Energy Flexible Buildings
IEA EBC Annex 67

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IEA EBC Technical day
Golden, November 12, 2019

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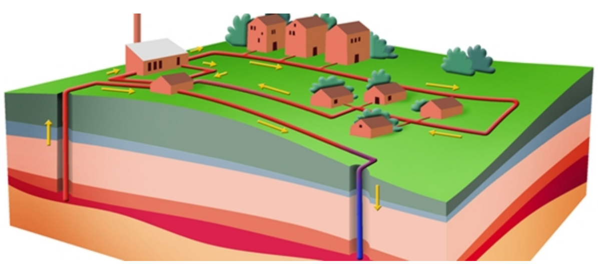
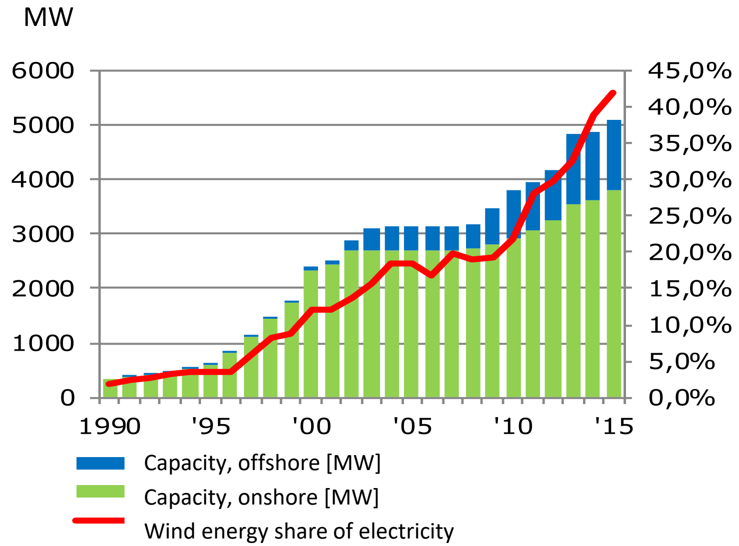
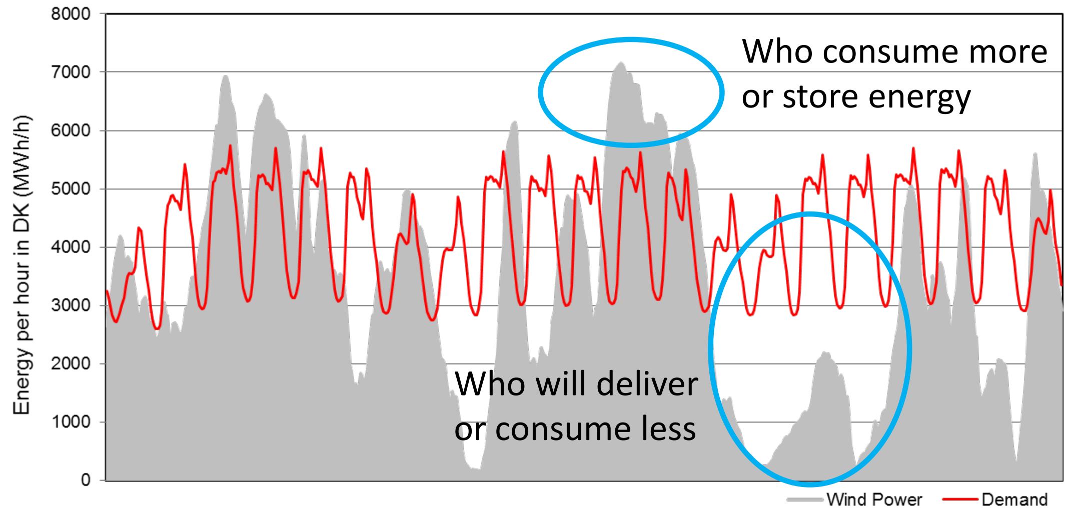
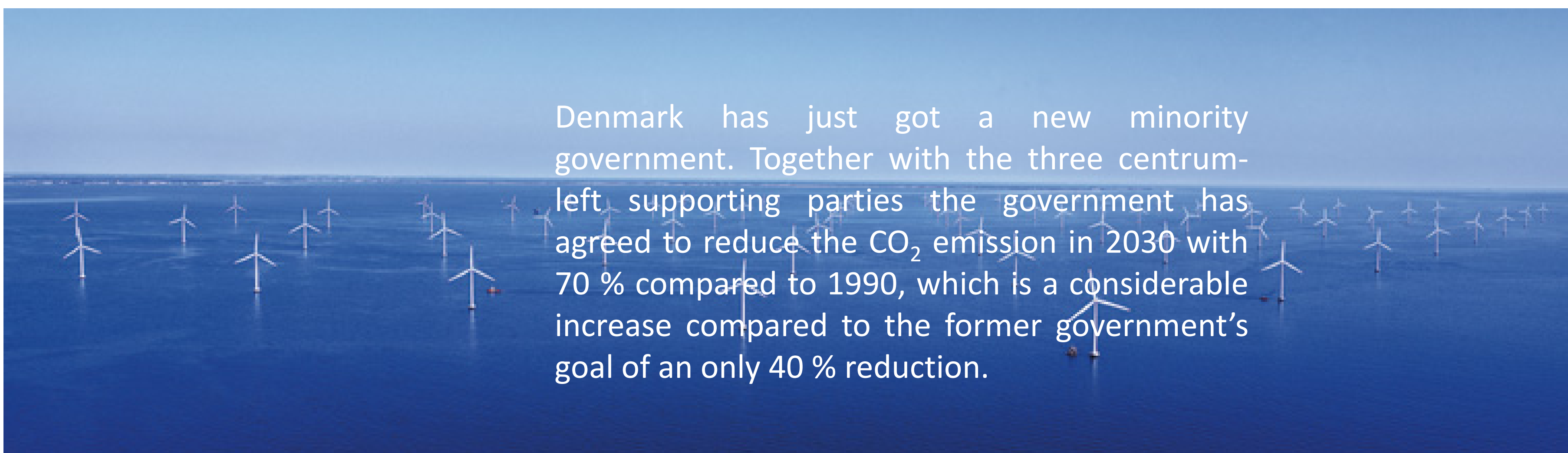
Common understanding that we need to replace fossil fuels with renewable energy



Example: Demnark
Goal: 50 % wind in power grid by 2020 and only RES in the total energy system by 2050







Denmark has just got a new minority government. Together with the three centrum-left supporting parties the government has agreed to reduce the CO_2 emission in 2030 with 70 % compared to 1990, which is a considerable increase compared to the former government's goal of an only 40 % reduction.

Solutions to large share of RES in the energy systems

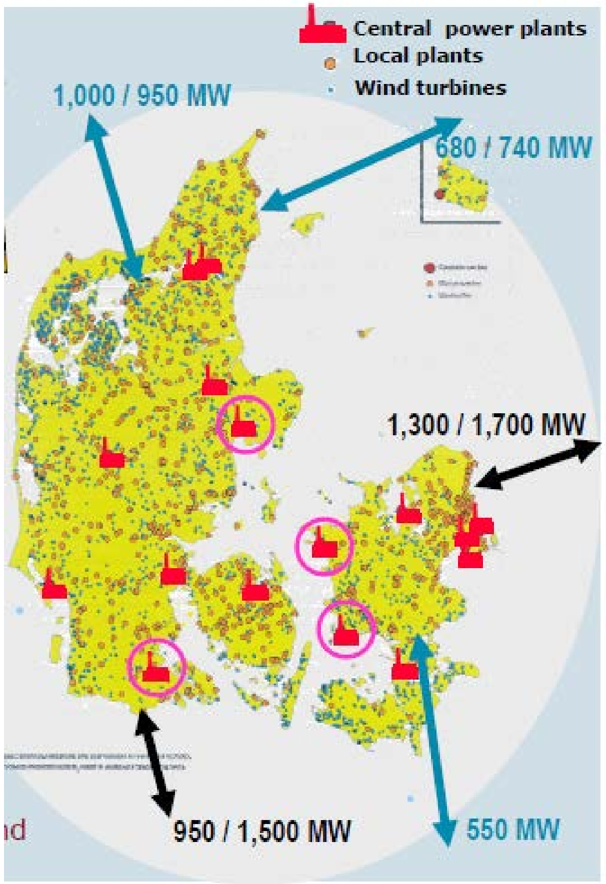
Large interconnectors - export/import

Heat pumps in district heating

Generation of hydrogen and upgrading of biogas

RES based fuel factories

Demand response – industry and buildings



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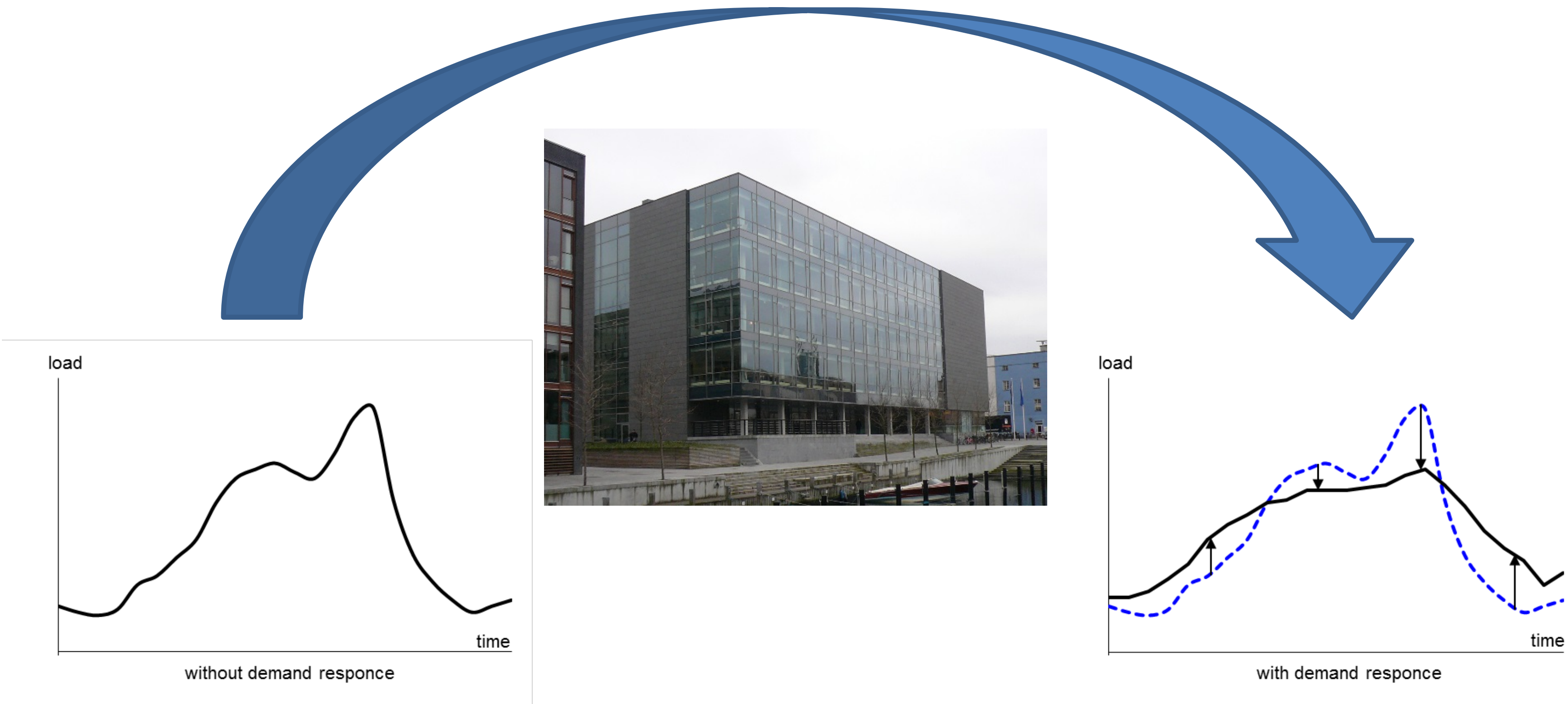
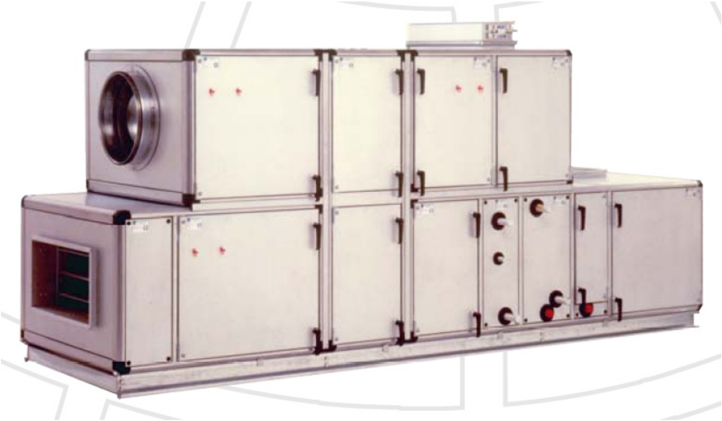
Most buildings have the ability to become energy flexible



Commercial buildings

ventilation systems



cooling systems

supermarkets

pumps

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Electricity demand in households

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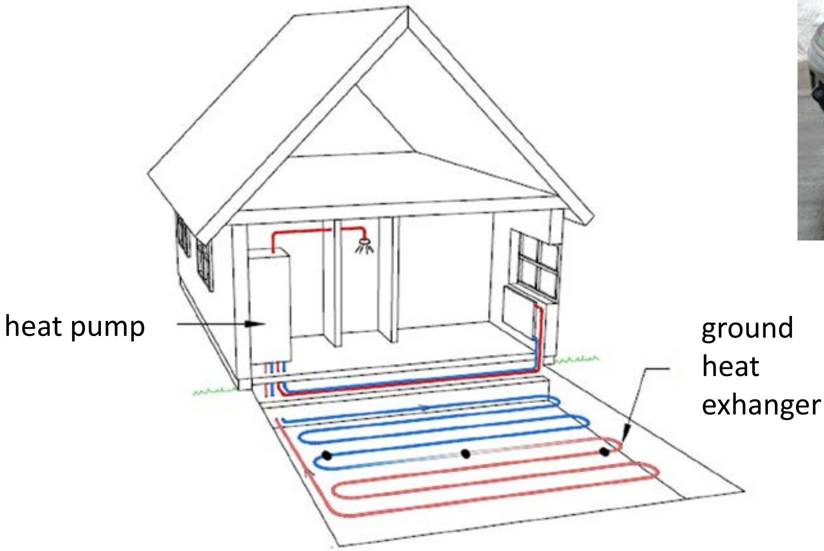
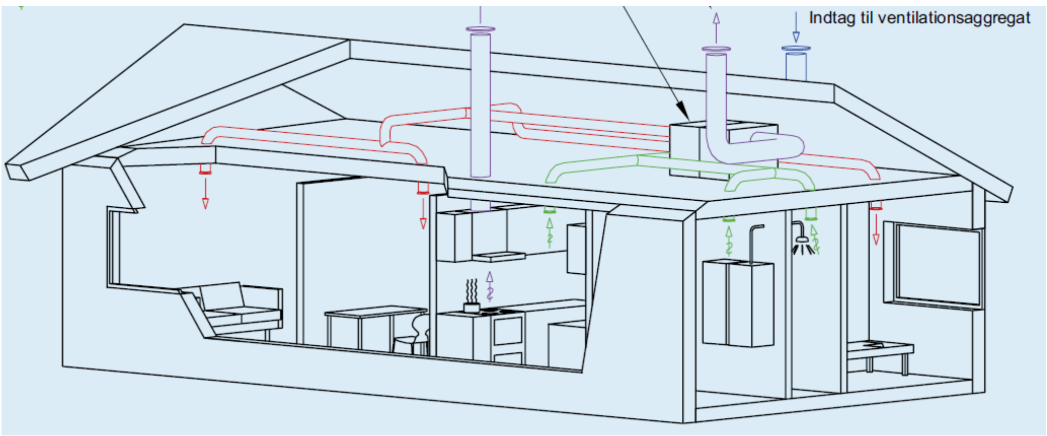
heat pumps (aircondition)



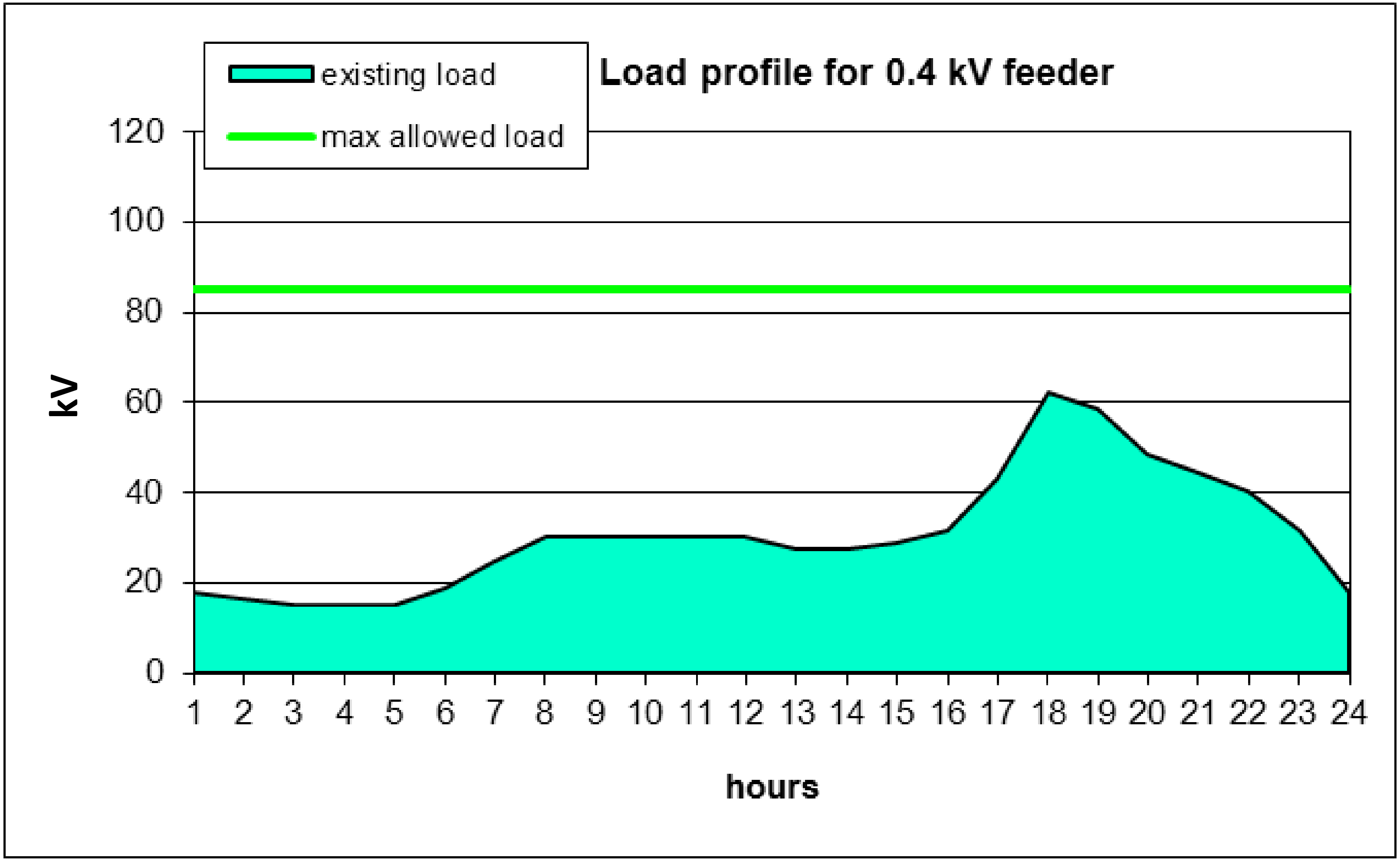
EVs

ventilation systems



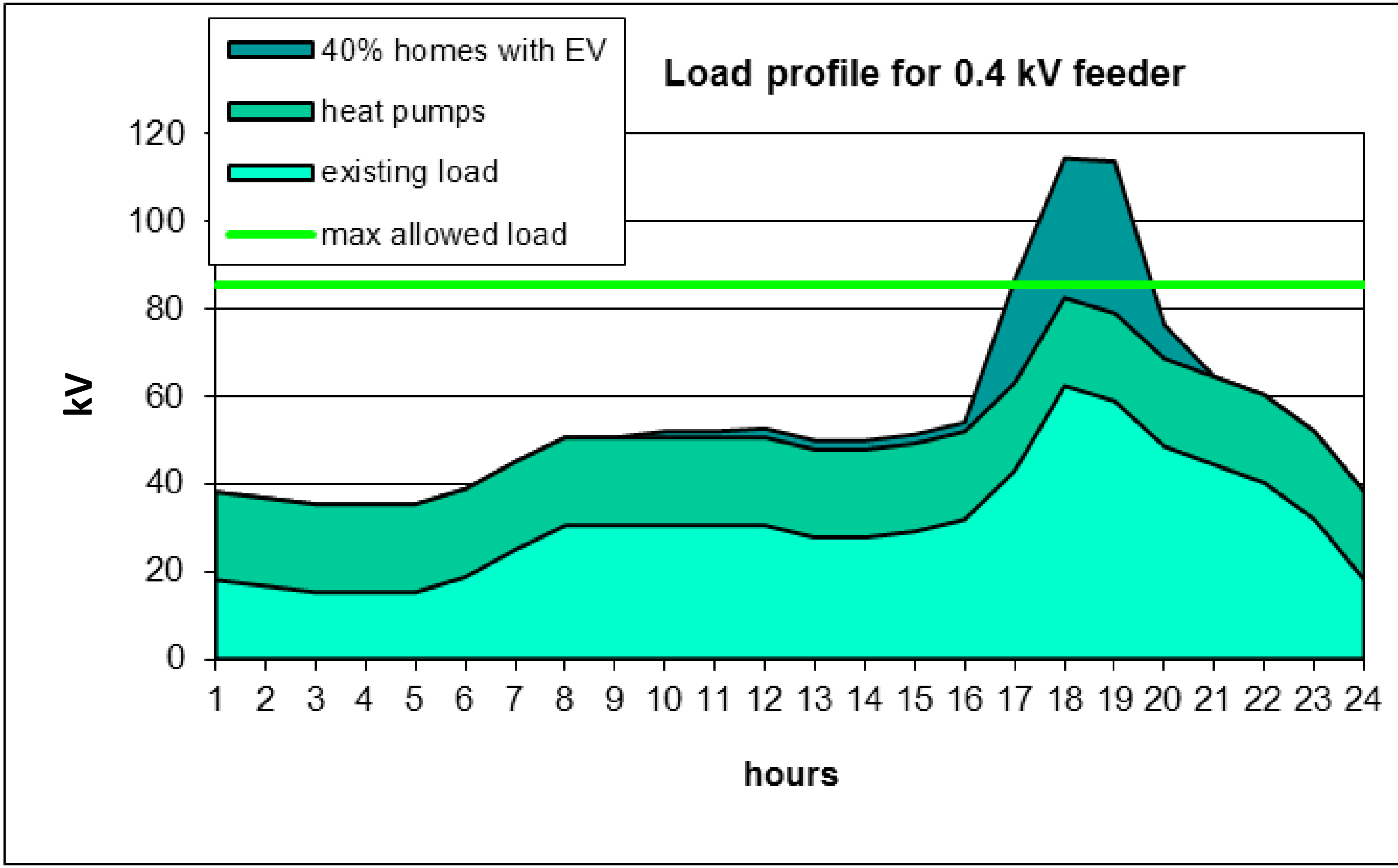
white goods

Example



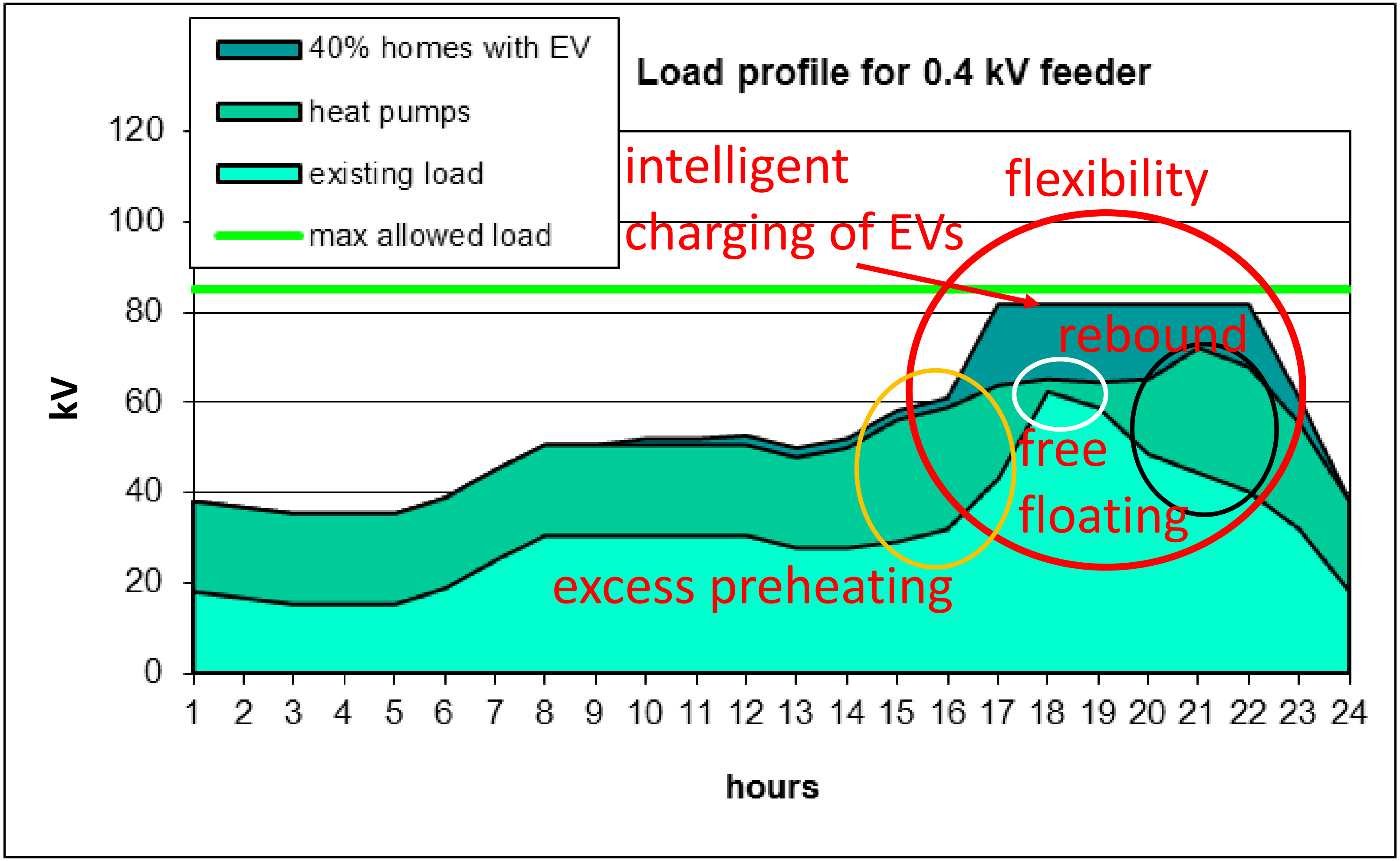
existing load
max allowed load
Load profile for 0.4 kV feeder
120
100
80
60
40
20
0
kV
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hours

Example



40% homes with EV
heat pumps
existing load
max allowed load
Load profile for 0.4 kV feeder
kV
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hours

Example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Load profile for 0.4 kV feeder
120
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80
60
40
20
0
kV
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hours
intelligent
charging of EVs
flexibility
rebound
free
floating
excess preheating

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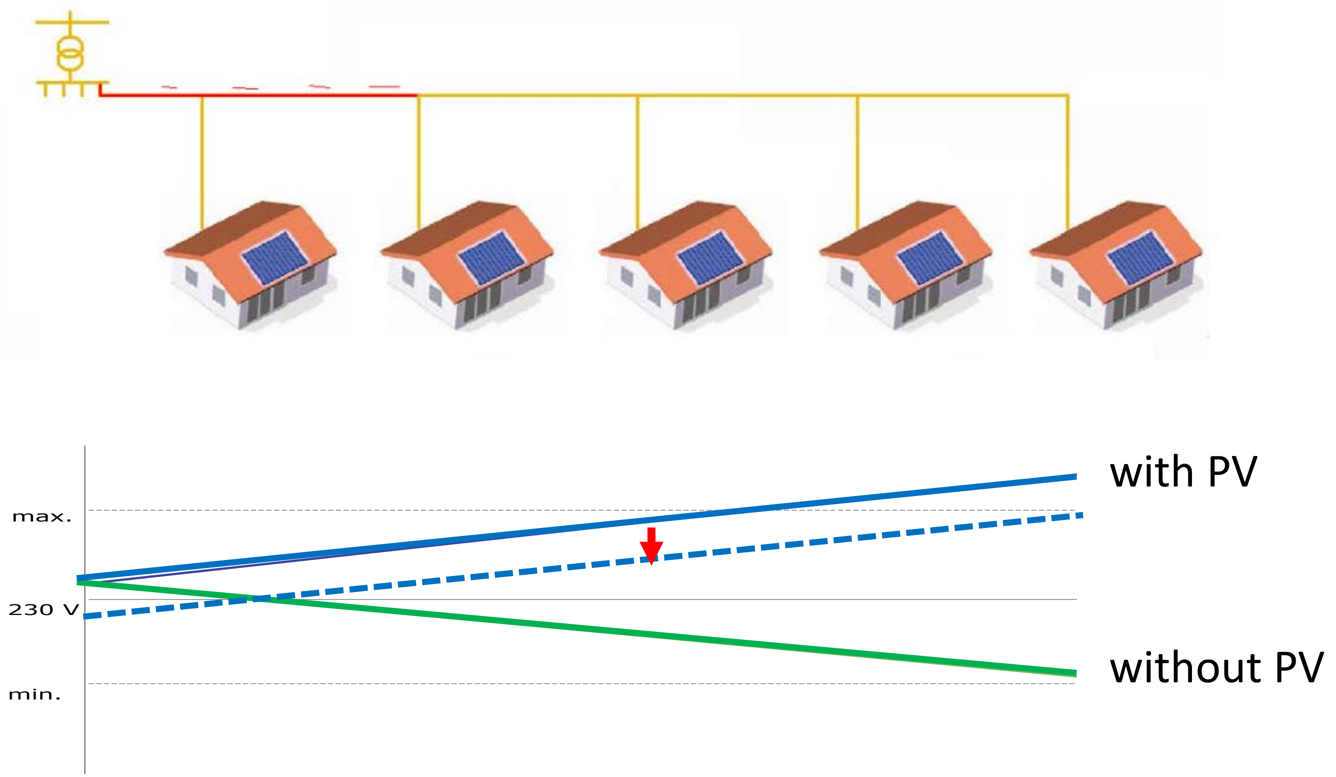
Prosumers

Voltage problems



European Union

Smart Readiness Indicators in EBPD (Energy Performance in Buildings Directive)

- The introduction of a smart readiness indicator rating the readiness of the building to adapt its operation to the needs of the occupant and the grid, and to improve its performance
- The smart readiness indicator should be used to measure buildings' capacity to use ICT and electronic systems to optimise operation and interact with the grid

Smart readyness indicator in EPBD

Annex 67 has written a Position paper

There is a need for an approach that takes in to account the dynamic behavior of buildings rather than a static counting and rating of control devices. It is further important to minimize the CO_2 emission in the overall energy networks rather than optimize the energy efficiency of the single energy components in a building.

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Energy Flexibility as a key asset in a smart building future

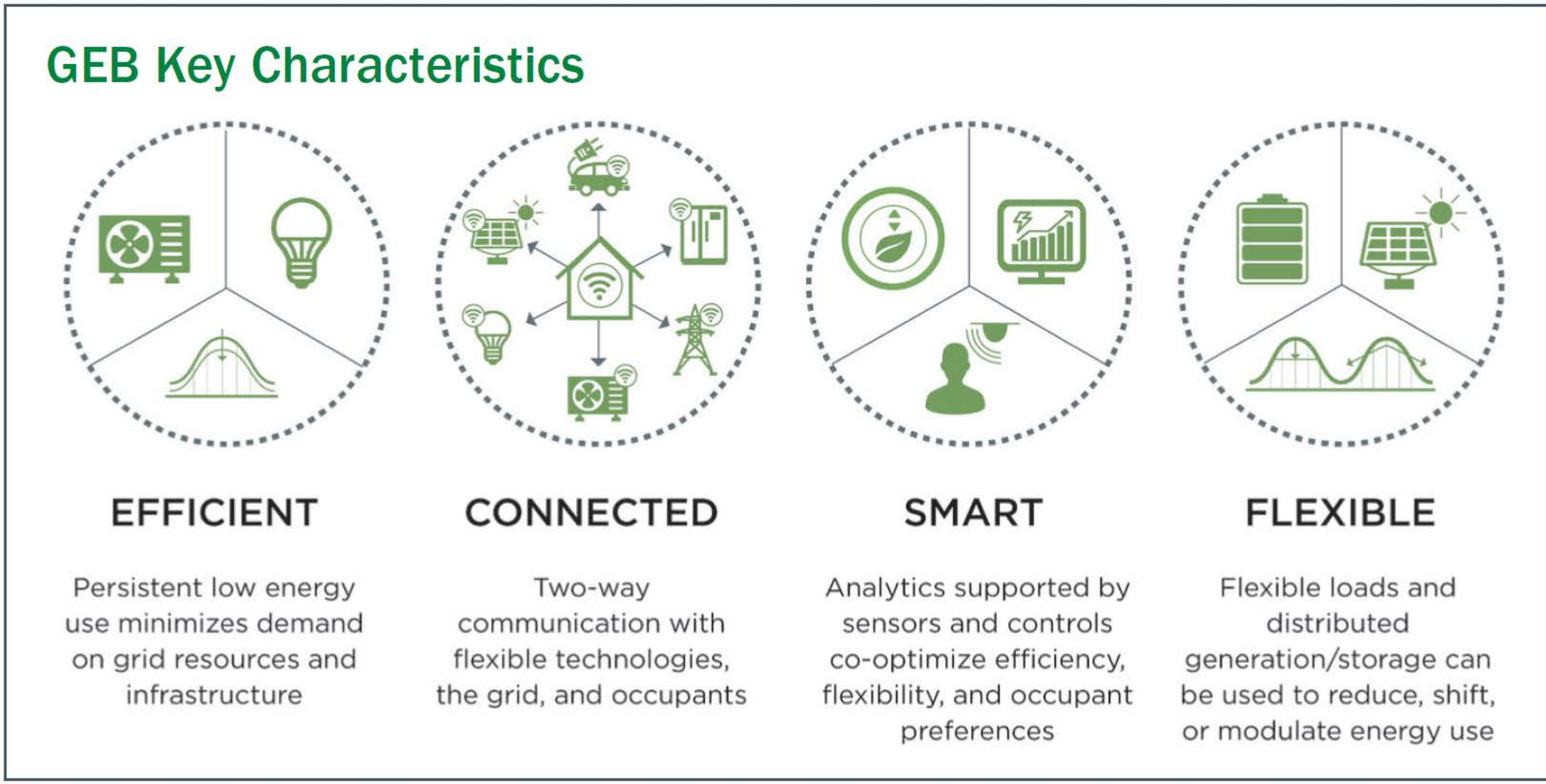
Contribution of Annex 67 to the European Smart Building Initiatives

Position Paper of the IEA Energy in Buildings and Communities Programme (EBC) Annex 67 "Energy Flexible Buildings"

October 2017

http://annex67.org/media/1470/position-paper-energy-flexibility-as-a-key-asset-i-a-smart-building-future.pdf

US DOE
Grid-interactive Efficient Buildings



https://www.energy.gov/sites/prod/files/2019/04/f61/bto-geb_overview-4.15.19.pdf

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IEA EBC Annex 67
Energy Flexible Buildings

June 2014 – June 2015: Preparation phase: done

June 2015 – June 2018: Working phase: done

June 2018 – November 2019: Reporting phase: nearly final

A follow-up annex is being considered:

Preparation workshop, September 19-20, 2019

Possible new workshop: Week 14, 2020 in Barcelona

Annex 67 work plan

Subtask A: Definitions and Context

- Common terminology and definition of Energy Flexibility in buildings
- Methodology for characterization of Energy Flexibility in buildings
- User needs, motivation and barriers for application of EF in building
- Market analysis

Subtask B: Analysis, Development and Testing

- Simulation of Energy Flexibility in single buildings and clusters of buildings
- Control strategies and algorithms
- Laboratory tests of components, systems and control strategies
- Example cases and design examples

Subtask C: Demonstration and User Perspectives

- Measurements in existing buildings
- Demonstration of Energy Flexibility in real buildings and clusters
- User motivation and acceptance

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Participating countries

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- Austria
- Belgium
- Canada
- China
- Denmark
- Finland
- France
- Germany
- Ireland
- Italy
- Norway
- Portugal
- Spain
- Switzerland
- The Netherlands
- UK

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Residual loads 2030

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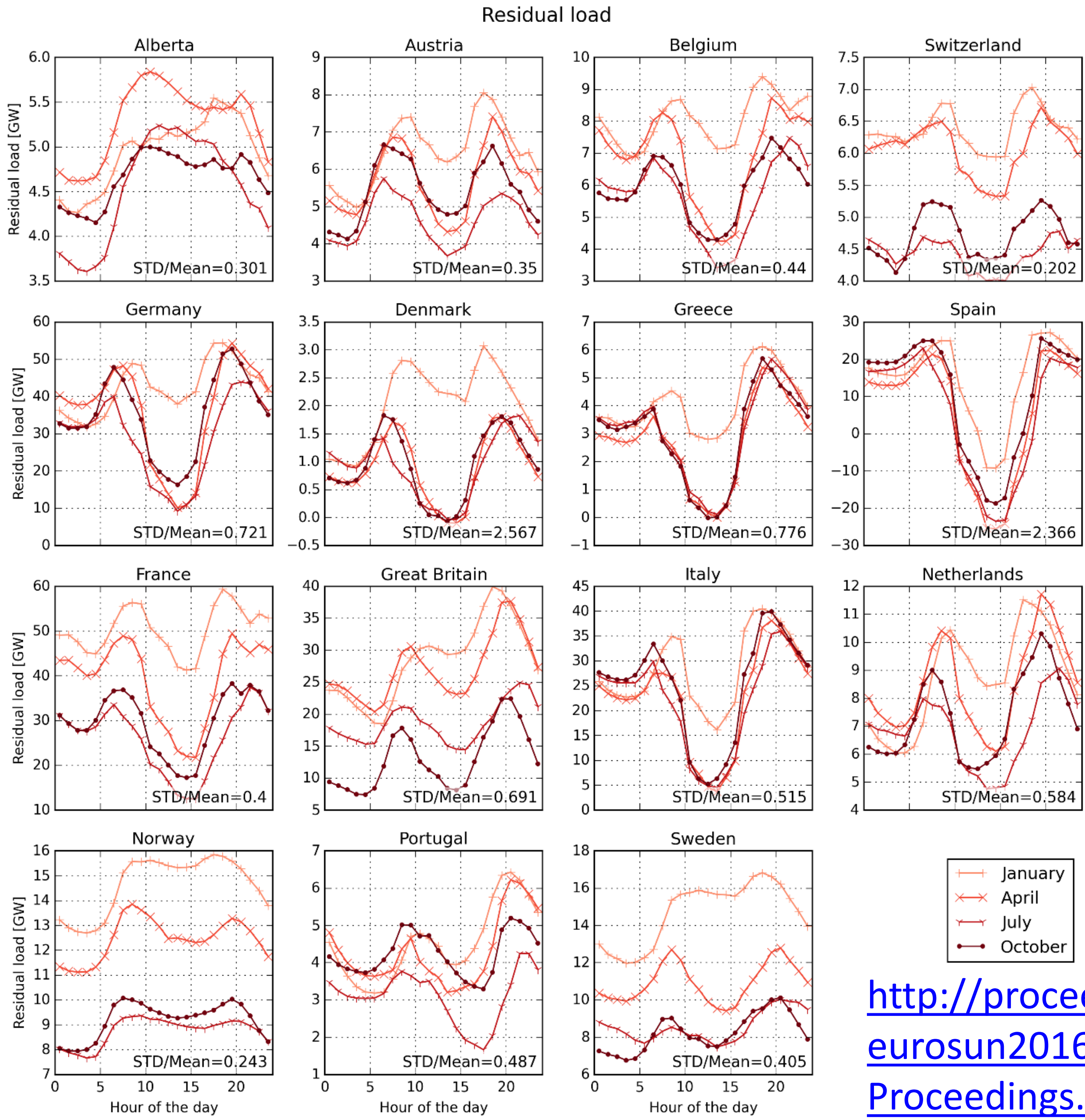
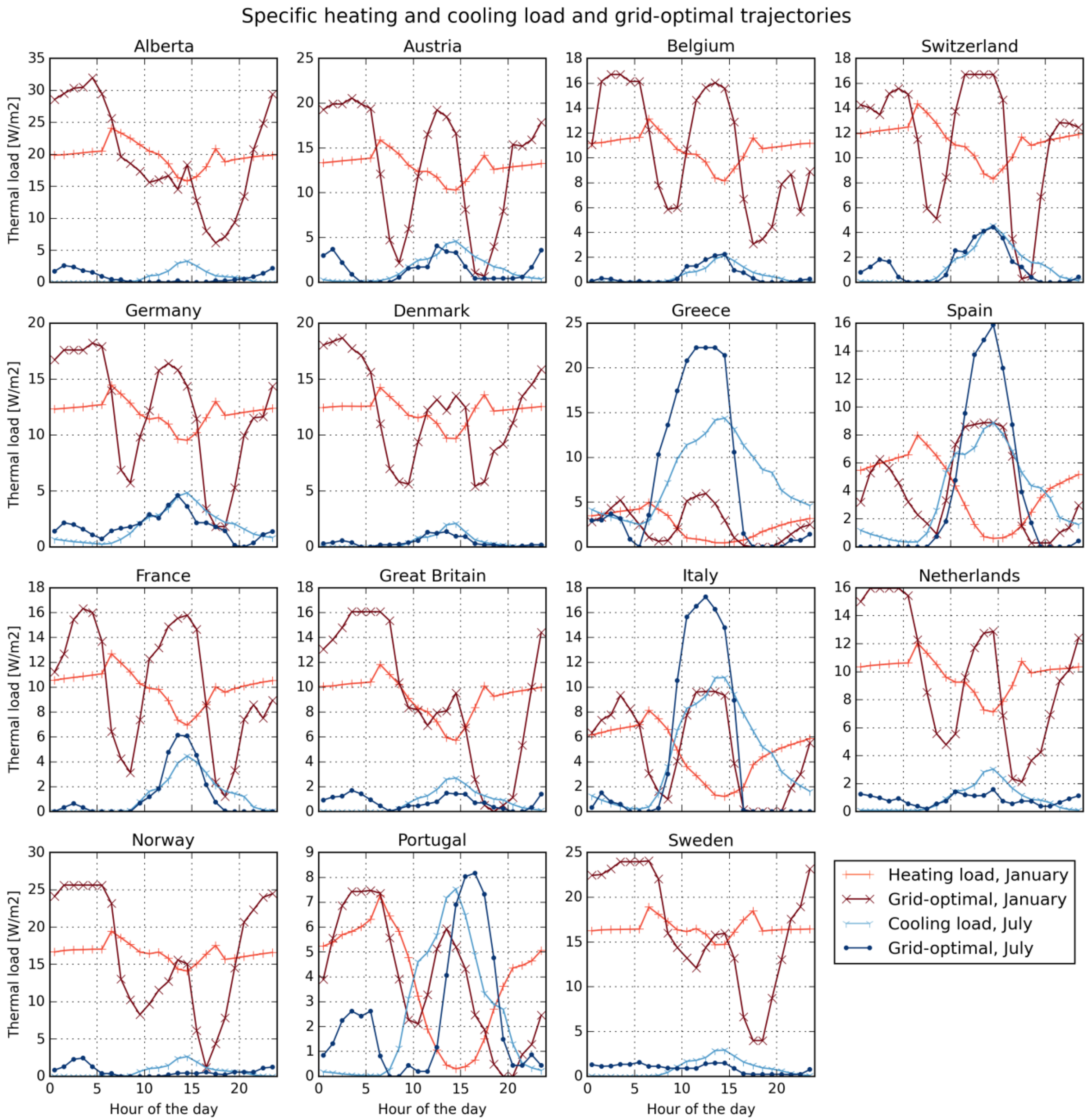


http://proceedings.ises.org/eurosun2016/EuroSun2016-Proceedings.pdf

Grid optimized performance



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Grid optimized performance

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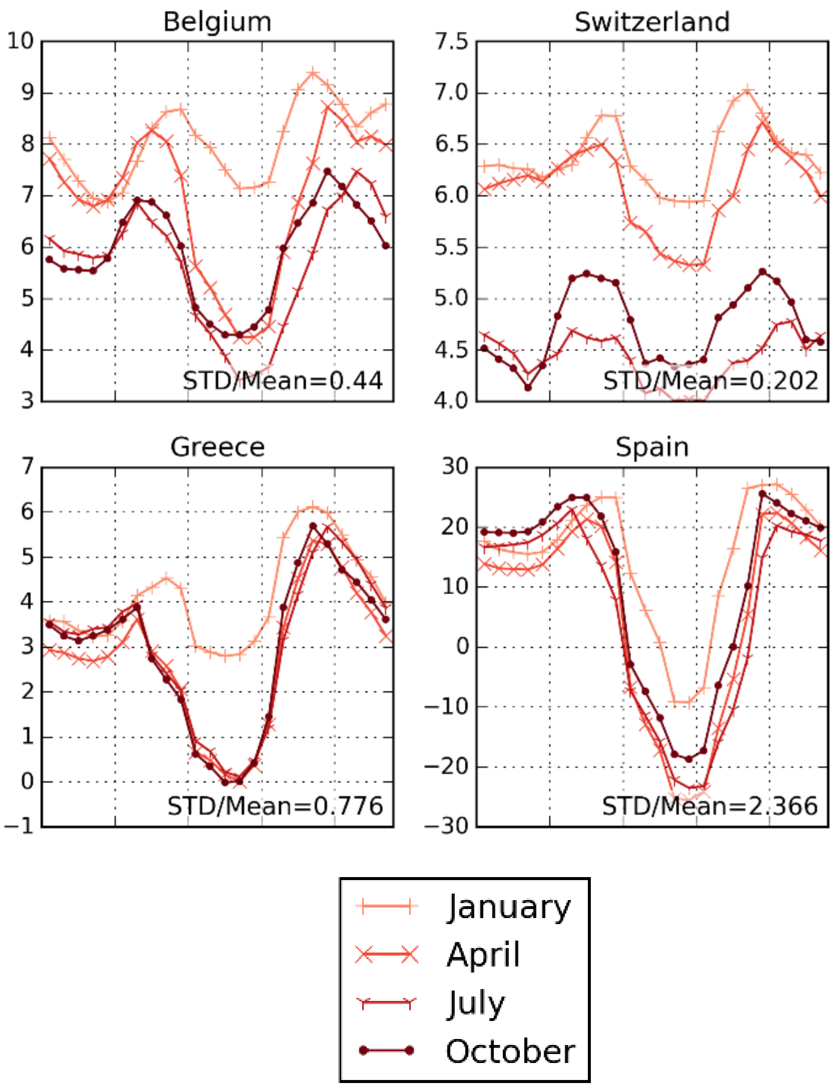
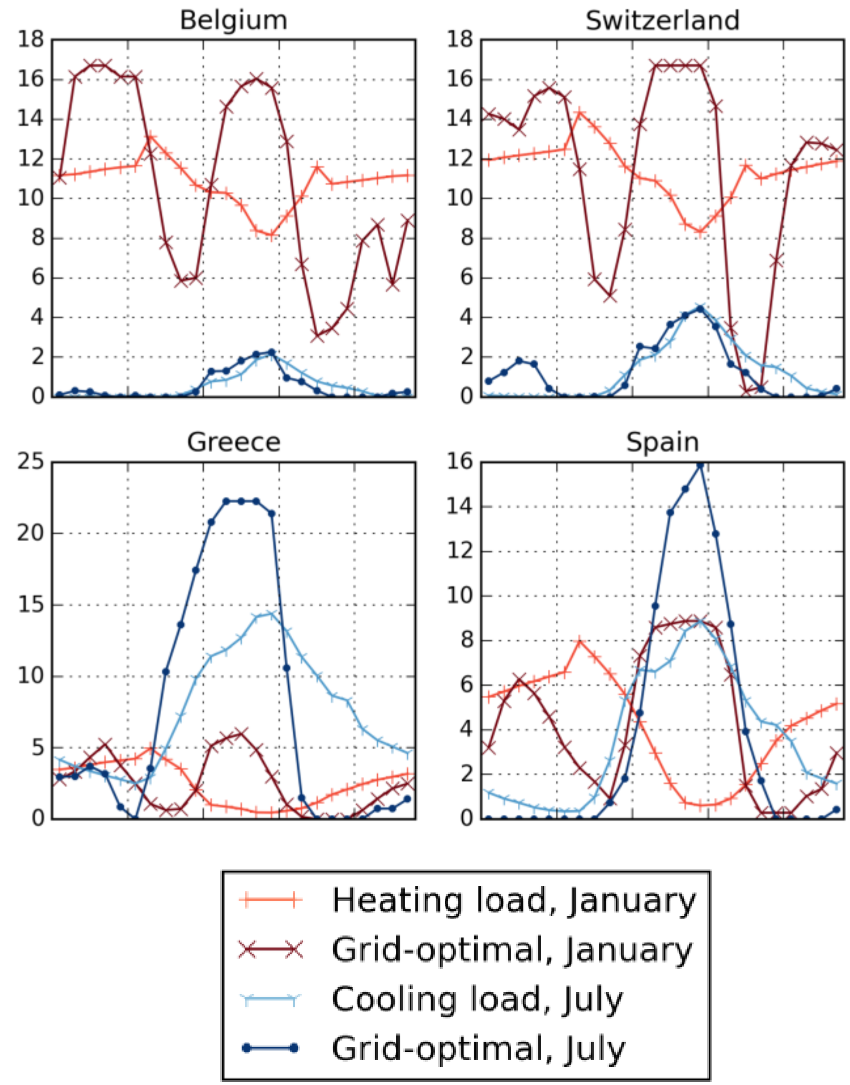
Residuals



Grid optimized performance



Website

annex67.org

Website

annex67.org

Publications

Here you can find publications connected to the project.

- Articles
- Conference papers
- Position paper
- Reports
- Software
- Deliverables
- Seminar

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Deliverables from Annex 67

- **Principles of Energy Flexible Buildings** summarizes the main findings of Annex 67 and targets all interested in what Energy Flexibility in buildings is, how it can be controlled, and which services it may provide.
- **Characterization of Energy Flexibility in Buildings** presents the terminology around Energy Flexibility, the existing indicators used to evaluate the flexibility potential and how to characterize and label Energy Flexibility.
- **Stakeholder perspectives on Energy Flexible buildings** displays the view point of different types of stakeholders towards Energy Flexible Buildings.
- **Control strategies and algorithms for obtaining Energy Flexibility in buildings** reviews and evaluates control strategies for Energy Flexibility in buildings.
- **Experimental facilities and methods for assessing Energy Flexibility in buildings** describes several test facilities including experiments related to Energy Flexibility and draws recommendations for future testing activities.
- **Examples of Energy Flexibility in buildings** summarizes different examples on how to obtain Energy Flexible Buildings.
- **Project Summary Report** brief summary of the outcome of Annex 67.

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Examples of Energy Flexibility in Buildings

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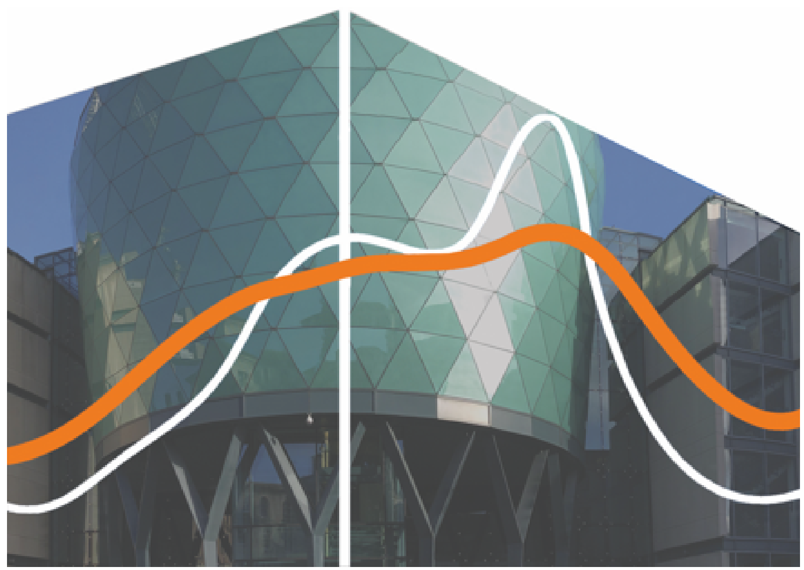
September 2019



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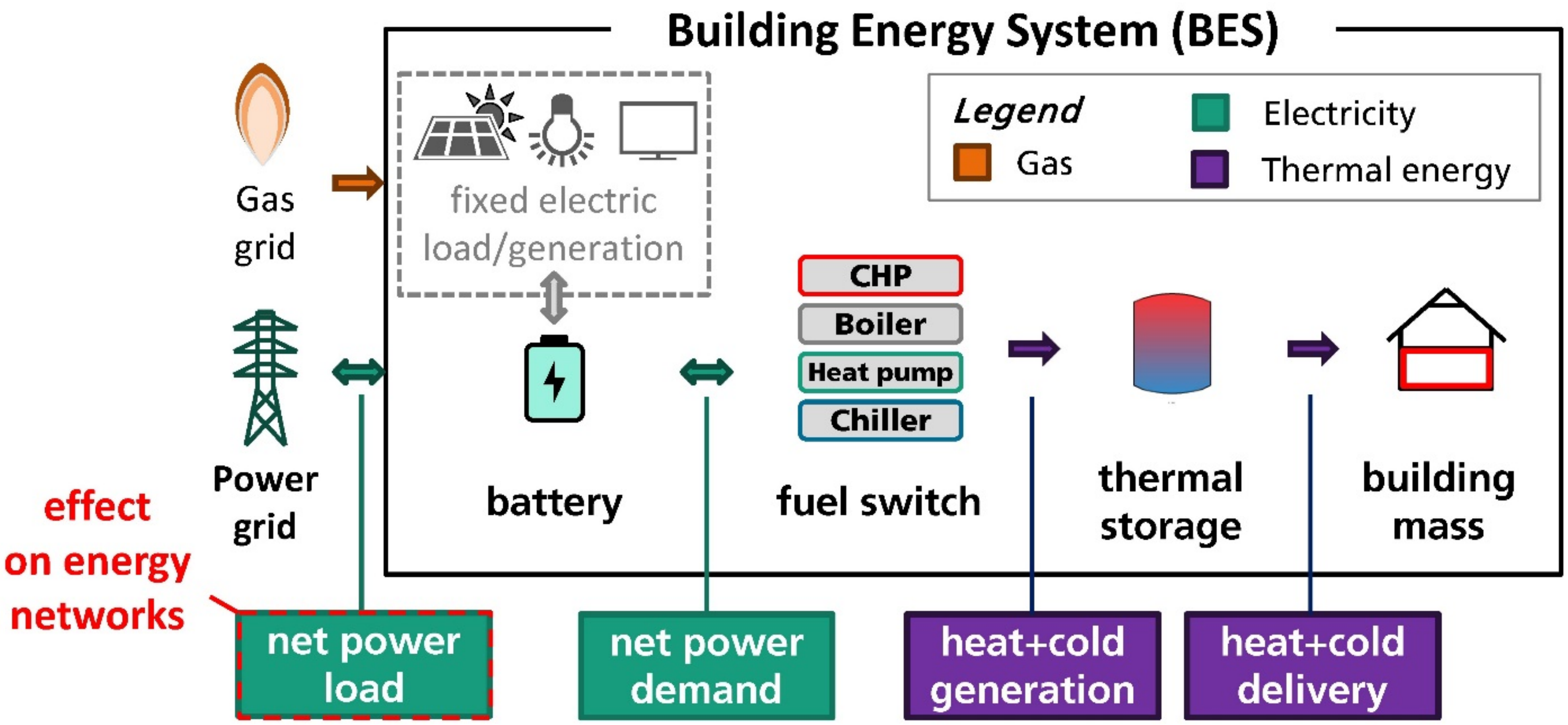
by iea

Energy Flexibility of buildings



Examples

	Building typology				Energy system				Source of flexibility				Control system		Results based on	
Chapter	Single-family house	Multi-family house	Non-residential building	Cluster of buildings	Heat pump	District heating	Other HVAC systems	PV	Constructions	Thermal storage	Batteries	Fuel switch	Rule based	Model based	Simulation	Measurements
3	X								X				X		X	
4	X								X				X		X	
5		X				X			X				X		X	
6	X	X				X	X		X				X		X	
7		X			X			X	X	X			X		X	X
8	X				X					X				X	X	
9	X				X		X		X	X		X		X	X	
10	X			X	X				X	X				X	X	
11	X			X		X		X	X				X		X	
12			X				X		X				X			X
13			X								X			X		X
14			X				X	X			X		X			X
15			X					X	X	X	X		X		X	X
16			X		X		X		X	X	X	X			X	
17			X						X					X	X	
18			X	X		X								X	X	X

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Examples

03 DK

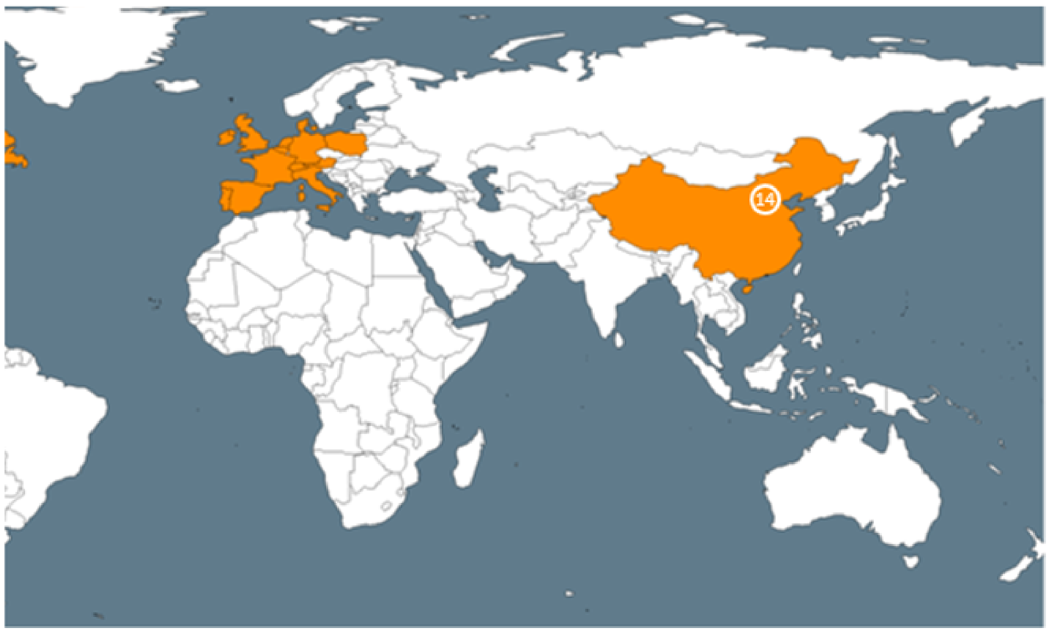
04 FR

05 DK

06 AT

07 CH

08 NL SP PL



09 DE

10 BE

11 IT

12 UK

13 UK IT FR DE

14 CN

15 PT

16 DE

17 DK

18 NL

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Examples

Chapter	Building typology				Energy system				Source of flexibility				Control system		Results based on	
	Single-family house	Multi-family house	Non-residential building	Cluster of buildings	Heat pump	District heating	Other HVAC systems	PV	Constructions	Thermal storage	Batteries	Fuel switch	Rule based	Model based	Simulation	Measurements
19			X			X	X		X				X	X	X	X
20	X				X				X					X	X	
21	X				X	X	X	X		X	X		X	X	X	
22	X	X			X				X	X				X	X	
23	X				X			X			X		X		X	
24	X				X				X	X			X		X	
25	X						X		X	X			X		X	
26	X			X	X					X				X		X
27	X				X		X	X	X					X		X
28			X				X		X				X		X	
29	X						X		X				X			X
30			X				X	X	X		X		X		X	
31		X		X	X				X				X		X	
32			X		X		X	X			X				X	X
33	X						X	X	X		X				X	
34	X			X	X					X			X	X	X	X
35	X				X		X	X			X		X		X	

http://annex67.org/media/1866/modelling-of-possible-energy-flexibility.pdf

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Examples

19 DK

20 NL

21 FI

22 ES

23 CN

24 DE

25 NO

26 DK

27 NL

28 IE

29 CA

30 IE

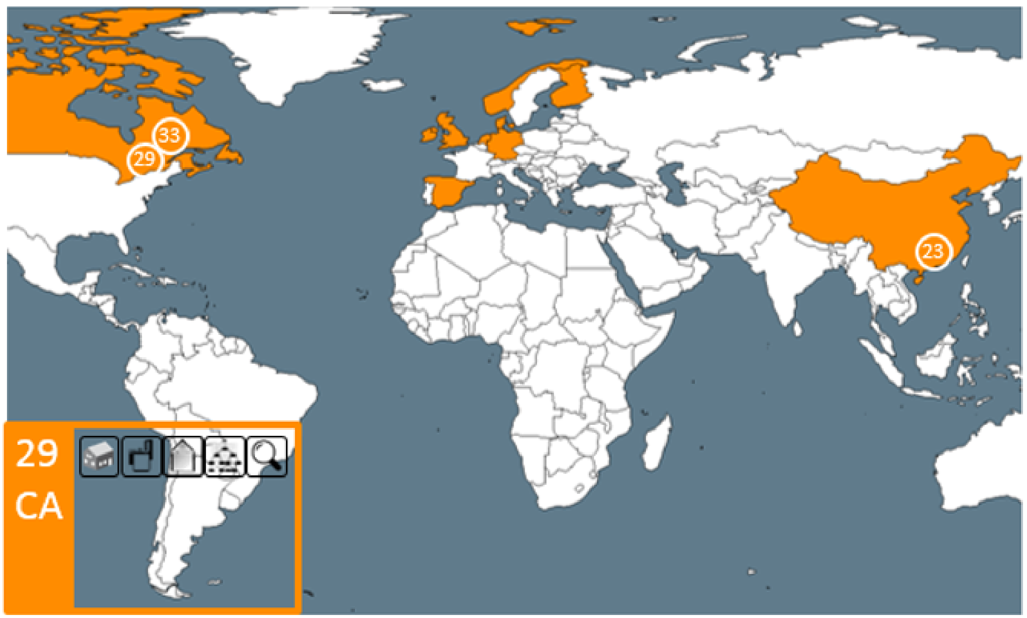
31 DK

32 UK

33 CA

34 NL

35 NL



What is the possible Energy Flexibility in buildings?

It depends

- type of building and energy service systems
- use of the building
- climate
- time of the day and the year
- occupants
- control possibilities
- state of storage (constructions, tank, battery, …)
- physical max vs. cost optimal energy flexibility
- surrounding grids
- energy tariffs
- …

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Characterization of Energy Flexibility in Buildings

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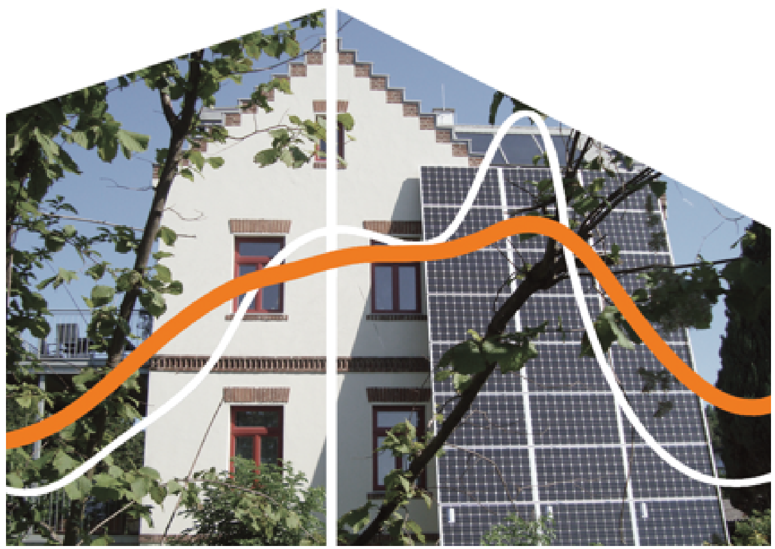
October 2019



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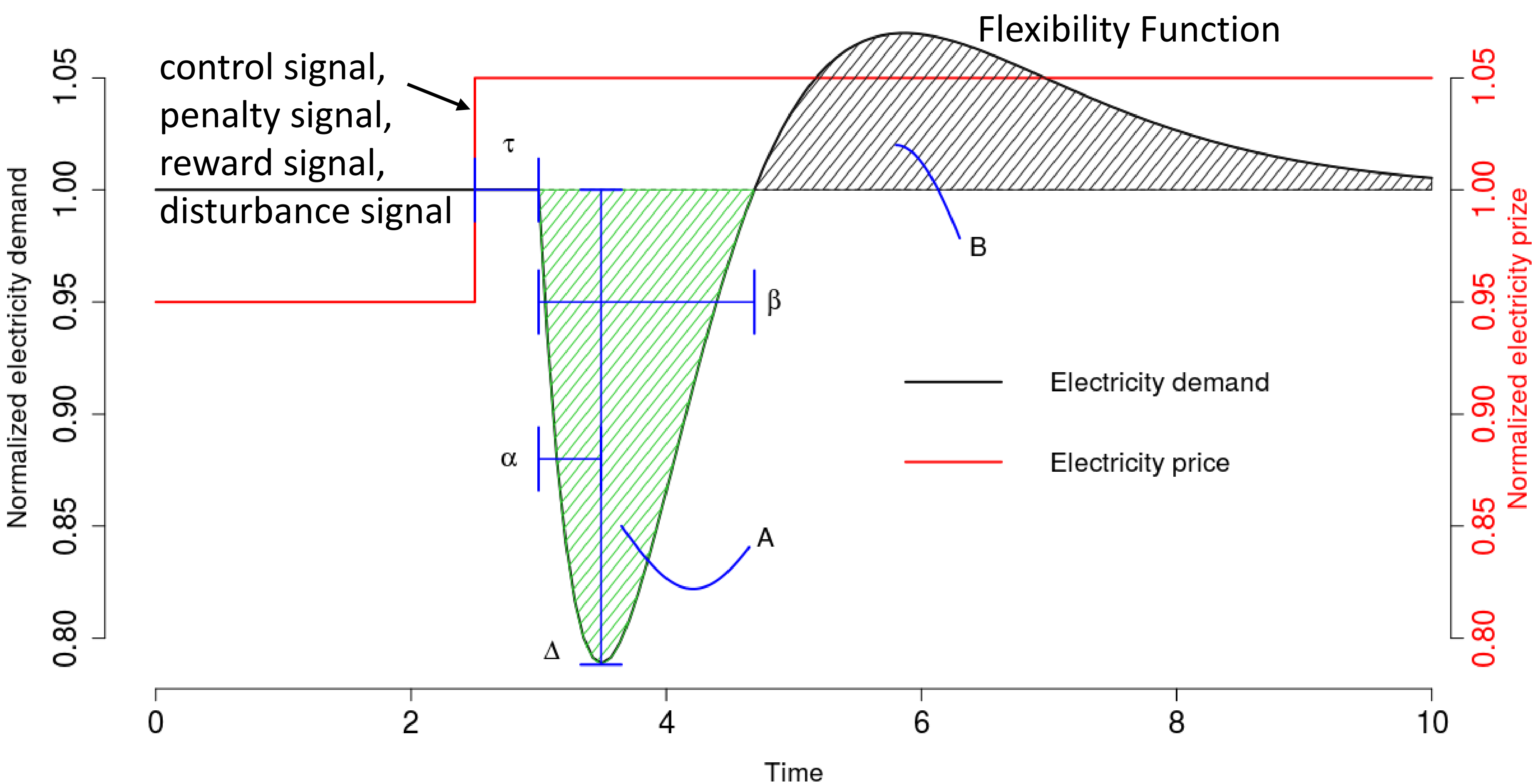
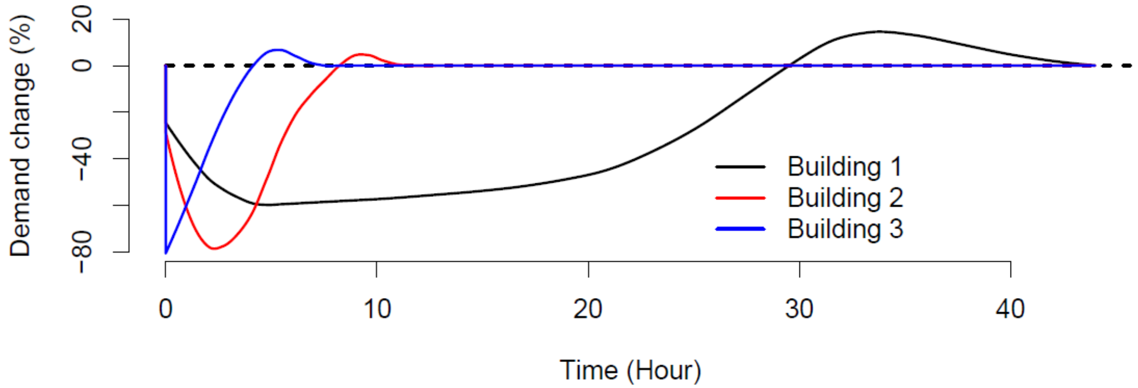
Definition of Energy Flexibility in buildings

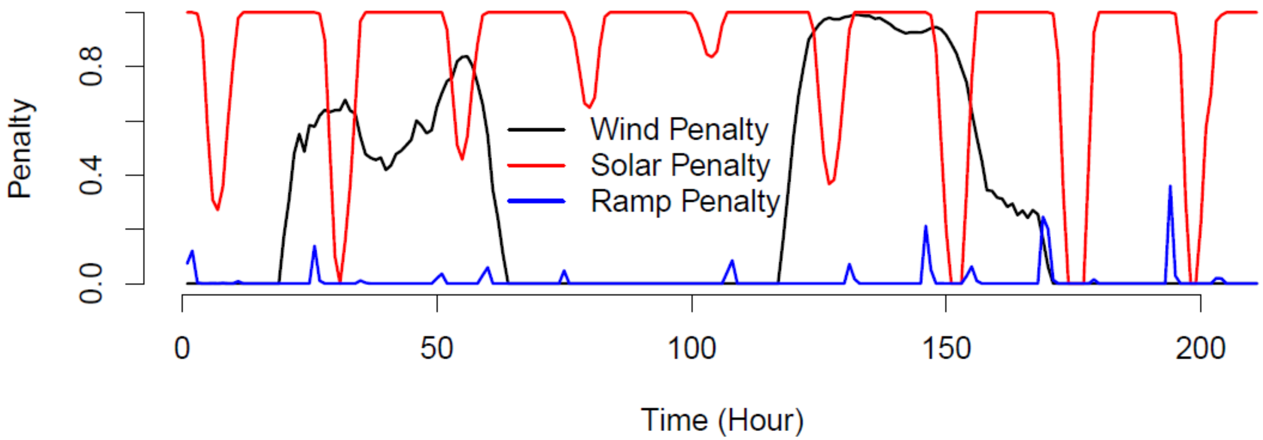
- The Energy Flexibility of a building is the ability to manage its demand and generation according to local climate conditions, user needs and grid requirements.
- Energy Flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding grids.

Characterization and labelling of Energy Flexibility in buildings



Expected Flexibility Saving Index





	Wind (%)	Solar (%)	Ramp (%)
Building 1	11.8	3.6	1.0
Building 2	4.4	14.5	5.0
Building 3	6.0	10.0	18.4

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Flexibility Index

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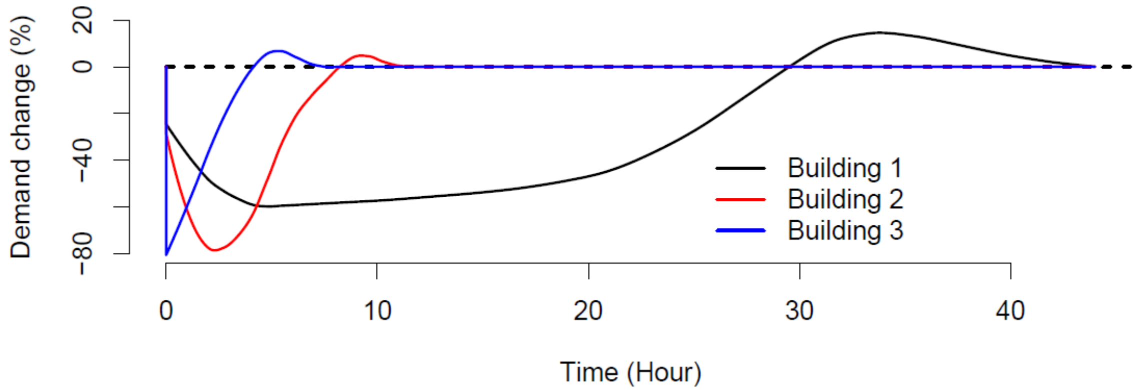

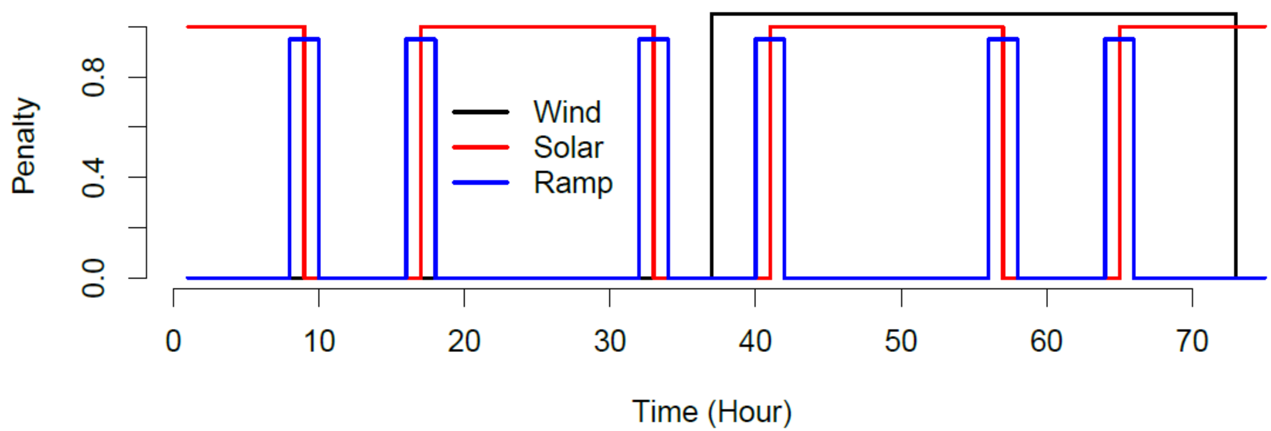

	Wind (%)	Solar (%)	Ramp (%)
Building 1	36.9	10.9	5.2
Building 2	14.4	47.9	22.3
Building 3	17.9	35.6	67.5

Expected Flexibility Saving Index vs. Flexibility Index

	Wind (%)	Solar (%)	Ramp (%)
Building 1	11.8	3.6	1.0
Building 2	4.4	14.5	5.0
Building 3	6.0	10.0	18.4

	Wind (%)	Solar (%)	Ramp (%)
Building 1	36.9	10.9	5.2
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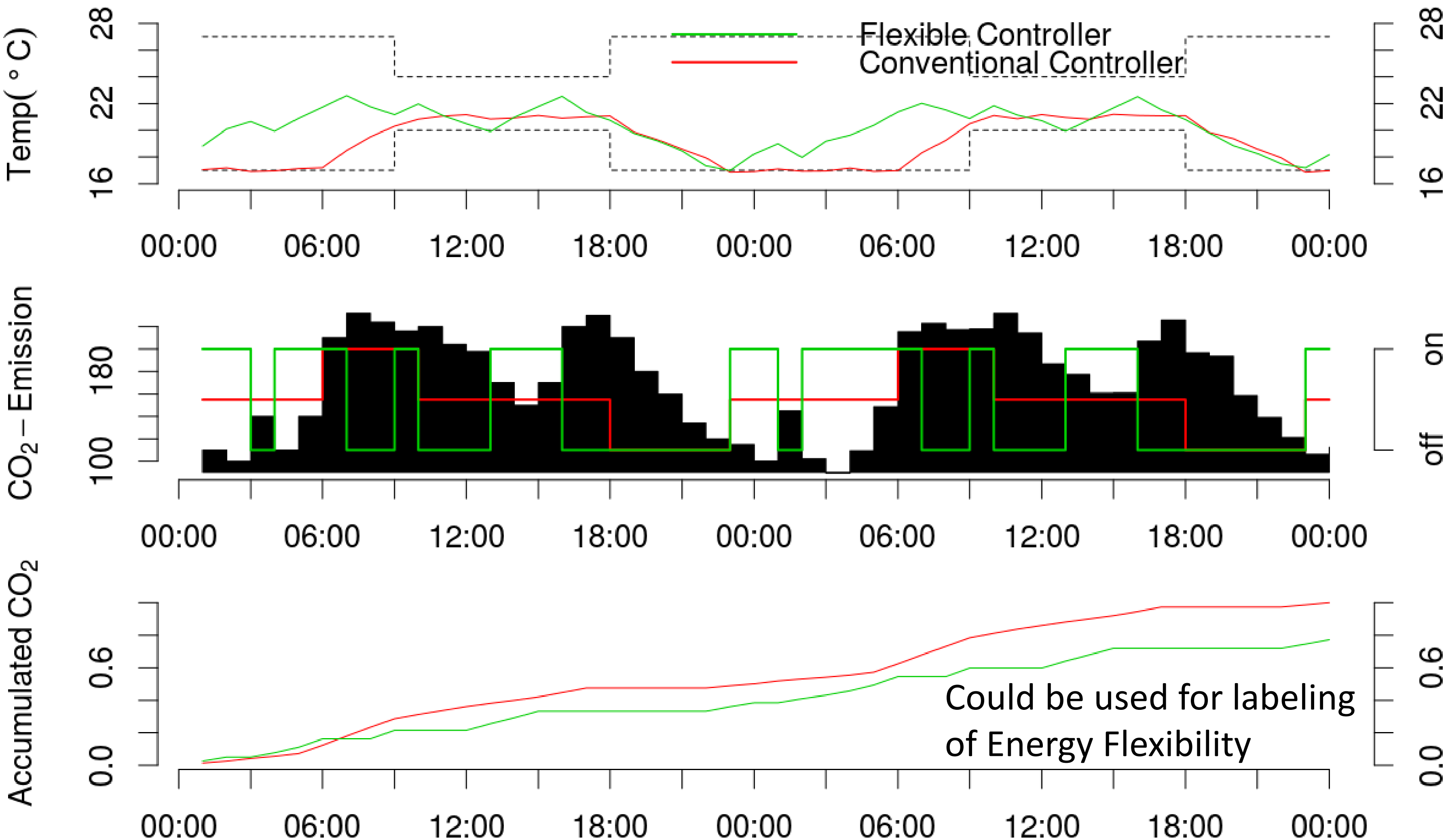
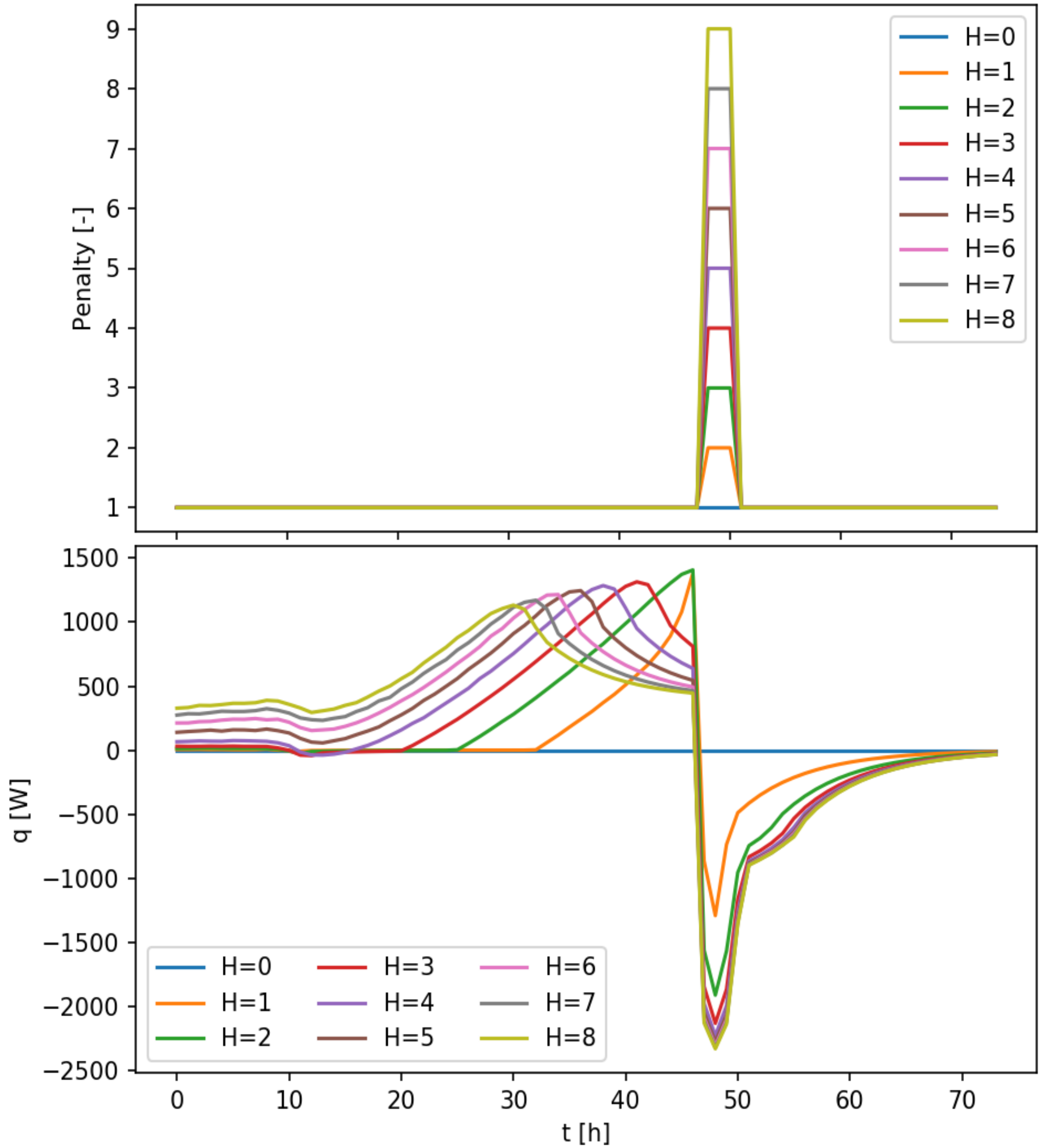
https://www.sciencedirect.com/science/article/pii/S030626191830730X

Energy Flexibility in buildings



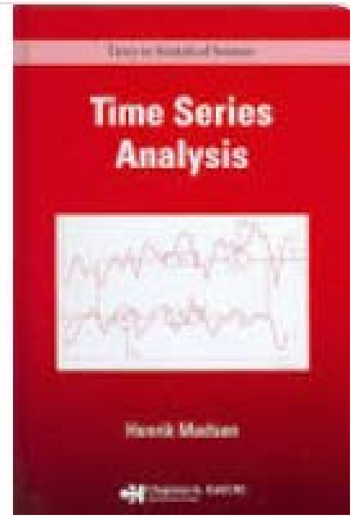
Characterizing the Energy Flexibility of Buildings and Districts.
https://www.sciencedirect.com/science/article/pii/S030626191830730X

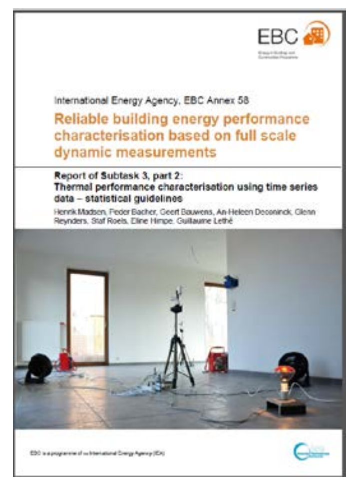
Model Predictive Control



Time series analysis

- Time Series Analysis, Henrik Madsen, Chapman and Hall, 2007
- Thermal performance characterization using time series data – statistical guide-lines. IEA EBC Annex 58 report. Madsen et al., 2016. https://www.iea-ebc.org/Data/publications/EBC_Annex_58_Final_Report_ST3b.pdf





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Control strategies and algorithms for obtaining energy flexibility in buildings

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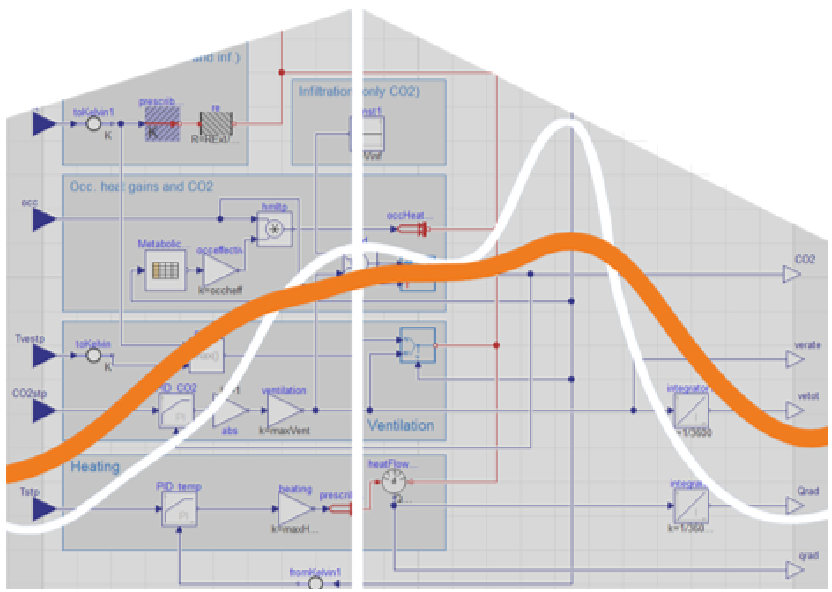

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Examples on control

Chapter	Building typology				Energy system				Source of flexibility				Control system		Results based on	
	Single-family house	Multi-family house	Non-residential building	Cluster of buildings	Heat pump	District heating	Other HVAC systems	PV	Constructions	Thermal storage	Batteries	Fuel switch	Rule based	Model based	Simulation	Measurements
19			X			X	X		X				X	X	X	X
20	X				X				X					X	X	
21	X				X	X	X	X		X	X		X	X	X	
22	X	X			X				X	X				X	X	
23	X				X			X			X		X		X	
24	X				X				X	X			X		X	
25	X						X		X	X			X		X	
26	X			X	X					X				X		X
27	X				X		X	X	X					X		X
28			X				X		X				X		X	
29	X						X		X				X			X
30			X				X	X	X		X		X		X	

Examples on control

Case study	Name	Managed by	Location
1	Multi-objective genetic algorithm for model predictive control in buildings	University of Southern Denmark	Denmark
2	Deep reinforcement learning for optimal control of space heating	Enervalis and KU Leuven	Belgium
3	A Model Predictive Controller for Multiple-Source Energy Flexibility in Buildings	Technical Research Centre of Finland Ltd	Finland
4	Model predictive control for carbon emissions reduction in residential cooling loads	Catalonia Institute for Energy Research	Spain
5	Investigation of the energy flexibility of a residential net-zero energy building involved with the dynamic operations of hybrid energy storages and various energy conversion strategies	The Hong Kong Polytechnic University	China
6	Rule-based load shifting with heat pumps for single family houses	Fraunhofer IEE	Germany
7	Predictive rule-based control to perform heating demand response in Norwegian residential buildings	Norwegian University of Science and Technology	Norway
8	CO_2-aware heating of indoor swimming	Technical University of Denmark	Denmark
9	Economic model predictive control for demand flexibility of a residential building	Eindhoven University of Technology	Netherlands
10	Implementation of demand response strategies in a multi-purpose commercial building	University College Dublin	Ireland
11	Experimental assessment of energy flexibility potential of a zone with radiant floor heating system	Concordia University	Canada
12	Aggregation of energy flexibility of commercial buildings	University College Dublin	Ireland

Simple rule based example

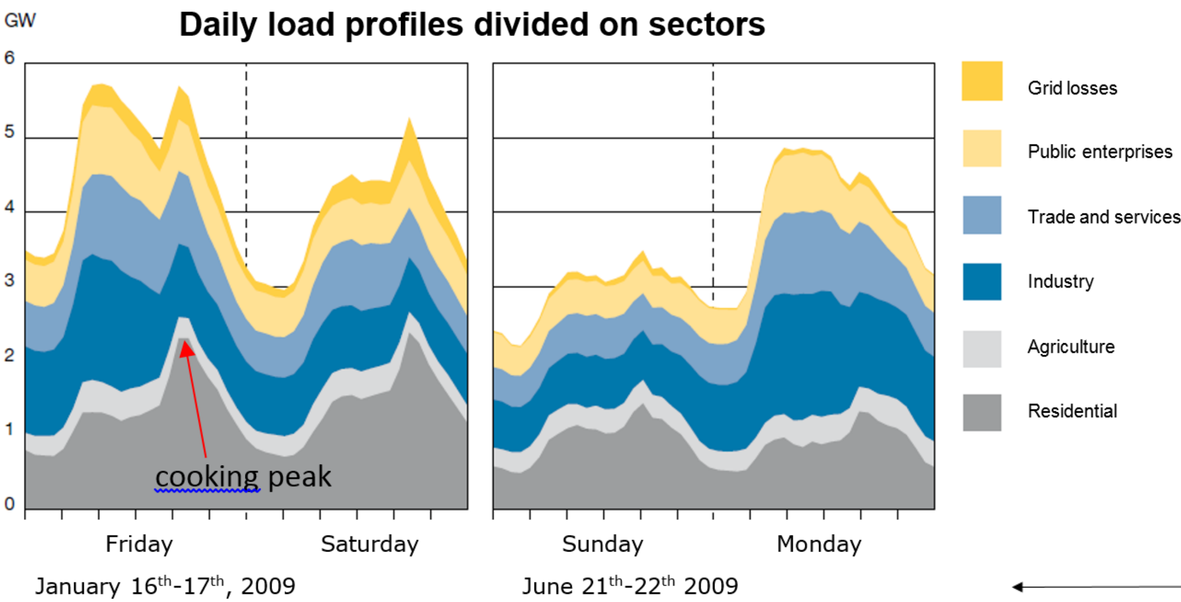
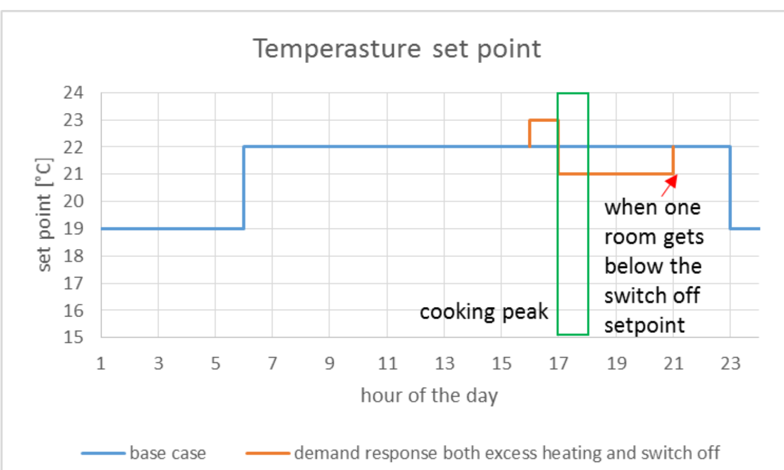
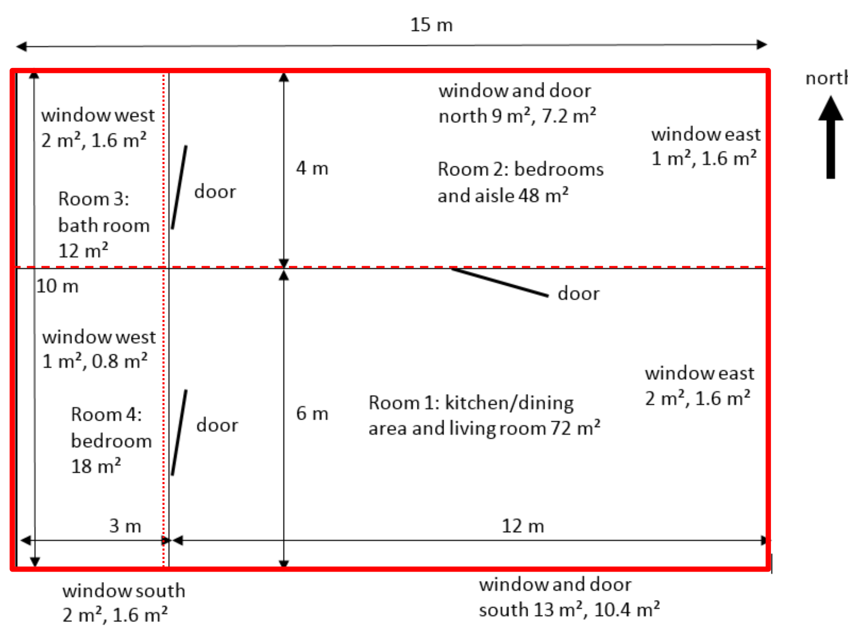


Figure 1. Typical load profiles in the Danish power grid.

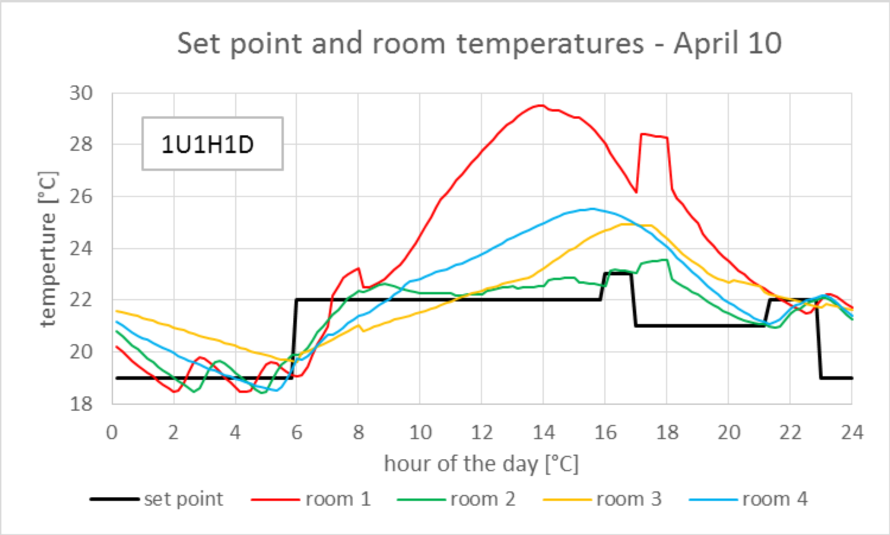


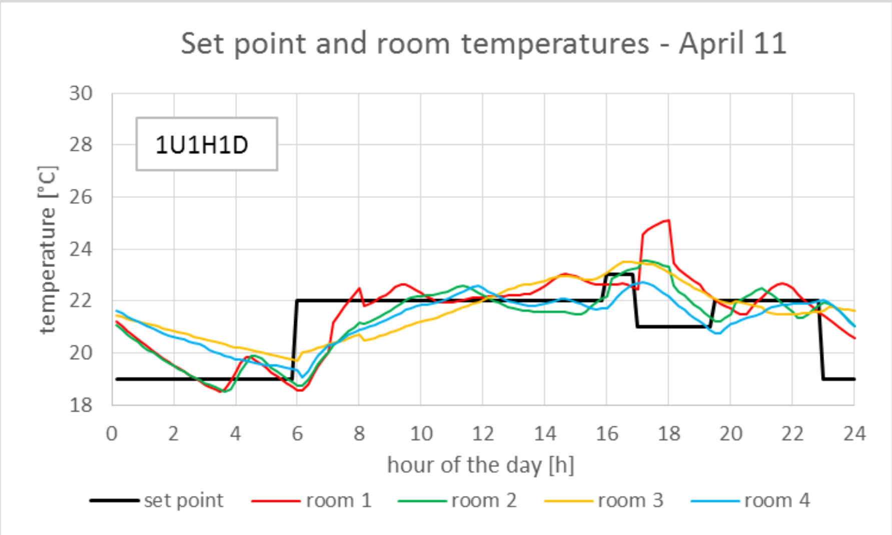
http://annex67.org/media/1838/report-opsys-flexibilitet.pdf

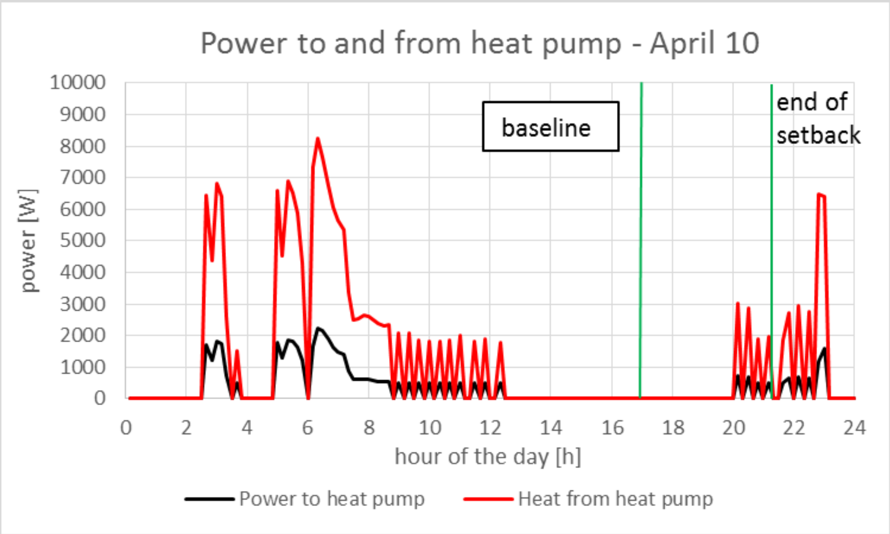
Single family house – 150 m²

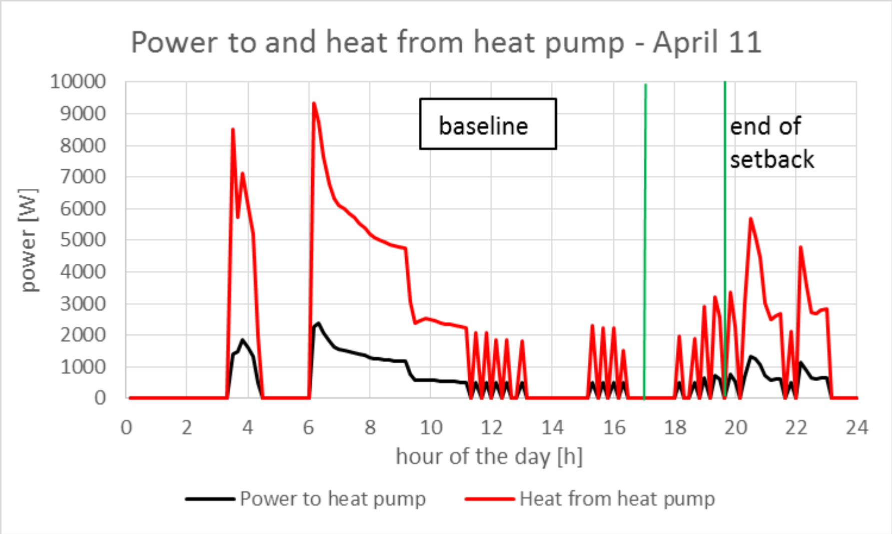


Heat pump in a single family house

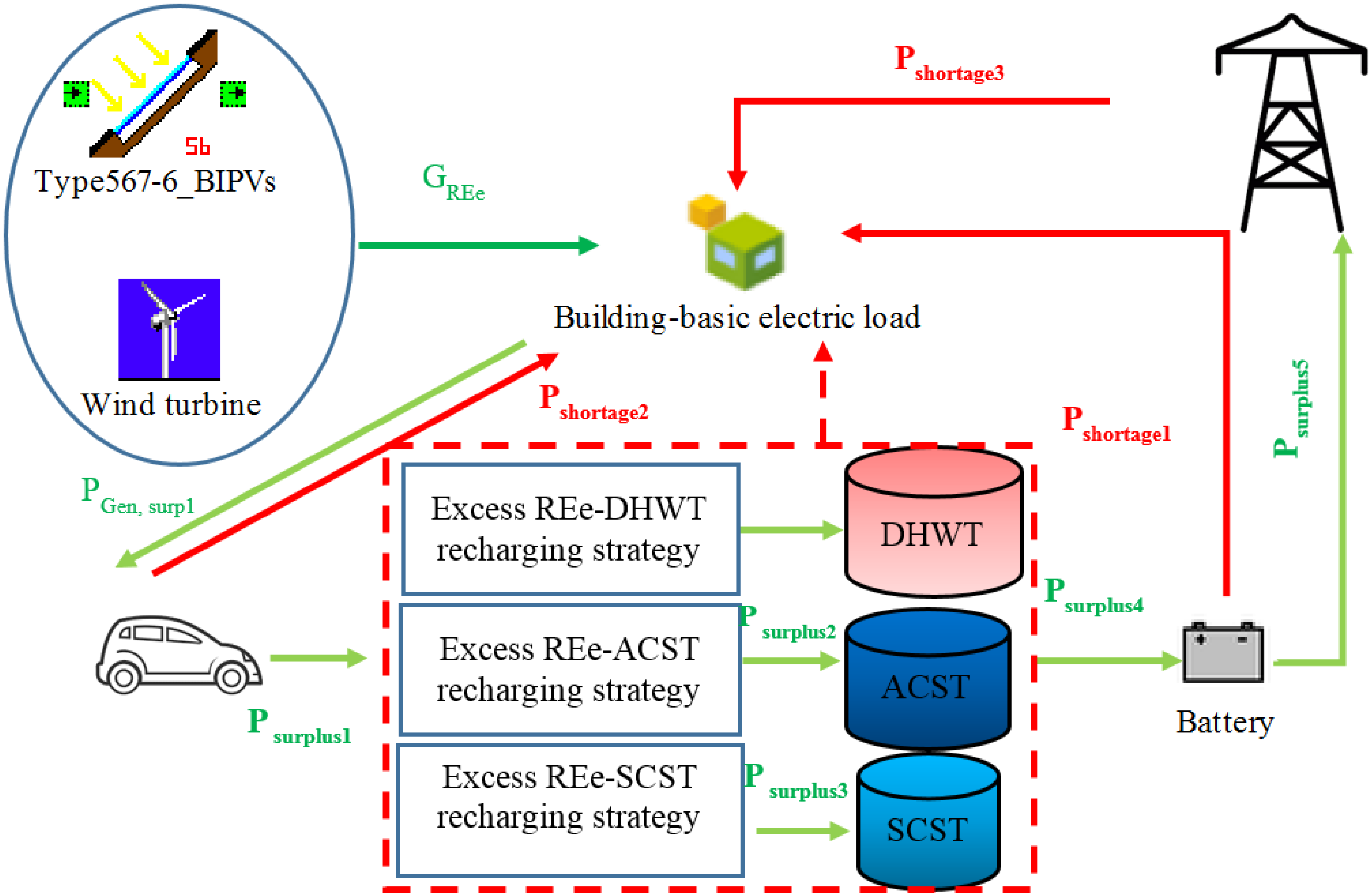








Hongkong: Building, PV, wind, battery and EV



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One control strategy

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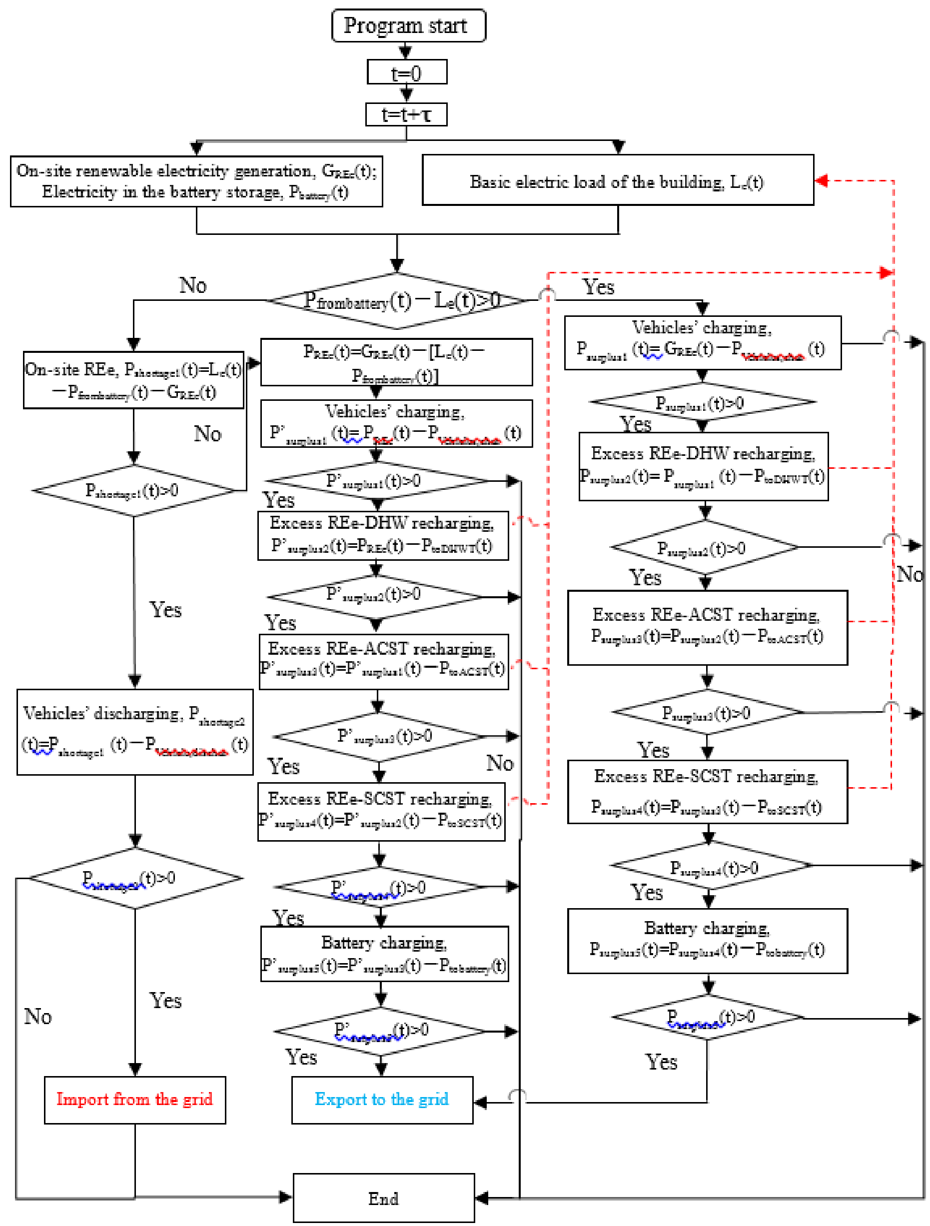
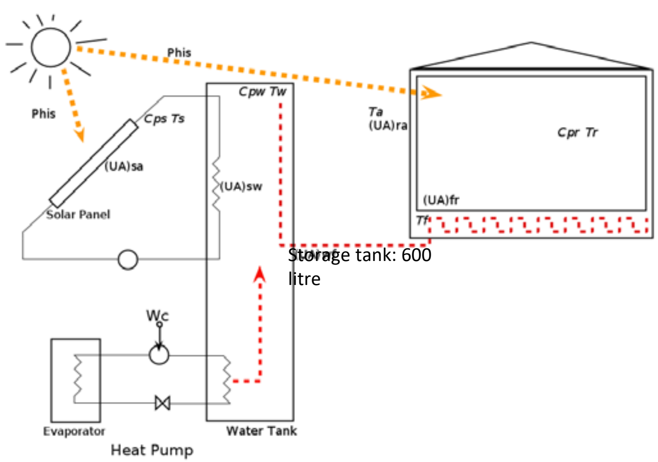
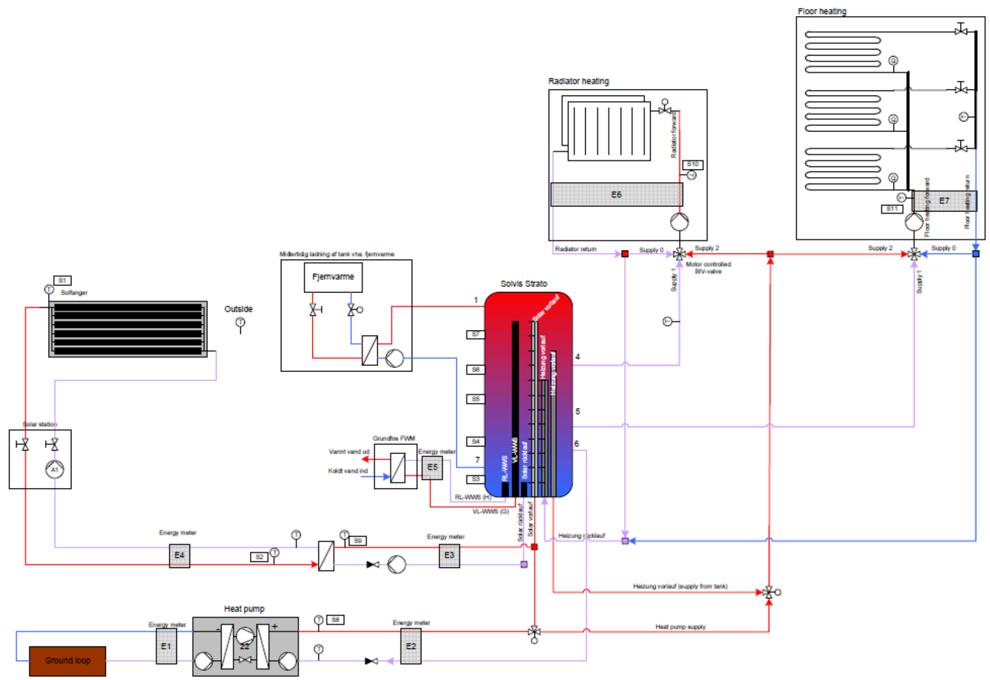


Example of a EMPC controller

Test house at Grundfos: indirect control, price signal, forecast, EMPC





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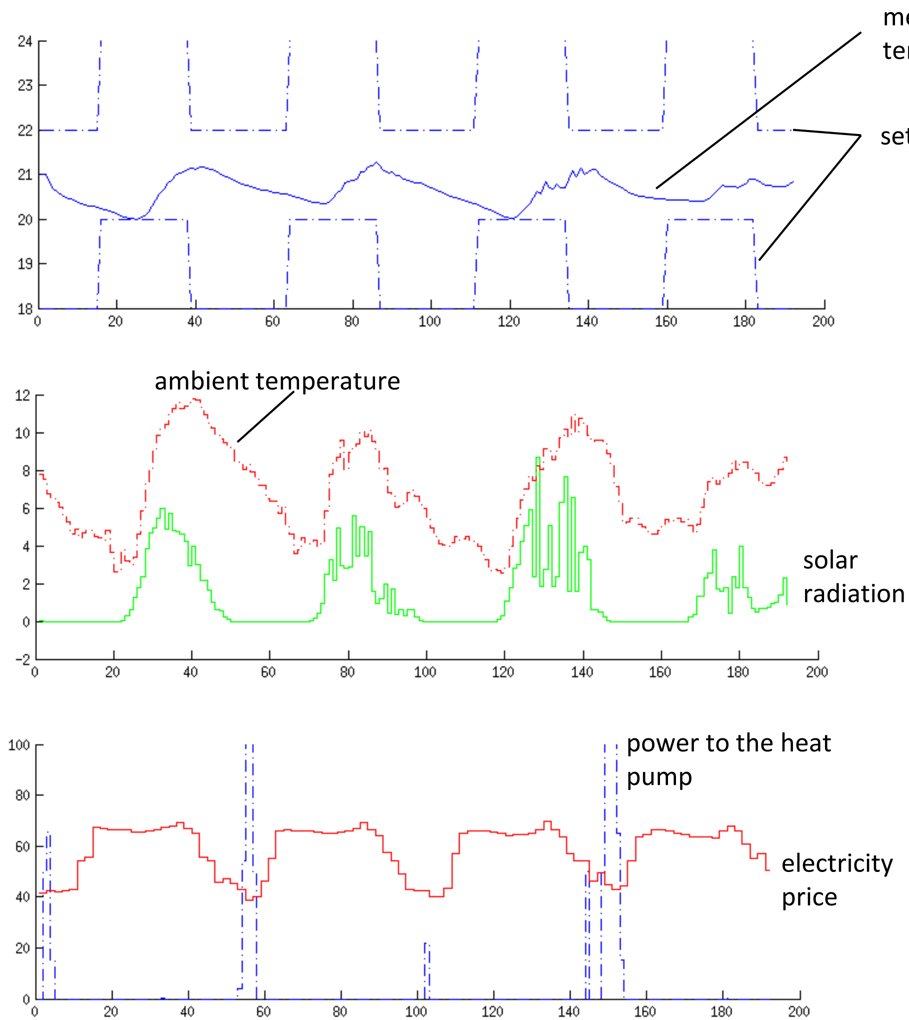
Example: EMPC



Test house at Grundfos: indirect control, forecast, price signal, EMPC

Simulation with 48 h prediction horizon using perfect forecasts.

Savings: 30 % in DKK but 8 % larger energy demand.

Results from test in the test house during January-May 2014 utilizing 24 h forecast: 16 % cost saving with dynamic tariffs and 8 % cost saving with flat tariffs.

Modeling and Control for Price Responsive Electricity Loads. Jacopo Parvizi
http://orbit.dtu.dk/en/publications/modeling-and-control-for-price-responsive-electricity-loads(7ff027e9-cb51-4baa-b28f-d940a9e94a1e).html

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Experimental facilities and methods for assessing energy flexibility in buildings

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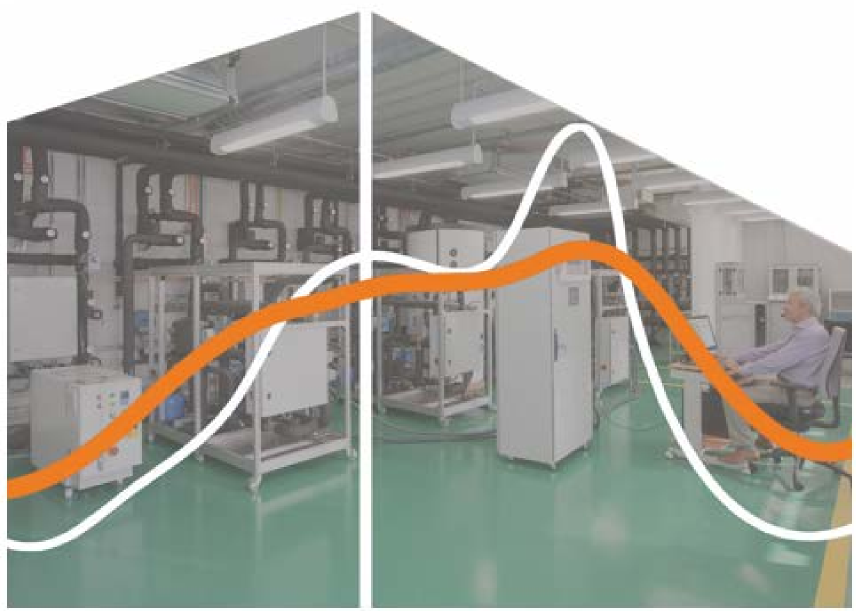
Annex 67 Energy Flexible Buildings

June 2019



Technology Collaboration Programme
by IEA

Hardware-in-the loop

Hardware-in-the-loop test facilities, where parts of a system are physical components while others are virtual, establish a bridge between cheap simulation and expensive tests in real buildings.

Systems and energy flexibility strategies are usually developed through simulations, so there is a need for validation through tests under dynamic, real (or as close as possible to real) operating conditions.

Hardware-in-the-loop test facilities represent, therefore, an important tool where researchers and industry can test, under controlled conditions, the performance of new systems before they are implemented in real buildings and/or field tests.

Test facilities

Name	Managed by	Location
SEILAB	IREC - Catalonia Institute for Energy Research	Tarragona, Spain
NZEB Emulator	Aalto University	Espoo, Finland
OPSYS test rig	Danish Technological Institute (DTI)	Taastrup, Denmark
ZEB Living Lab	NTNU / SINTEF	Trondheim, Norway
Energy Research Lab	Institute Energy in Building, FHNW	Muttenz, Switzerland
Semi-Virtual Laboratory	Polytechnique Montréal	Montréal, Canada
EnergyVille labs	EnergyVille (VITO, KU Leuven, IMEC)	Genk, Belgium
Test Lab Heat Pumps and Chillers	Fraunhofer Institute for Solar Energy Systems	Freiburg, Germany
Energy Smart Lab	IREC - Catalonia Institute for Energy Research	Barcelona, Spain

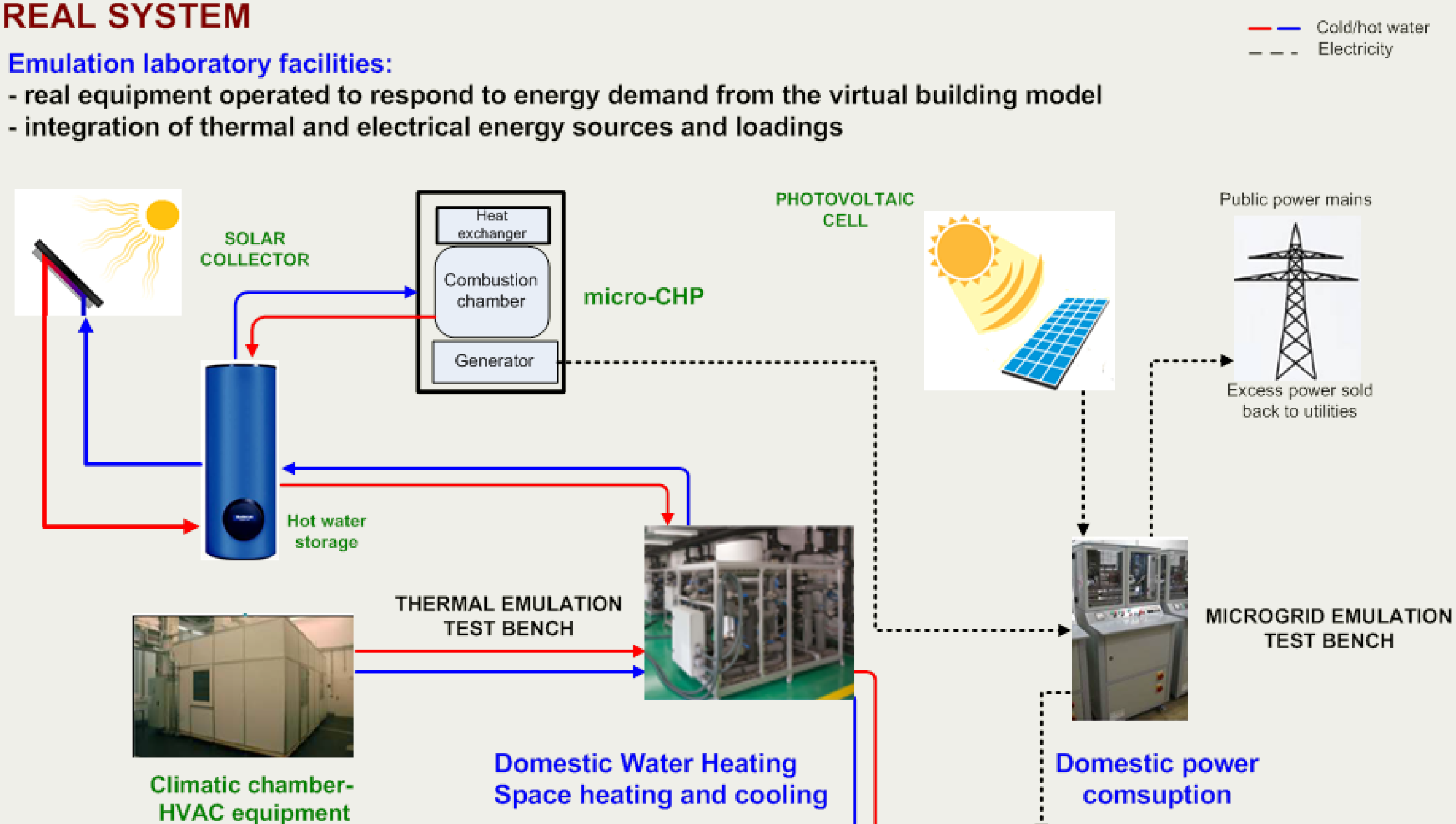
http://annex67.org/media/1708/laboratory-facilities-used-to-test-energy-flexibility-in-buildings-2nd-edition.pdf

IREC, Spain

REAL SYSTEM

Emulation laboratory facilities:

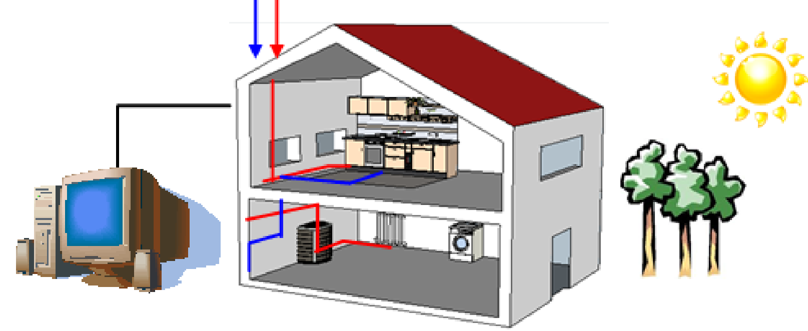
- real equipment operated to respond to energy demand from the virtual building model
- integration of thermal and electrical energy sources and loadings



VIRTUAL SYSTEM

SCADA integrated with dynamic building simulation model:

- climatic conditions
- 3D building design
- building occupancy and user behaviour
- simulation of thermal and electric loadings



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Results from IRAC

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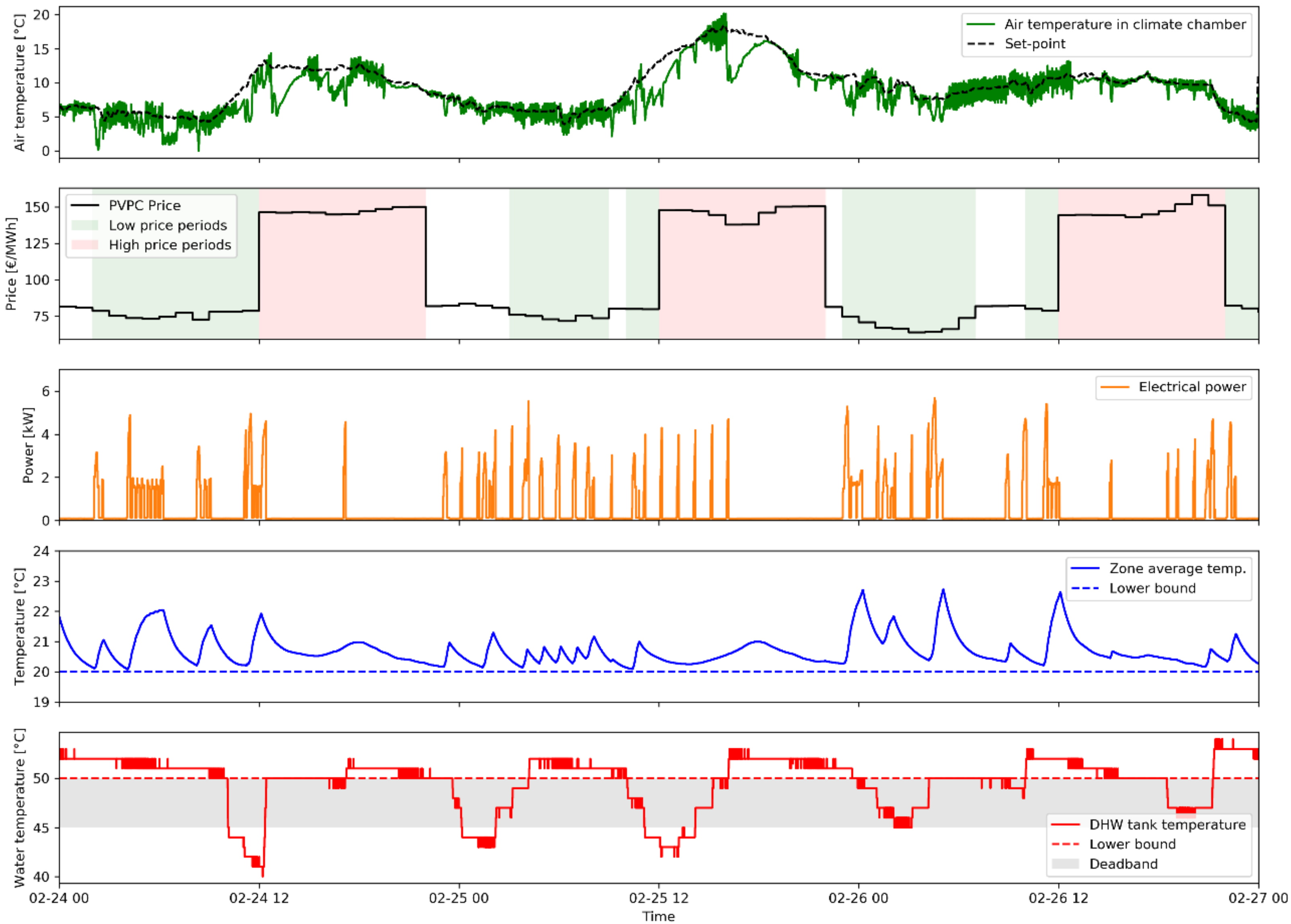
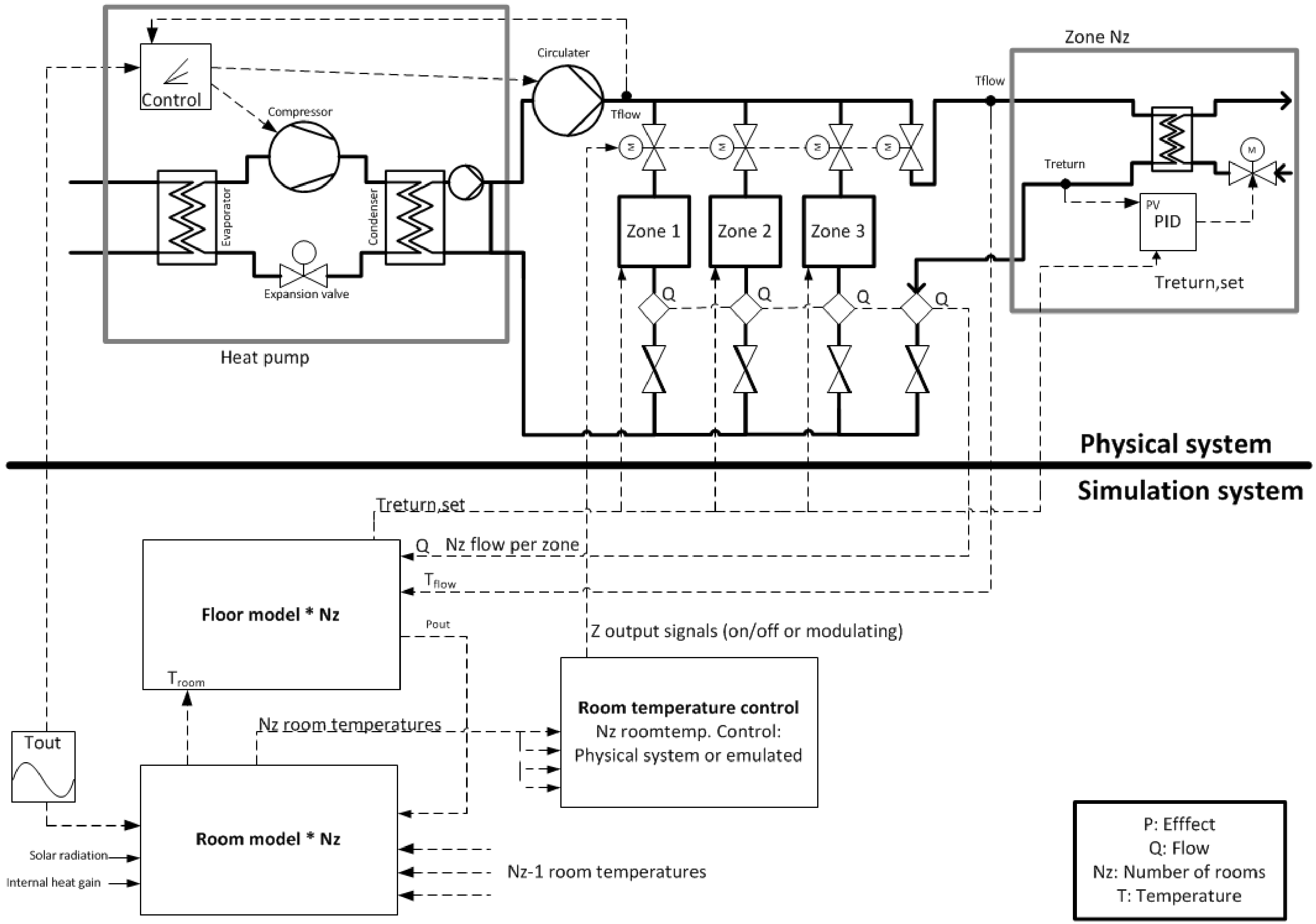


DTI, Danmark



Control
Compressor
Circulater
Tflow
Zone Nz
Treturn
PV
PID
Treturn,set
Evaporator
Condenser
Expansion valve
Zone 1
Zone 2
Zone 3
Q
Heat pump
Physical system
Simulation system
Treturn,set
Q Nz flow per zone
T_{flow}
Pout
Floor model * Nz
T_{room}
Z output signals (on/off or modulating)
Nz room temperatures
Room temperature control
Nz roomtemp. Control:
Physical system or emulated
Tout
Room model * Nz
Solar radiation
Internal heat gain
Nz-1 room temperatures
P: Efffect
Q: Flow
Nz: Number of rooms
T: Temperature

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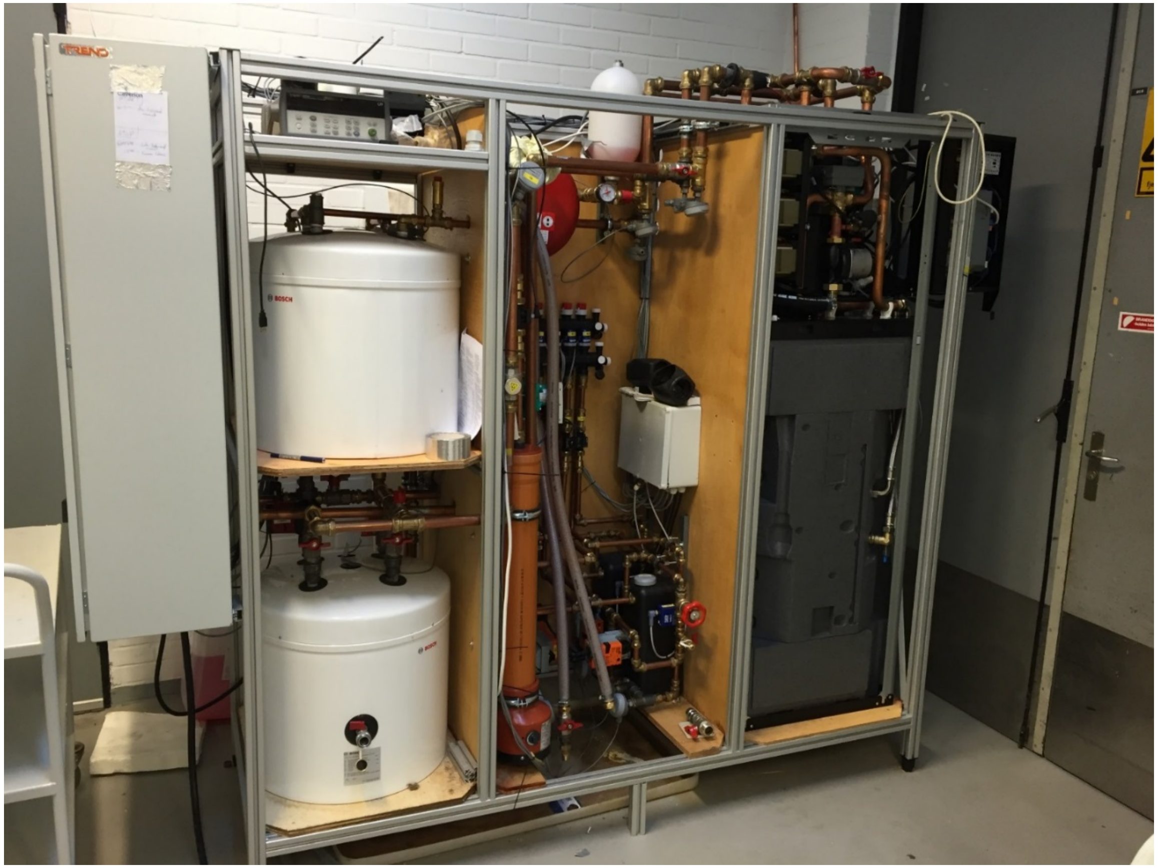
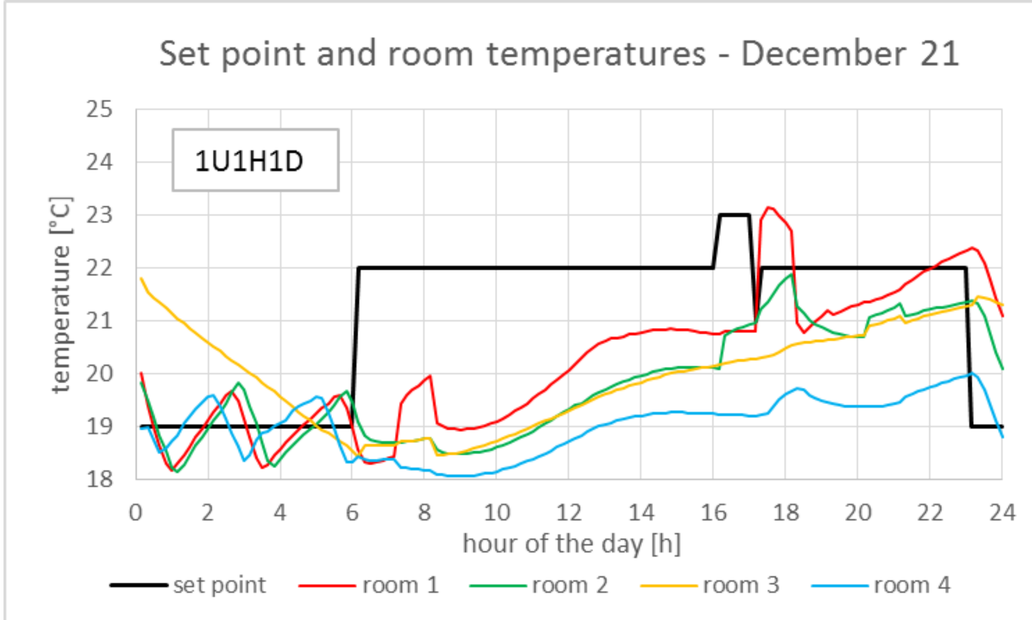
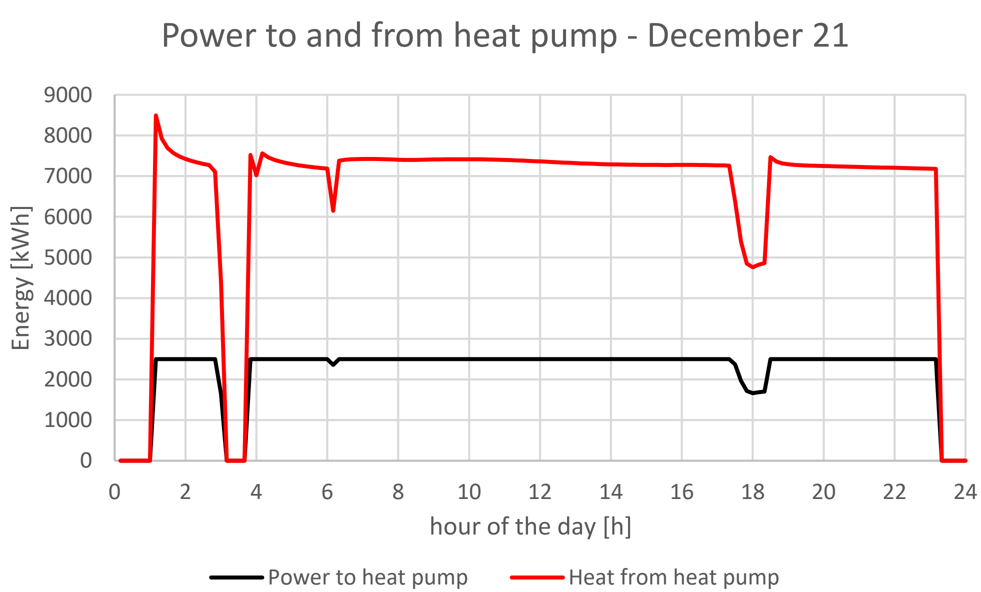
DTI, Danmark



Results DTI, Denmark





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International Energy Agency

Stakeholders' perspectives on Energy Flexible Buildings

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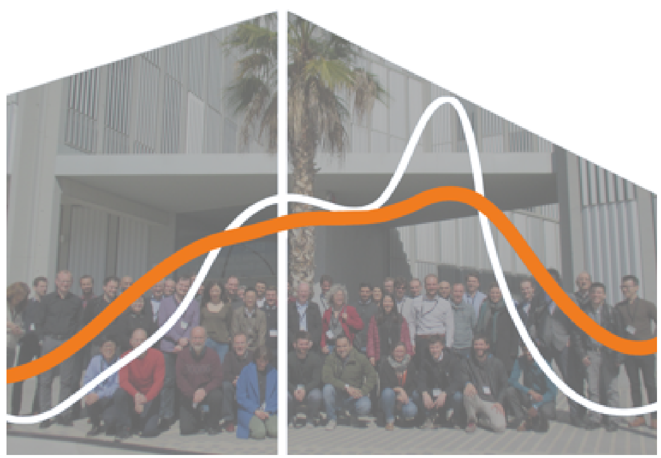
Annex 67 Energy Flexible Buildings

September 2019



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The perspective of the stakeholders

Stakeholder acceptance and behaviour are crucial to the success of strategies for energy flexibility in buildings.

Without careful design and implementation, introducing energy flexibility has the potential to disrupt occupant lifestyles, building systems for thermal comfort and health, as well as potentially increasing cost or energy consumption.

Stakeholder acceptance and behaviour may also be a barrier, but this can be reduced, or overcome entirely, if the related stakeholders are informed about flexibility measures and support any measures that are introduced.

The perspective of the stakeholders

There is a wide range of different stakeholders who may be affected by energy flexibility measures:

At the building level: end-users (occupants of buildings), building owners, facility managers, Energy Service Companies (ESCOs), developers, architects, contractors, and product/system suppliers.

The energy flexibility is ultimately useful for aggregators, DSOs (District System Operators of both power and district heating and cooling networks) and TSOs (Transmission System Operators).

It is important to establish a comprehensive understanding of acceptance, behaviour, and motivation at different levels of involvement for the relevant stakeholders.

Research by Annex 67

16 studies bases on questionnaires and/or interviews have been carried out among:

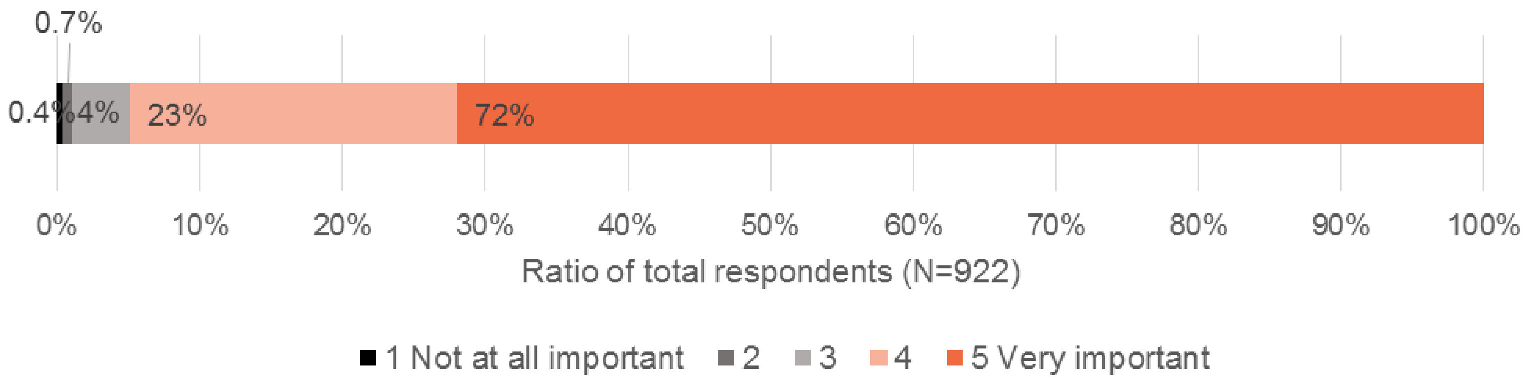
- Building managers – both campus and retail buildings
- Occupants – households, office and campus buildings
- Industrial consumers
- Energy suppliers
- Aggregators
- Technology providers
- Building energy analytics and consulting
- National regulation authority

Occupants

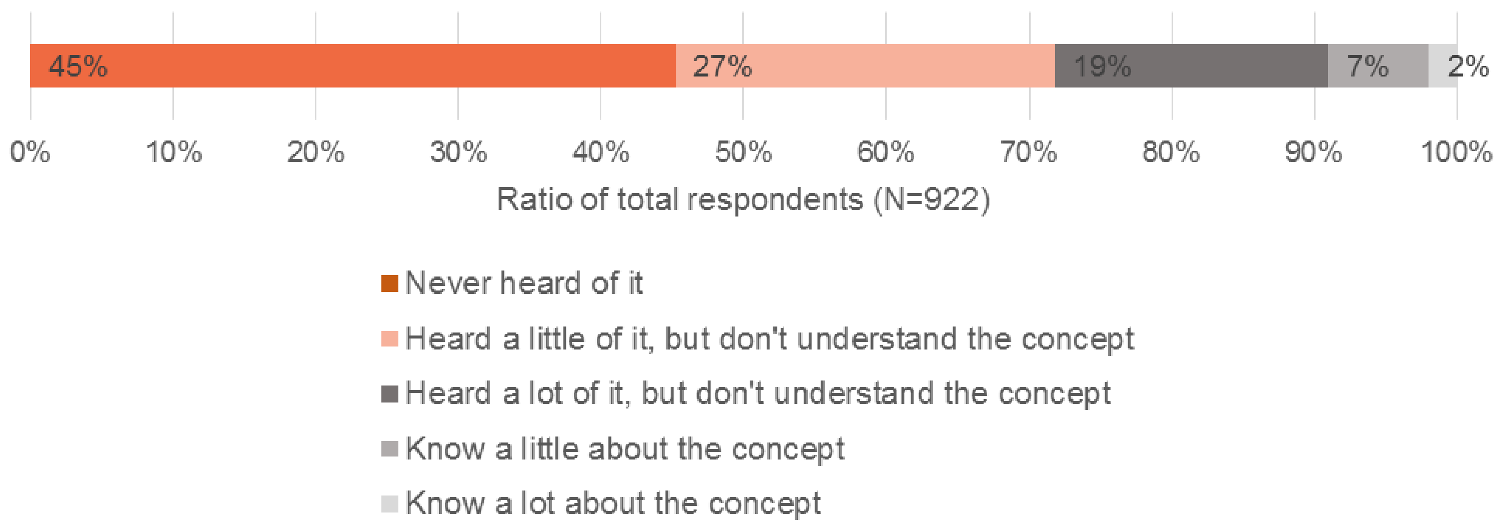
based on 922 completed questionnaries by employees in offices in the Province of Bolzano, Italy

Characteristics	Survey sample
Gender	39 % male, 61 % female
Age (years old)	< 30: 4 %, 30-39: 17 % 40-49: 37 % 50-59: 35 % 60-69: 7 %
Educational level	Secondary school or lower: 3 % High school: 53 % University level: 39 % Ph.D.: 5 %
Position	Employee: 77 % Manager: 13 % Intern: 0.4 % PhD/researcher: 0.1 % Team leader: 6 % Team member: 2 % Other: 2 %
Office typology	Single office: 42 % Shared office with another colleague: 40 % Shared office with two other colleagues: 7 % Shared office with 3 or more other colleagues: 6 % Open space: 2 % Other: 2 %

Results

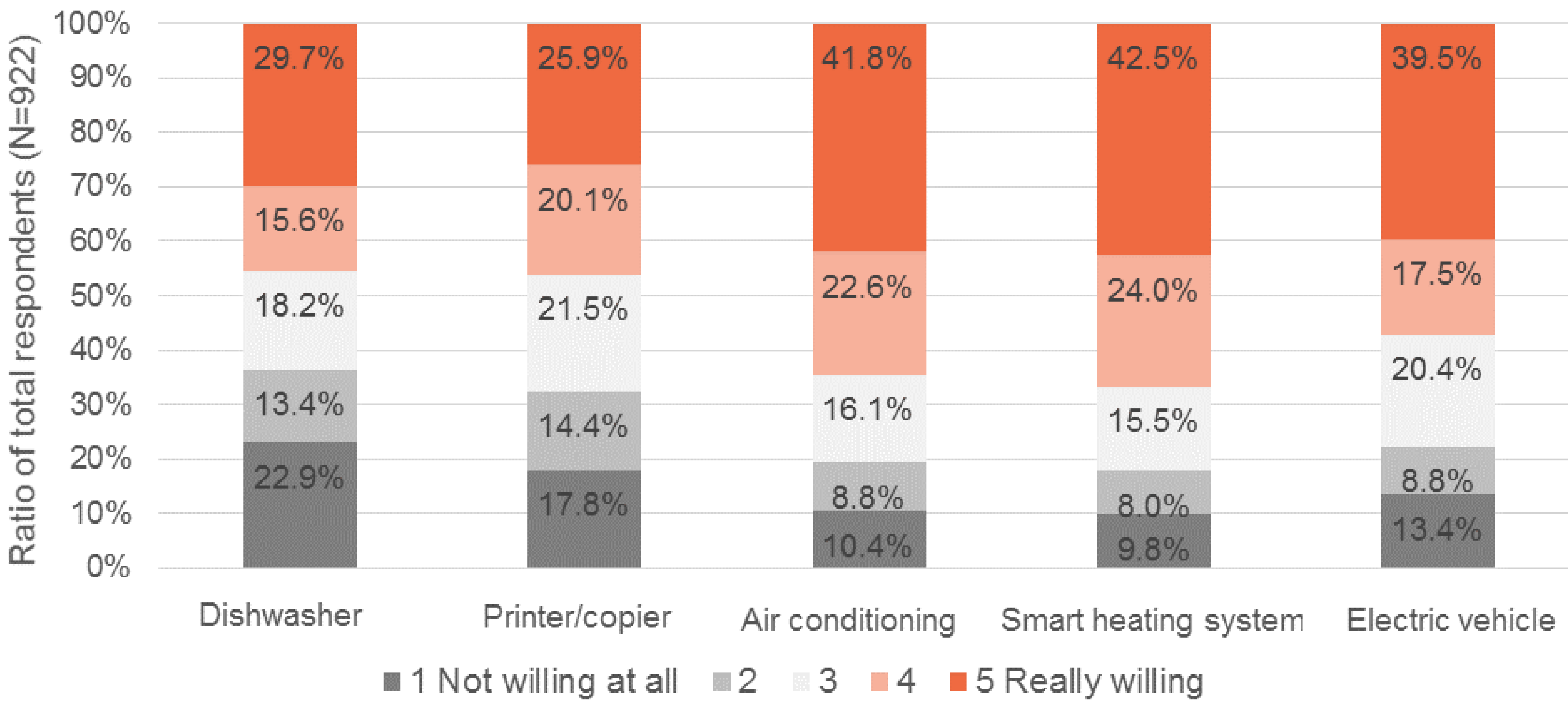


Importance of using renewables instead of fossil fuels



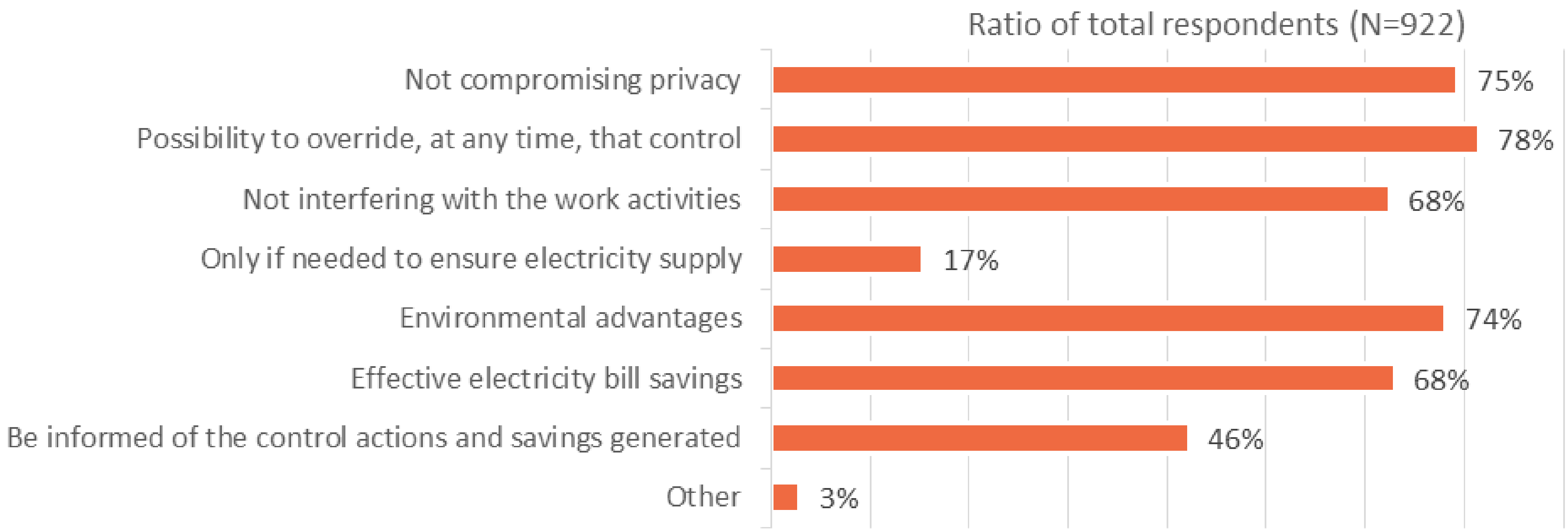
Familiarity with smart grid

Results



Willingness to let some smart appliances be remotely controlled by the electricity utility

Results



Conditions to accept the remote control of some appliances by the electricity utility

Conclusions

- It is essential to understand stakeholders' needs and behaviour, not only regarding comfort and energy requirements, but also regarding their possible position within business models, in order to be able to develop feasible market access strategies for different types of actors.
- Although 'consumer driven/centred' approaches have been emphasized in recent years, policy makers are still the lead stakeholders for strengthening opportunities and eliminating barriers in the energy system. To establish and realize the markets for energy flexible buildings, decentralization of the power hierarchy is necessary, especially for international collaboration and trading.

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Possible new IEA EBC annex:

Energy flexible buildings towards resilient low carbon energy systems

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Research topics for a new annex

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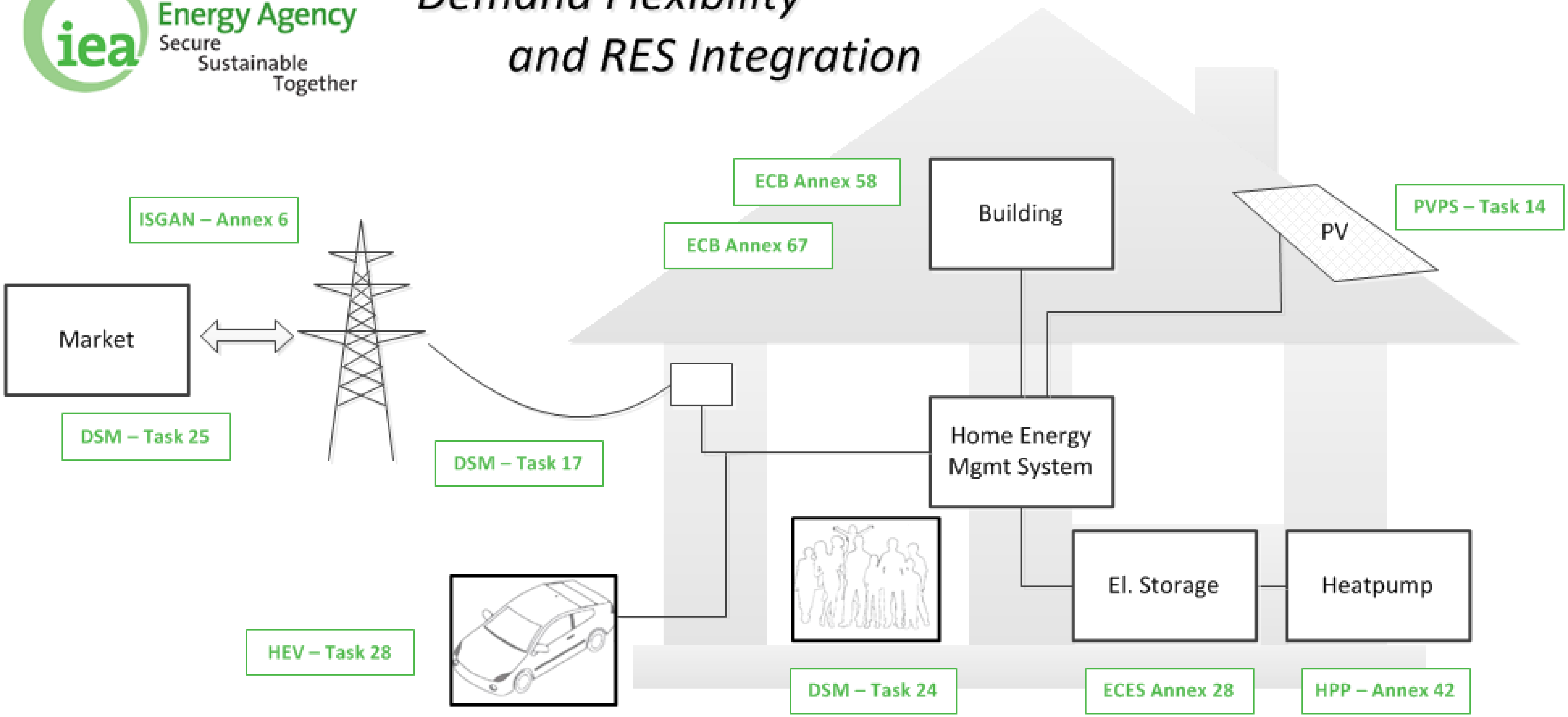
- Scaling from single buildings to clusters of buildings
- Flexibility and resilience in a multi carrier energy system
- Stakeholder acceptance and engagement
- Development of business models

Other related IEA activities

Demand Flexibility and RES Integration



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Thank you for your attention