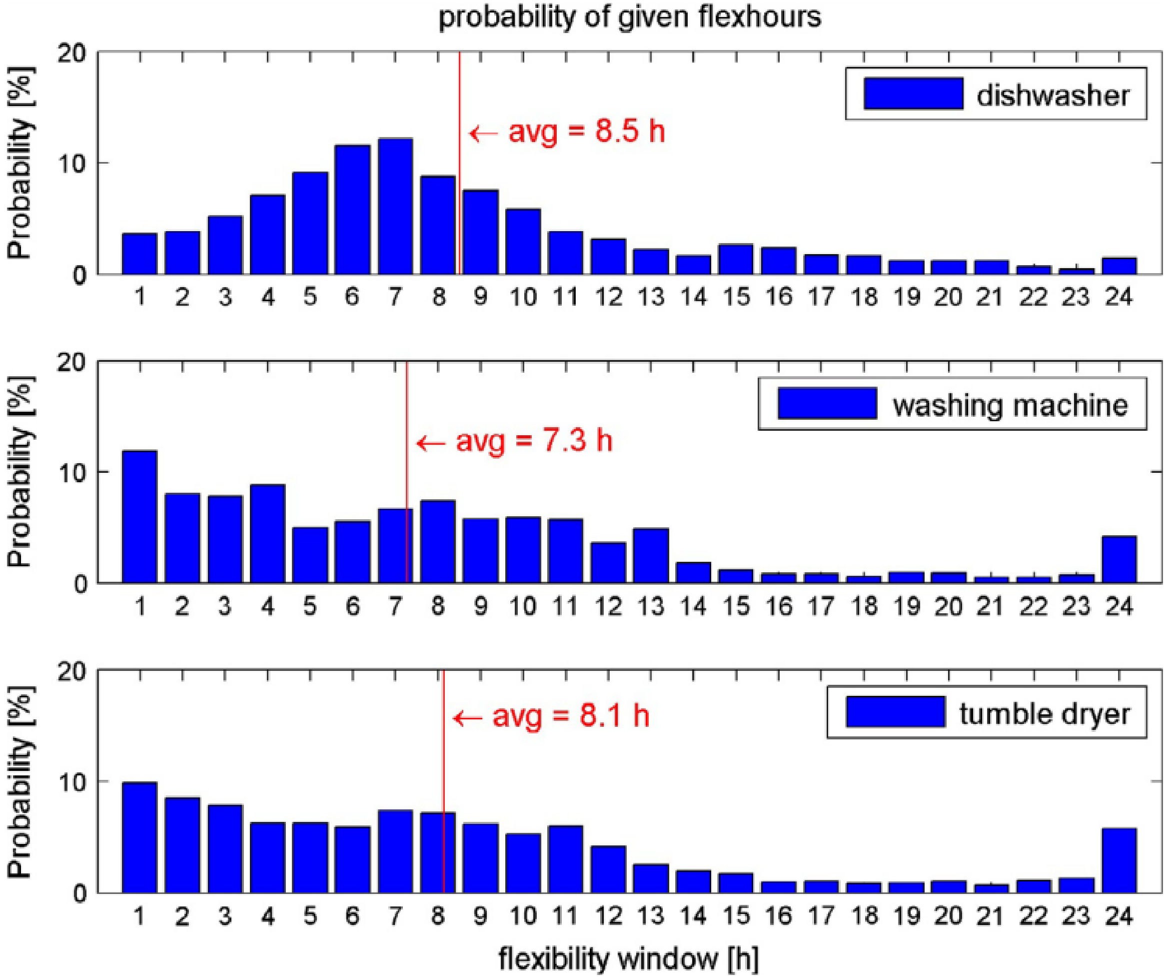


Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

5. Results from field tests

LINEAR Project

Probability distribution for the length of the flexibility window, per wet appliance.
The average number of flexibility hours is also indicated.

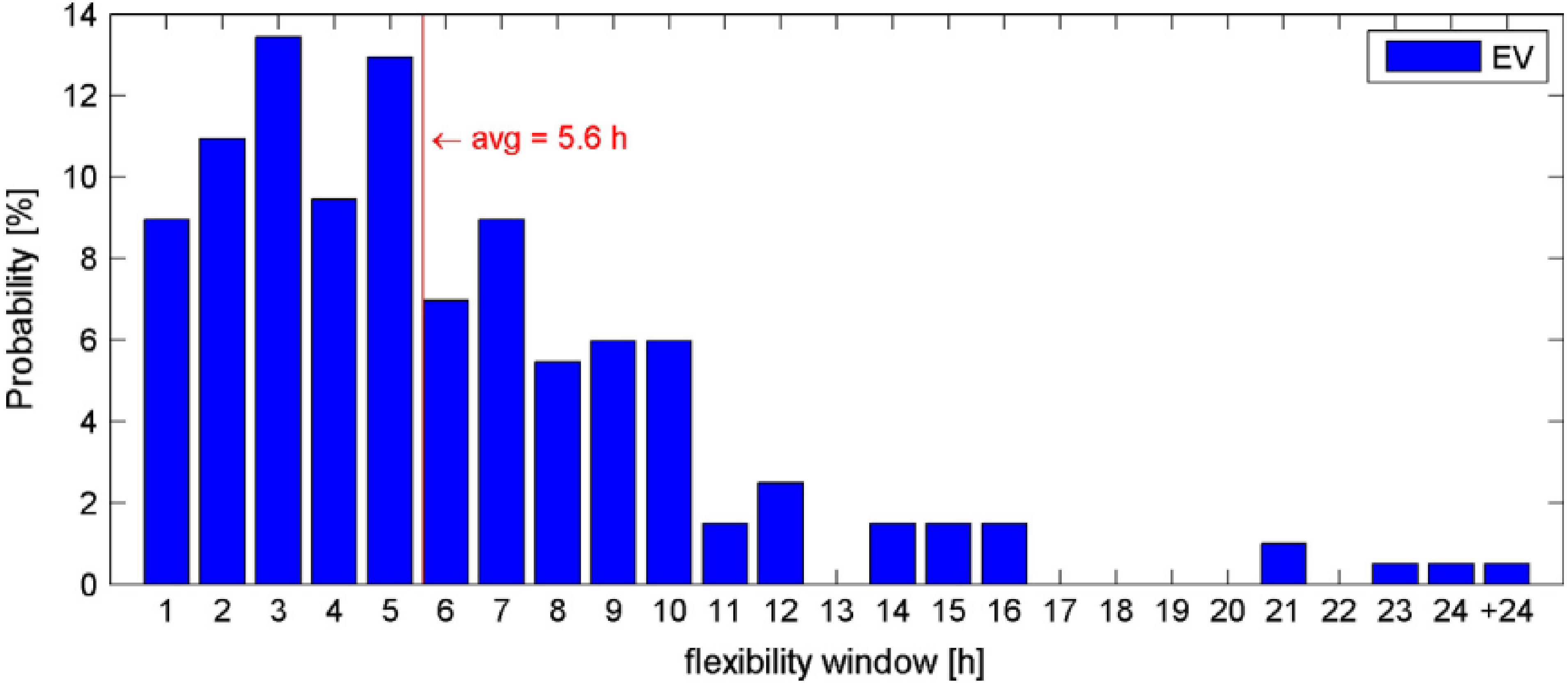


Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

5. Results from field tests

LINEAR Project

Probability of the length of the flexibility window per smart charging configuration of an EV.
The average flexibility window length is also indicated.

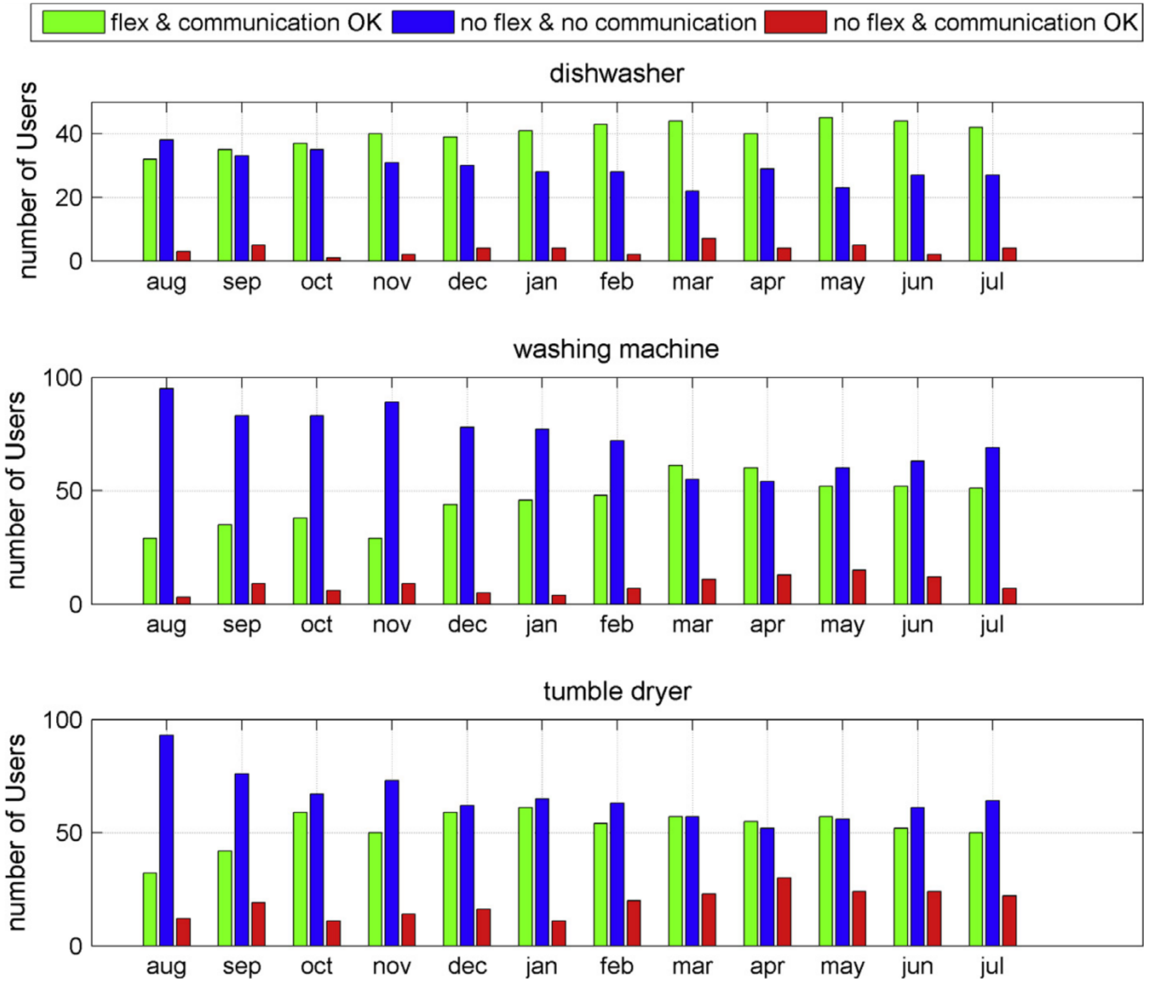


Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

5. Results from field tests

LINEAR Project

The number of households giving flexibility (green), not giving flexibility but experiencing technical issues (blue), not giving flexibility and no technical issues (red) per month and per appliance, from mid-2013 until mid-2014

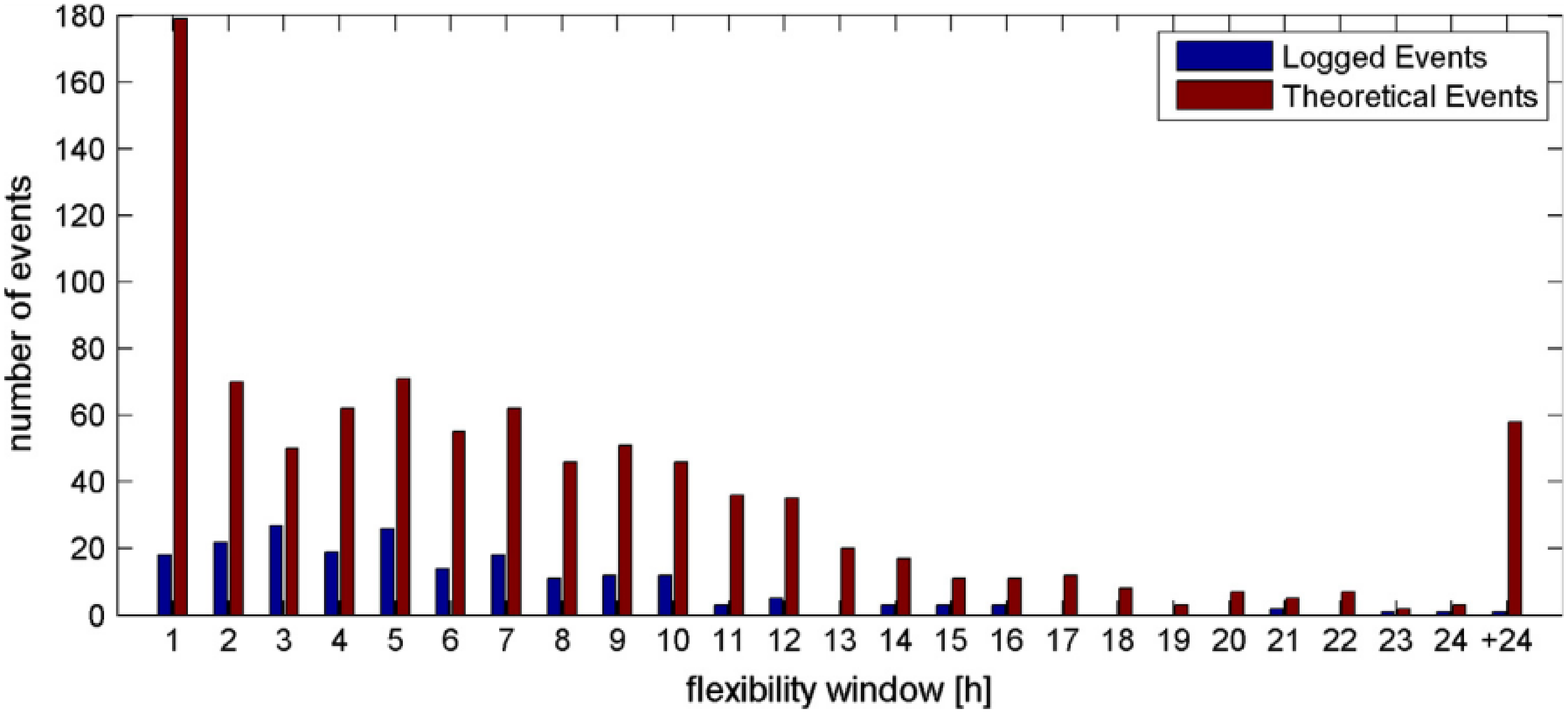


Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

5. Results from field tests

LINEAR Project

Number of logged EV configuration events in function of the flexibility window length, versus the theoretically possible number of EV configurations.

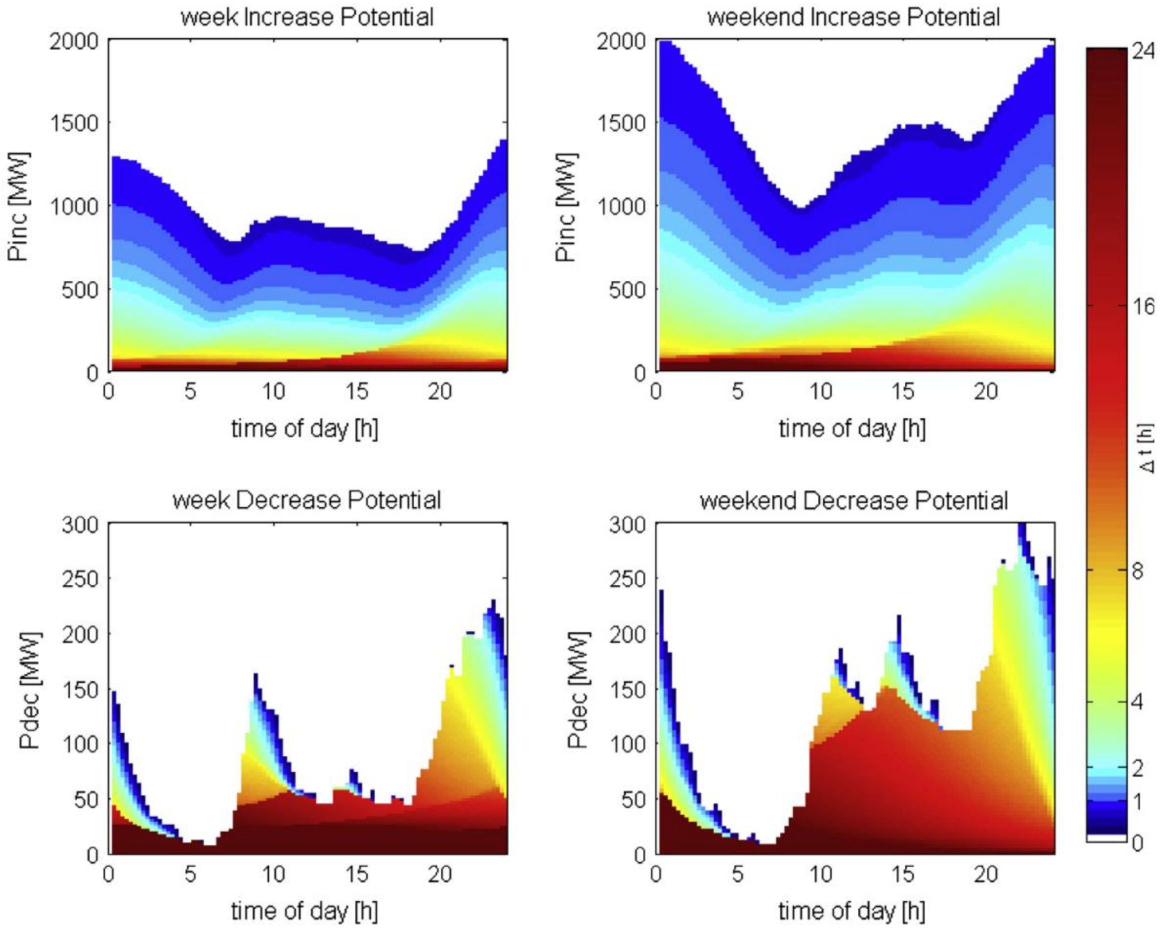


Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

5. Results from field tests

LINEAR Project

Flexibility potential of all postponable wet appliances combined (dishwasher, tumble dryer, washing machine) for the Belgian population. The top figures indicate what power consumption increase is possible in function of the time of day (P_{inc}), while the bottom figures show the potential in terms of power consumption decreases (P_{dec})



remember…

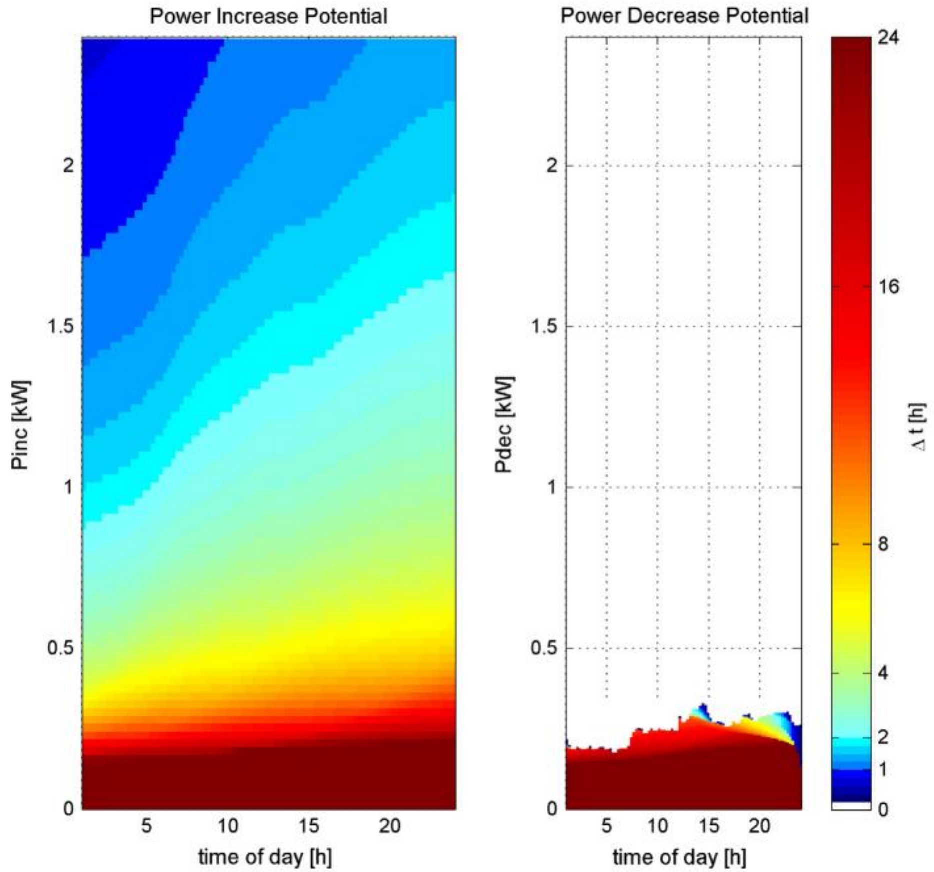
- the flexibility potential for power consumption increase can be calculated, based on the principle that the potential for demanding extra power at any moment is maximized when the reference consumption is maximal postponement.
- the flexibility potential for power consumption decrease can then be calculated based on the principle that the potential for decreasing power consumption at any moment is maximized when the reference consumption is consumption as early as possible.

Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

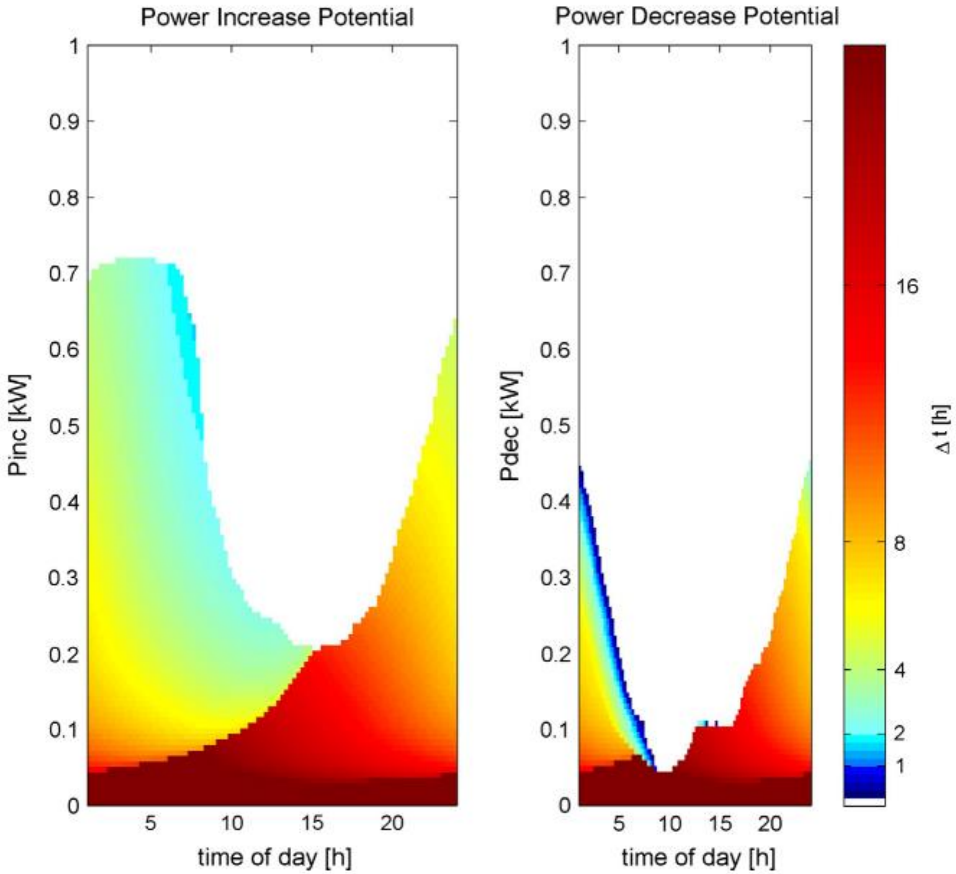
5. Results from field tests

LINEAR Project

Flexibility potential of an average DHW buffer as used in the LINEAR pilot. Both consumption increase and decrease potential are shown.



Theoretic maximal flexibility potential of the average electric vehicle as used in the LINEAR pilot. Both potential power increases and decreases are shown.

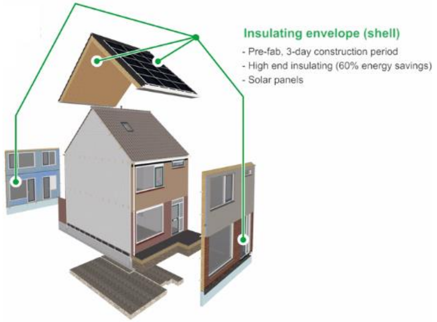


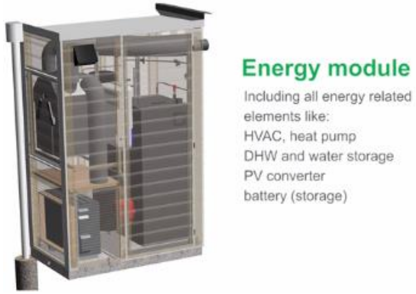
Source: R. D'hulst, W. Labeeuw, B. Beusen, S. Claessens, G. Deconinck, and K. Vanthournout, "Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium," Appl. Energy, vol. 155, pp. 79–90, 2015.

5. Results from field tests

REnnovates Project

RENNOVATES is a "holistic systemic deep renovation concept using smart services and developing smart energy-based communities resulting in **energy-neutral housing** – up to and beyond Zero Net Energy – by **reducing energy consumption** and **maximizing** the use of **renewable energy**."





- Houses in social districts in The Netherlands were renovated and equipped with a smart heat pump and a PV installation and some of them also equipped a battery
  - Residential DHW buffers:
    - some type of flexibility associated
      - existence of a dissociation between energy service provided and electricity consumption
      - possibility to store thermal energy
  - Batteries:
    - can store locally produced PV energy helping to increase self-consumption and decreasing grid injection

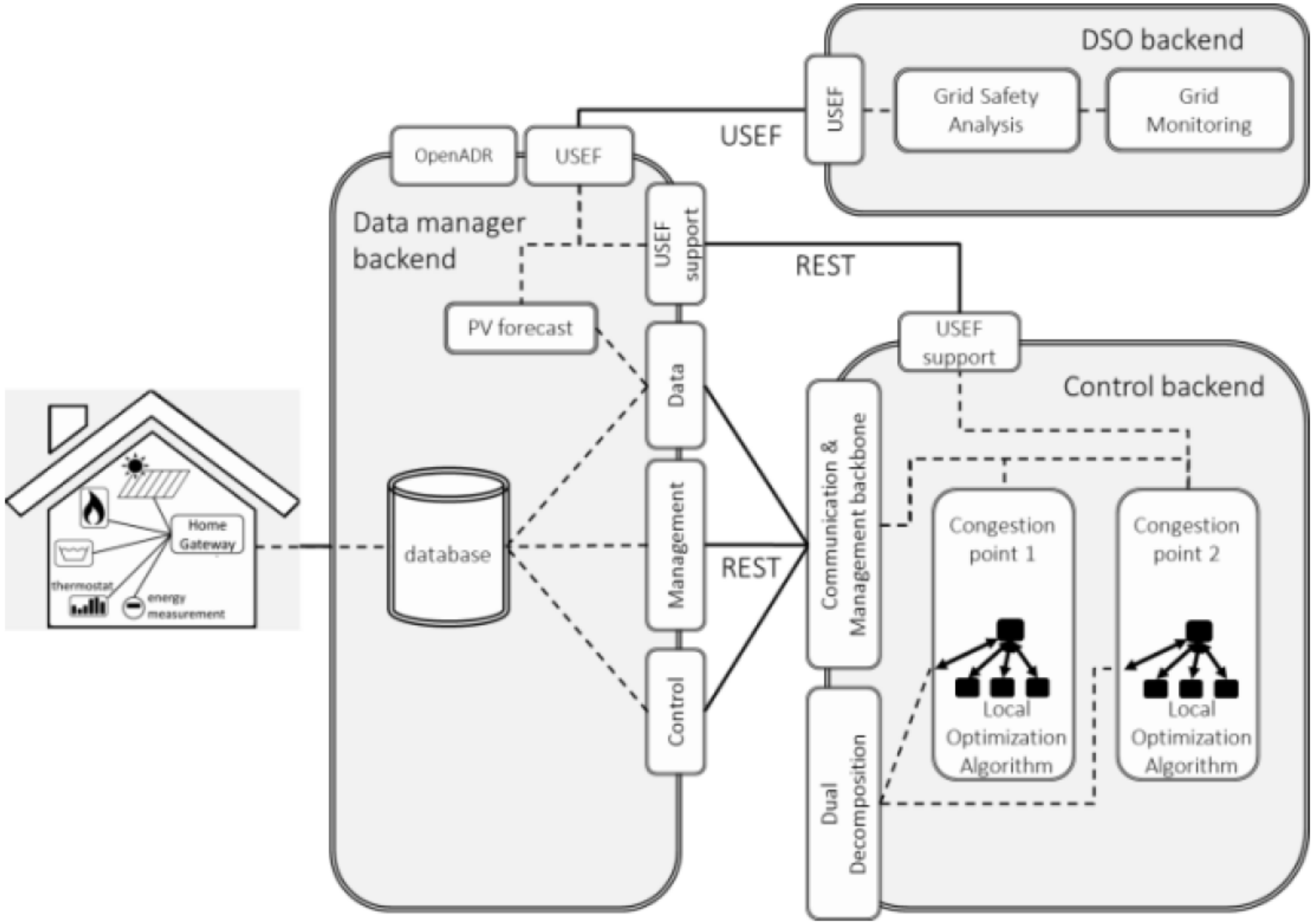
AIM: **Optimally schedule** the heating **cycles** of the **heat pump** and the working cycles of the battery to **maximize** the **self-consumption** of the local **PV** production.

Main contribution: *real-life implementation* of the self-consumption algorithm

5. Results from field tests

REnnovates Project

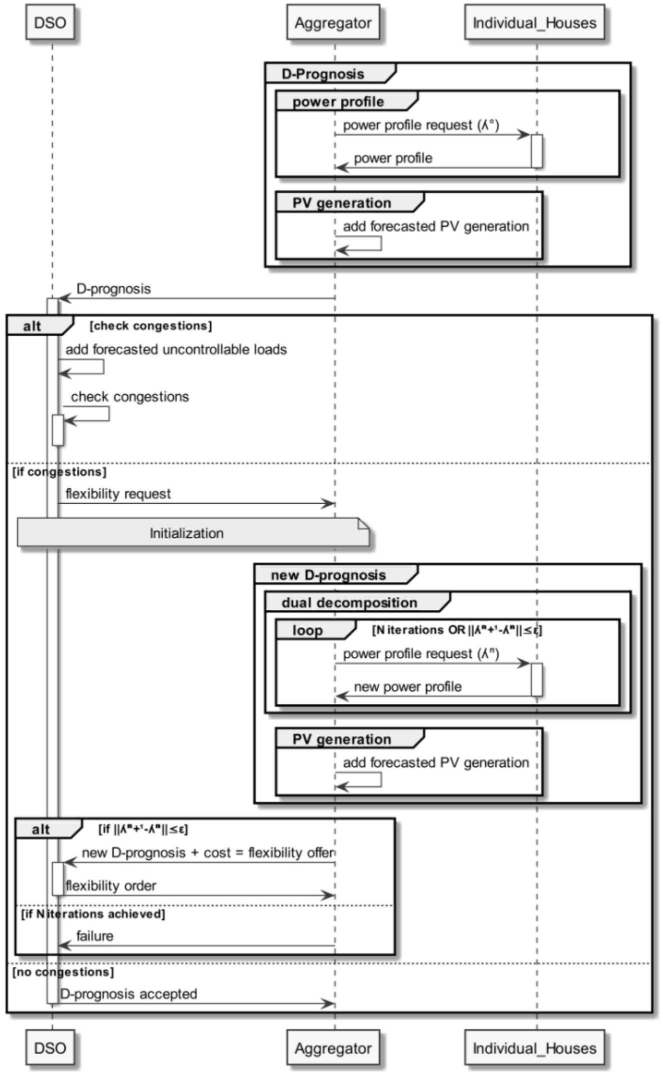
Overview of the REnnovates infrastructure - test field

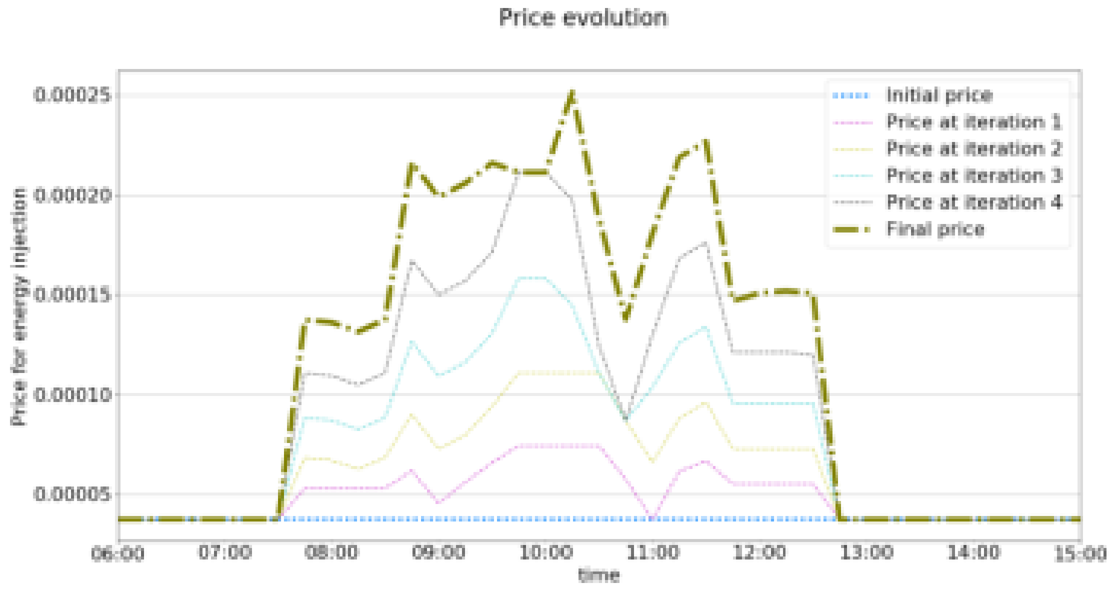


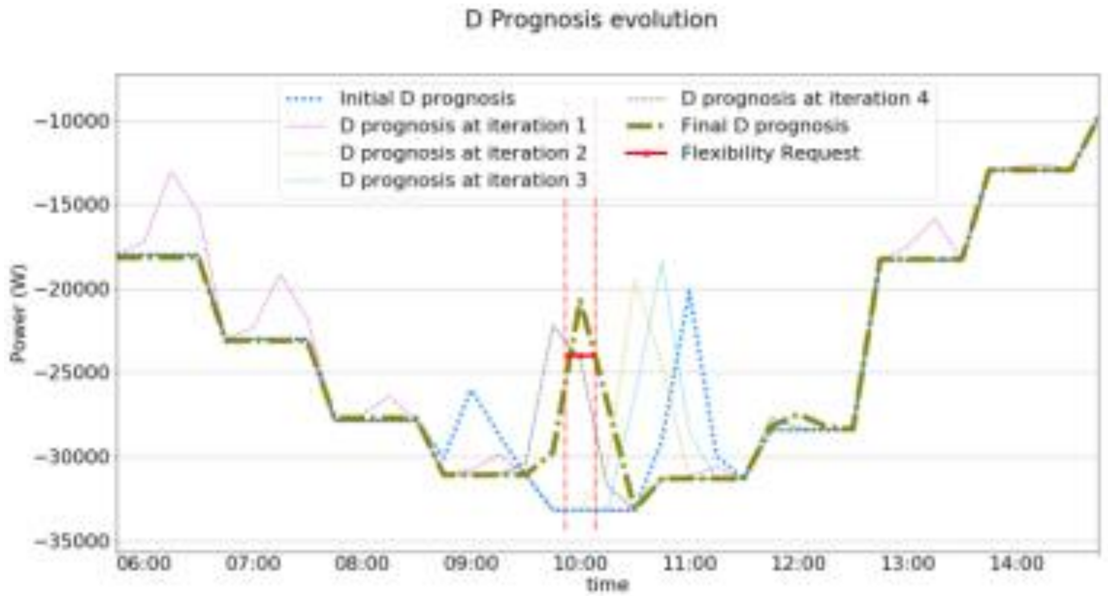
Source: "REnnovates." [Online]. Available: http://www.rennovates.eu/

5. Results from field tests

REnnovates Project



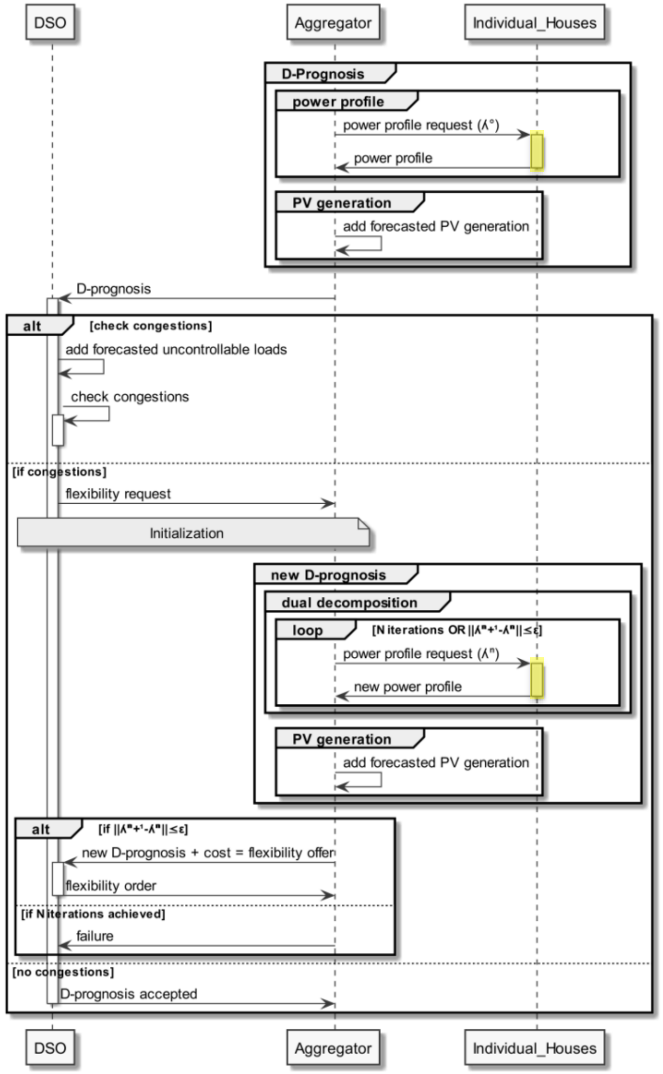


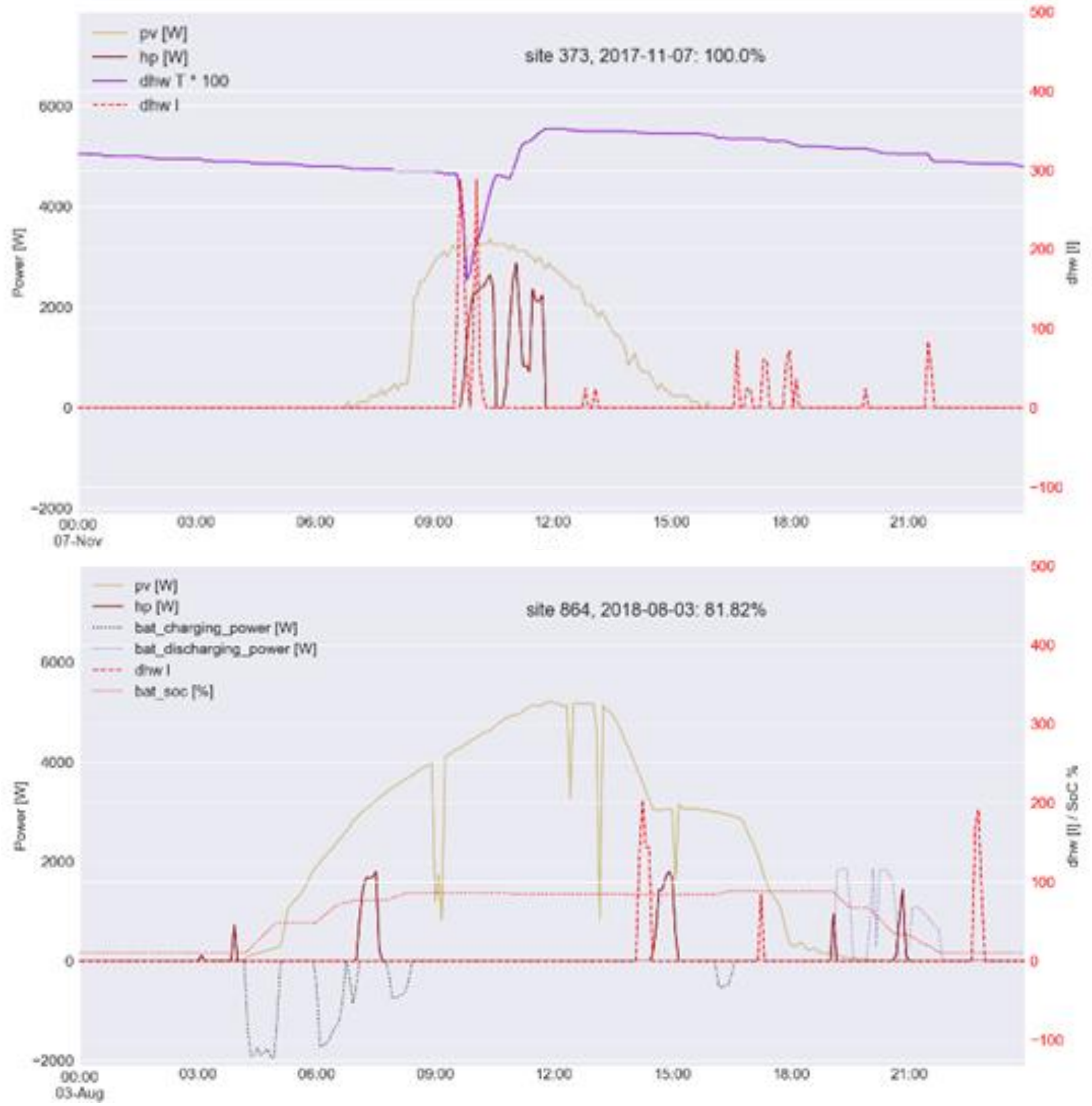


Source: A. Soares et al., "Distributed Optimization Algorithm for Residential Flexibility Activation - Results from a Field Test," IEEE Trans. Power Syst., pp. 1–1, 2018.

5. Results from field tests

REnnovates Project

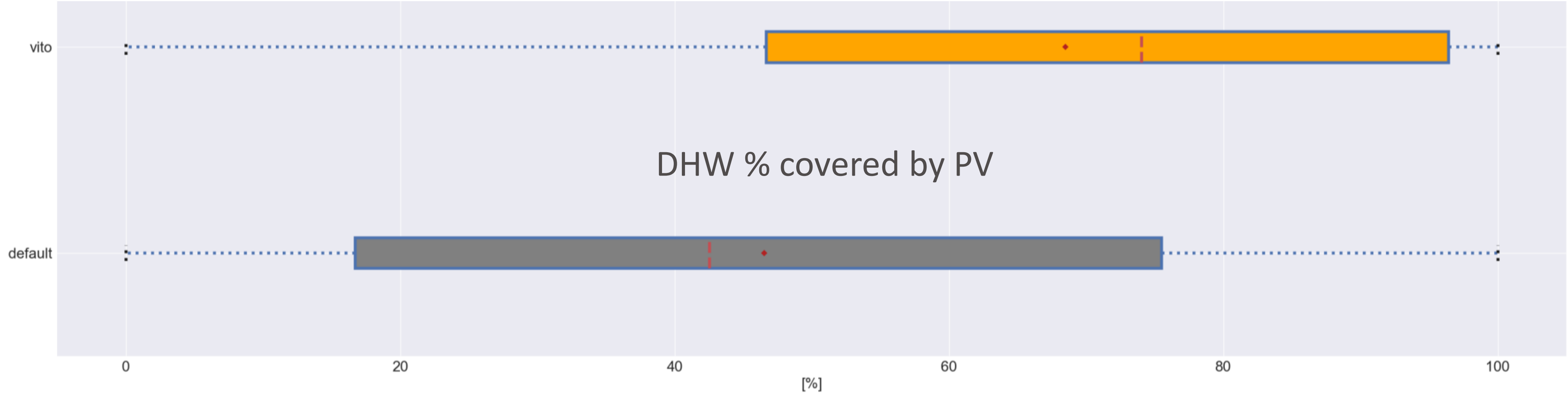




Source: A. Soares et al., "Distributed Optimization Algorithm for Residential Flexibility Activation - Results from a Field Test," IEEE Trans. Power Syst., pp. 1–1, 2018.

5. Results from field tests
REnnovates Project

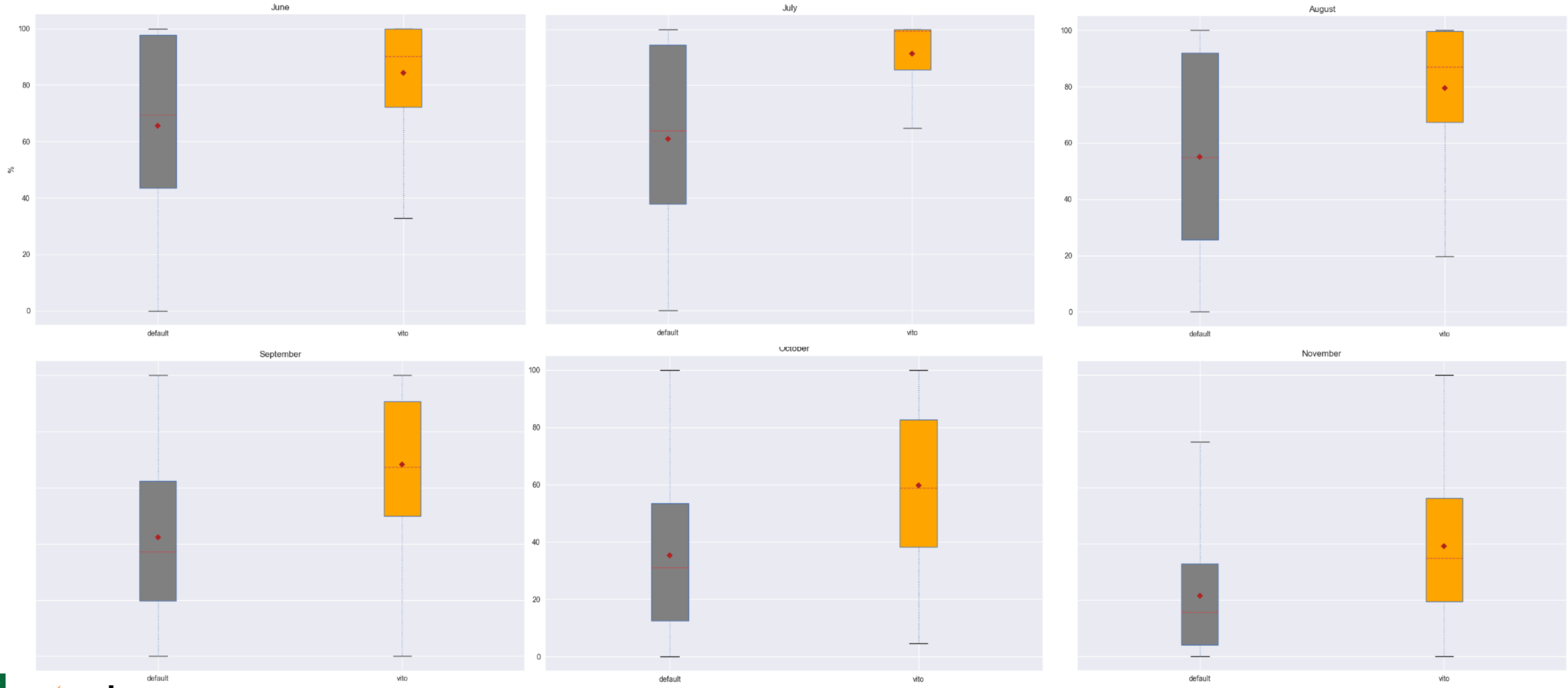
Box-plot showing the self-consumption percentage for two of the three types of control used in REnnovates: *default* (default thermostat control without smart control) and *vito* (PV self- consumption algorithm)



5. Results from field tests

REnnovates Project

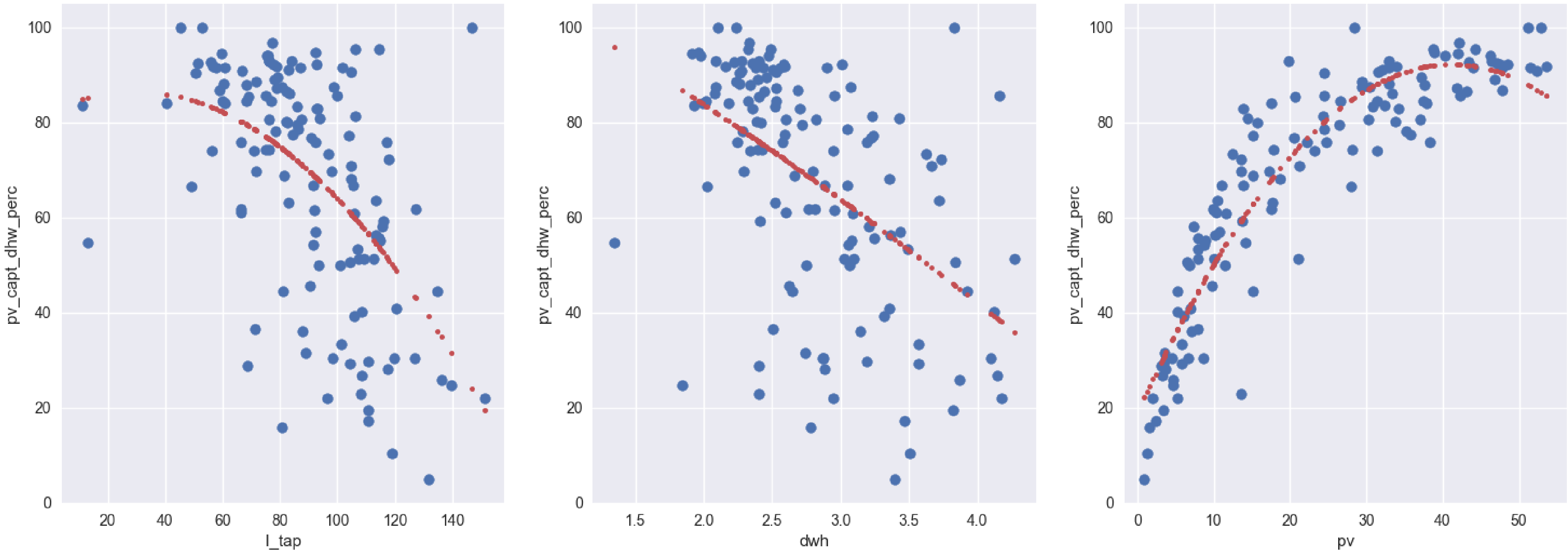
Box-plots per month showing the self-consumption percentage for two of the controls used in REnnovates: ‘default’ (default thermostat control without smart control) and ‘vito’ (PV self- consumption algorithm



5. Results from field tests

REnnovates Project

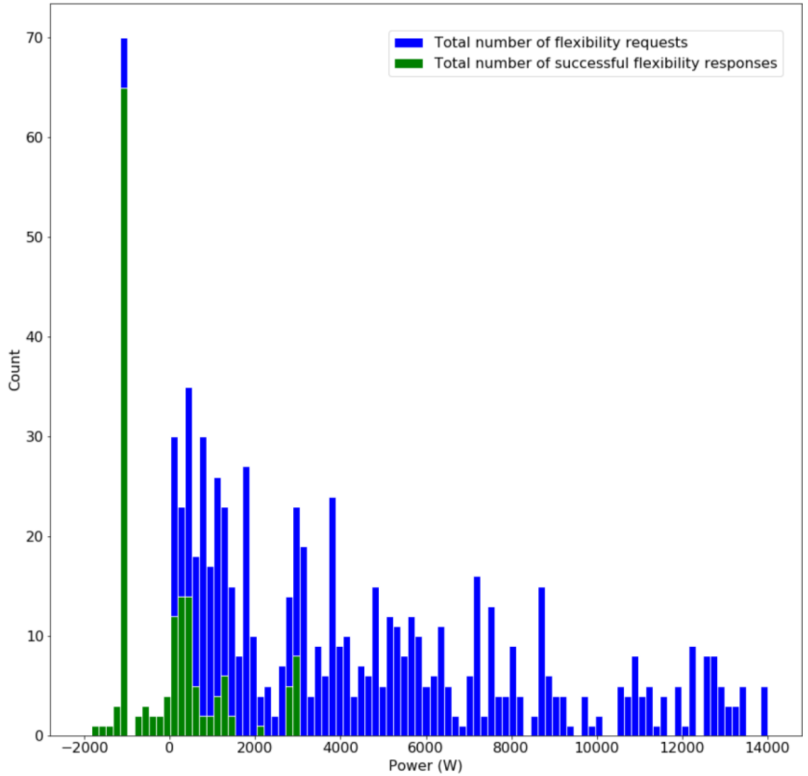
Plots with the correlations between the PV self-consumption performance and, respectively, the consumption of hot water, electrical energy consumed for DHW production and local PV generation (data from June to November 2017)

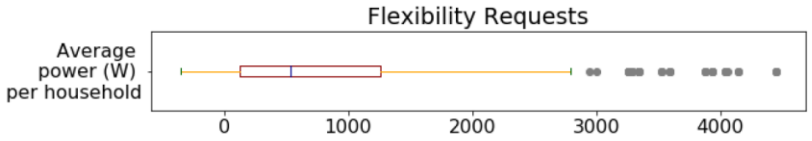


5. Results from field tests

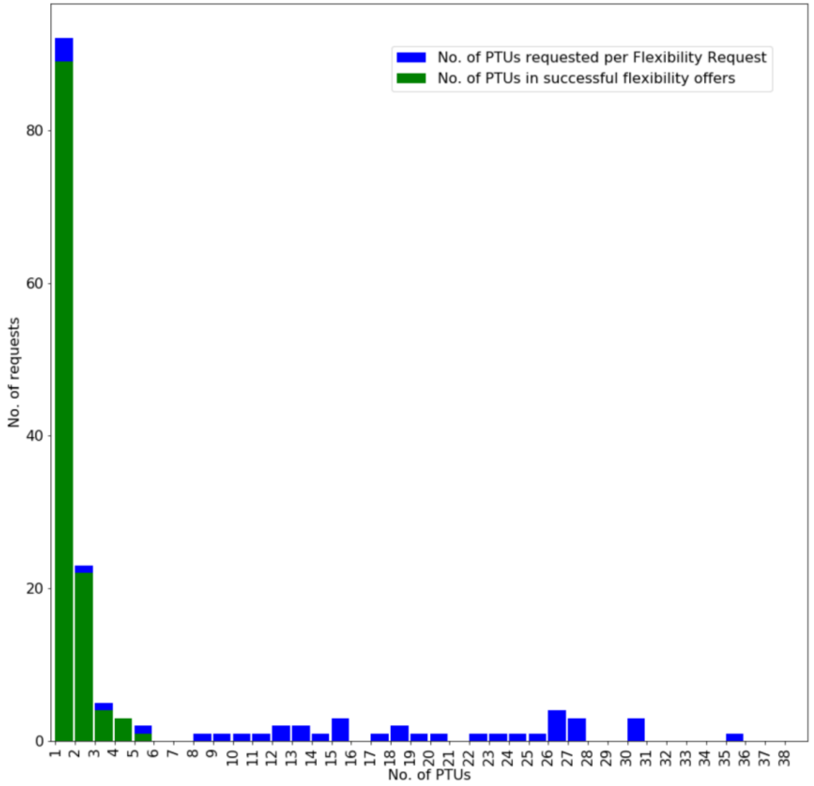
REnnovates Project

Amount of power requested per PTU in the flexibility





PTUs during which flexibility is requested and successful flexibility offers



Source: A. Soares et al., "Distributed Optimization Algorithm for Residential Flexibility Activation - Results from a Field Test," IEEE Trans. Power Syst., pp. 1–1, 2018.

6. Other Projects

FHP (Flexible Heat and Power)

- connecting heat and power networks by harnessing complexity in distributed thermal flexibility)
- mitigate (local) RES curtailment by means of a coordinated control of clusters of heat pumps and large Power-to-Heat conversion and storage vessels, taking the local grid conditions into account

SmarThor

- Data cloud for intelligent combined power and heat network within ThorPark
- DSM is included through the building management systems

STORY

- demonstrate and evaluate innovative approaches for energy storage systems in residential and industrial environments (residential and industrial levels)

6. Other Projects

SymbiOptima

- synergy and optimization of the flows of a cluster thanks to the hierarchical decentralization of operations management tasks to multiple collaborating Production Units

STORM

- focus on thermal energy from various sources in district heating networks
- DSM entailed on storage and excertion of thermal energy
- use of self-learning algorithms to increase the use of waste heat and renewable energy sources (optimization of DHC)

SmartNet

- Smart TSO-DSO interaction schemes, market architectures and ICT solutions for the integration of ancillary services from demand side management and distributed generation

7. Conclusion

Challenges and opportunities of DR

- flexibility potential associated with DR varies along the day
- the potential for increasing or decreasing power consumption is in general not equal
- uncertainty and dynamics
  - stochastic approaches
  - machine learning
- hierarchical or decentralized?

➢ Simpler ➢ Single point of control ➢ More compatible with integrated companies ➢ …	*vs.*	➢ More scalable ➢ No single point of failure ➢ More compatible to liberalized market model ➢ …

- decentralized interaction and interference
  - multi-agent simulations, peer-to-peer computing
  - game theory
- cybersecurity and dependability
- from smart electric power systems to smart multi-carrier energy systems
- scalability to millions of devices, interoperability
  - inspiration from cloud computing, big data

8. Quick Sneak Peek into our Home Lab

What is it?

A real life test infrastructure for home energy management systems, residential demand response technologies involving smart appliances and in-home communication systems.

What can we do there?

The Home Lab enables the testing of residential energy management systems, communication systems, novel optimization algorithms, etc. in real life conditions.

8. Quick Sneak Peek into our Home Lab

What about infrastructure?

- Two residential electrical distribution boards, each of which represents a household;
- A flexible electrical connection system that facilitates devices and appliances to be connected in any single or three-phase configuration to the distribution boards;
- All measurement and peripheral equipment is powered separately as to not influence test results;
- Each electrical node is individually measured for a wide range of electrical parameters;
- Measurement data is automatically synchronized and stored in a central database. Via the dedicated interface configuration, management of the measurement campaigns is easy;
- Each electrical connection point is equipped with an Ethernet connection that is part of an ICT infrastructure. Each of these connection points can be routed into any number of parallel secured, open or islanded network configuration;
- The Home Lab is equipped with an external internet connectivity.

8. Quick Sneak Peek into our Home Lab

Some Technical Notes

The EnergyVille Home Lab set-up enables the integrated testing of products and services that are key to the implementation of Smart Grids, such as home energy management systems, residential demand response technology and in-house communication technology.

Periphericals

- A programmable load (10kW) with a dedicated interface that allows for easy configuration of consumption profiles
- A PV inverter simulator (2.5 kW)
- A PV panel simulator (2 kW)
- Multiple types of smart meters, energy management systems, smart plugs
- Multiple smart appliances, including state of the art smart washing machines, dishwashers, tumble dryers, air conditioners and domestic hot water (DHW) buffers
- Various battery packs

Inter-lab connections

- The Home Lab can be connected to the Smart Grid Infrastructure Lab to set up low voltage distribution grid tests.
- The Home Lab can be connected to the Thermo Technical Lab in order to include (smart) heat pumps, µCHPs and thermal storage components.

Thank you for your attention!

Questions?

Contact details:

Ana Soares

ana.soares@vito.be | ana.soares@energyville.be

Researcher Energy Technology | Algorithms, Models and Optimization

VITO NV | Boeretang 200 | 2400 Mol

EnergyVille 1 | Thor Park, Poort Genk 8310 | B-3600 Genk