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TOWARDS ZERO-ENERGY DISTRICTS

From modelling to optimisation

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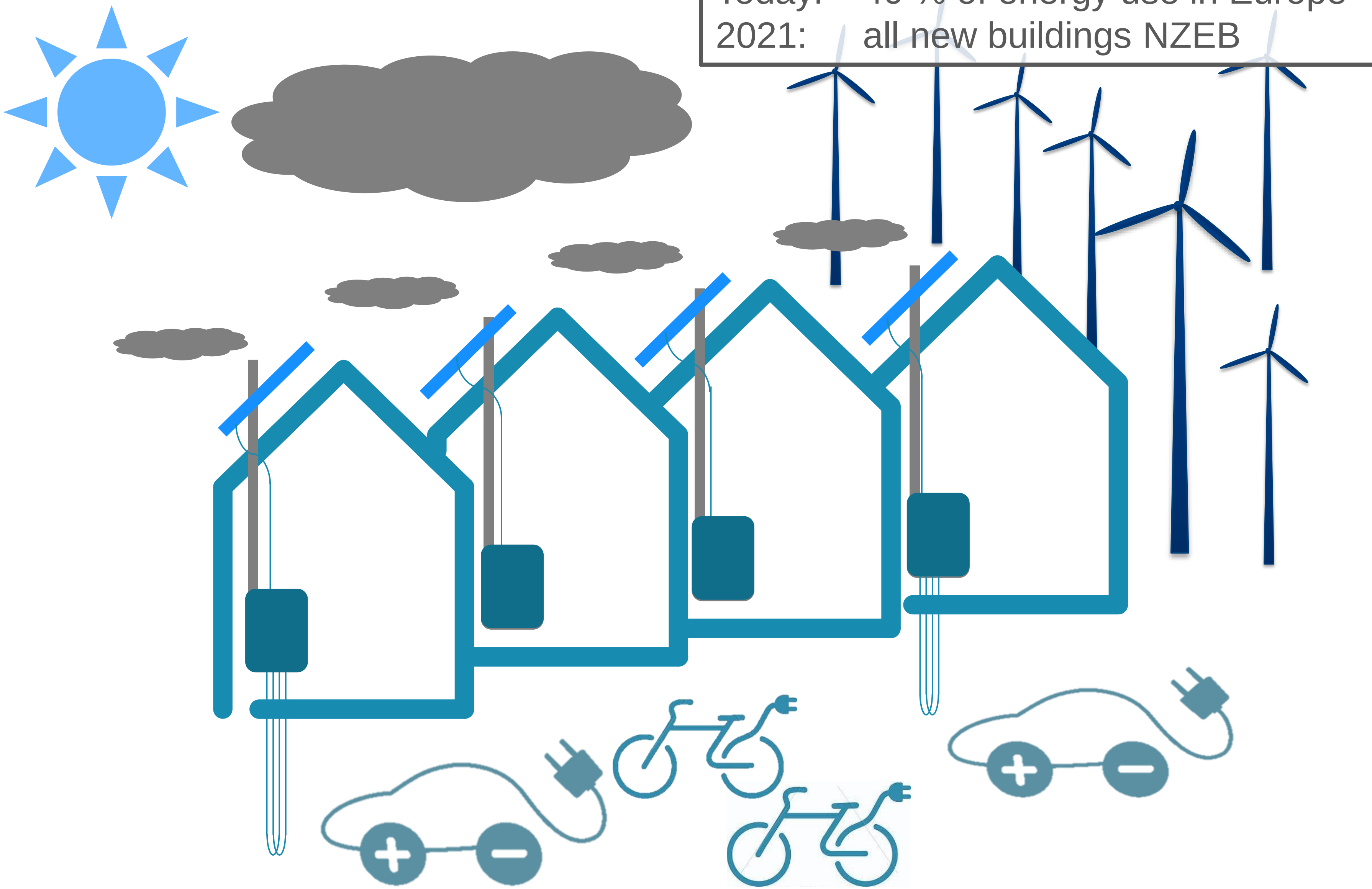
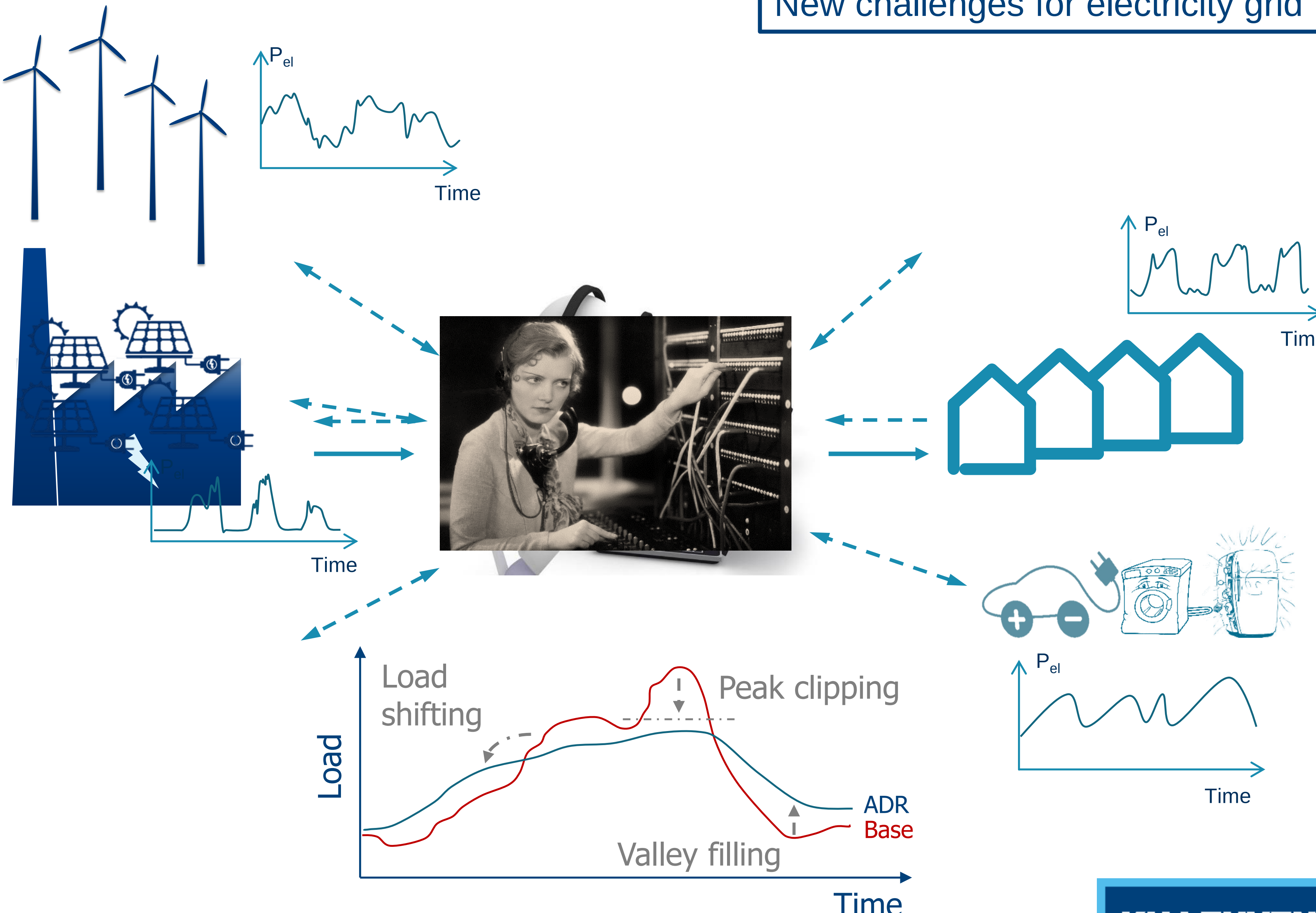
Today: 40 % of energy use in Europe
2021: all new buildings NZEB



New challenges for electricity grid



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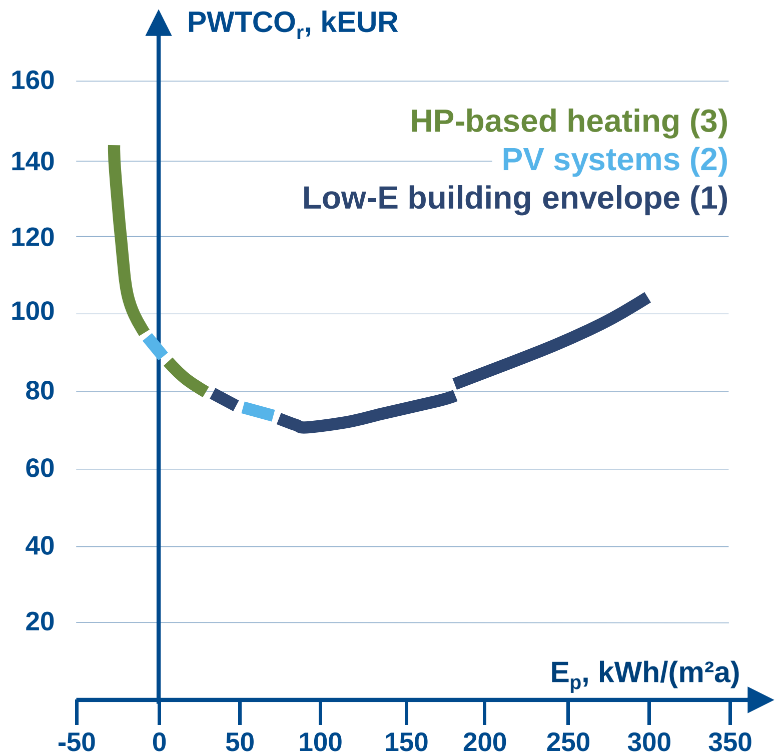

Source: J. Van der Veken *et al.* (2013). *Studie naar kostenoptimale niveaus van de minimumeisen inzake energieprestaties van gerenoveerde bestaande residentiële gebouwen.*

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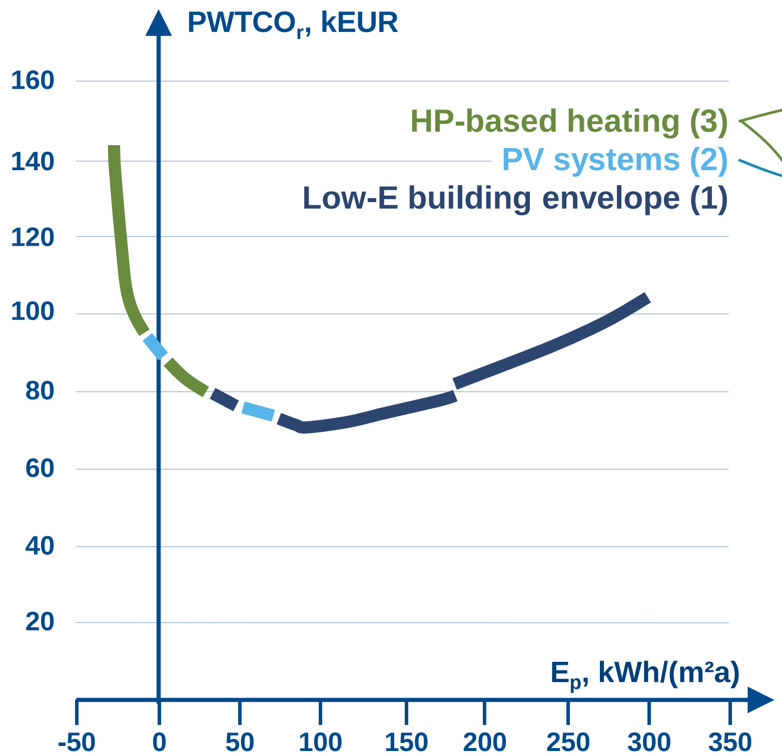

On the one hand,
Extra load for distribution network, possibly resulting severe voltage drops or overloading

On the other hand,
High thermal inertia, thus
significant amount of flexible consumption if heating power can be controlled

Source: J. Van der Veken *et al.* (2013). *Studie naar kostenoptimale niveaus van de minimumeisen inzake energieprestaties van gerenoveerde bestaande residentiële gebouwen.*

Content

0. Introduction

I. Building energy simulations
   - From building to district level
   - Interdisciplinary energy simulation models
   - Case: impact of heat pump-based building design on distribution grid level

II. Buildings in a demand response context
   - Quantifying flexibility
   - Impact of building design on structural storage potential
   - Case: impact of structural storage on Belgian electricity level

III. Food for discussion

I. Building energy simulations

From building to district level

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Traditional Building Energy Simulation

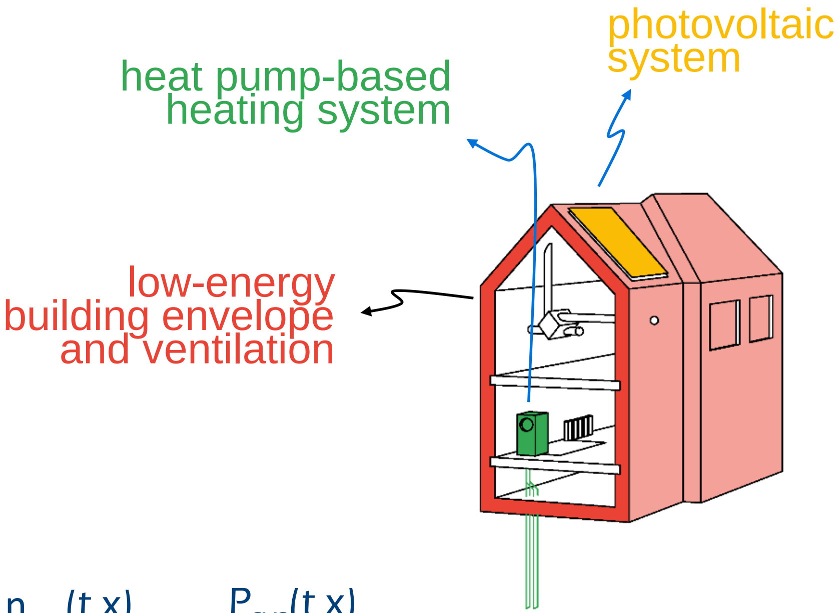
Detailed modelling of

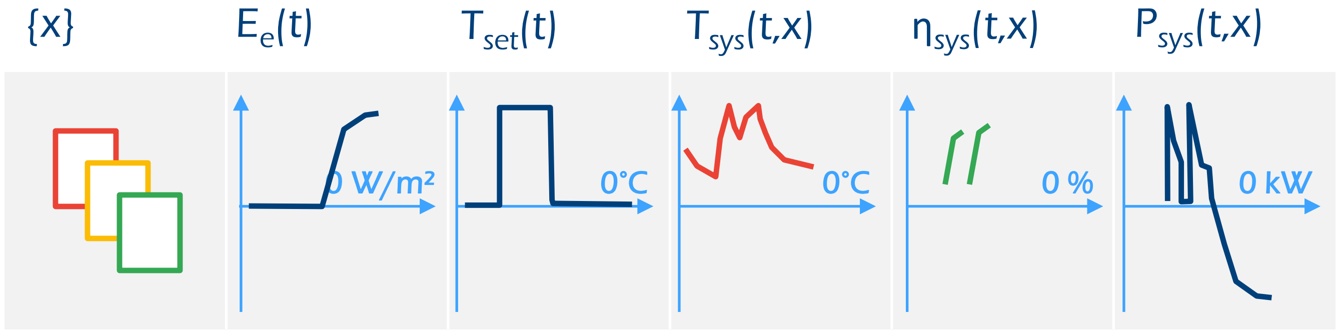
- Envelope
- Systems
- Occupants

Evaluate

- Energy use
- Energy cost
- Comfort

} Building level





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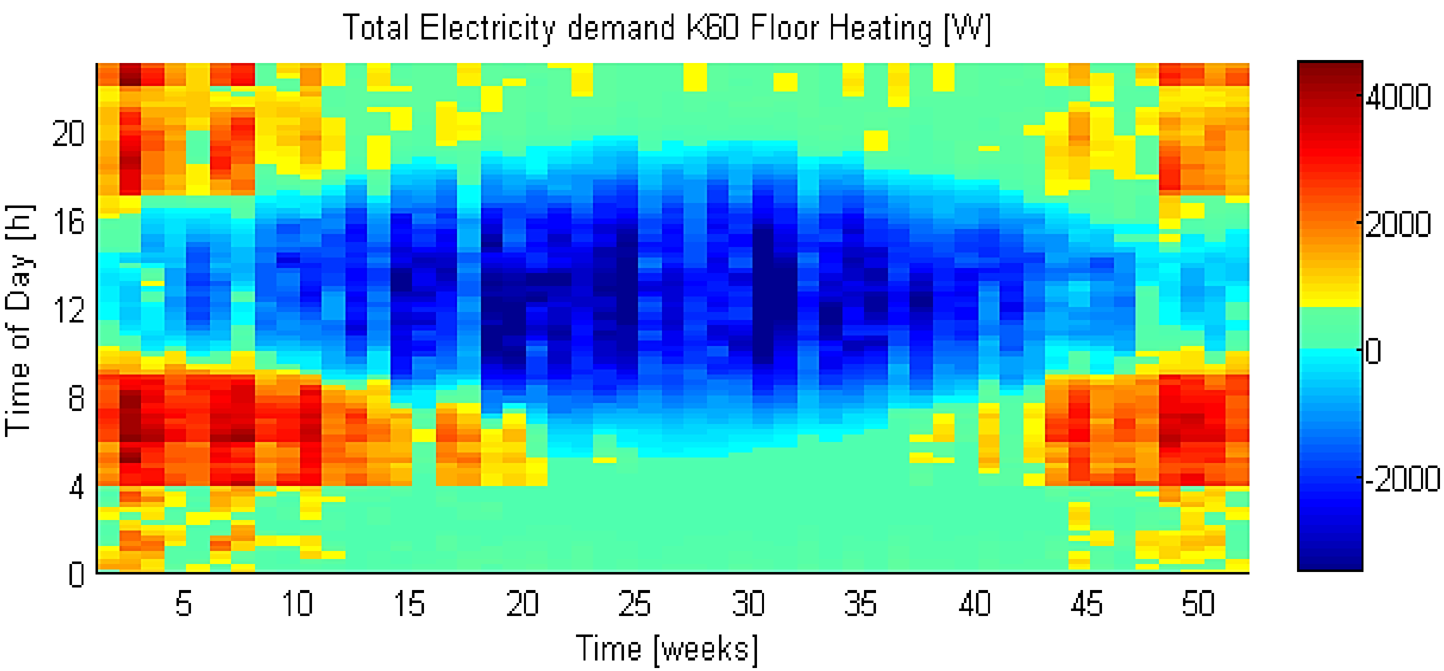
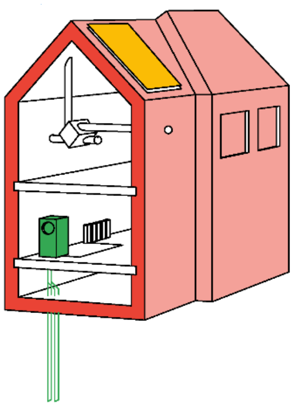
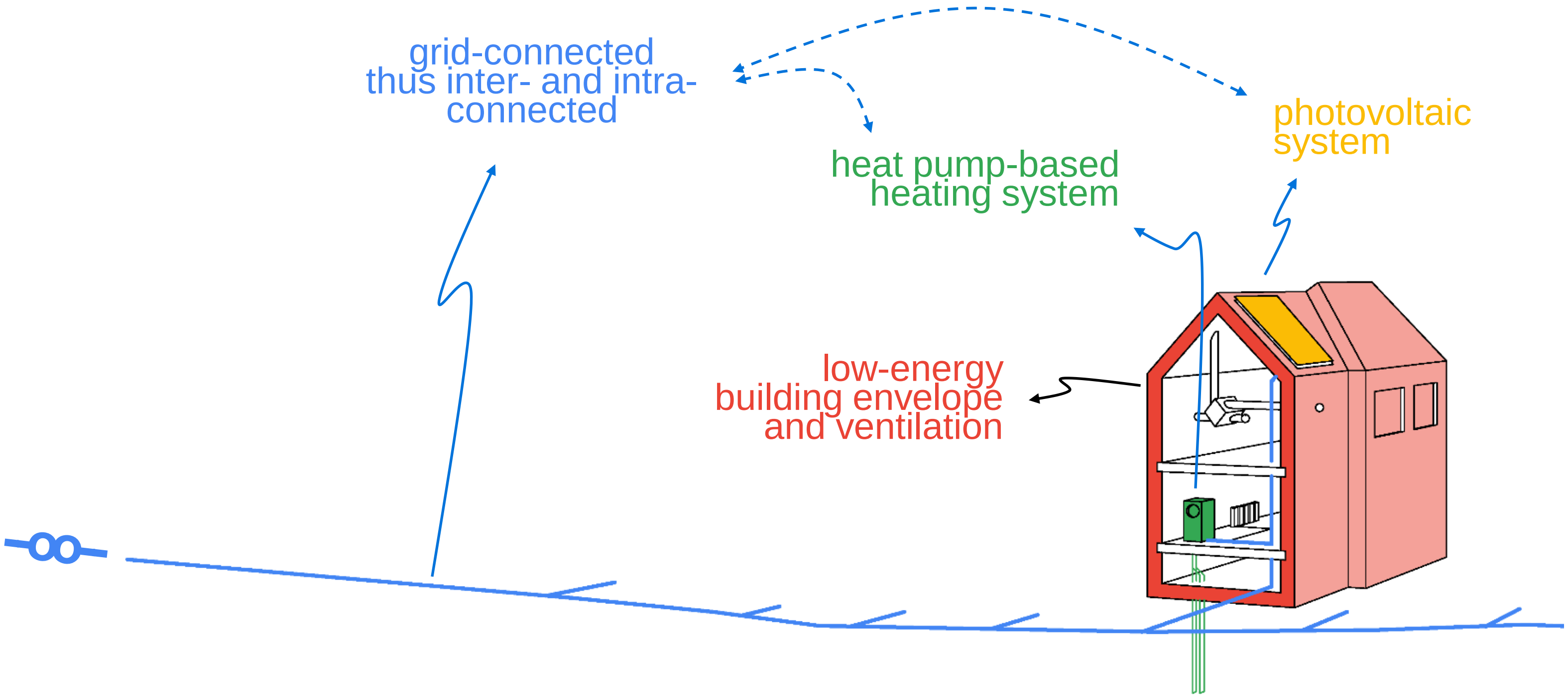
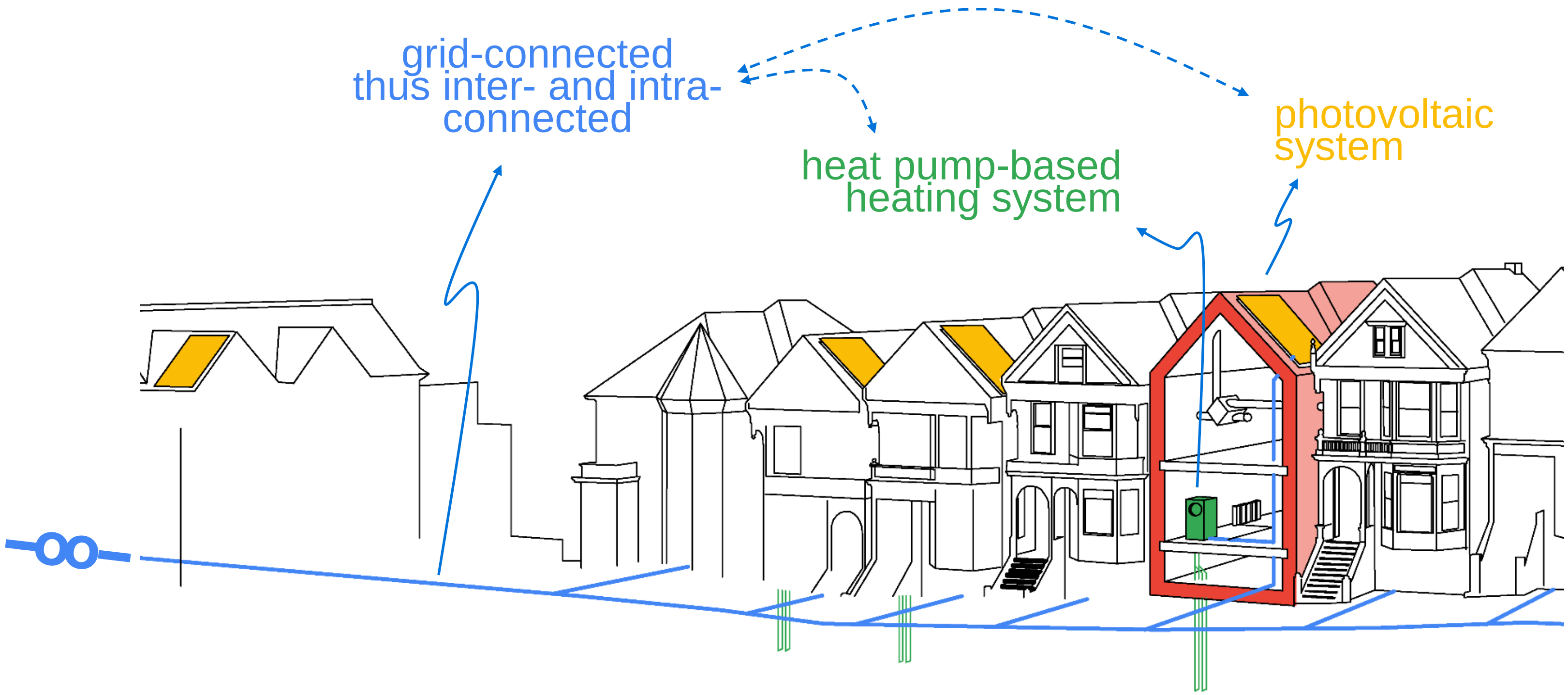

Total Electricity demand K60 Floor Heating [W]
Time of Day [h]
0
4
8
12
16
20
Time [weeks]
5
10
15
20
25
30
35
40
45
50
4000
2000
0
-2000




grid-connected
thus inter- and intra-
connected
heat pump-based
heating system
photovoltaic
system
low-energy
building envelope
and ventilation

New **challenges** for building simulation

- multi-domain modelling
- increase of dimensionality
- reduction of time-scale



I. Building energy simulations

Interdisciplinary energy simulation models

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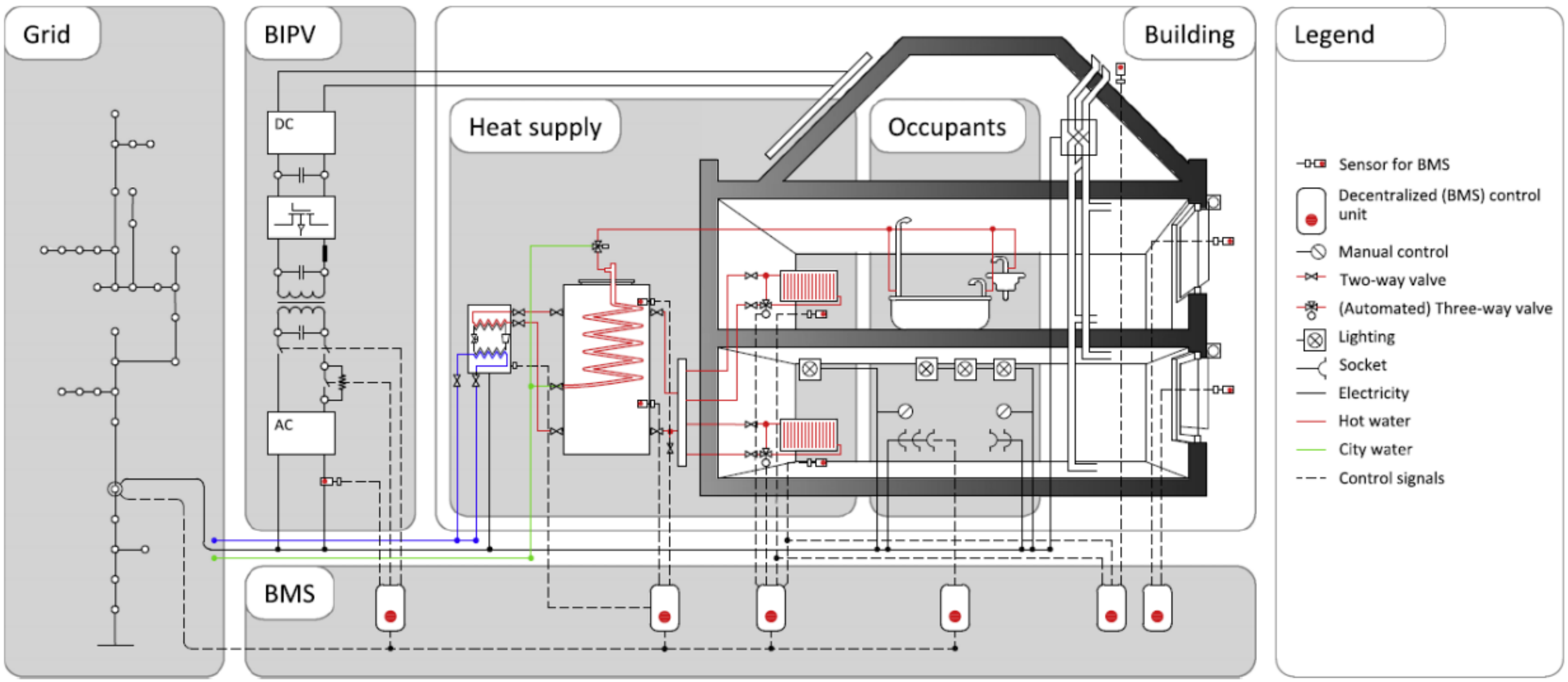
IDEAS.mo – Integrated District Energy Assessment Simulation

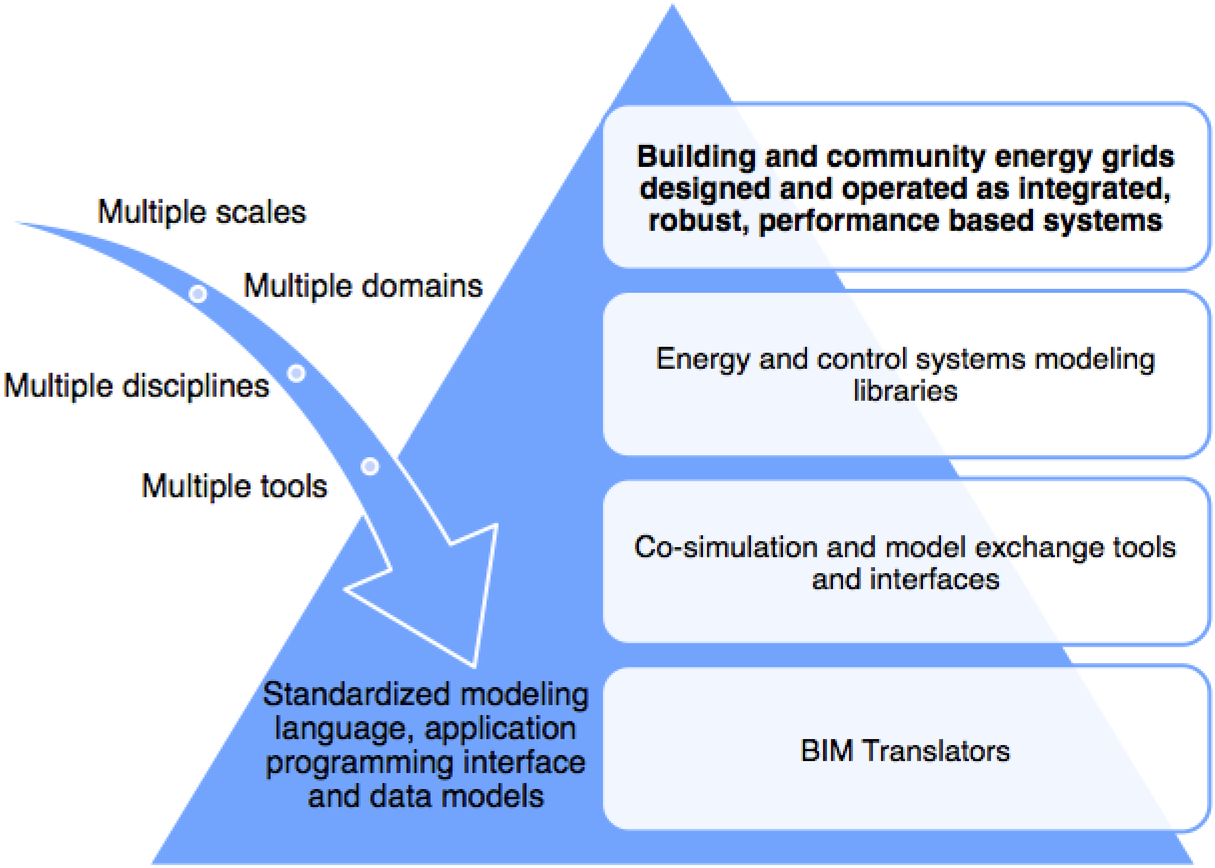


R. Baetens, R. De Coninck, J. Van Roy, B. Verbruggen, J. Driesen, L. Helsen, D. Saelens, Assessing electrical bottlenecks at feeder level for residential net zero-energy buildings by integrated system simulation, Applied Energy, Volume 96, August 2012, Pages 74-83, ISSN 0306-2619, 10.1016/j.apenergy.2011.12.098.

Open-source library: github.com/open-ideas

IEA EBC Annex 60:

"New generation computational tools for building and community energy systems based on the Modelica and Functional Mockup Interface standards"



IDEAS.mo – Integrated District Energy Assessment Simulation

Buildings.mo

- Components
  - Window.mo
  - Zone.mo
  - SlabOnground.mo
  - OuterWall.mo
  - …
- GreyboxModels
  - TiTeThTsAe.mo
  - …
- Data
- Validation
  - BESTEST.mo
- Examples

Thermal.mo

- Components
  - Production
    - Boiler.mo
    - HP_AirWater.mo
    - …
  - Emission
  - Storage
  - Distribution
  - DHW
  - Ventilation
  - GroundTubes
- Control
- HeatingSys
- VentilationSys
- Data
- Validation
- Examples

Electric.mo

- Distribution
  - Grid.mo
  - Components
  - Examples
- Photovoltaic
  - PvSystem.mo
  - Components
  - Examples
- Battery
  - ElectricVehicle.mo
- Connections
- Data
- Validation
- Examples

Occupants.mo

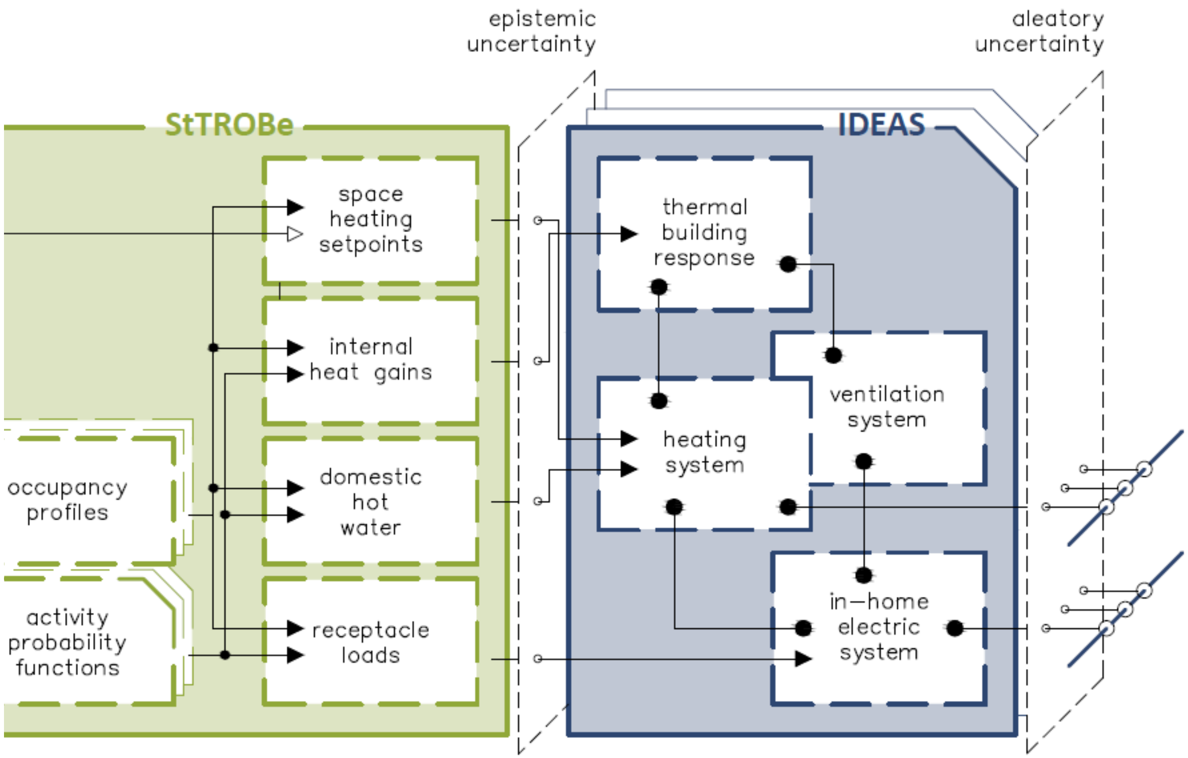
- Components
  - Fanger.mo
- Standards
  - ISO13790.mo
- Extern
  - SingleZone.mo
  - MultiZone.mo
- Examples

StROBe.py

StROBe.py
short for Stochastic Residential Occupant Behavior
providing boundary conditions for IDEAS.mo
in a residential context.

Figure 4.1

General overview of the implemented approach in StROBe *as input for* IDEAS*-based neighborhood simulations.*



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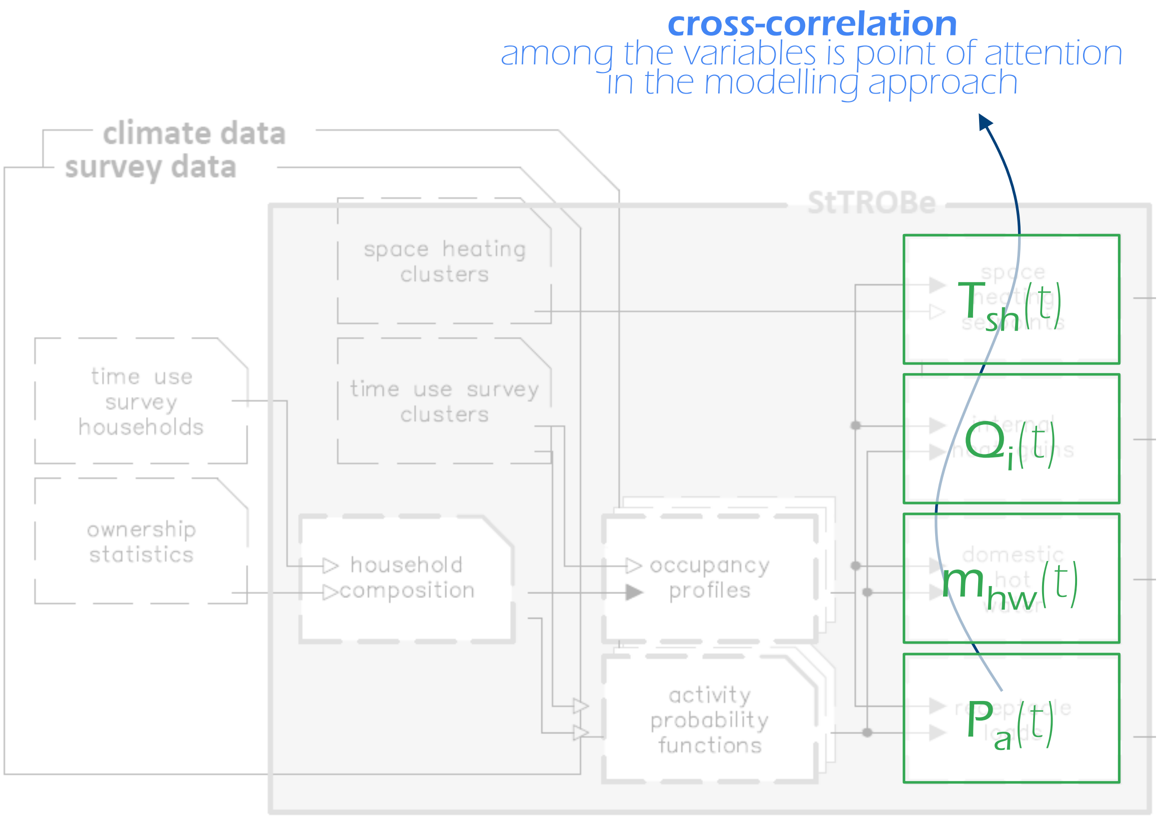

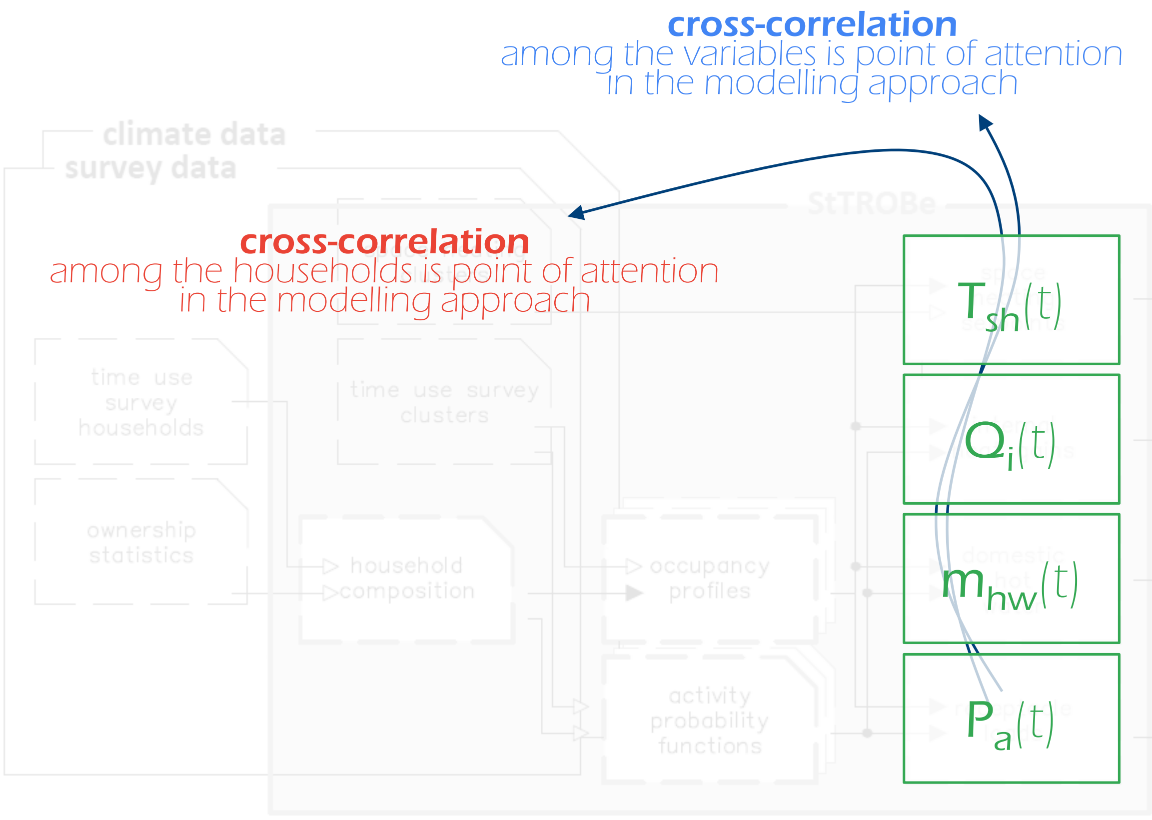

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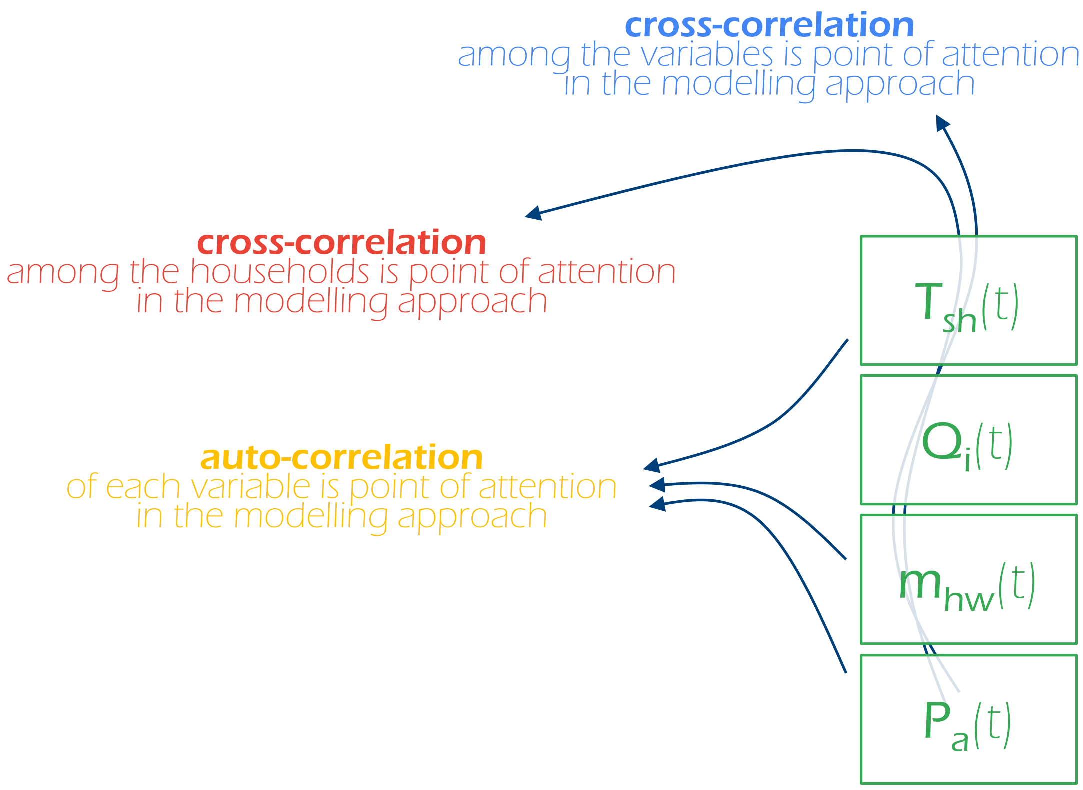
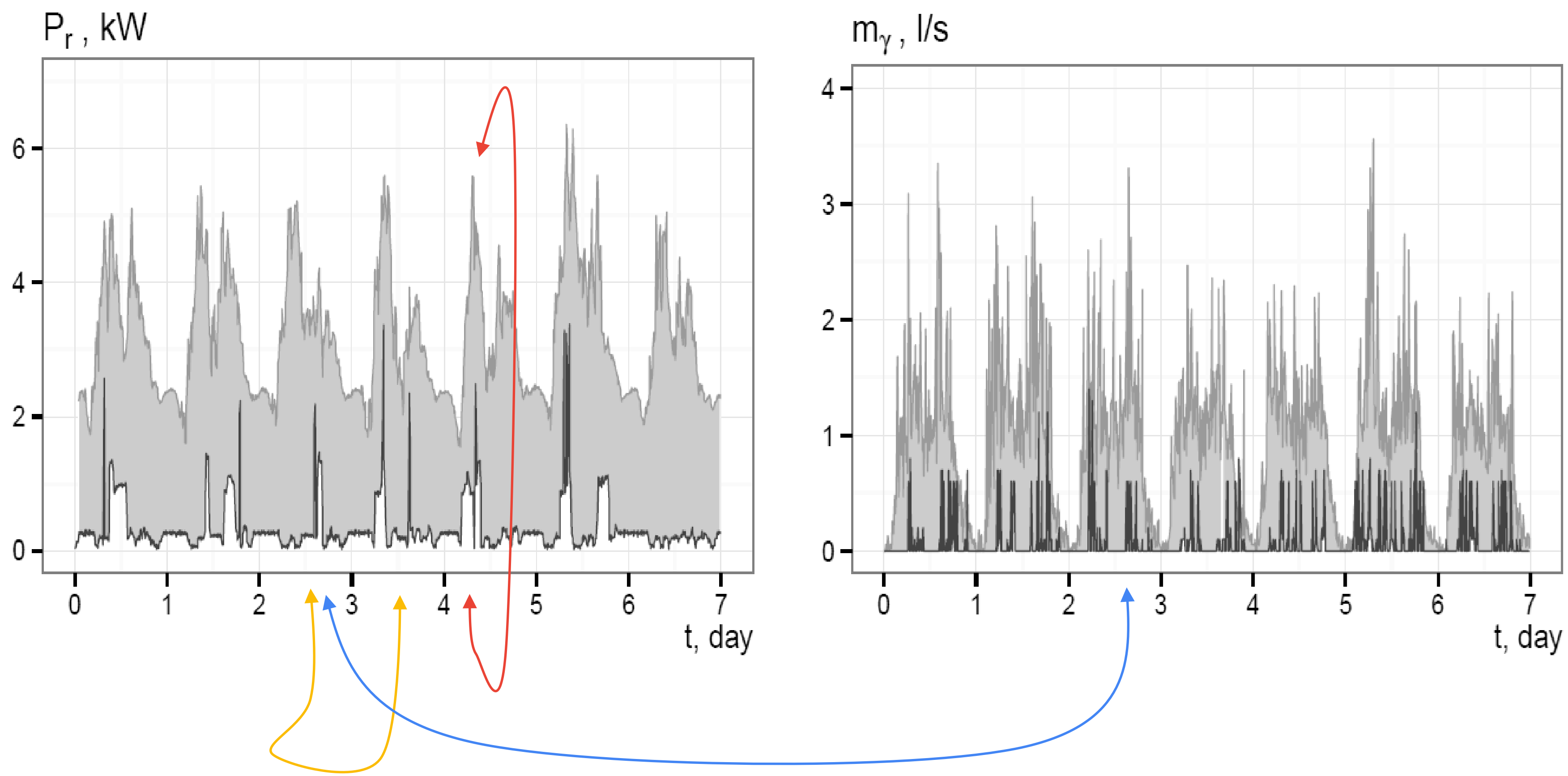




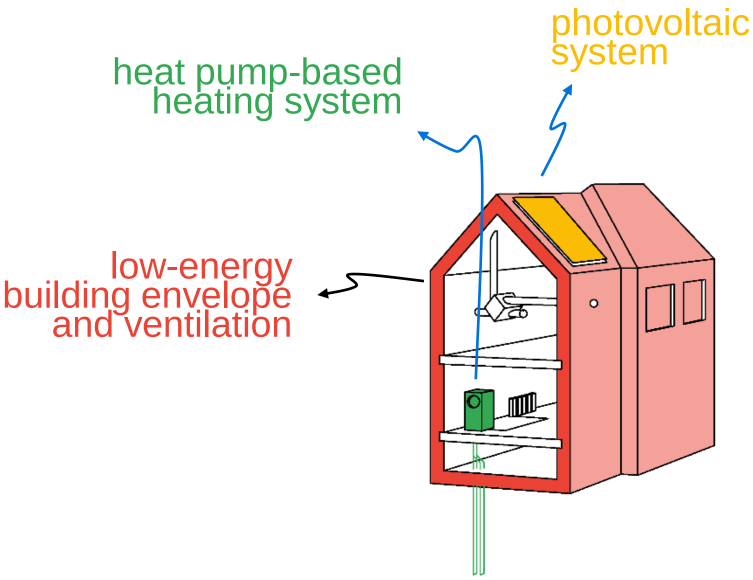
P_r , kW
6
4
2
0
0 1 2 3 4 5 6 7
t, day
m_γ , l/s
4
3
2
1
0
0 1 2 3 4 5 6 7
t, day

I. Building energy simulations

Case study

Case study

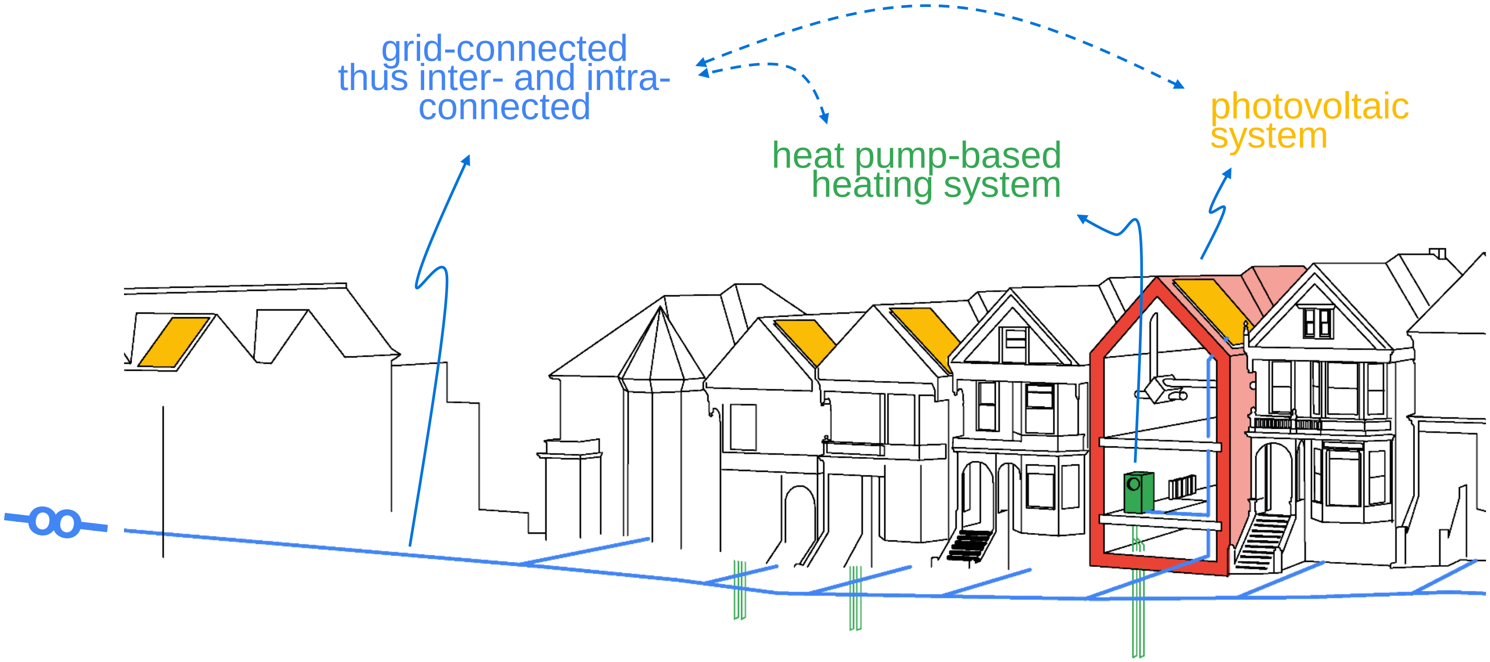
Evaluation of nZEB's



Baetens, R., De Coninck, R., et.al. (2012). Assessing electrical bottlenecks at feeder level for residential net zero-energy buildings by integrated system simulation. Applied Energy, 96, 74–83.

Case study

Evaluation of nZEB's taking into account electric bottlenecks



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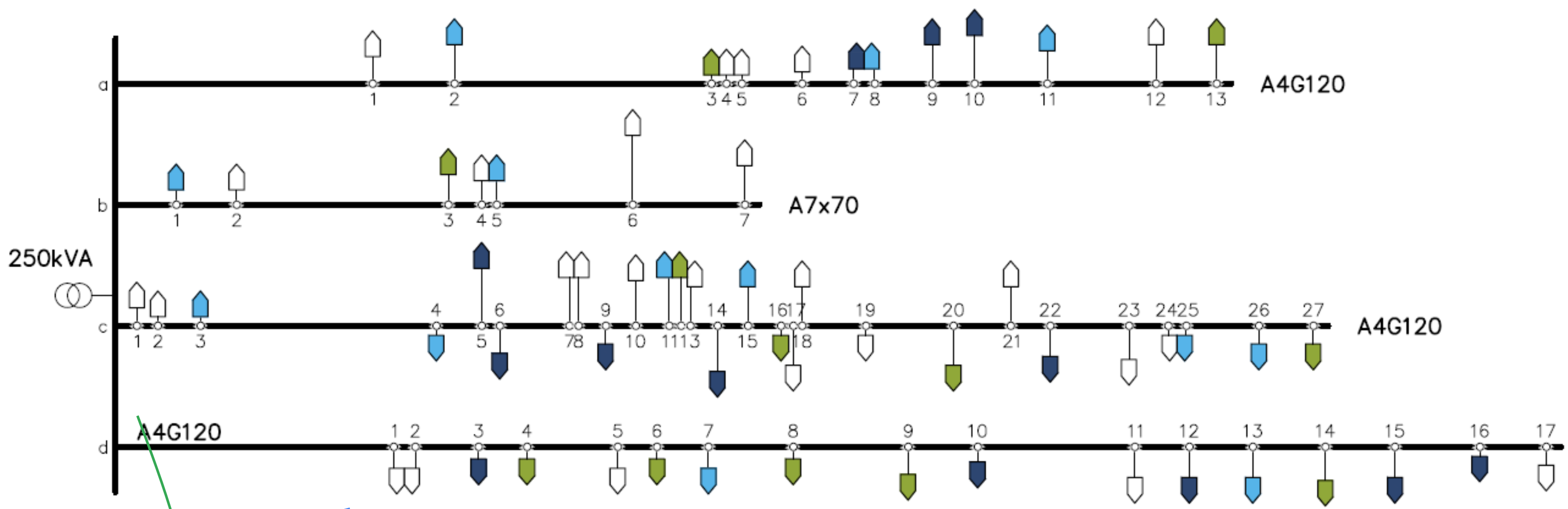

- **Increasing nZEB implementation,**
  i.e. individual dwellings
  have a HP and PV system designed for nZEB
- **3 feeder strengths,**
  i.e. a weak, moderate and strong version

Baetens, R., De Coninck, R., et.al. (2012). Assessing electrical bottlenecks at feeder level for residential net zero-energy buildings by integrated system simulation. Applied Energy, 96, 74–83.

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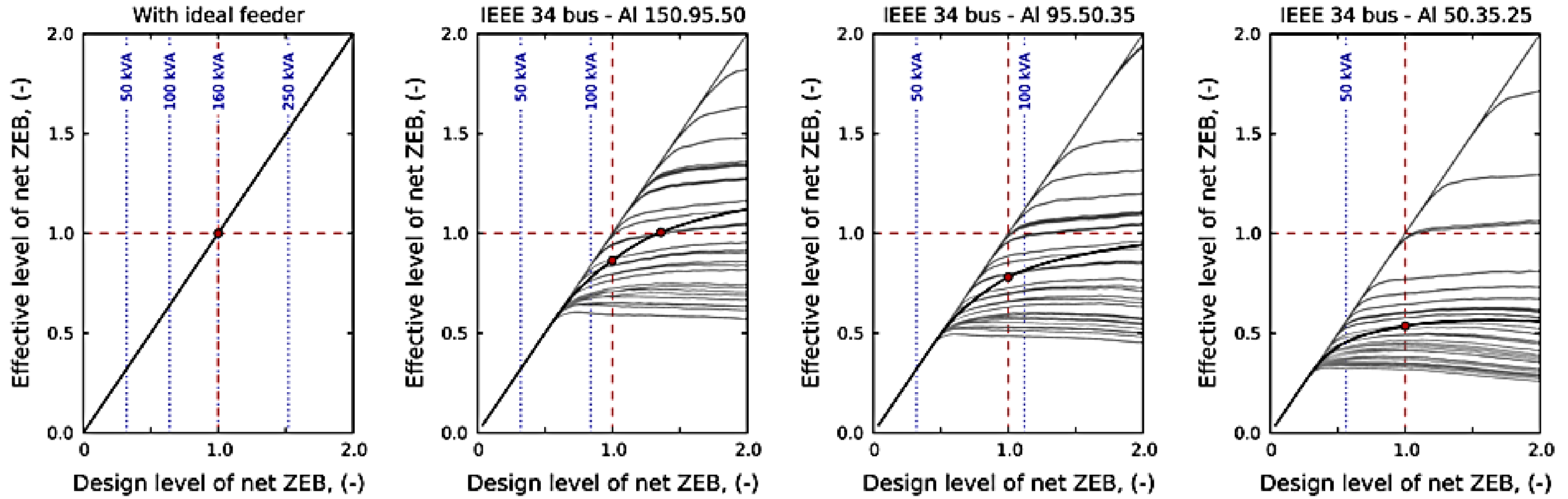

(a) Individual buildings (b) Strong feeder (c) Moderate feeder (d) Weak feeder

Fig. 7. Effective levels of net zero-energy plotted against the design level of net zero-energy at building (gray) and aggregated (black) level determined ideally at building level and after integrated district energy system simulation including feeder consequences for the considered feeder designs. Here, a depicted design level of net zero-energy of 1.0 denotes the exact dimensioning of the photovoltaic capacities as described whereas a design level of net zero-energy of e.g. 0.8 depicts an under-sizing by a fraction of 20% at annual basis of the provided local supply of renewable energies. The dotted lines indicate the required transformer capacity.

Baetens, R., De Coninck, R., et.al. (2012). Assessing electrical bottlenecks at feeder level for residential net zero-energy buildings by integrated system simulation. Applied Energy, 96, 74–83.

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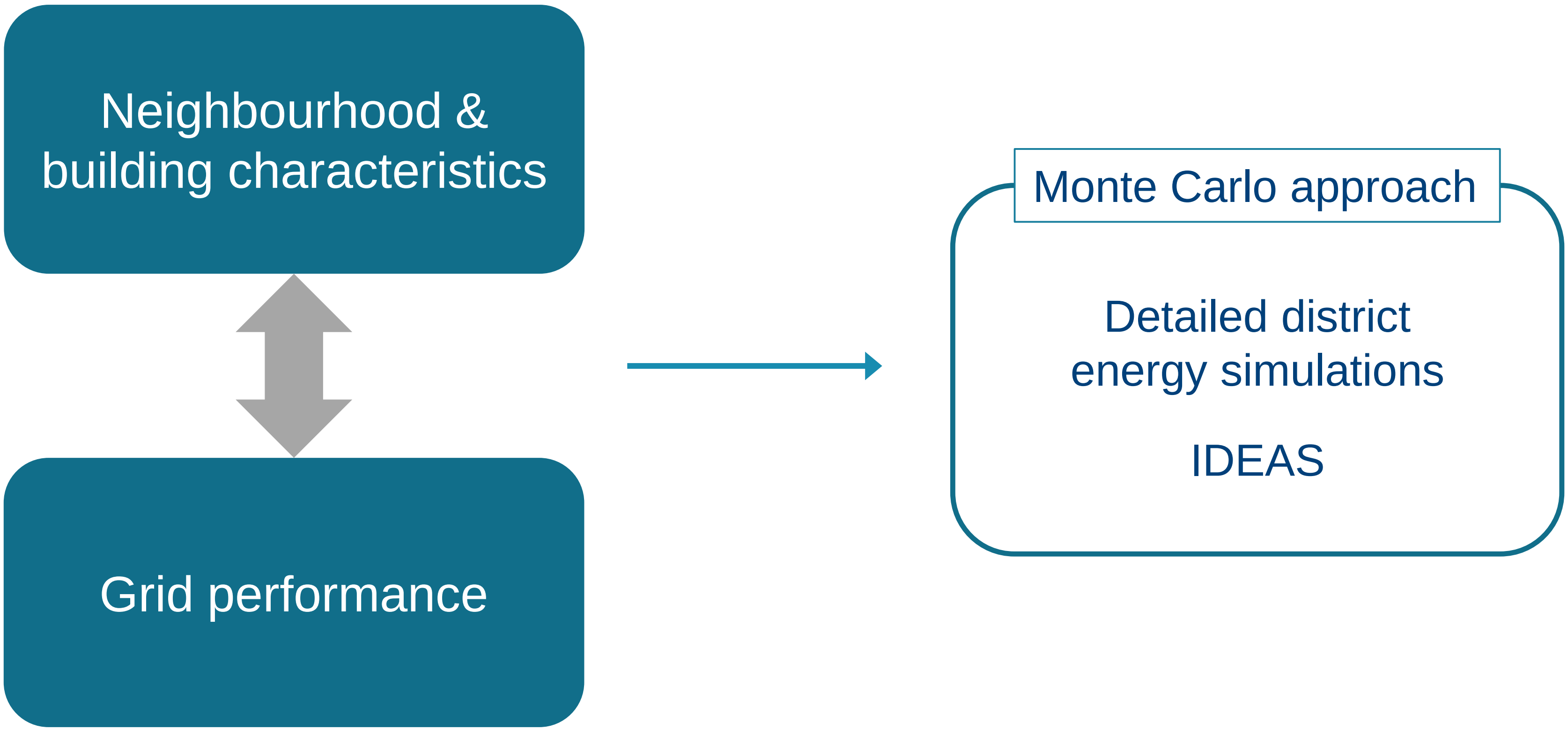
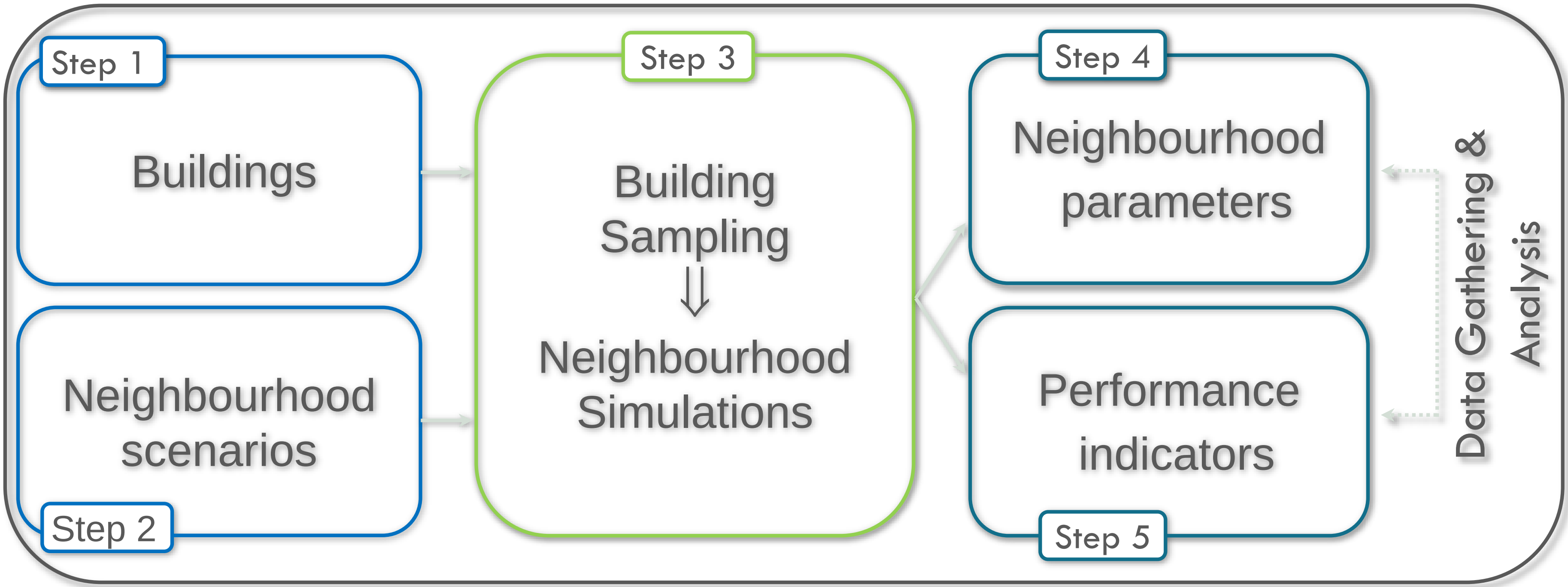


Protopapadaki C., Baetens R. and Saelens D. (2015) Exploring the impact of heat pump-based dwelling design on the low-voltage distribution grid. Proceedings of Building Simulation 2015, Hyderabad, India.



Protopapadaki C., Baetens R. and Saelens D. (2015) Exploring the impact of heat pump-based dwelling design on the low-voltage distribution grid. Proceedings of Building Simulation 2015, Hyderabad, India.

(1200) Feeder simulations

IDEAS district model

Simulation outputs
Electrical demand
Transformer load
Voltage profiles
PV curtailment
Grid losses

CORRELATIONS ?

Neighbourhood parameters
Cable type
HP impl. rate
PV impl. rate
HP el. Demand*
Q_{design}*
Volume*
UA-value*
gA-value*
avg U-value
wwr
n_{50}
Building ori.
SPF
PV capacity*
PV orientation

*also total values

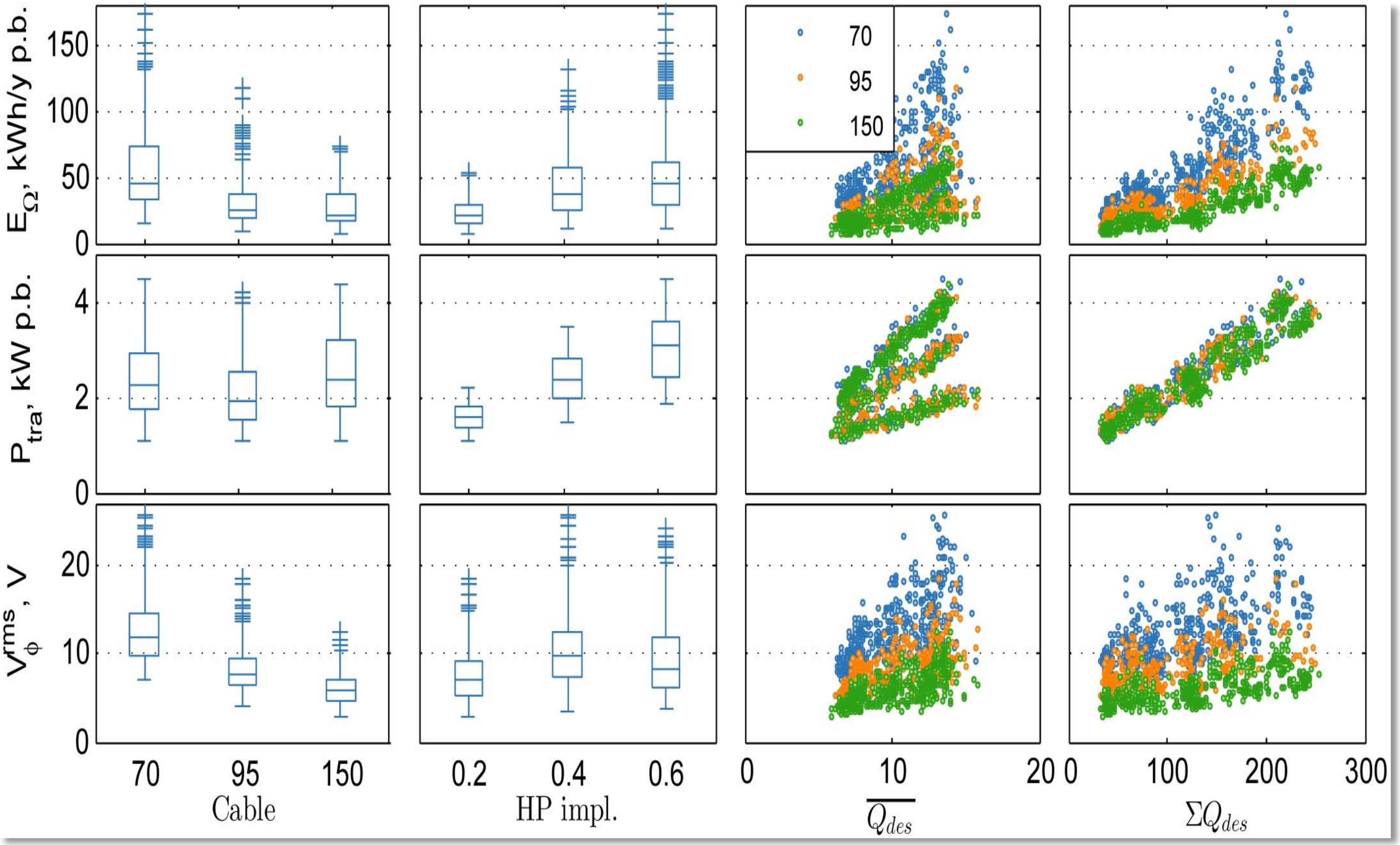


Figure: Rural feeder. The different colors of the scatter plots denote a different cable type.

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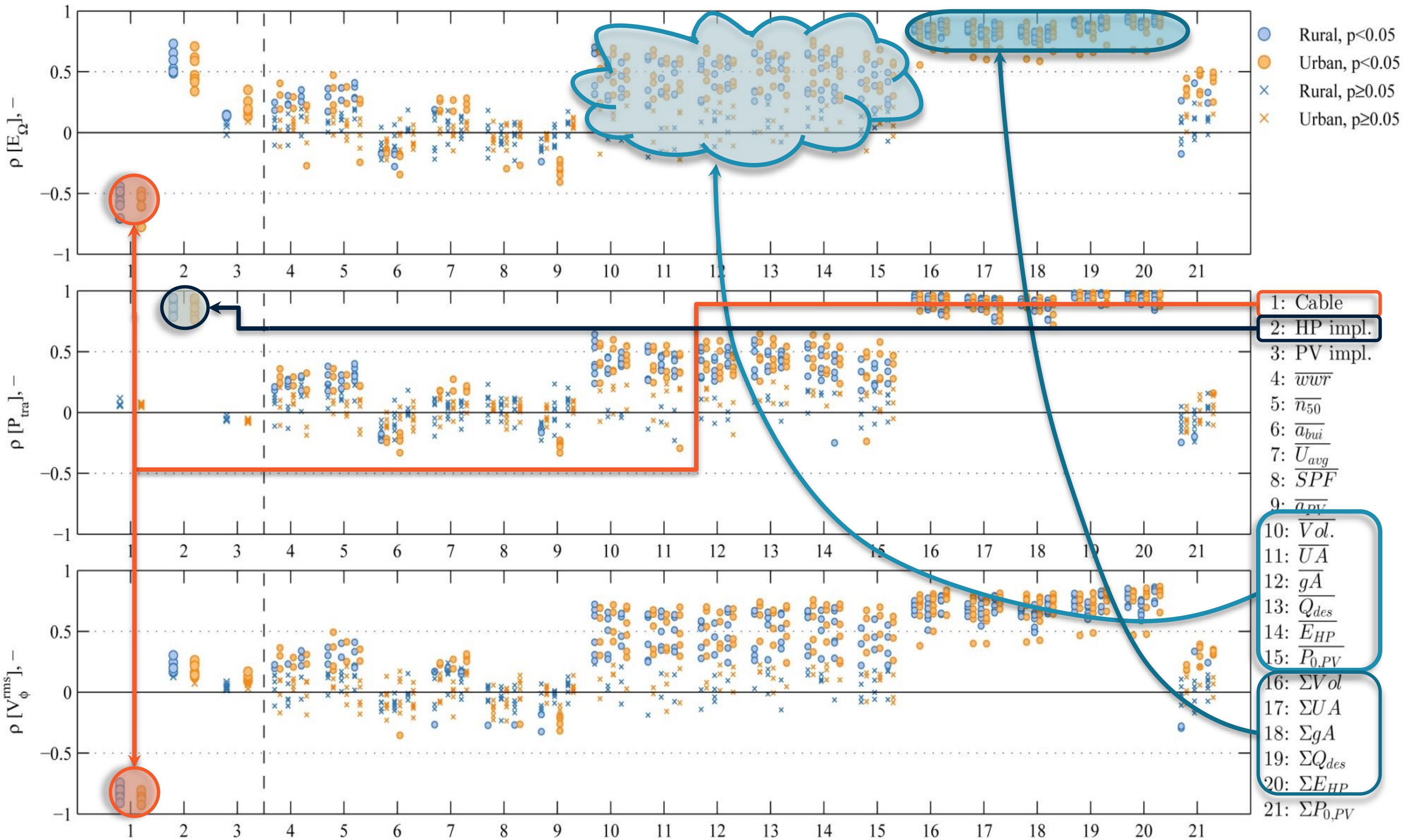
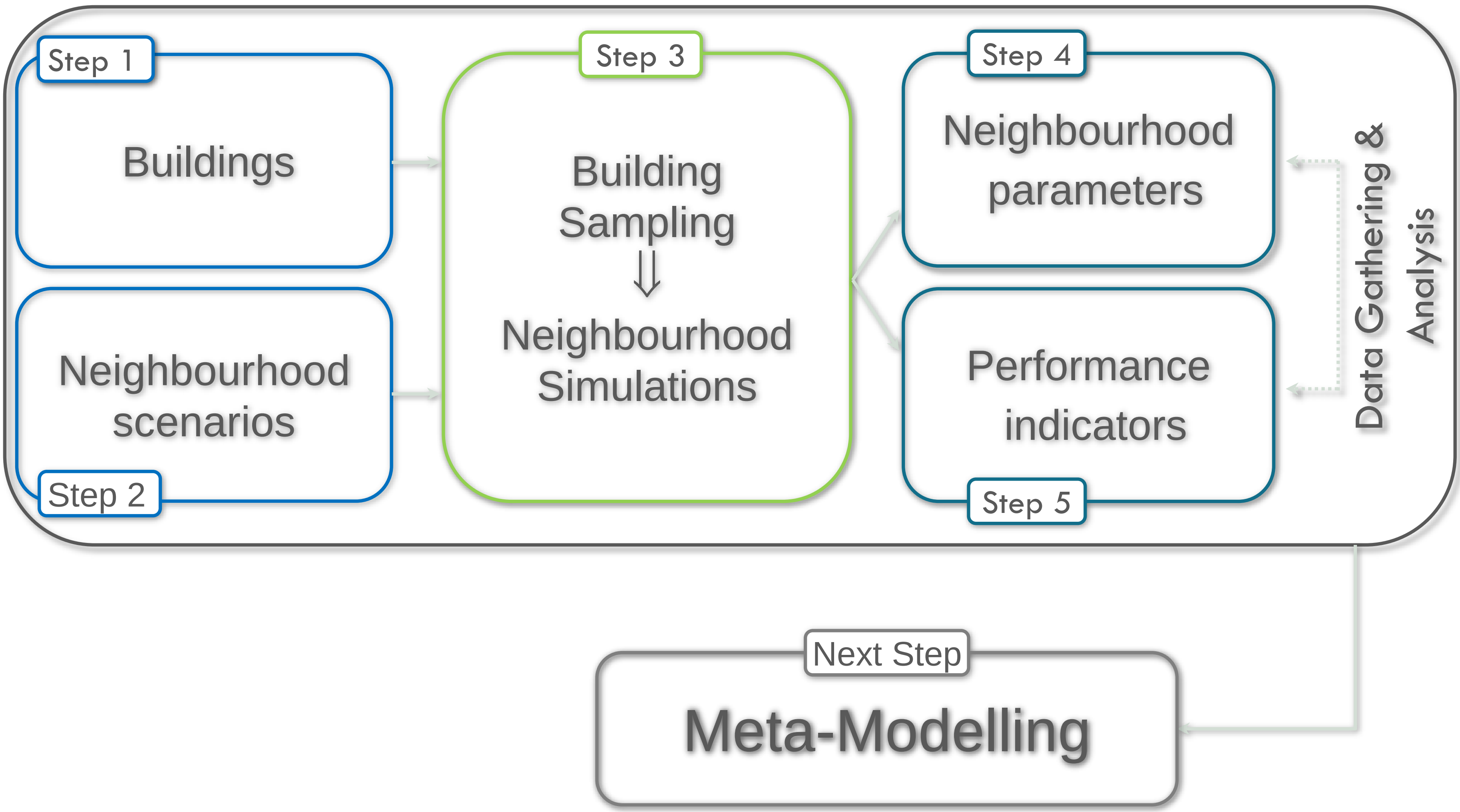


Spearman's correlation coefficients of all neighbourhood parameters based on the simulation set, feeder configuration and cable type. Different color for different feeder (Rural, Urban). Three column sets represent the cable types (from left to right: cable section 70, 95 and 150 mm2). No disaggregation by cable type for the scenario parameters (1-3). Filled dots (•) denote p-values smaller than 0.05, while crosses (ˣ) denote values above 0.05.



Step 1
Buildings
Step 2
Neighbourhood scenarios
Step 3
Building Sampling
⇓
Neighbourhood Simulations
Step 4
Neighbourhood parameters
Step 5
Performance indicators
Data Gathering & Analysis
Next Step
Meta-Modelling

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Wrap up - From building to district level

- Large scale implementation of nZEB has impact on grid
  - Obtained level nZEB not only function of building design, also of what happens on aggregated level
- New <u>challenges</u> for simulations
  - Detailed models on high time resolution
  - Evaluation at aggregated level
  - Multi-domain approach

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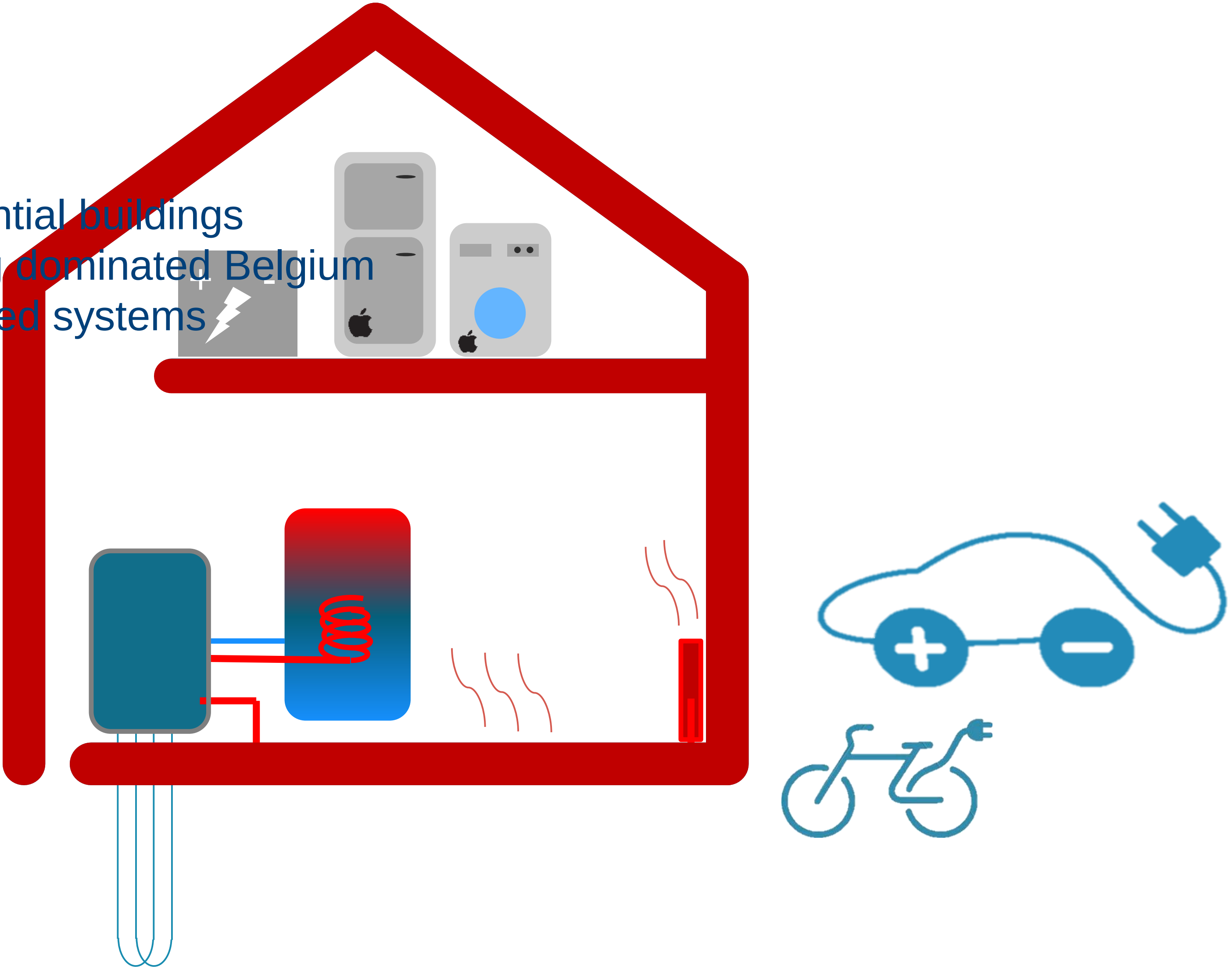
II. BUILDINGS IN AN ACTIVE DEMAND RESPONSE CONTEXT

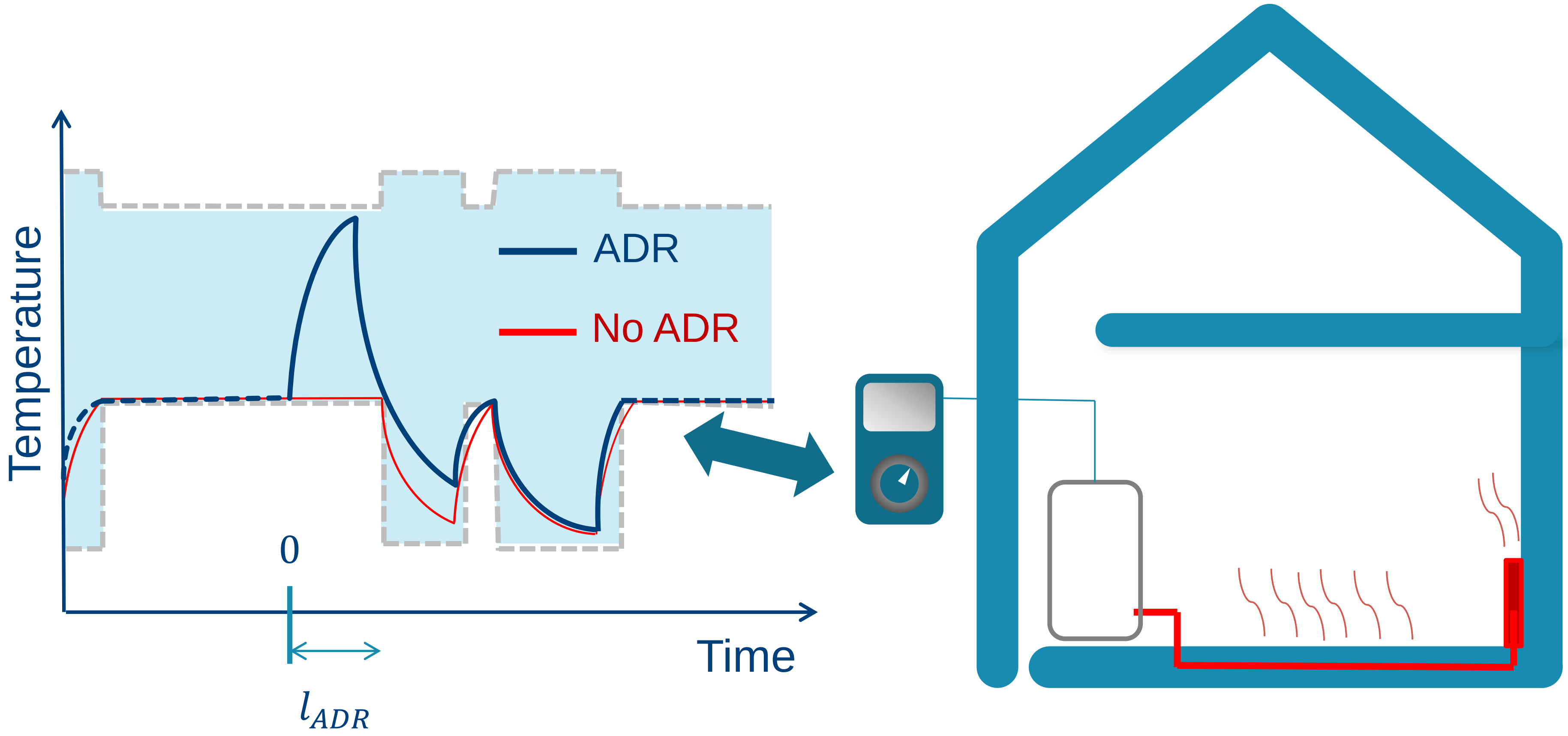
Using structural thermal energy storage

Scope

- Residential buildings
- Heating dominated Belgium
- Simplified systems



Activation of structural thermal mass – The concept



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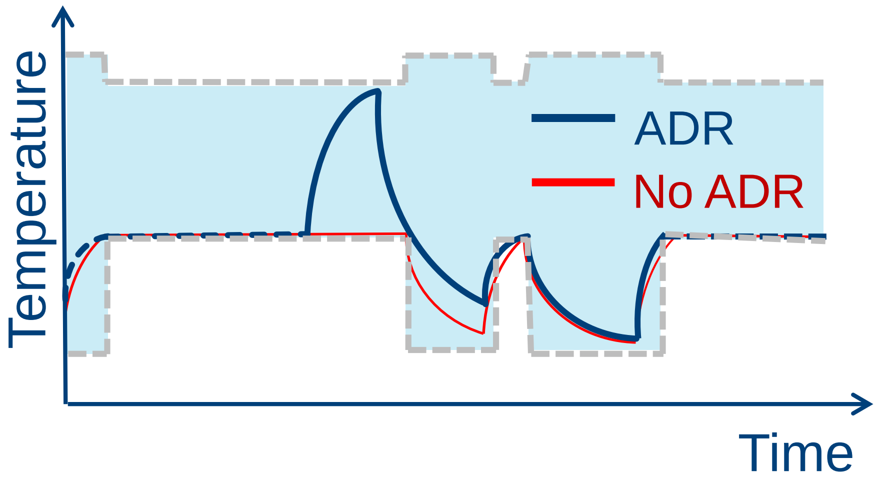

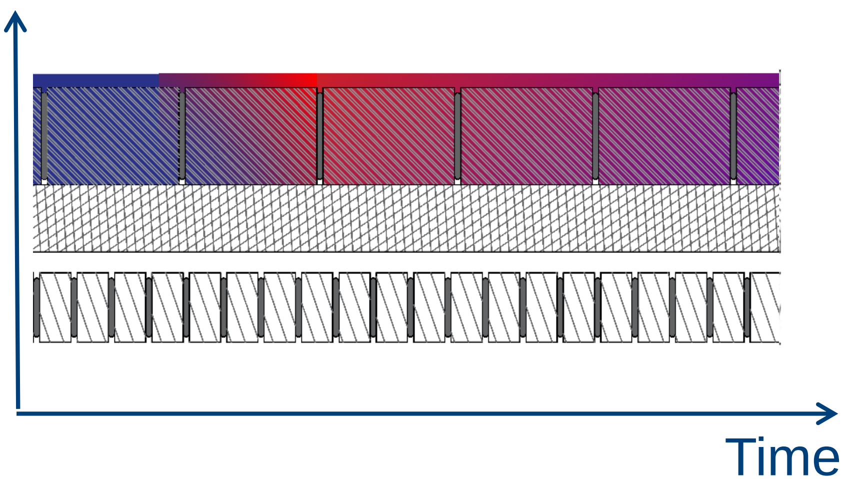

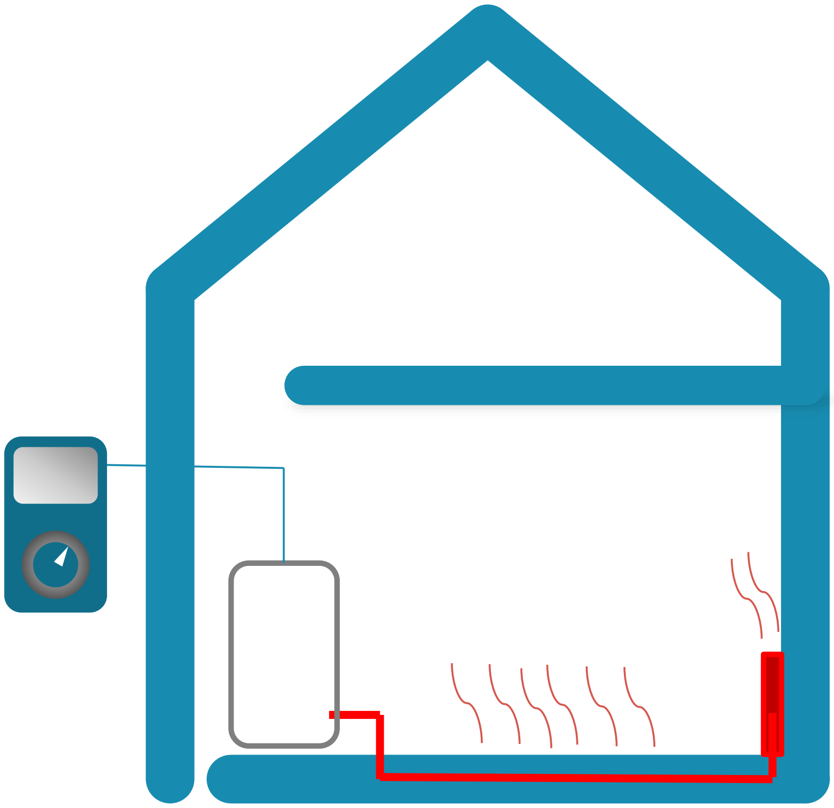

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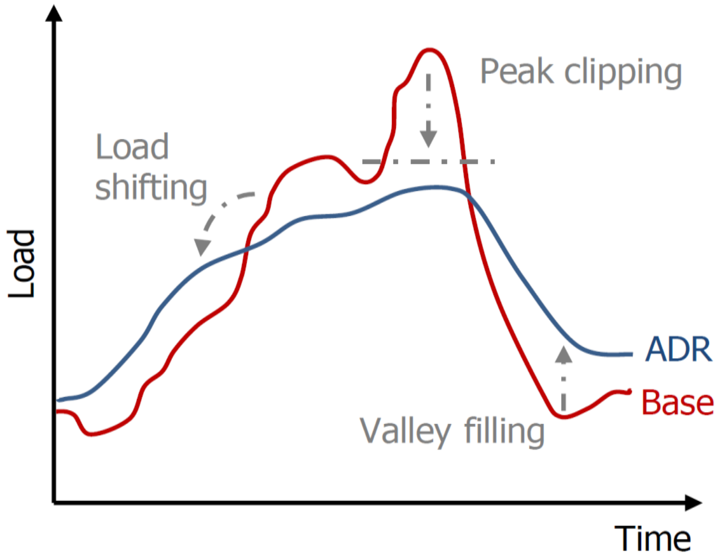
"How do building design parameters of new and existing buildings influence the potential for active demand response using structural thermal storage?"



II. Buildings in an active demand response context

Quantifying flexibility

grid perspective

- Size (kWh)
- Power (kW)
- Availability (s)
- Investement cost (€ + kWh)
- Current state (-)

building perspective

- Comfort
- Cost / Profit (€)
- Energy use (€ + kWh)

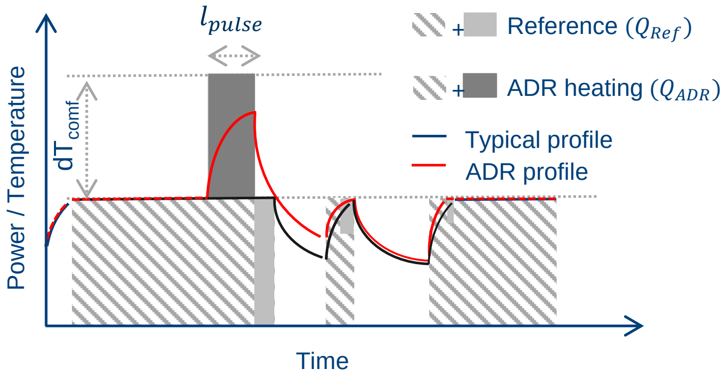
4 Performance indicators

- Available capacity
- Storage Efficiency

- State of Charge
- Power shifting capability

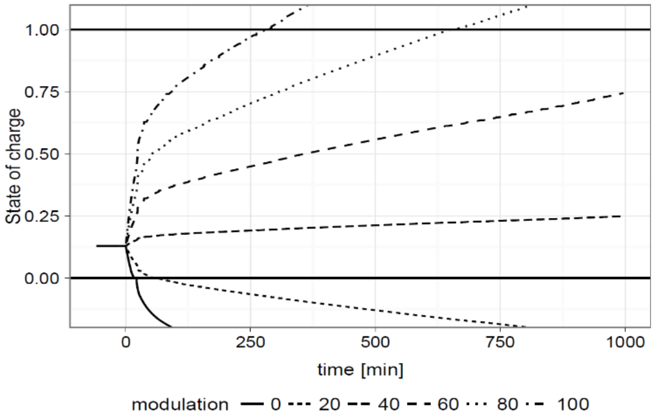
C_{ADR} : Available storage capacity [kWh]
η_{ADR} : Storage efficiency [%]

- Interpretation: ADR signature
- Interesting for: planning, design



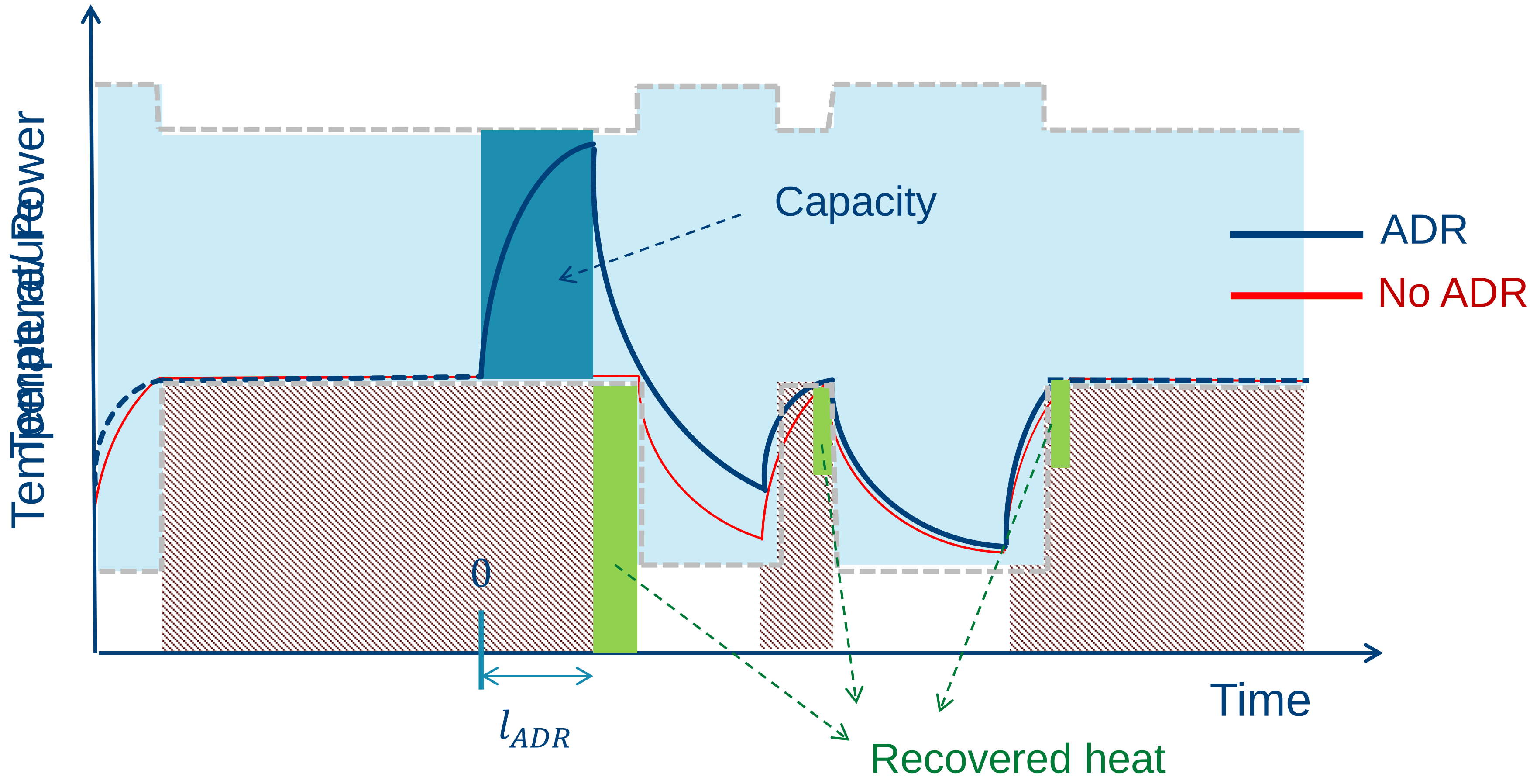
SOC : State-of-charge [-]
PSC : Power-shift capability [s]

- Interpretation: snapshot of flexibility
- Interesting for: control, operation



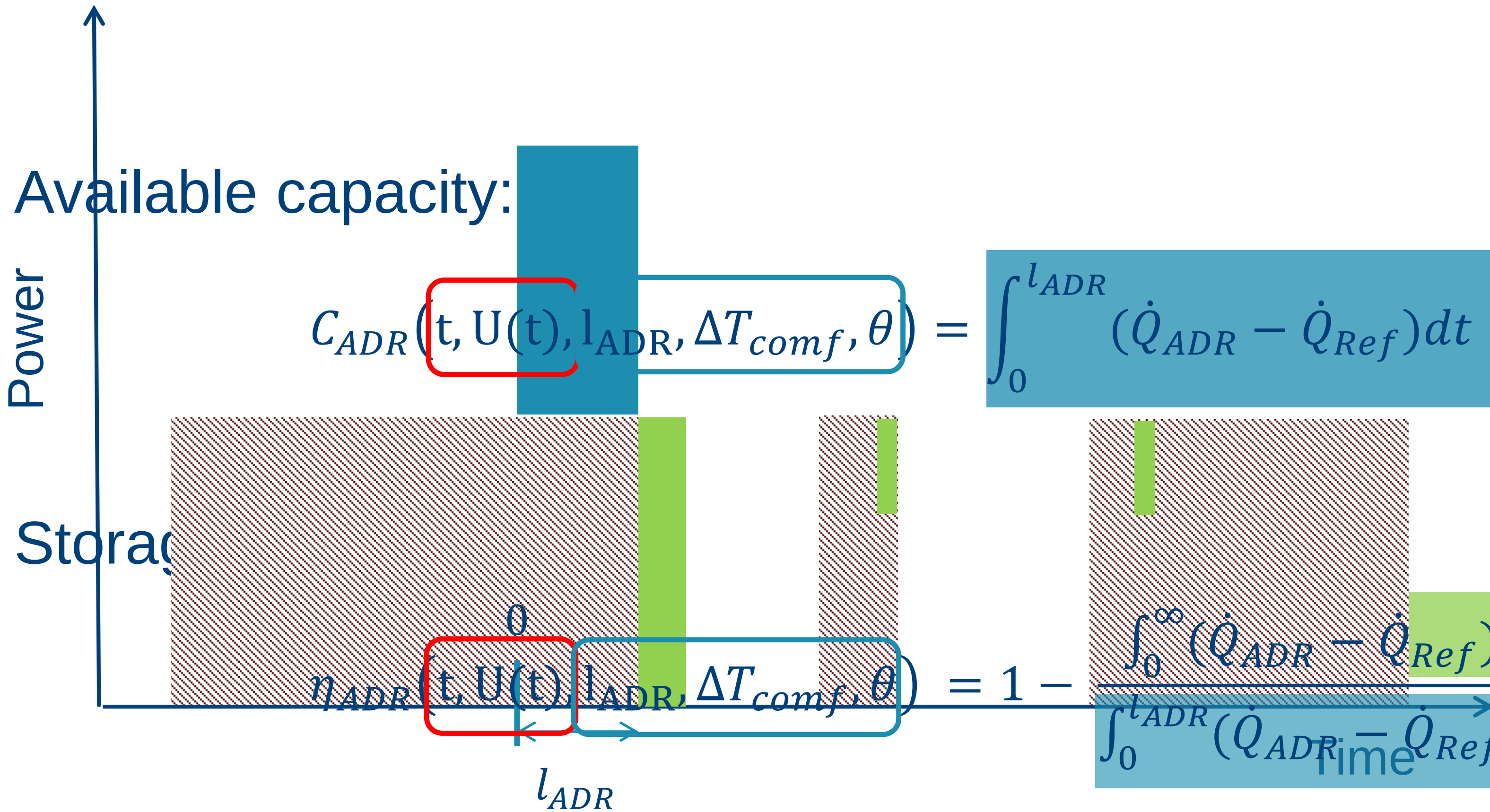
Quantifying available capacity and efficiency

Methodology



Quantifying available capacity and efficiency

METHODOLOGY



Available capacity:

$$C_{ADR}\left(\mathrm{t}, \mathrm{U}(\mathrm{t}), \mathrm{l}_{\mathrm{ADR}}, \Delta T_{comf}, \theta\right) = \int_{0}^{l_{ADR}} (\dot{Q}_{ADR} - \dot{Q}_{Ref})dt$$

Storag

$$\eta_{ADR}\left(\mathrm{t}, \mathrm{U}(\mathrm{t}), \mathrm{l}_{\mathrm{ADR}}, \Delta T_{comf}, \theta\right) = 1 - \frac{\int_{0}^{\infty} (\dot{Q}_{ADR} - \dot{Q}_{Ref})dt}{\int_{0}^{l_{ADR}} (\dot{Q}_{ADR} - \dot{Q}_{Ref})dt}$$

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II. Buildings in an active demand response context

Impact of building design

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Parameter study

Impact building design?

- Detailed analysis of C_{ADR} and η_{ADR}
- Theoretic parameter study
  - Wide range of building parameters
    - Geometry
    - Thermal properties
    - System and control settings
  - Radiators vs. floor heating

	Parameter	Range
Geometry	A_{floor} [m²]	75 – 250
	Height [m]	2.75 – 3.5
	Compactness [m]	0.75 – 2.5
	Int. Wall ratio [-]	0.5 – 2.0
Thermal properties	$d_{insul,roof}$ [m]	0 – 0.25
	$d_{insul,walls}$ [m]	0 – 0.25
	$d_{brick,walls\_e}$ [m]	0 – 0.20
	$d_{walls,i}$ [m]	0 – 0.30
	n_{vent} [ACH]	0 – 0.8
System & control	$f_{sys,size}$ [-]	0.8 – 2
	$ADR_{duration}$ [min]	15 – 480
	ADR_{comf} [°C]	1 – 4

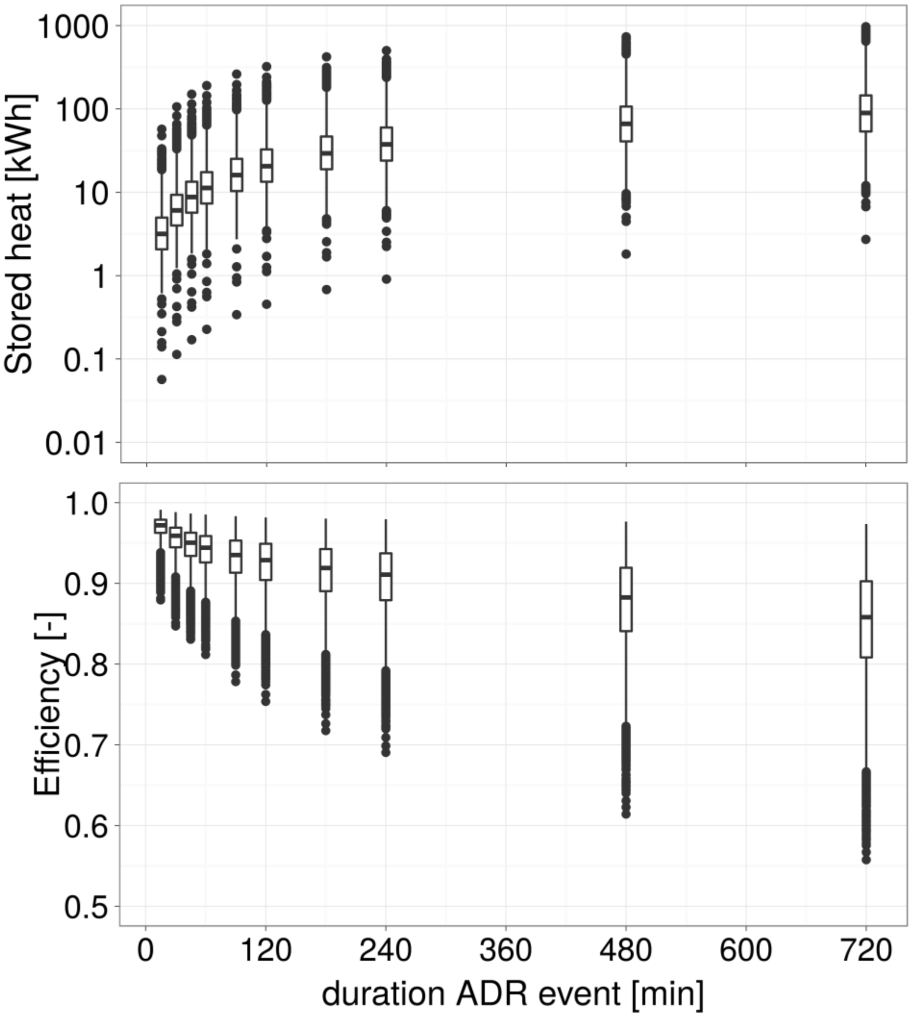
Parameter study

Impact building design?

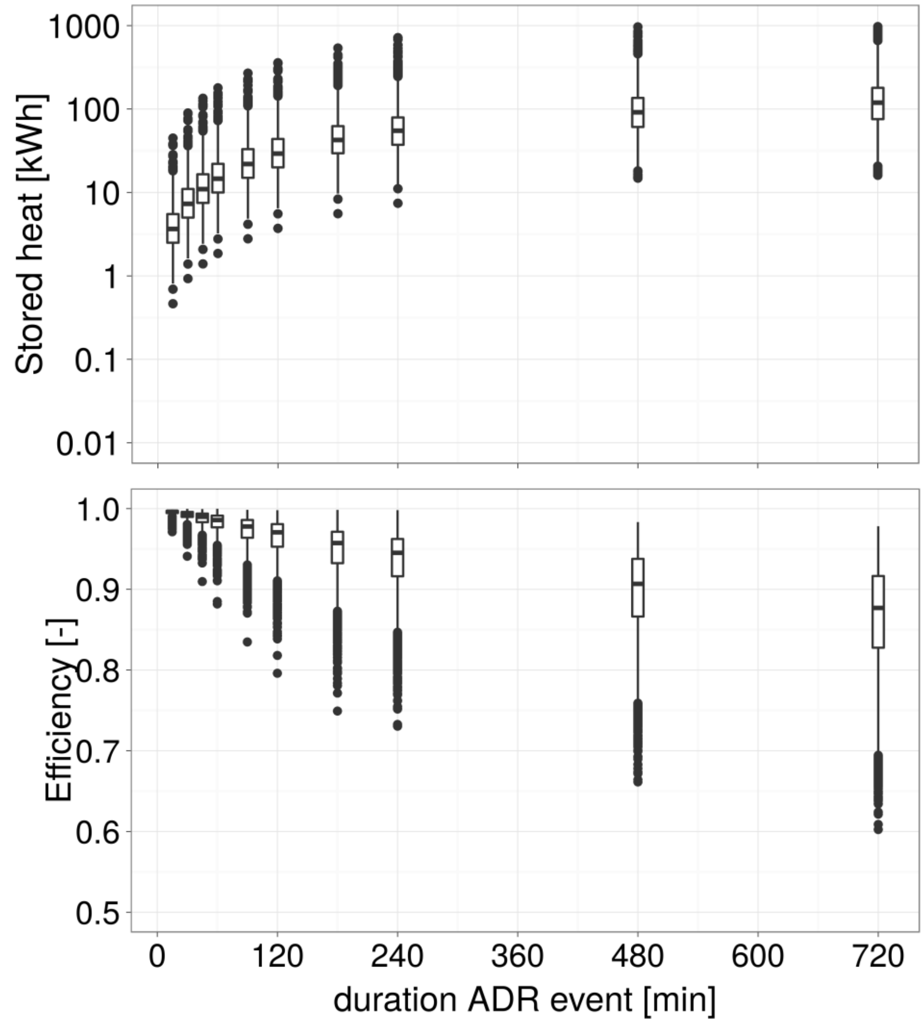
- Detailed analysis of C_{ADR} and η_{ADR}
- Theoretic parameter study
- Simplified boundary conditions
  - Constant outdoor temperature
  - No solar gains
  - Constant comfort range

	Parameter	Range
Geometry	A_{floor} [m²]	75 – 250
	Height [m]	2.75 – 3.5
	Compactness [m]	0.75 – 2.5
	Int. Wall ratio [-]	0.5 – 2.0
Thermal properties	$d_{insul,roof}$ [m]	0 – 0.25
	$d_{insul,walls}$ [m]	0 – 0.25
	$d_{brick,walls\_e}$ [m]	0 – 0.20
	$d_{walls,i}$ [m]	0 – 0.30
	n_{vent} [ACH]	0 – 0.8
System & control	$f_{sys,size}$ [-]	0.8 – 2
	$ADR_{duration}$ [min]	15 – 480
	ADR_{comf} [°C]	1 – 4

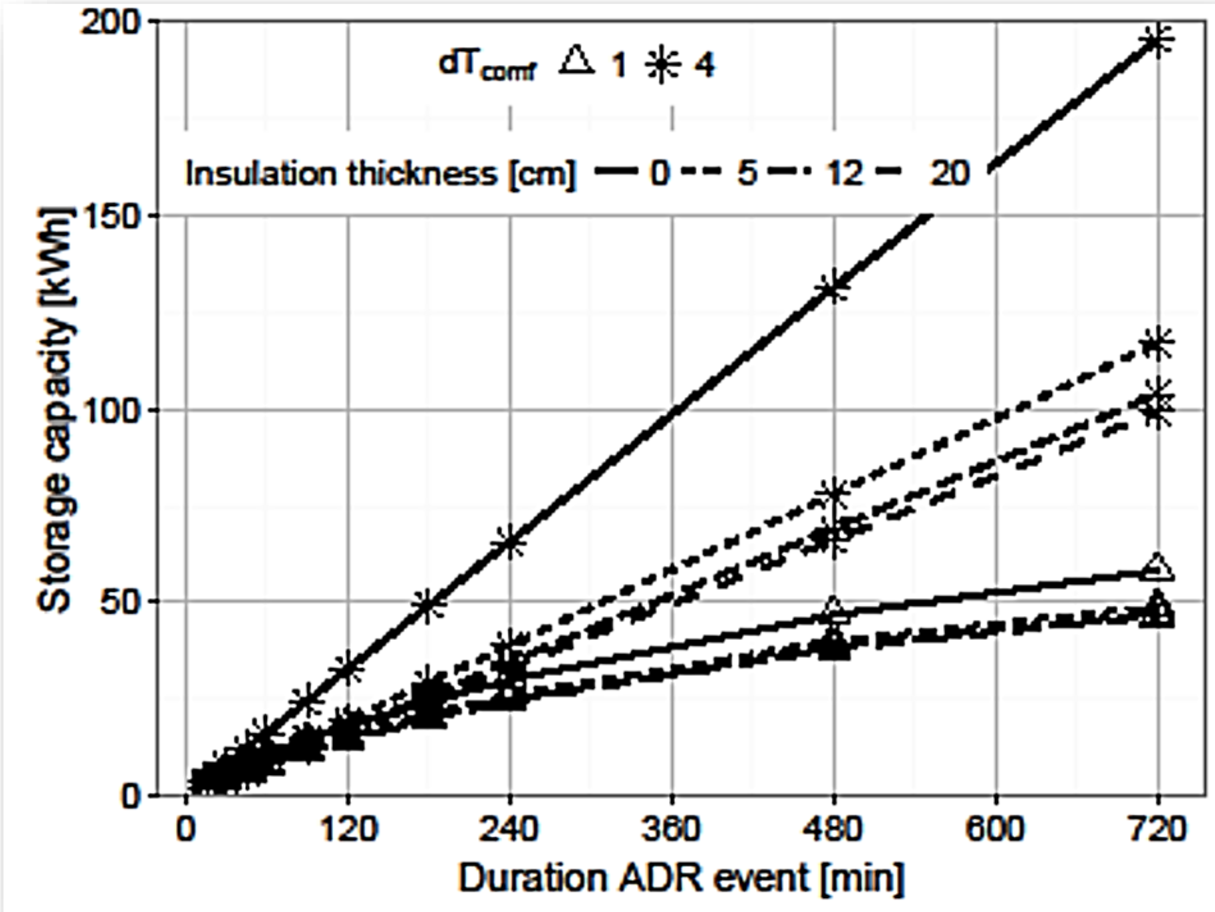
Radiators



Floor Heating



Example: Impact of insulation thickness outer walls



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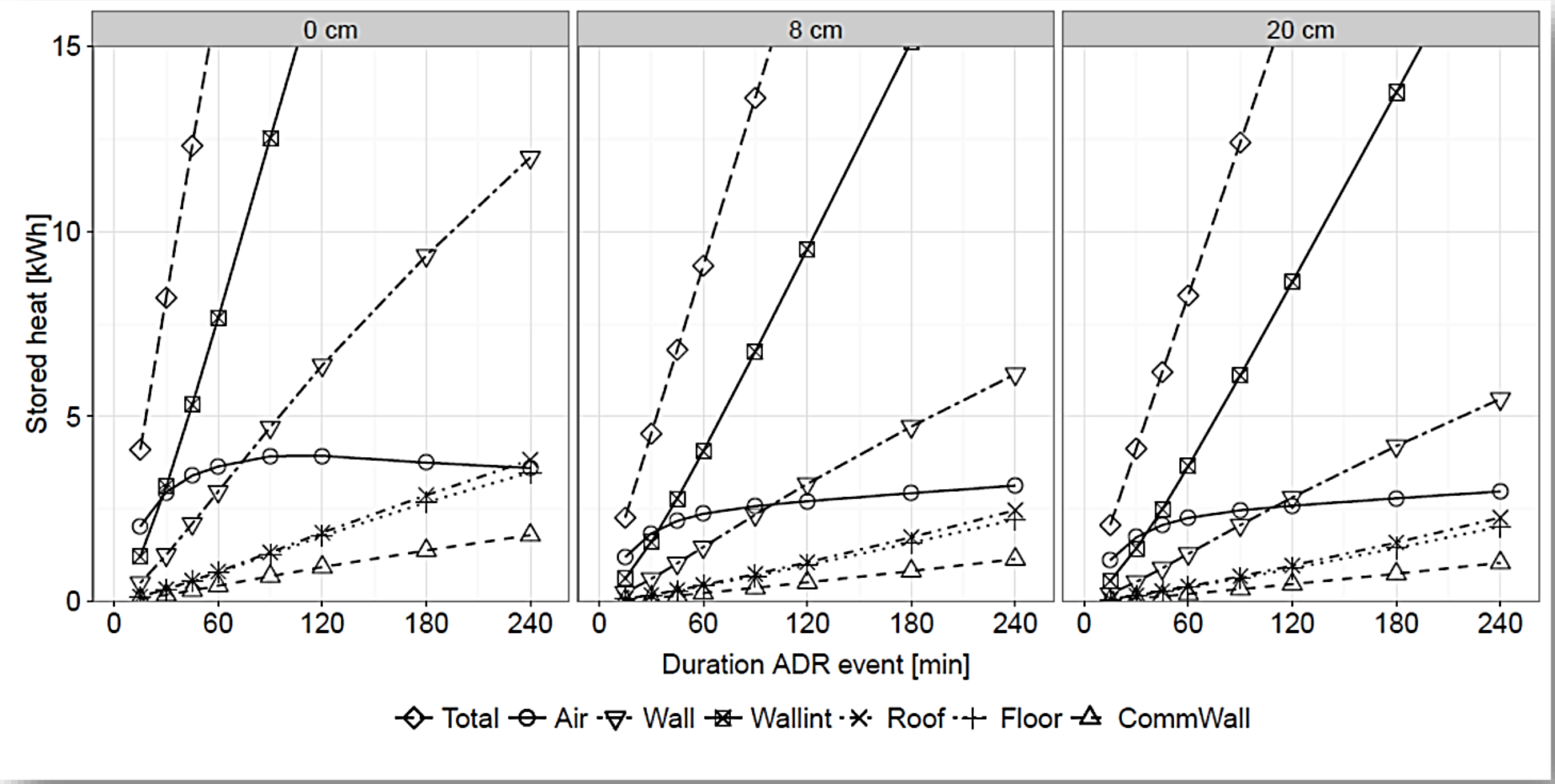
Example: Impact of insulation thickness outer walls



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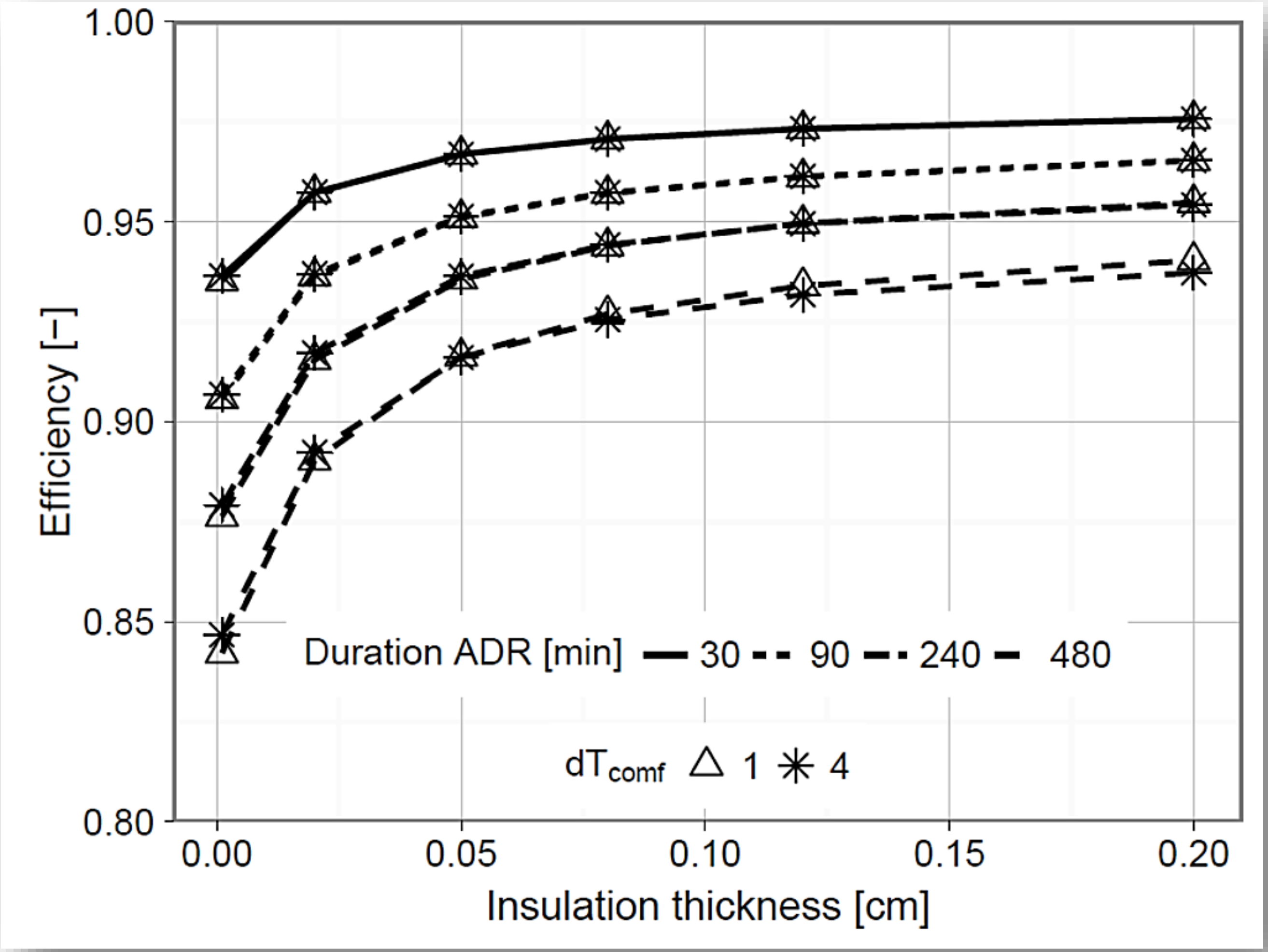

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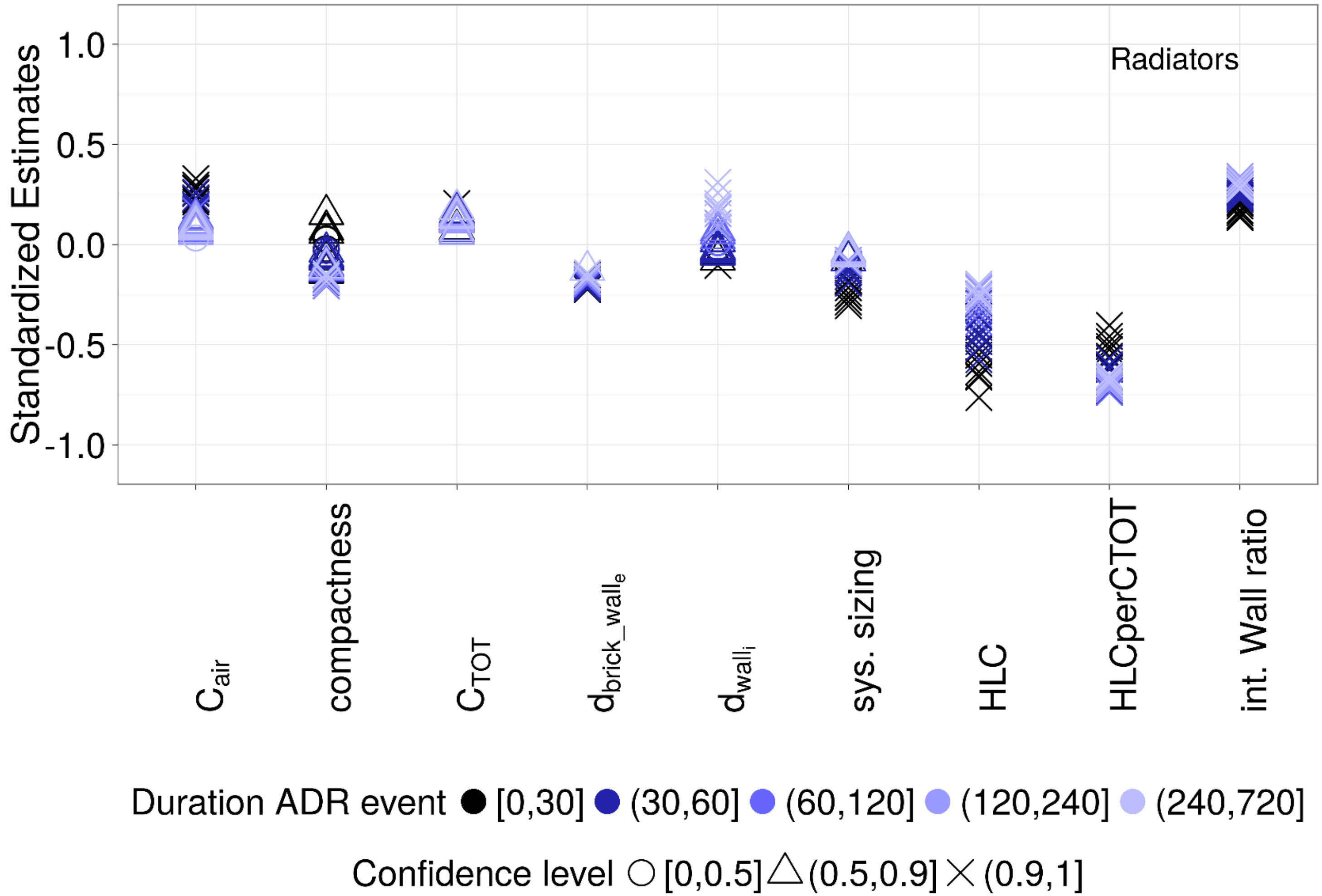
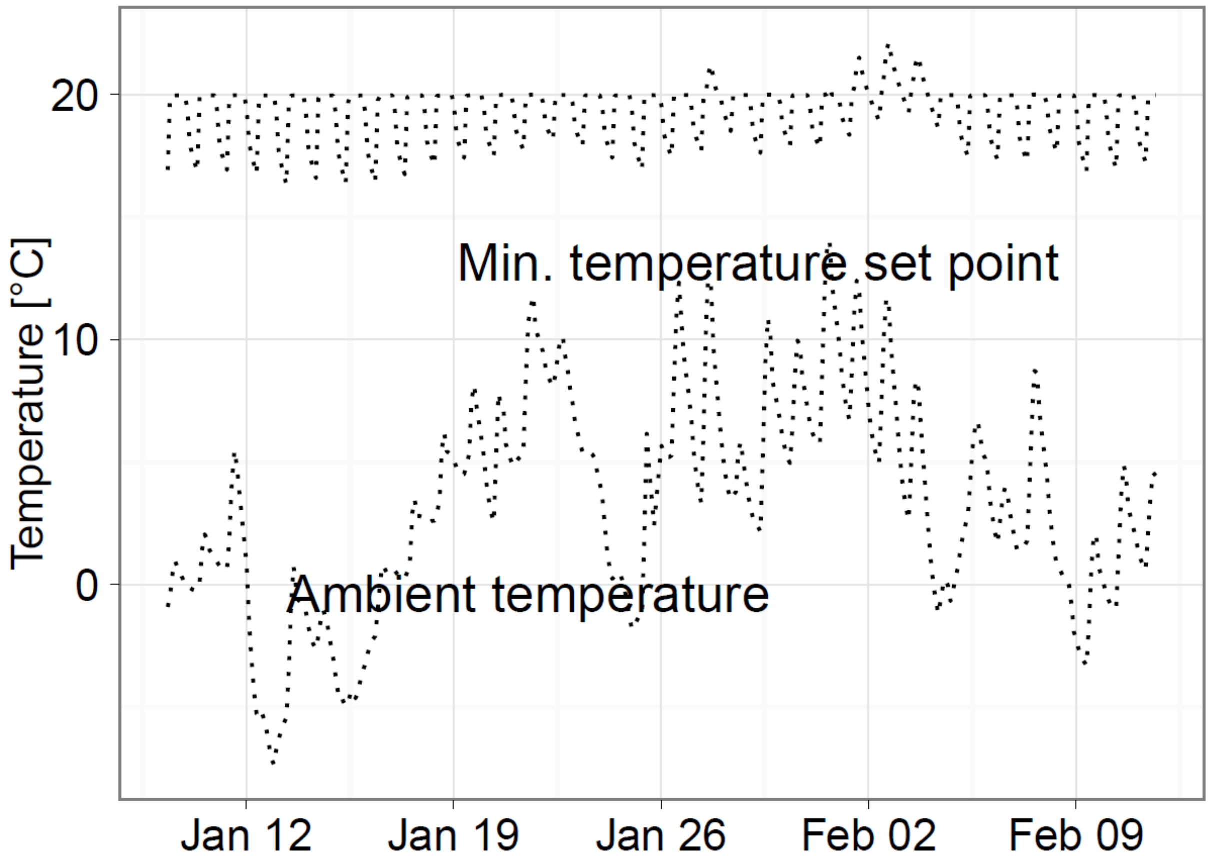
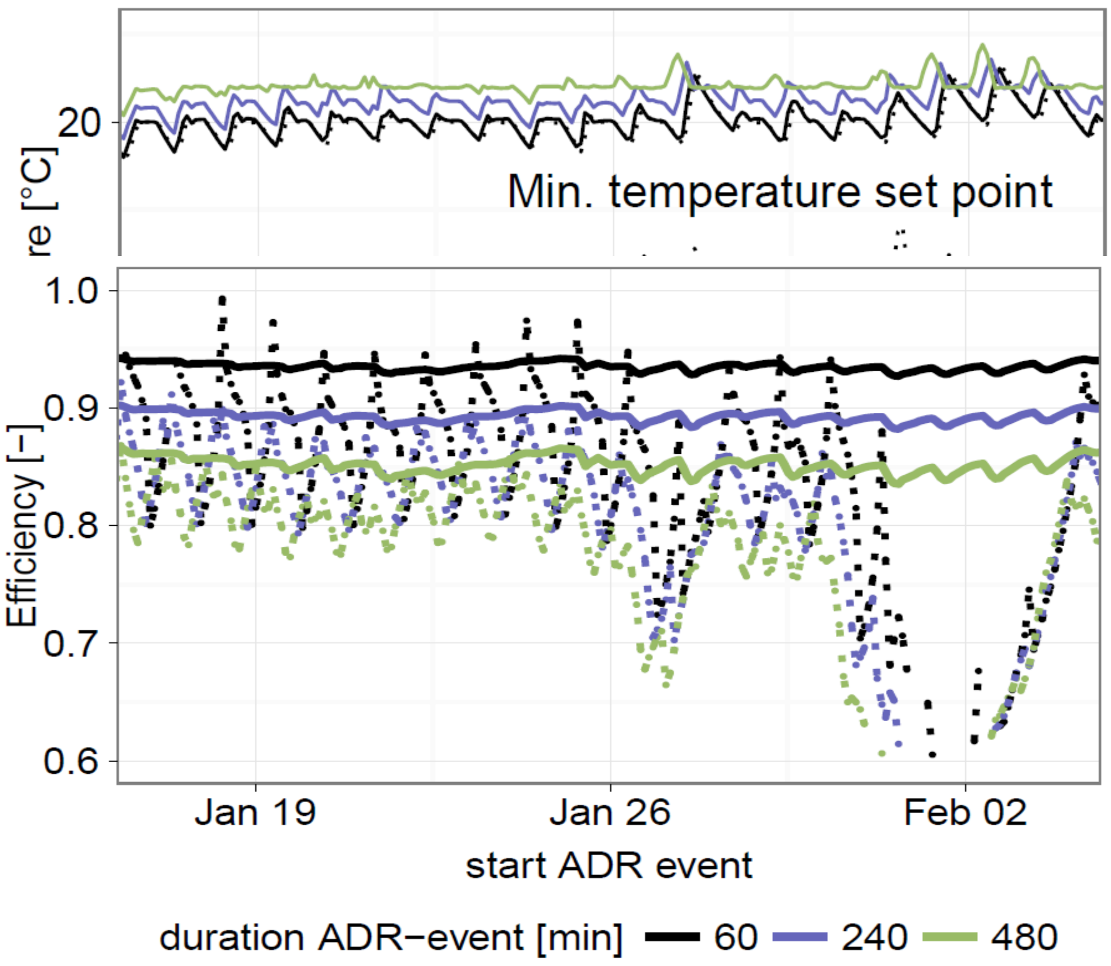

Standardized Estimates
1.0
0.5
0.0
-0.5
-1.0
Radiators
C_{air}
compactness
C_{TOT}
$d_{brick\_wall_e}$
d_{wall_i}
sys. sizing
HLC
HLCperCTOT
int. Wall ratio
Duration ADR event [0,30] (30,60] (60,120] (120,240] (240,720]
Confidence level [0,0.5] (0.5,0.9] (0.9,1]



Temperature [°C]
20
10
0
Min. temperature set point
Ambient temperature
Jan 12
Jan 19
Jan 26
Feb 02
Feb 09



20
re [°C]
Min. temperature set point
1.0
0.9
0.8
0.7
0.6
Efficiency [−]
Jan 19
Jan 26
Feb 02
start ADR event
duration ADR−event [min]
60
240
480

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ADR Characteristics

Wrap up

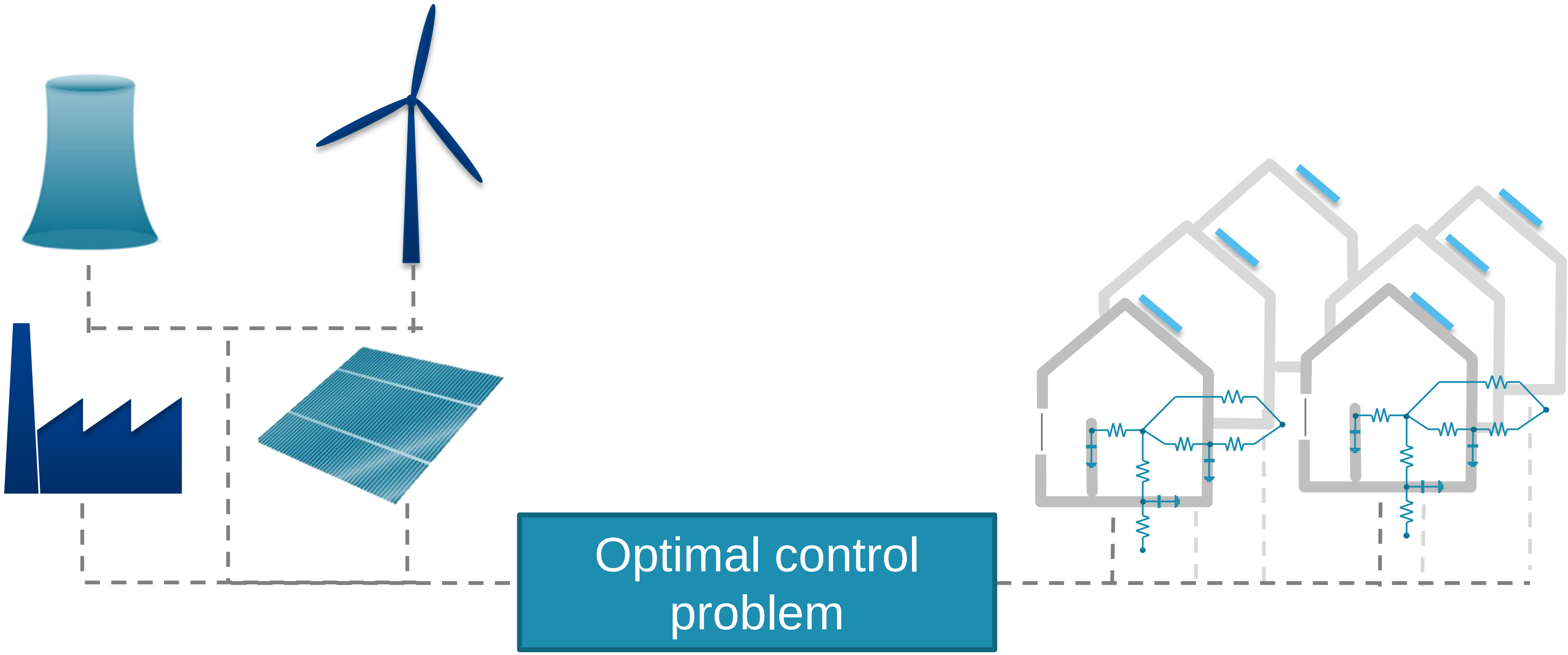
- Generic definition & dynamic quantification method
  - general comparison between buildings (and other storage technologies)
  - instantaneous flexibility
- Available capacity & storage efficiency interpretable as building signature
  - mainly influenced by:

    - heat emission system
    - heat loss coefficient
    - heat loss coefficient / thermal mass
- Characteristics are coupled and <u>not constant</u>!

II. BUILDINGS IN AN ACTIVE DEMAND RESPONSE CONTEXT

Case study

ADR potential of Belgian residential stock

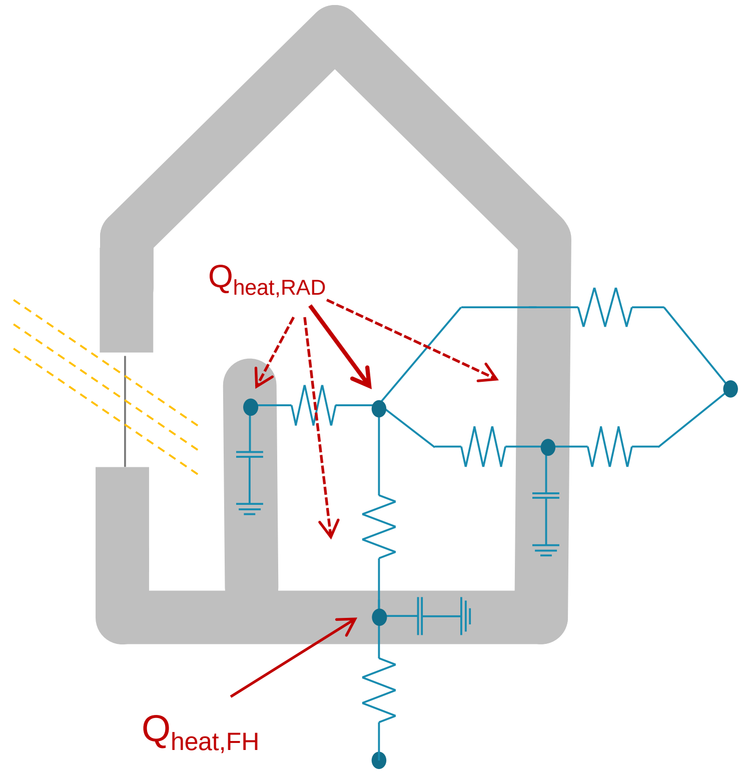


ADR potential of Belgian residential stock

I. Reduced-order building stock model

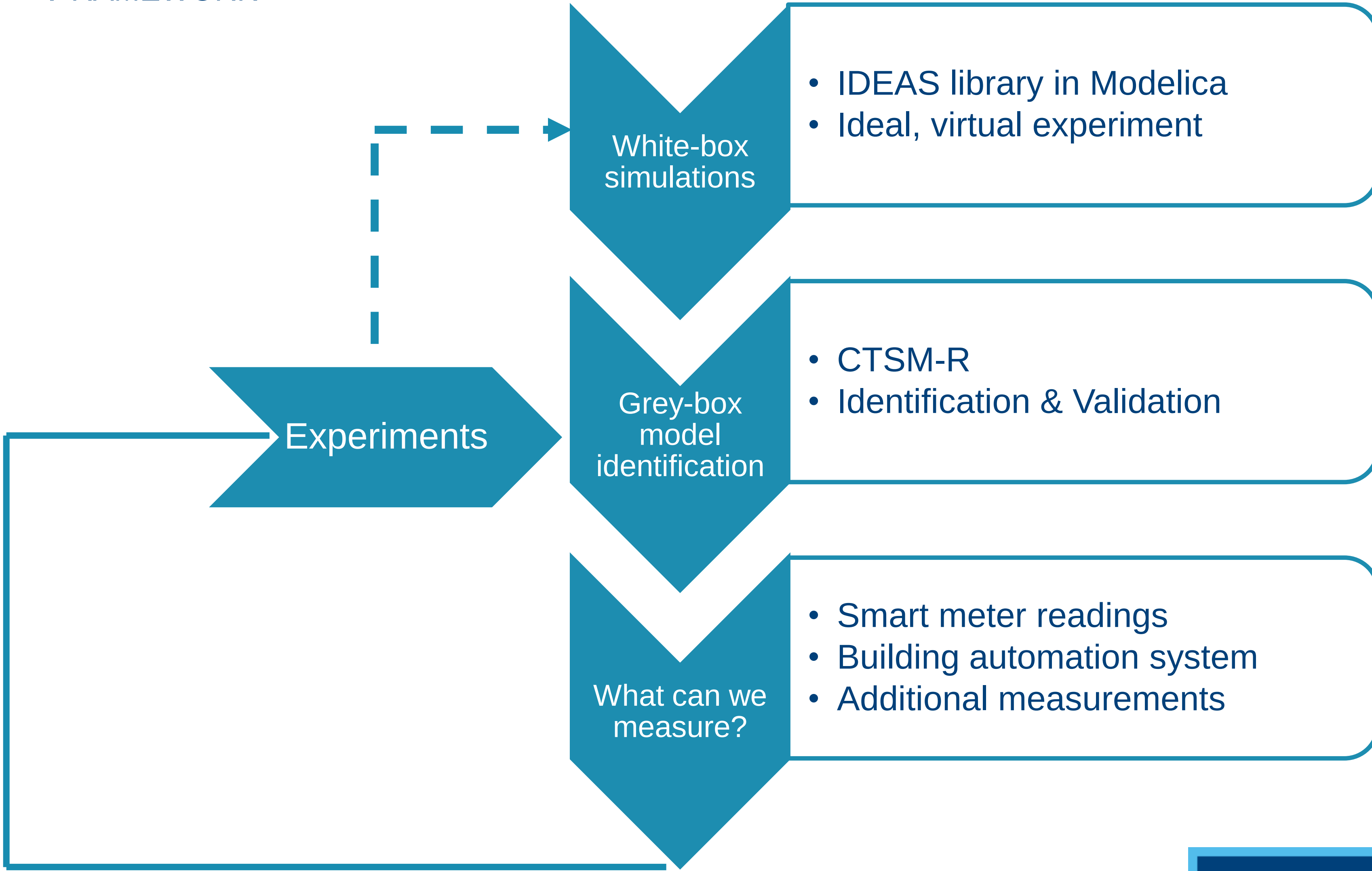
Main matrix of the Belgian housing typology

	Region	Construction Year Class	Single Family House - Detached	Single Family House – Semi detached	Single Family House - Terraced
1	national (Belgium)	... 1945	BE.N.SFH.01.deta	BE.N.TH.01.semi	BE.N.TH.01.terr
6	national (Belgium)	1946 - 1970	BE.N.SFH.02.deta	BE.N.TH.02.semi	BE.N.TH.02.terr
12	national (Belgium)	1971 - 1990	BE.N.SFH.03.deta	BE.N.TH.03.semi	BE.N.TH.03.terr
18	national (Belgium)	1991 - 2005	BE.N.SFH.04.deta	BE.N.TH.04.semi	BE.N.TH.04.terr
24	national (Belgium)	2006 ...	BE.N.SFH.05.deta	BE.N.TH.05.semi	BE.N.TH.05.terr



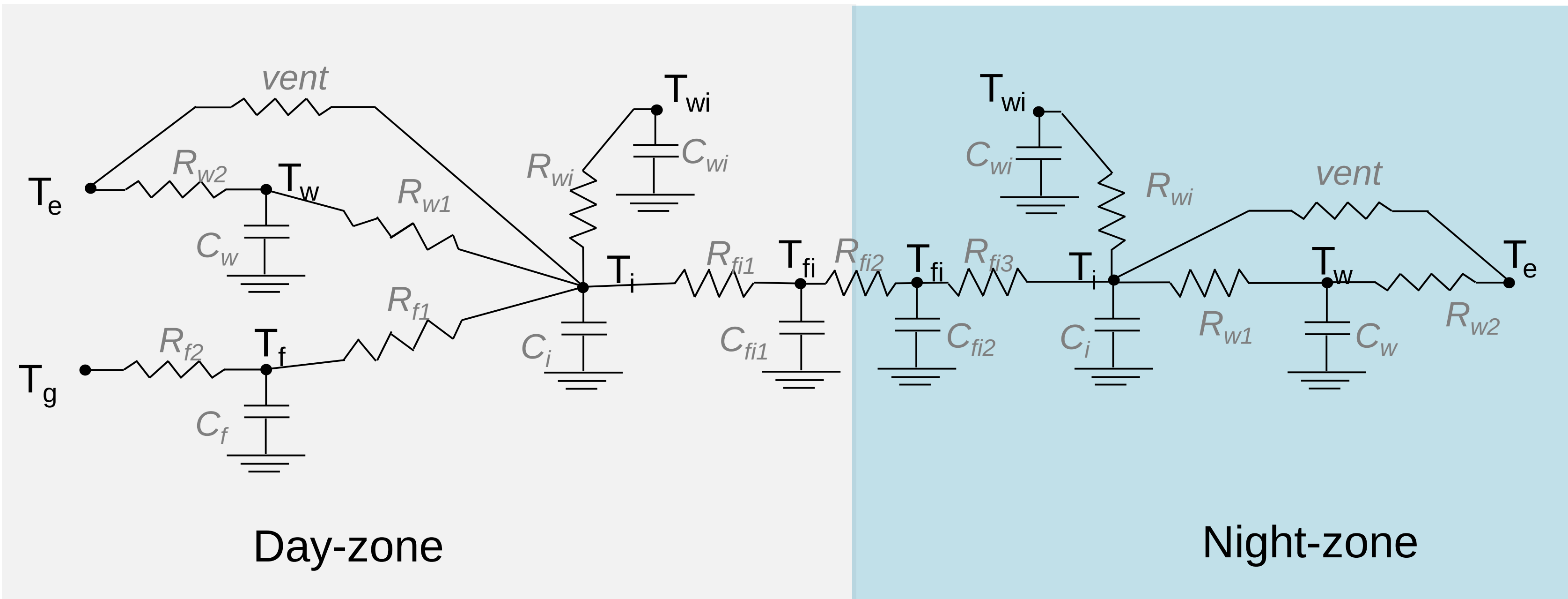
Reduced-order building stock model

FRAMEWORK



Reduced-order building stock model

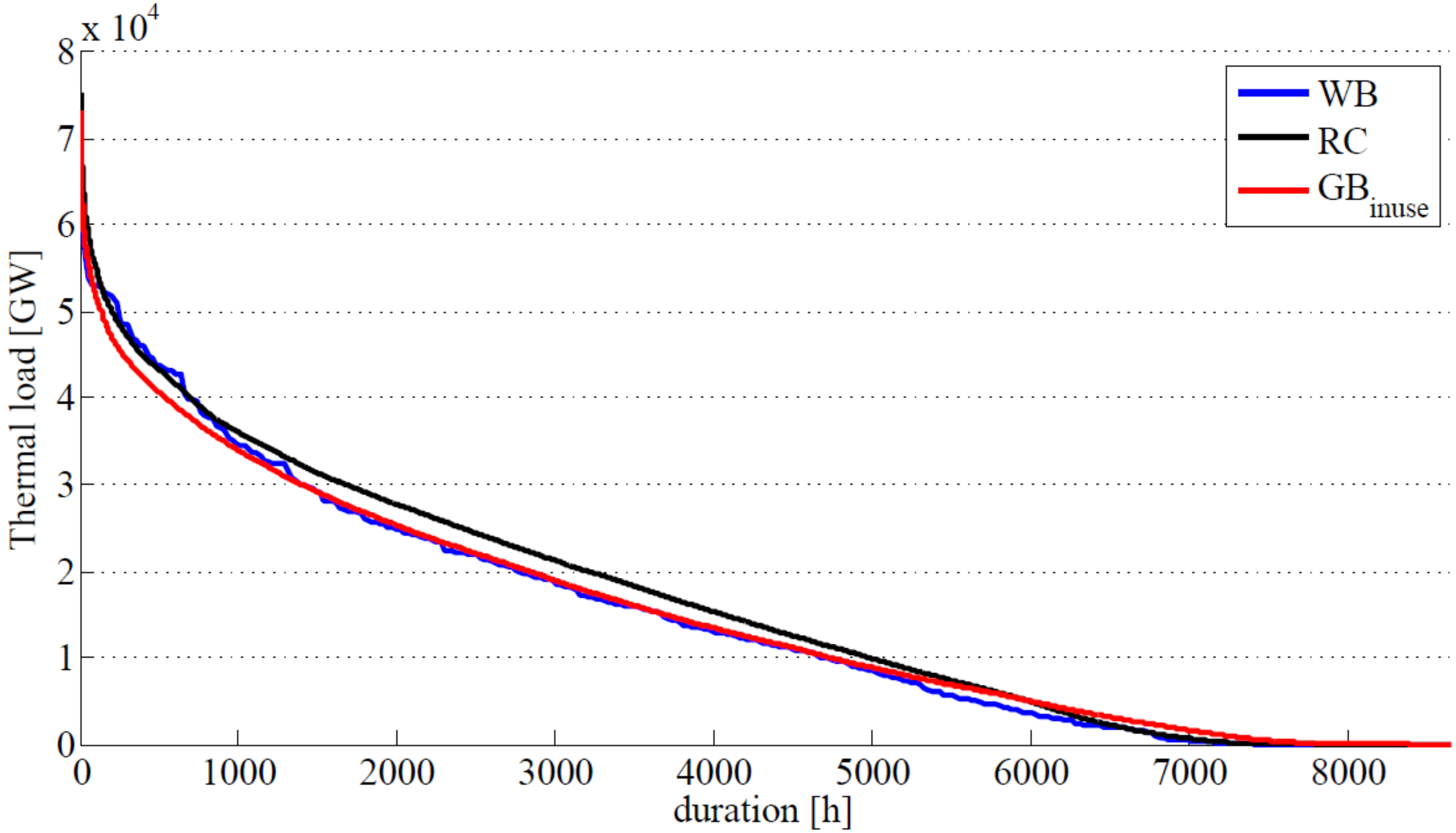
Model structure



Reduced-order building stock model

VERIFICATION IDENTIFIED MODELS

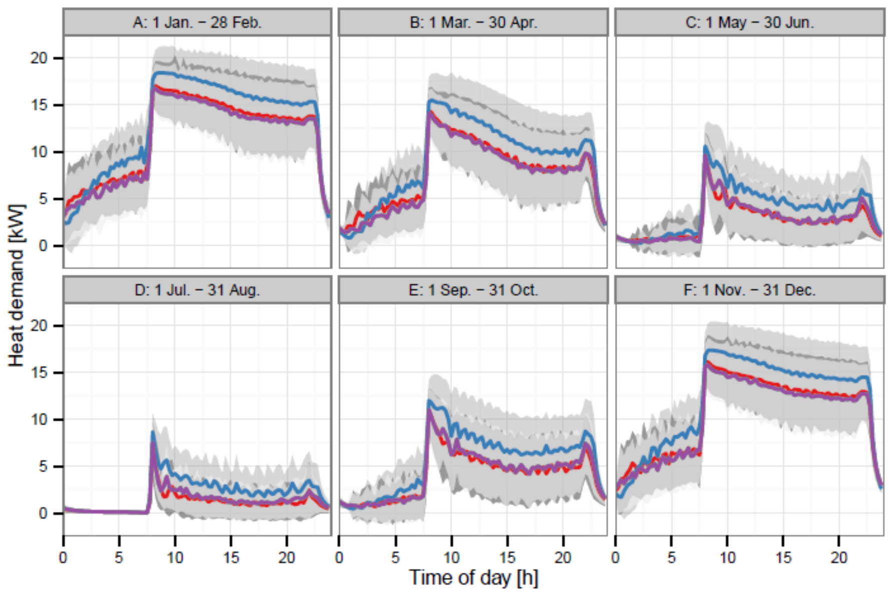
Aggregated load-duration curve



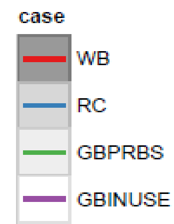
Reduced-order building stock model

Verification identified models

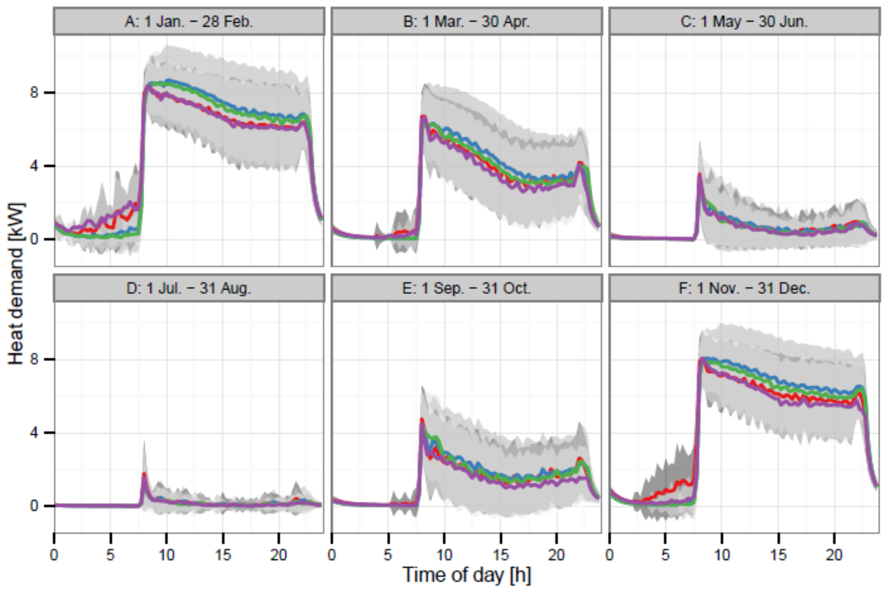
Instantaneous heat demand profiles



Detached pre-'45



Detached post-'05



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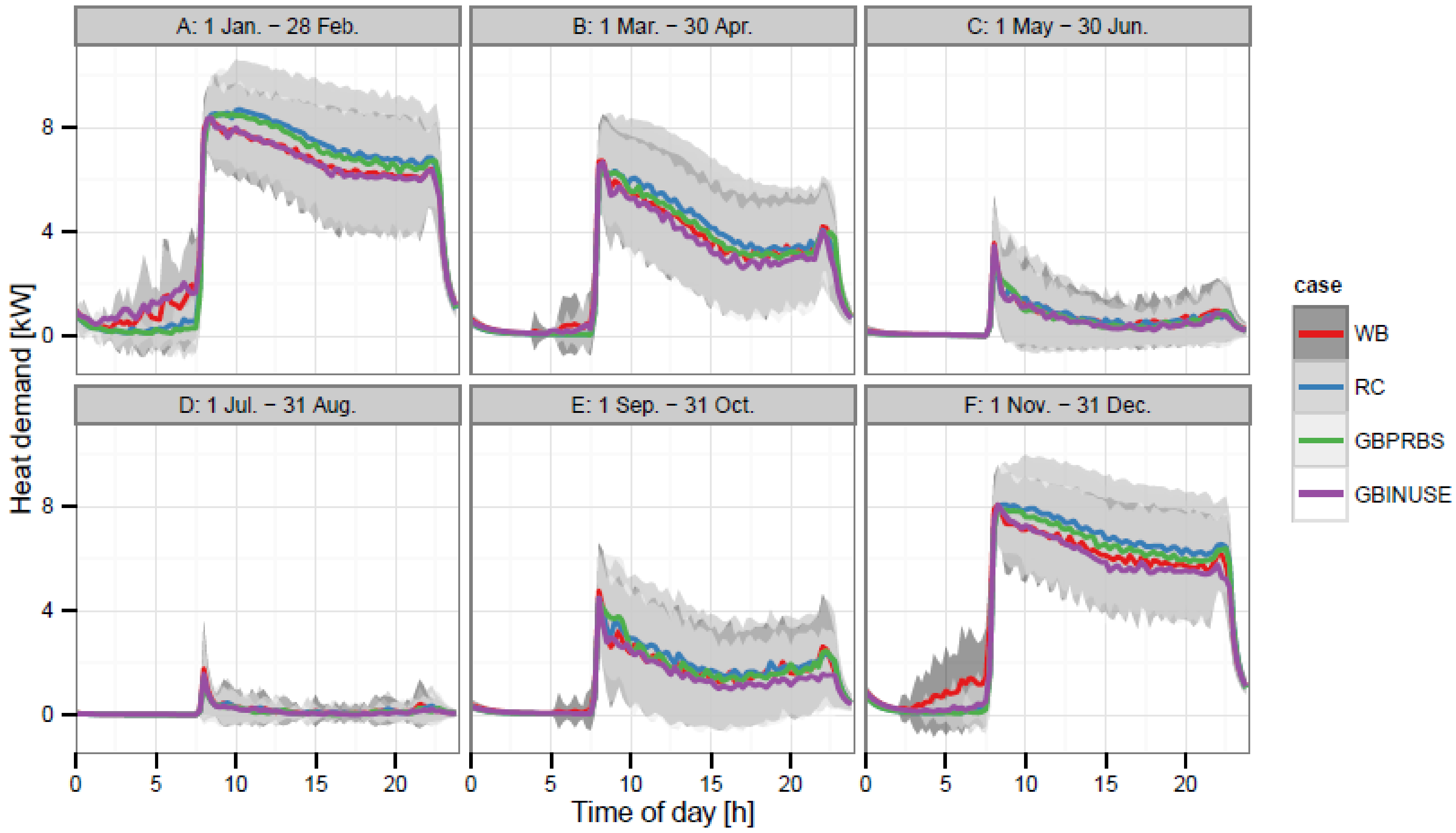
Reduced-order building stock model

VERIFICATION IDENTIFIED MODELS

Instantaneous heat demand profiles (Detached post ‘05)



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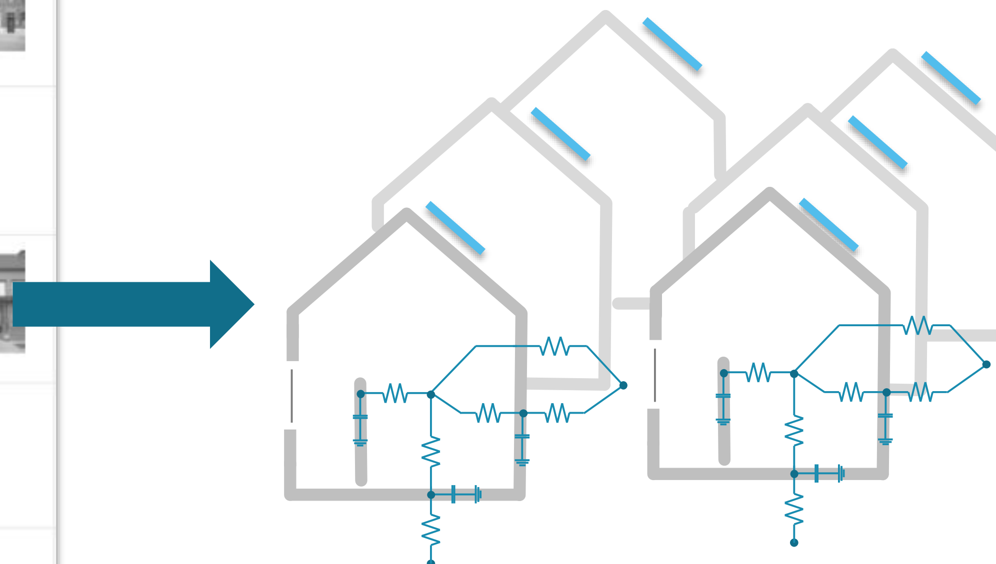

What is demand response potential of building stock?

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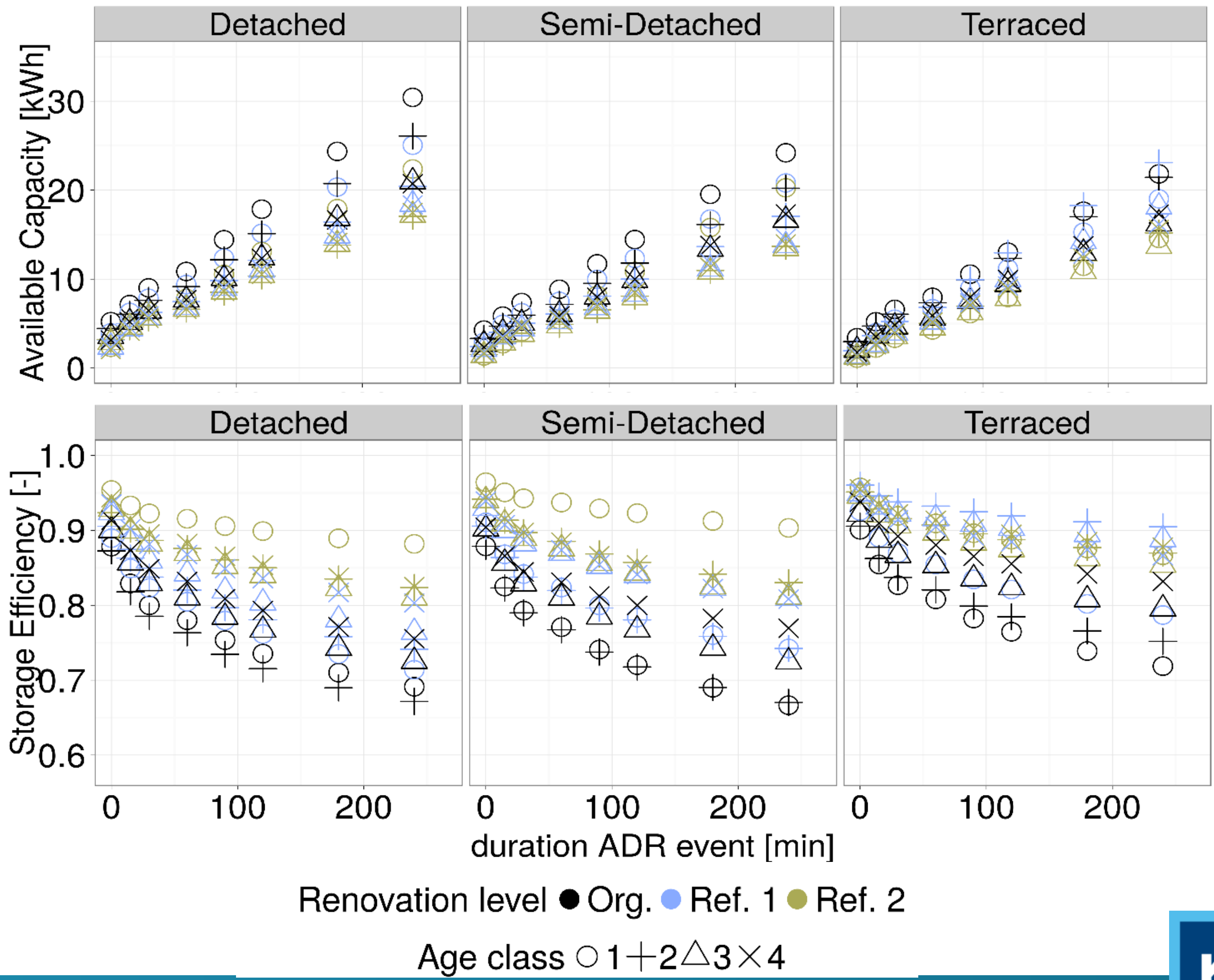
ADR potential of Belgian residential stock

ADR Characteristics



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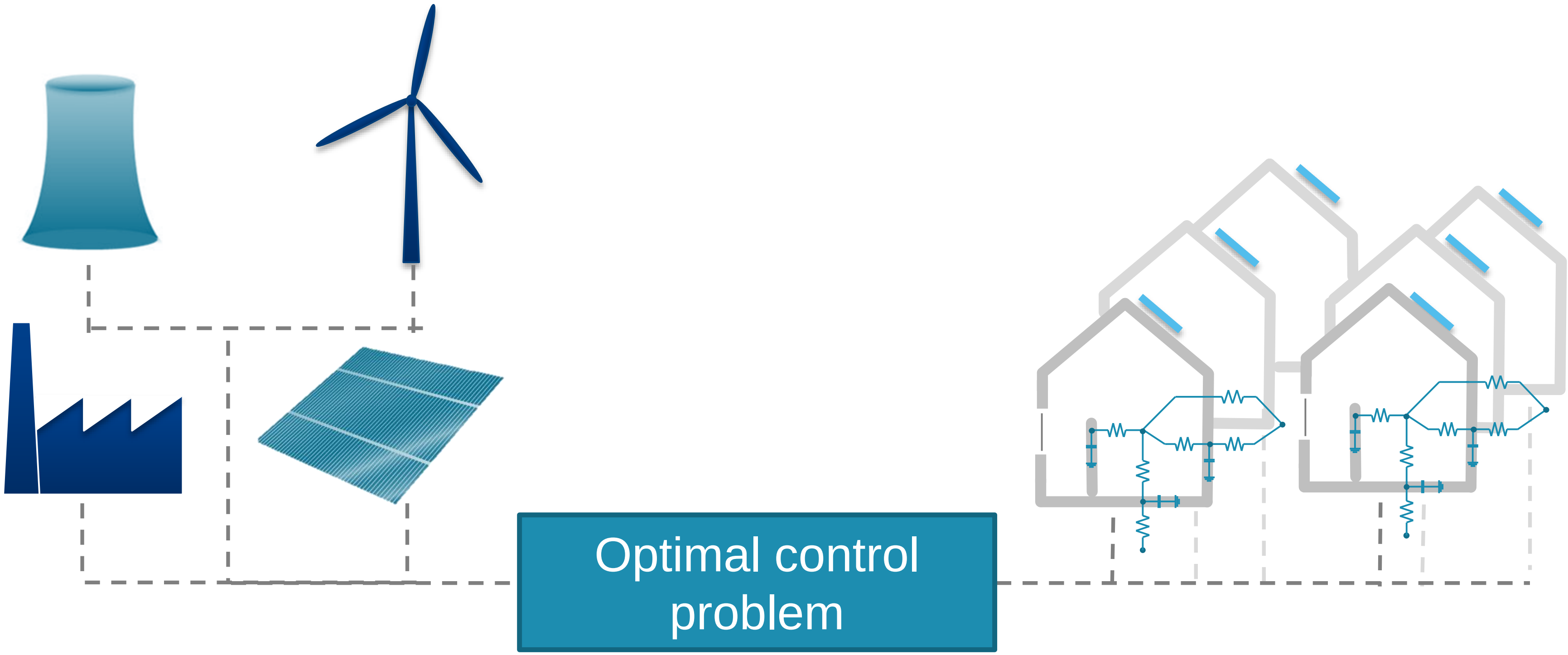
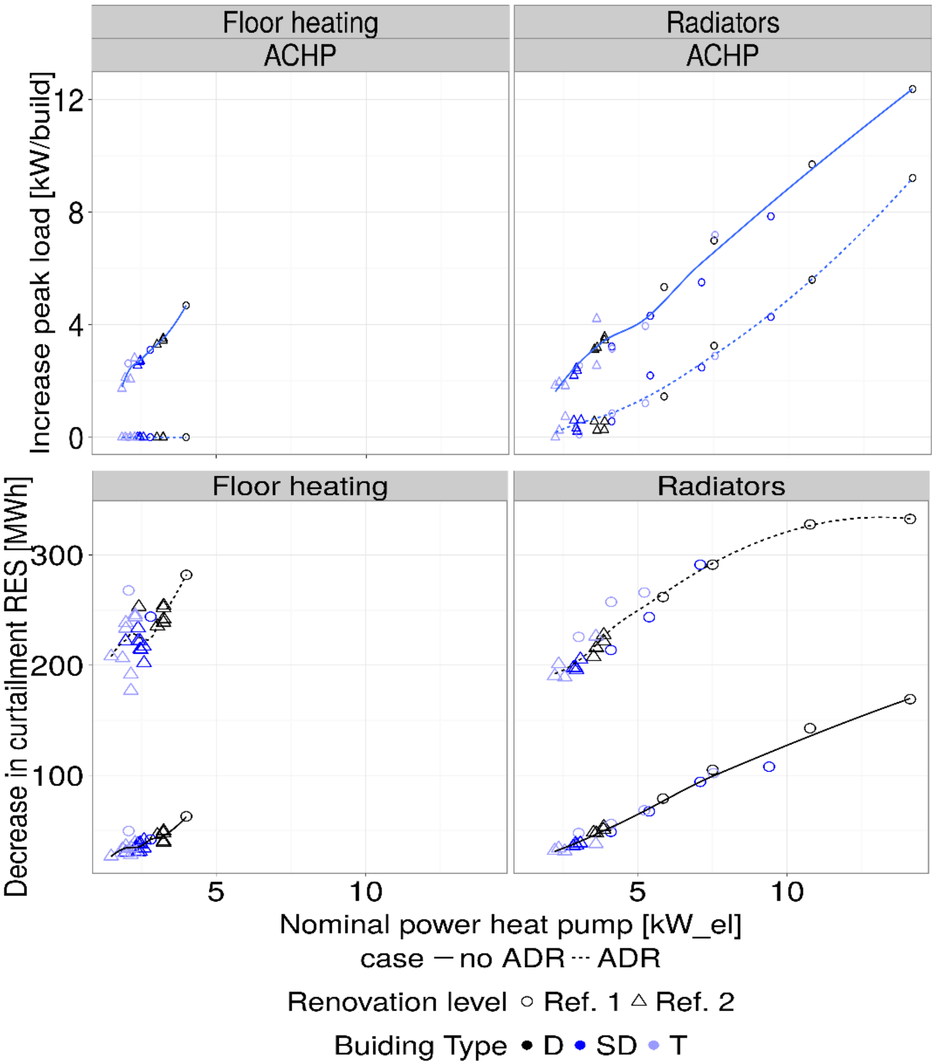
ADR potential of Belgian residential stock

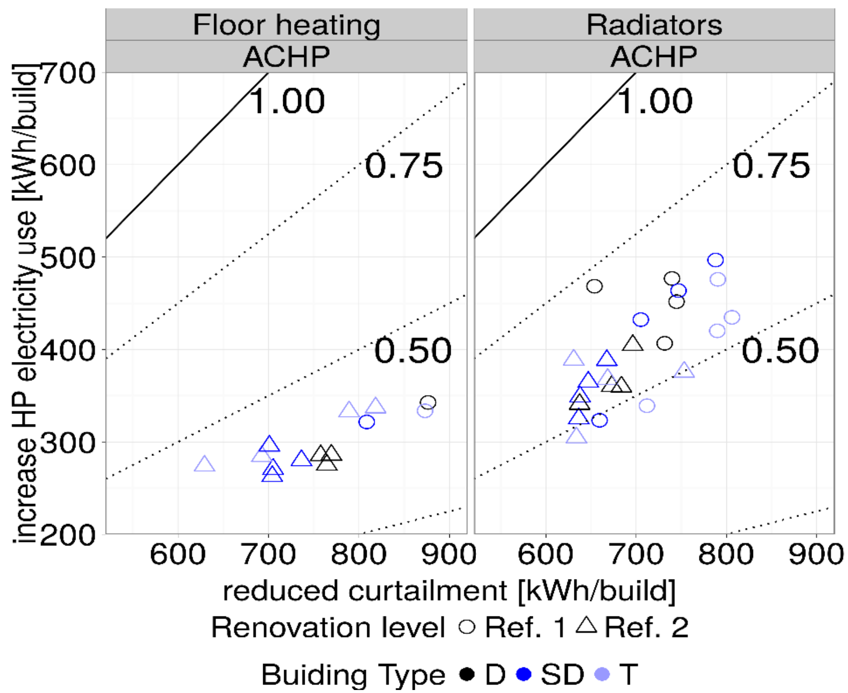
Integrated Operational Model



ADR potential of Belgian residential stock

GRID IMPACT





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Wrap up – Buildings for ADR

- Simulation-based, generic methodology to quantify ADR potential
    - Design: Available capacity & Storage efficiency
    - Operational: Power shifting capability & State of charge
    - All Time dependent!
- Parameter study for building design
    - Floor heating > Radiators
    - Minimum level of insulation
    - Limit duration
    - Optimal control strategy to anticipate solar gains and occupant behavior
- Application on Belgian stock
    - Reduced-order dynamic stock model
    - Significant peak load, curtailment & CO_2 reductions
    - Efficiency loss lead to higher energy use

Food for discussion

Conclusions and future research

Lessons learned

Grid impact important in evaluation of new building technologies

- avoid gird stability issues
- improve overall energy efficiency

New challenges in simulation

- multi-domain
- larger scale
- smaller timescale

Lessons learned

Building thermal mass is source of flexibility

- short-term storage (few hours)
- storage efficieny < 1
- minimum level of insulation

Grey-box modelling important potential for model simplification and on-site characterization

Application on Belgian level

- Siginificant peak-load, CO_2 and curtailment reductions
- Price is increased use

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Food for discussion

Multi-domain approach 2.0

- social sciences
- economics
- statistics
- …

Validation

- High quality, transient data is largely missing
- data distributed over multi-domain agencies
- *balance between top-down and bottom-up??*

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Thank you!

"All models are wrong. Some of them are useful." --George Box

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