KU LEUVEN

TOWARDS ZERO-ENERGY DISTRICTS

From modelling to optimisation

dr. ir. ***Glenn Reynders***
KU Leuven, Building Physics Section
Glenn.Reynders@bwk.kuleuven.be

Practical announcement!

- Requirements
  - IDEAS: specific branch for exercise with additional models https://github.com/GlennReynders/IDEAS/tree/GenSim2016
  - Annex60 library
  - Gensim.mo https://github.com/ibpsa/project1/blob/master/meetings/2016-10-24-gensim/thursday/District/GenSim16.mo
- Opt ional
  - TEASER
  - StROBe.py https://github.com/GlennReynders/StROBe/tree/GENSIM

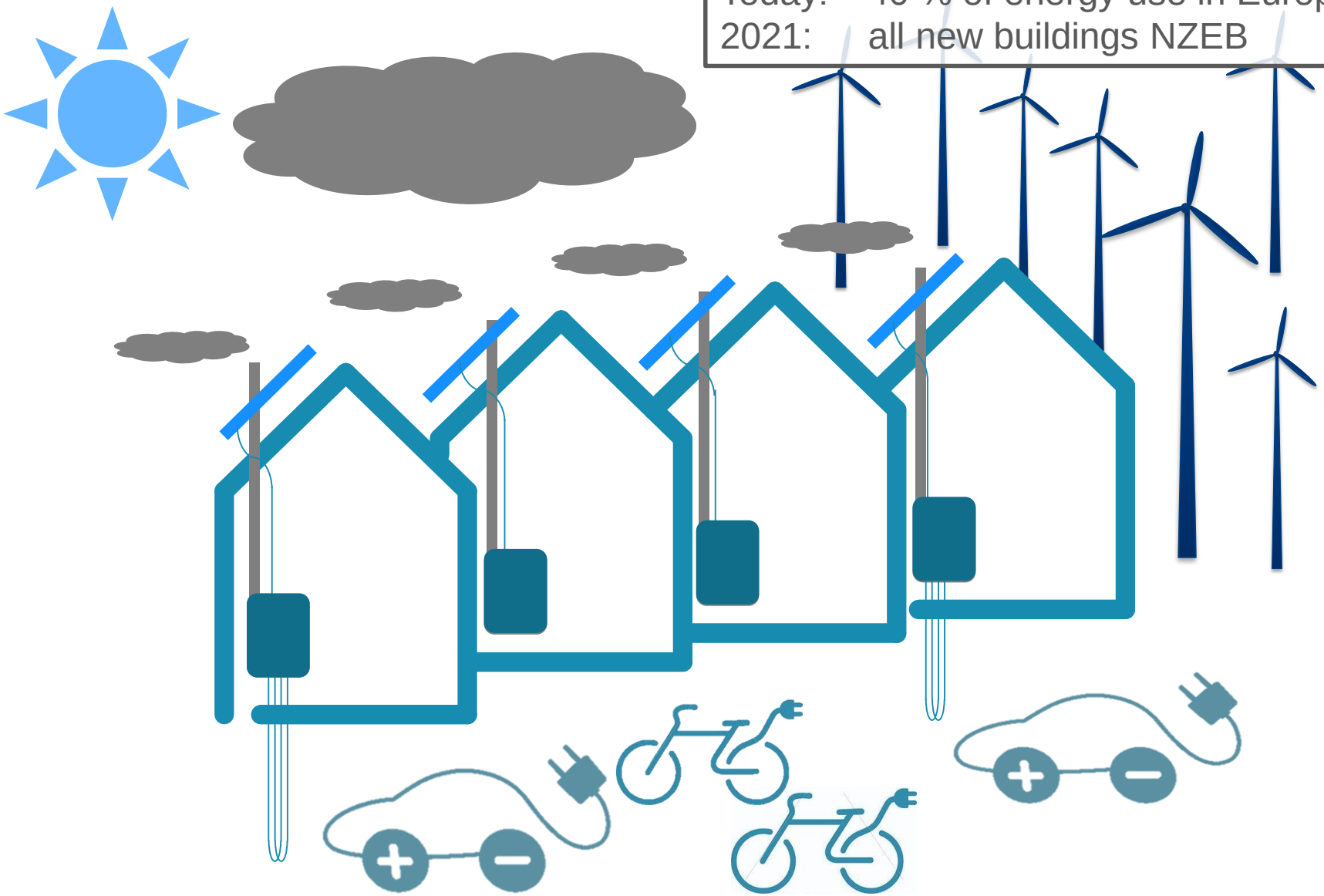
KU LEUVEN

TOWARDS ZERO-ENERGY DISTRICTS

From modelling to optimisation

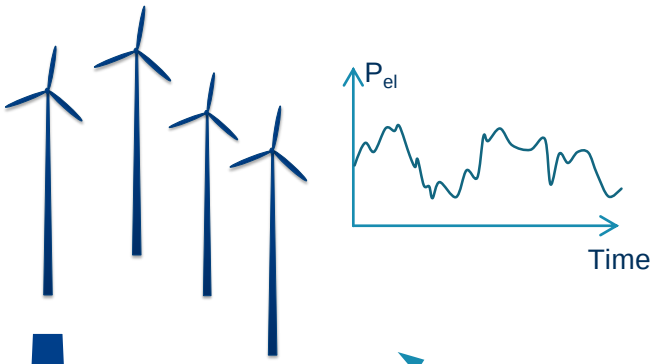
dr. ir. ***Glenn Reynders***
KU Leuven, Building Physics Section
Glenn.Reynders@bwk.kuleuven.be

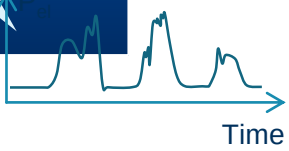
Today: 40 % of energy use in Europe
2021: all new buildings NZEB

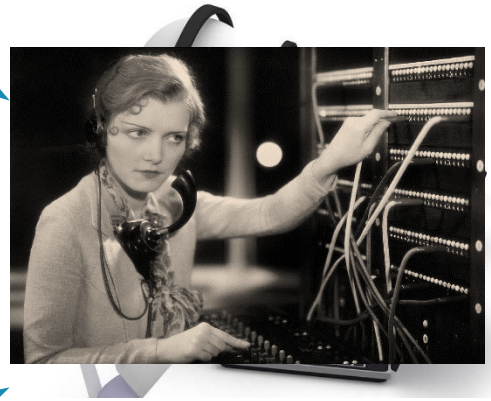


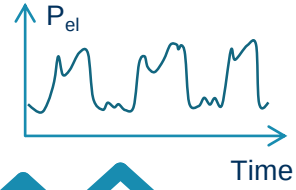
KU LEUVEN

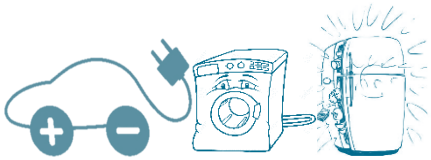
New challenges for electricity grid

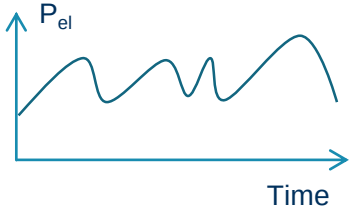


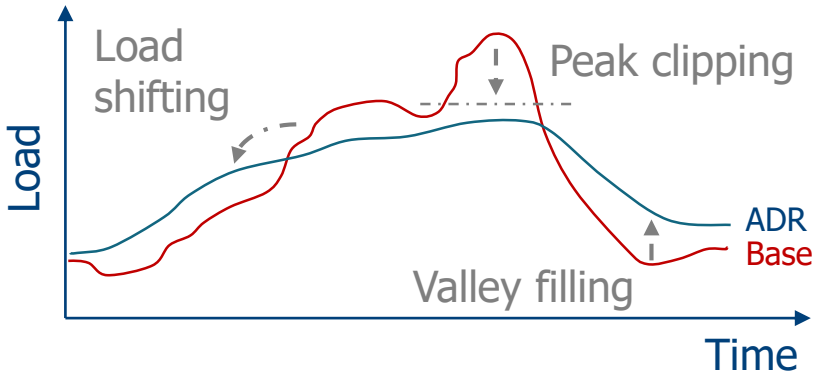




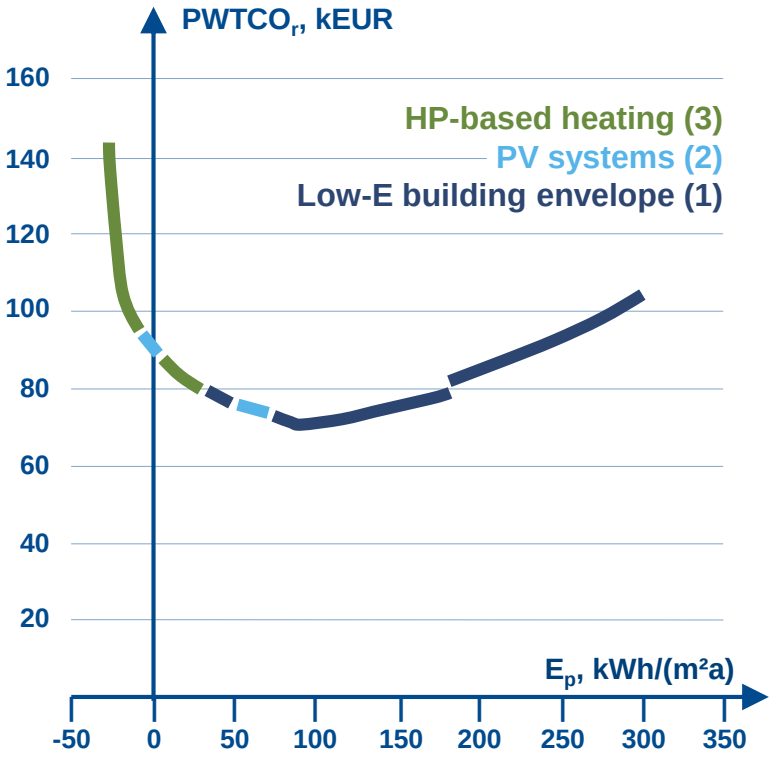




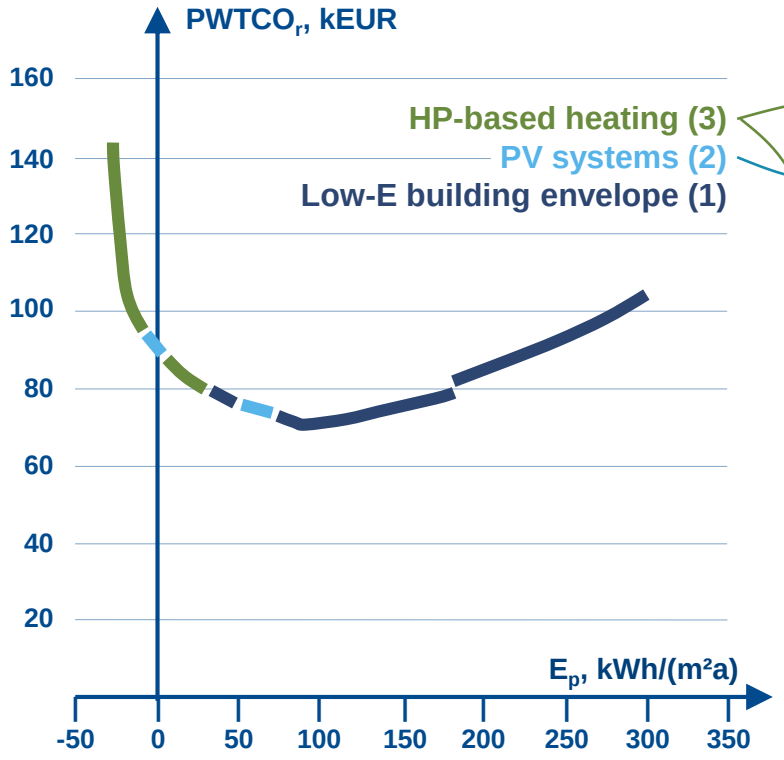




KU LEUVEN



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



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

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

KU LEUVEN

Content

0. Introduction

I. Case study: District Energy Assessment
   - Impact of heat pump-based building design on distribution grid level

II. Integrated District Energy Assessment
   - IDEAS
   - Reduced-order building models
   - Stochastic residential occupant behaviour
   - District heating distribution system

III. Workshop

KU LEUVEN

I. CASE STUDY

Impact of heat pumps on district level

KU LEUVEN

Traditional Building Energy Simulation

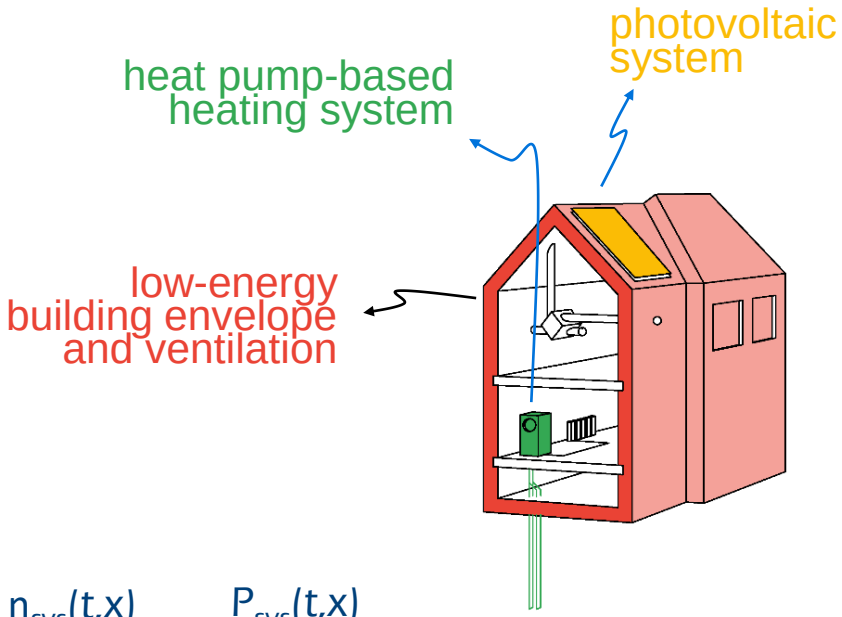
Detailed modelling of

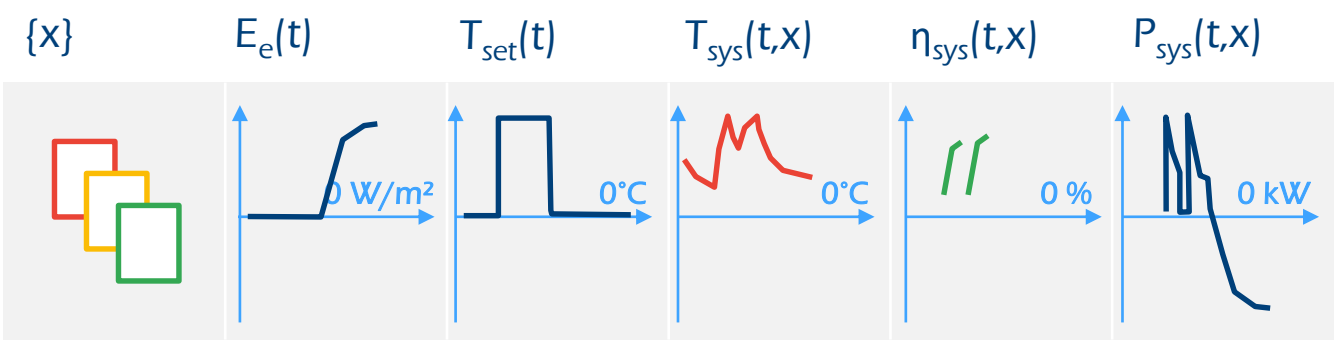
- Envelope
- Systems
- Occupants

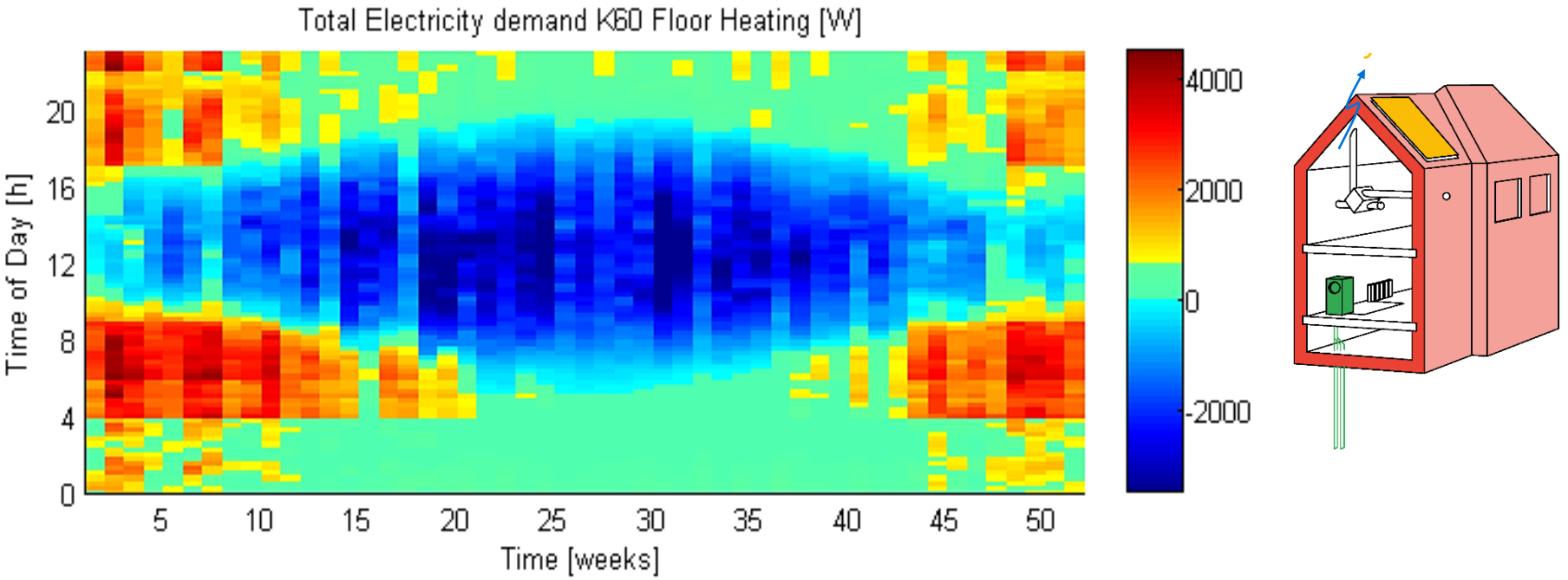
Evaluate

- Energy use
- Energy cost
- Comfort

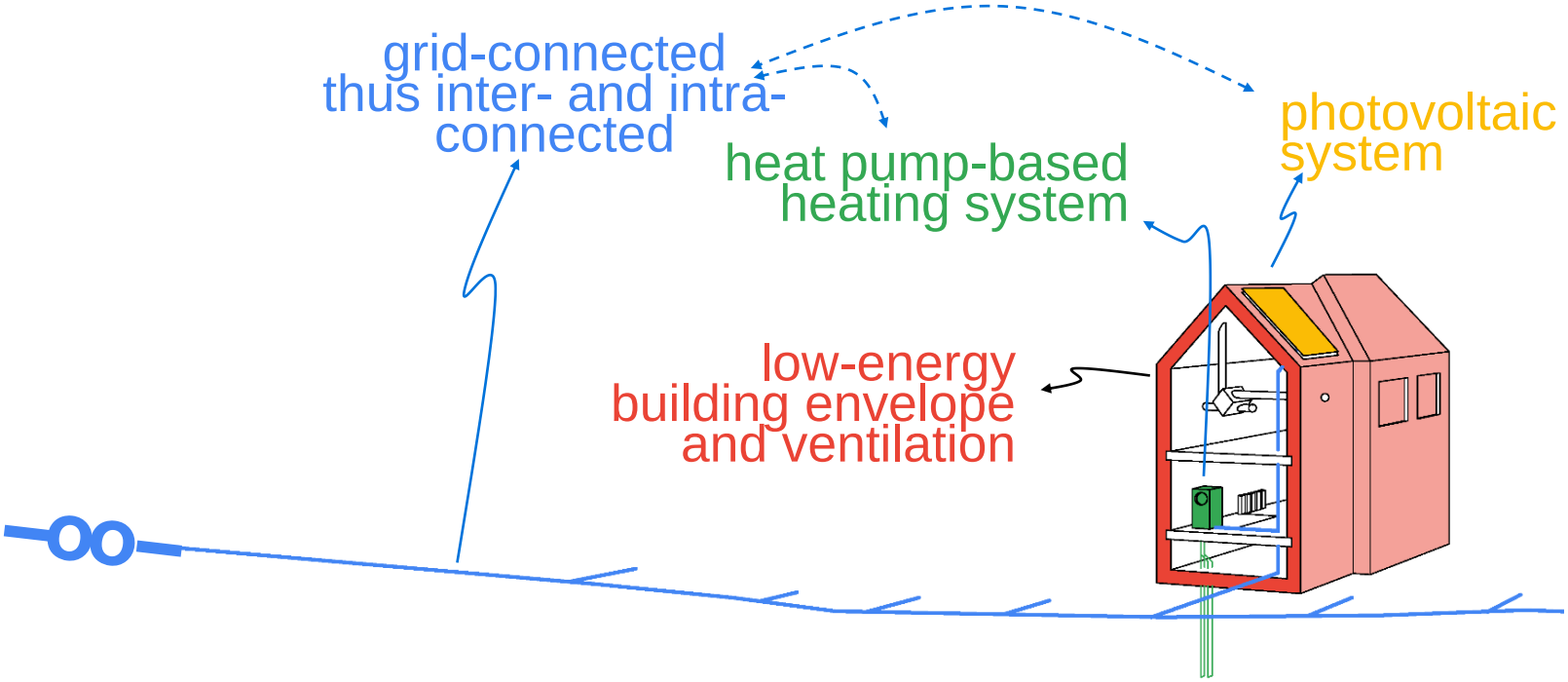
} Building level



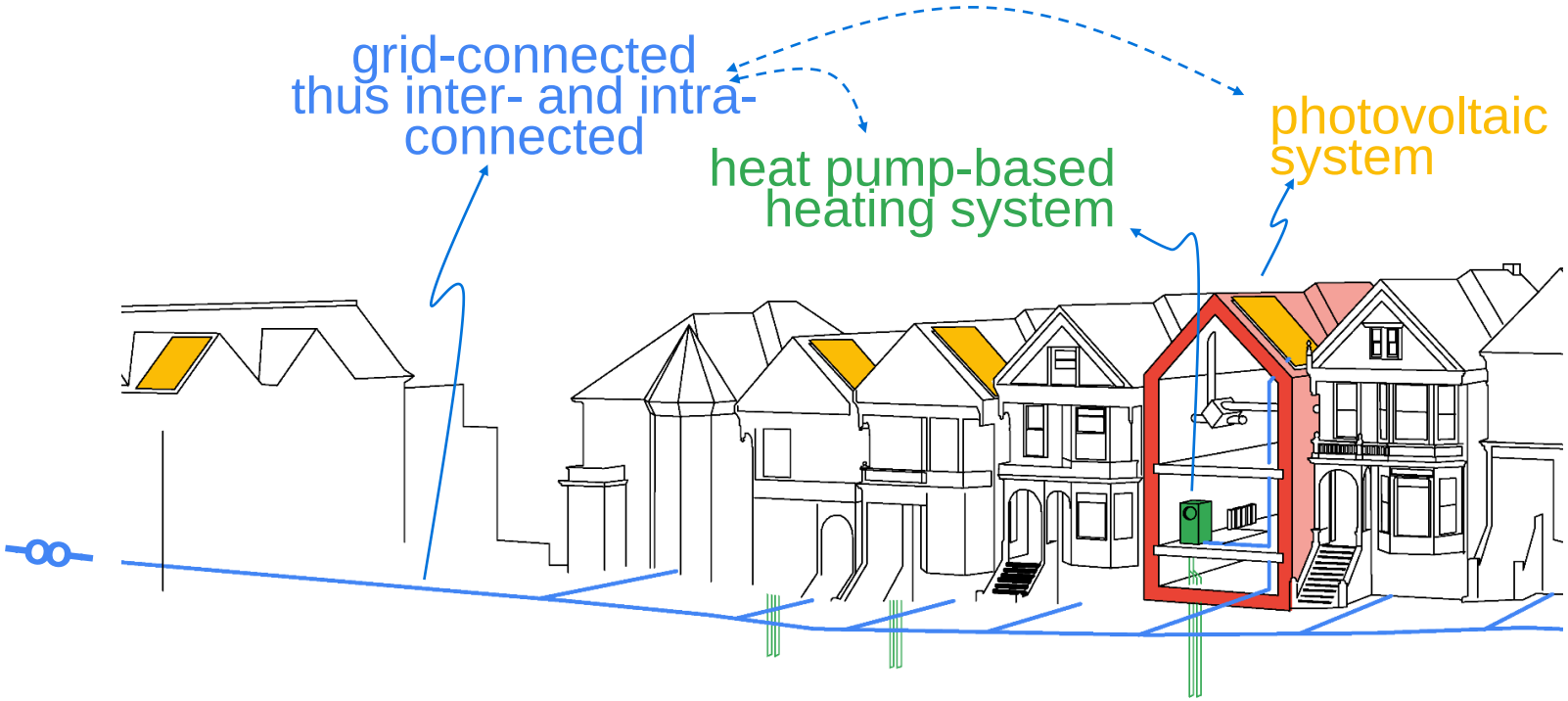



Total Electricity demand K60 Floor Heating [W]
Time of Day [h]
0
4
8
12
16
20
5
10
15
20
25
30
35
40
45
50
Time [weeks]
4000
2000
0
-2000

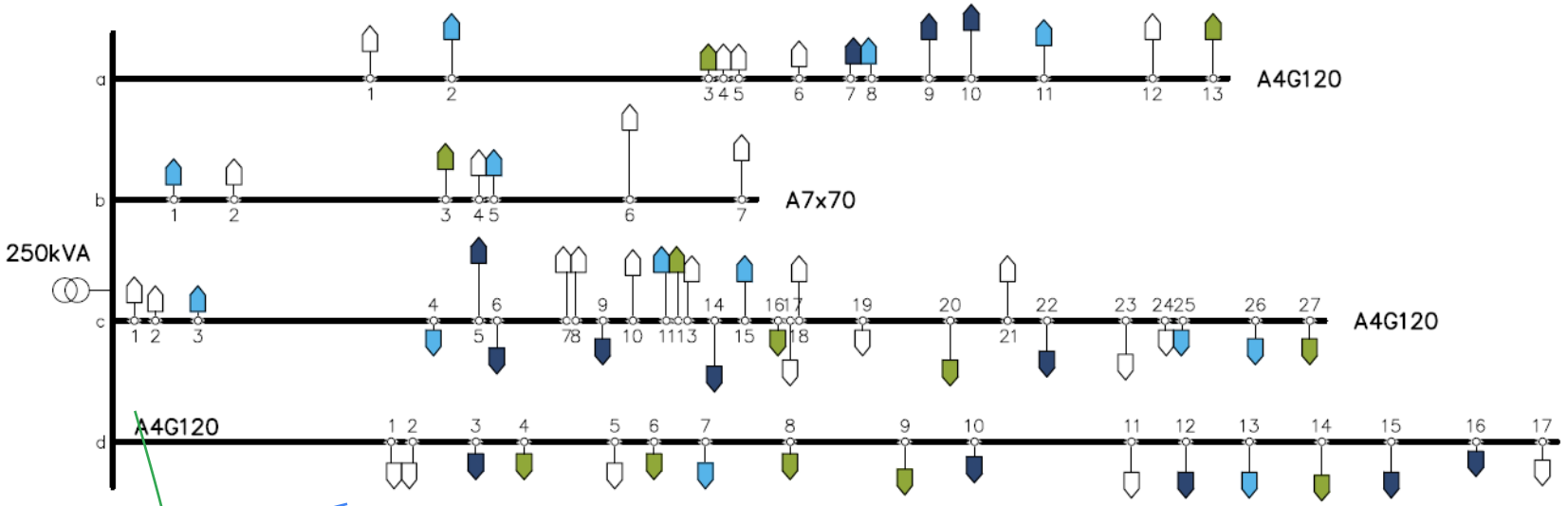
KU LEUVEN


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

Is grid-interaction affecting obtained level of nZEB?



KU LEUVEN



- **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.

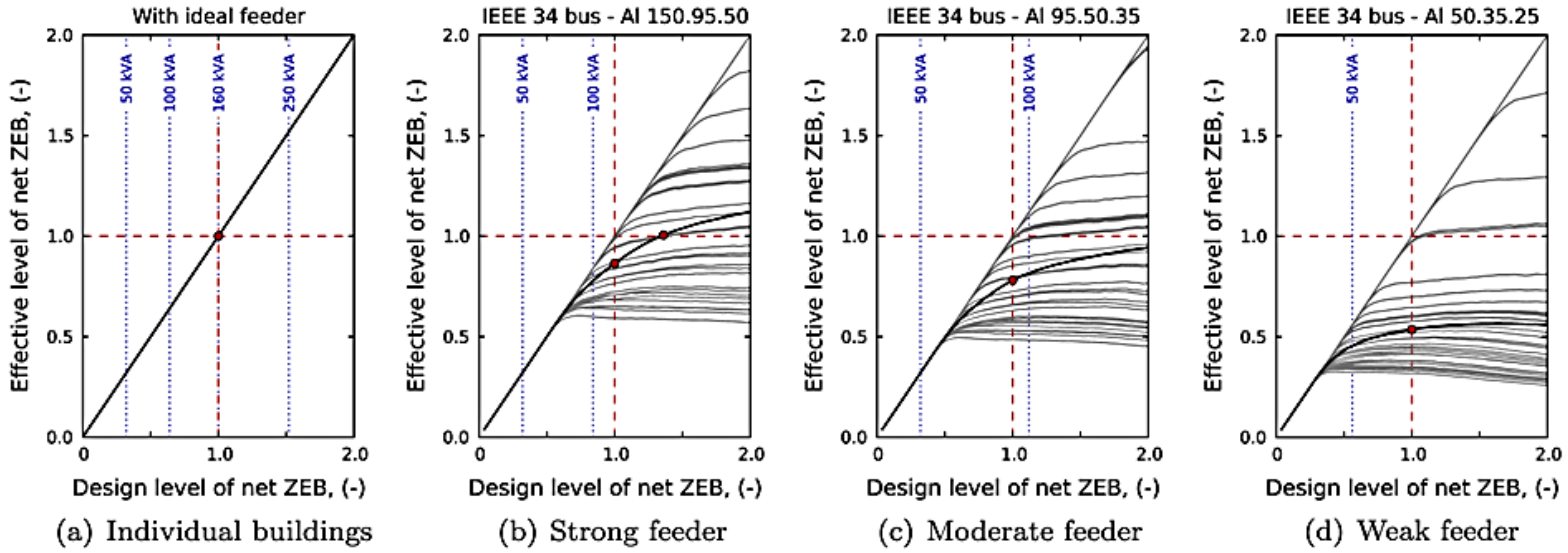


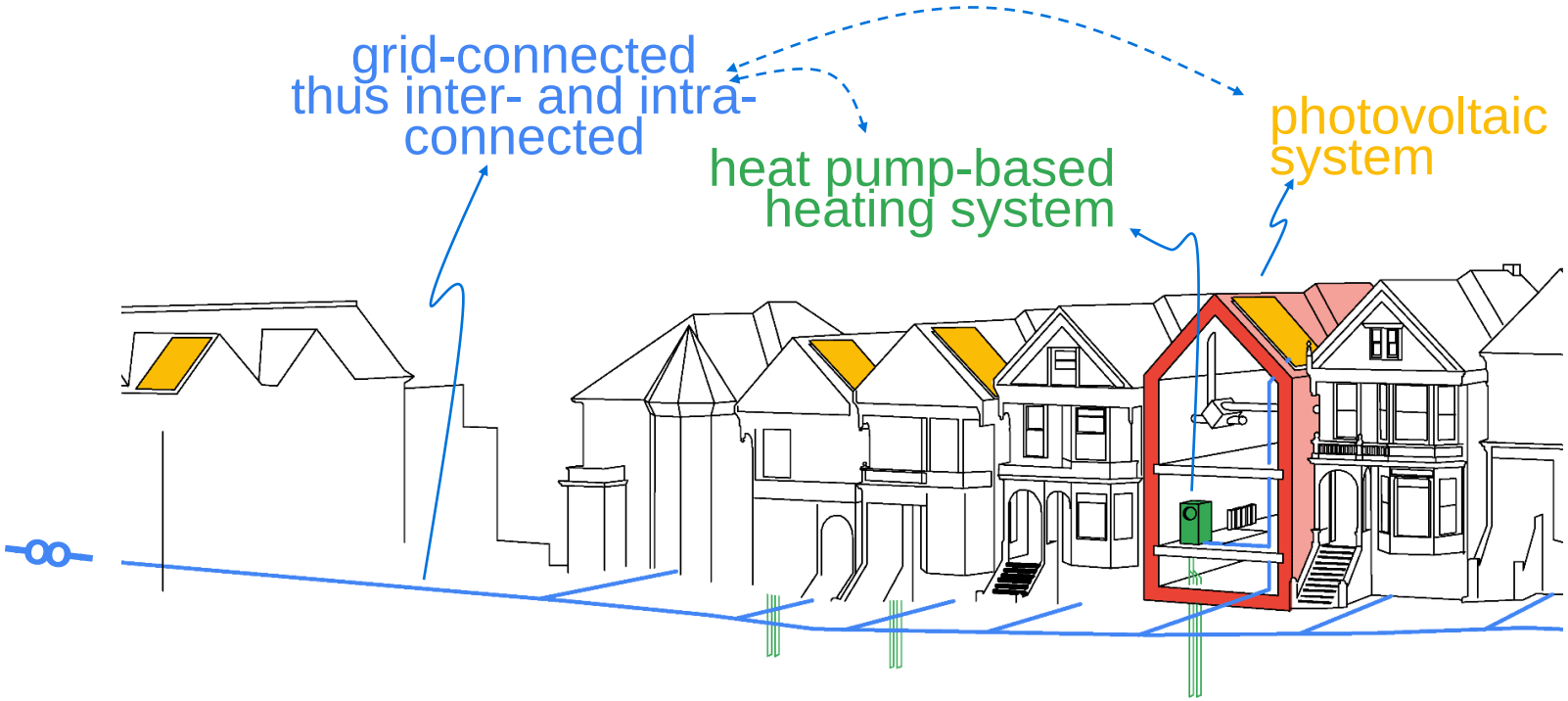
Fig. 7. Effective levels of net zero-energy plotted against the design level of net zero-energy at building (gray) and aggregated (black) level determined ideally at building level and after integrated district energy system simulation including feeder consequences for the considered feeder designs. 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.

KU LEUVEN

New challenges for energy assessment tools

- High time resolution
- Multi-domain
- Increase of dimensionality



IDEAS – Integrated District Energy Assessment by Simulation

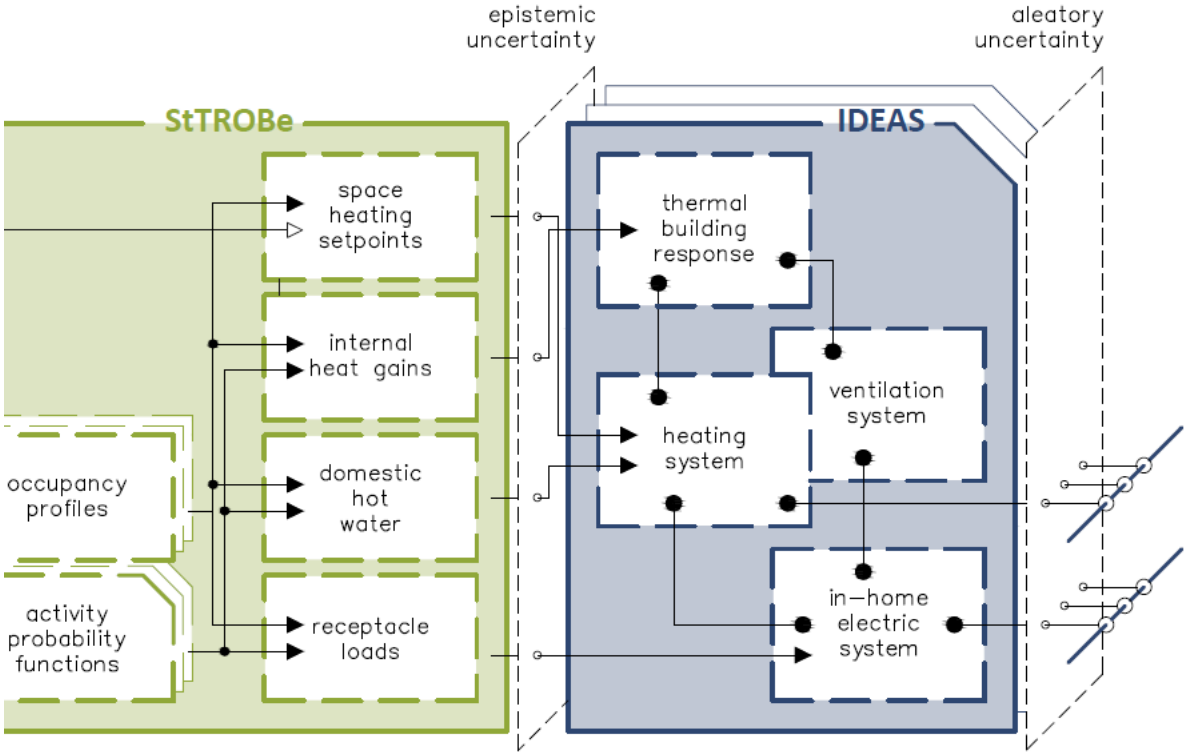


Figure 4.1

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

KU LEUVEN

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 challenges for simulations
  - Detailed models on **high time resolution**
  - Evaluation at aggregated level with **large number** of dwellings
  - **Multi-domain** approach

Content

0. Introduction

I. Case study: District Energy Assessment
   - Impact of heat pump-based building design on distribution grid level

II. Concepts for District Energy Assessment
   - Reduced-order building modelling
   - Stochastic occupant behaviour
   - Grouping of subcomponents in *partial models*

III. Workshop

KU LEUVEN

II. Concepts for District Energy Assessment

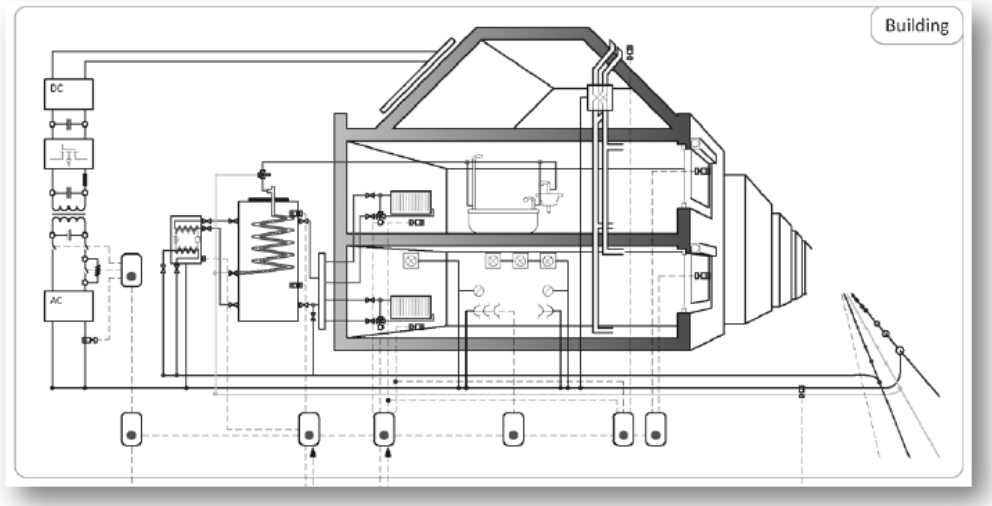
Reduced-order building modelling

KU LEUVEN

Reduced order building modelling

Main matrix of the Belgian housing typology

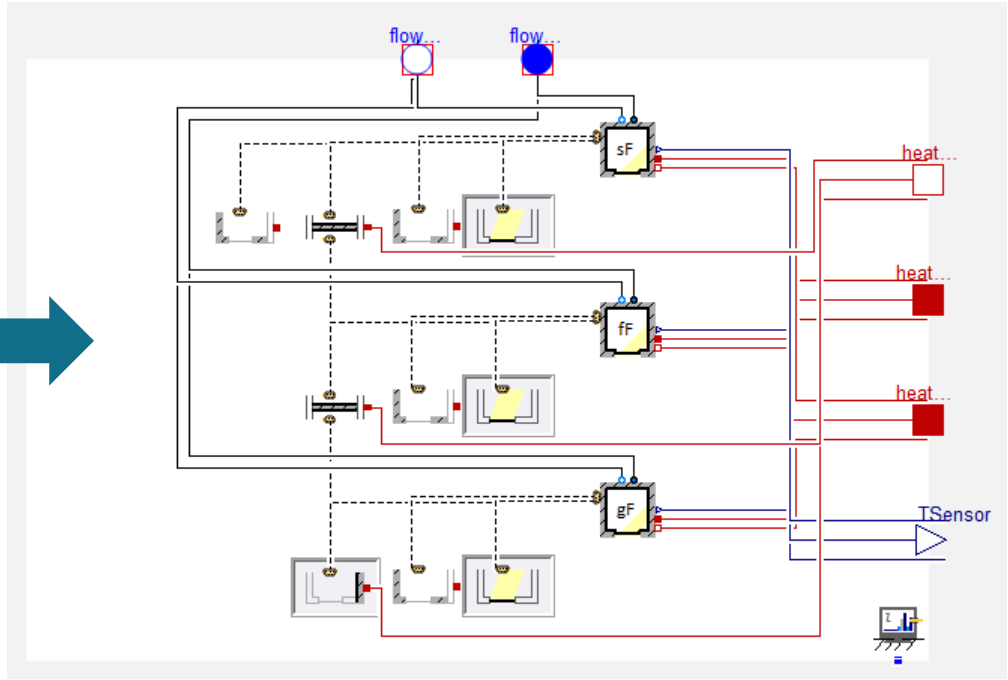
	Region	Construction Year Class	Single Family House - Detached	Single Family House – Semi detached	Single Family House - Terraced
1	national (Belgium)	... 1945	 BE.N.SFH.01.deta	 BE.N.TH.01.semi	 BE.N.TH.01.terr
6	national (Belgium)	1946 - 1970	 BE.N.SFH.02.deta	 BE.N.TH.02.semi	 BE.N.TH.02.terr
12	national (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 modelling

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

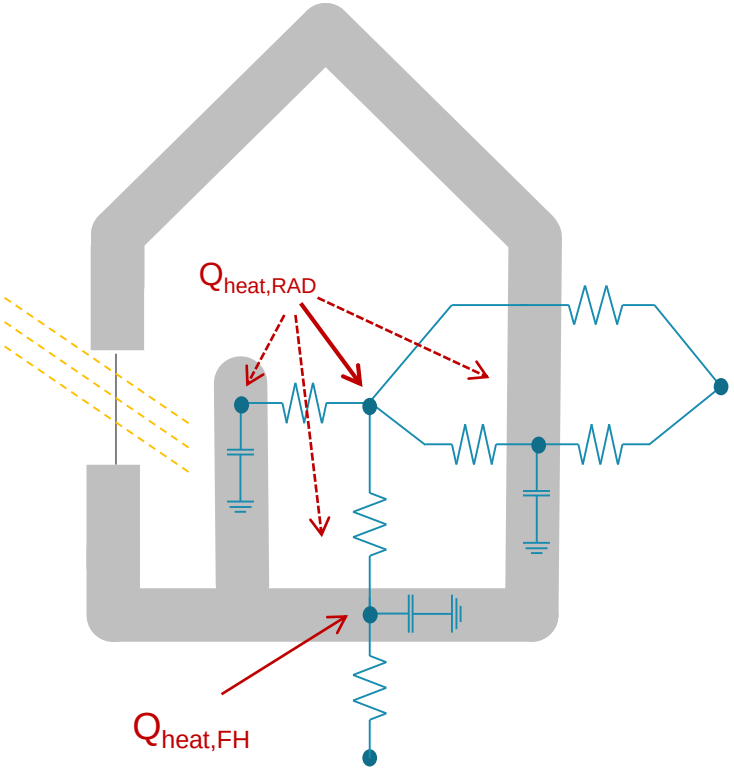


KU LEUVEN

Reduced order building modelling

Main matrix of the Belgian housing typology

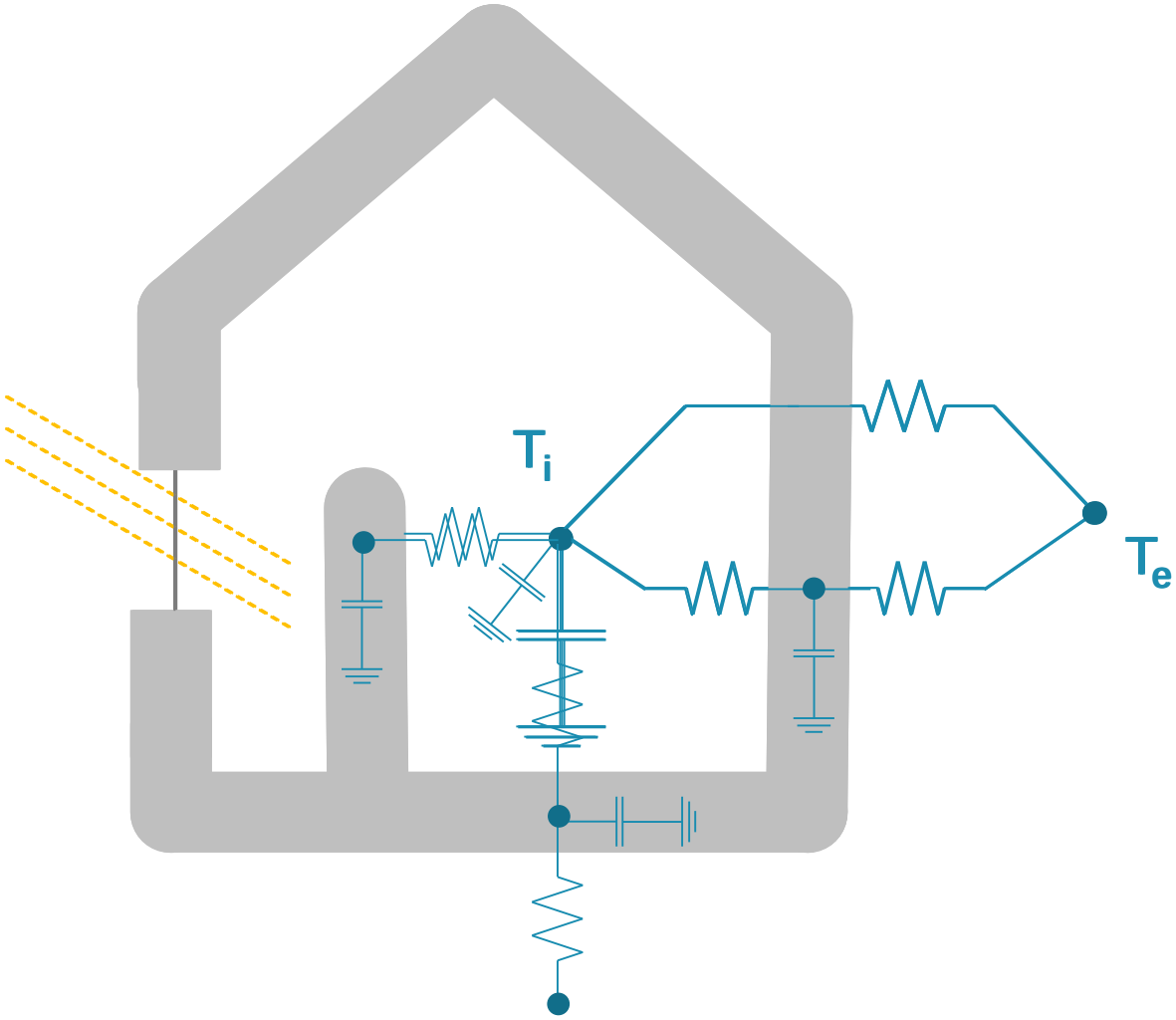
	Region	Construction Year Class	Single Family House - Detached	Single Family House – Semi detached	Single Family House - Terraced
1	national (Belgium)	... 1945	 BE.N.SFH.01.deta	 BE.N.TH.01.semi	 BE.N.TH.01.terr
6	national (Belgium)	1946 - 1970	 BE.N.SFH.02.deta	 BE.N.TH.02.semi	 BE.N.TH.02.terr
12	national (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



KU LEUVEN

Finding the right order?

MODELS

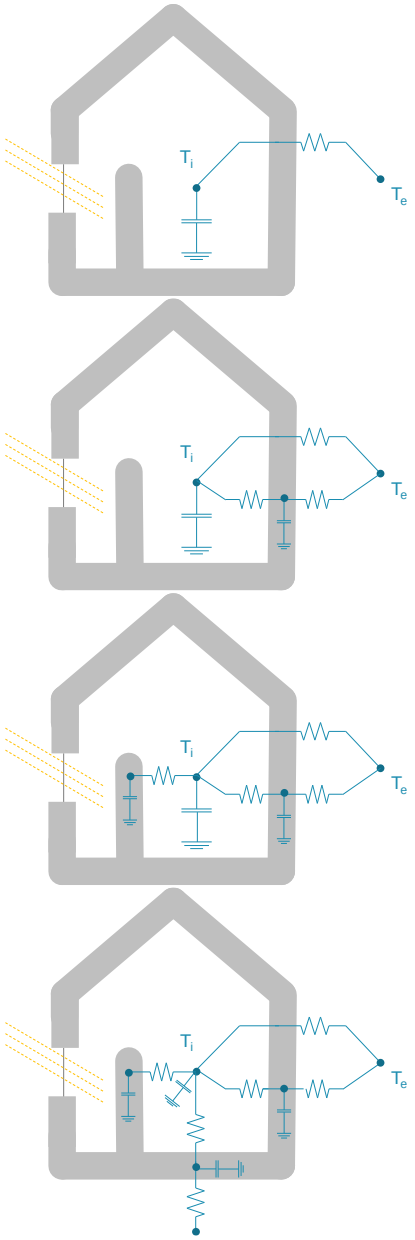


KU LEUVEN

Reduced order building models

RESEARCH QUESTIONS

- Model order?
- Allocation of gains?
- Influence of heating system (FH vs RAD)?
- Prediction horizon?

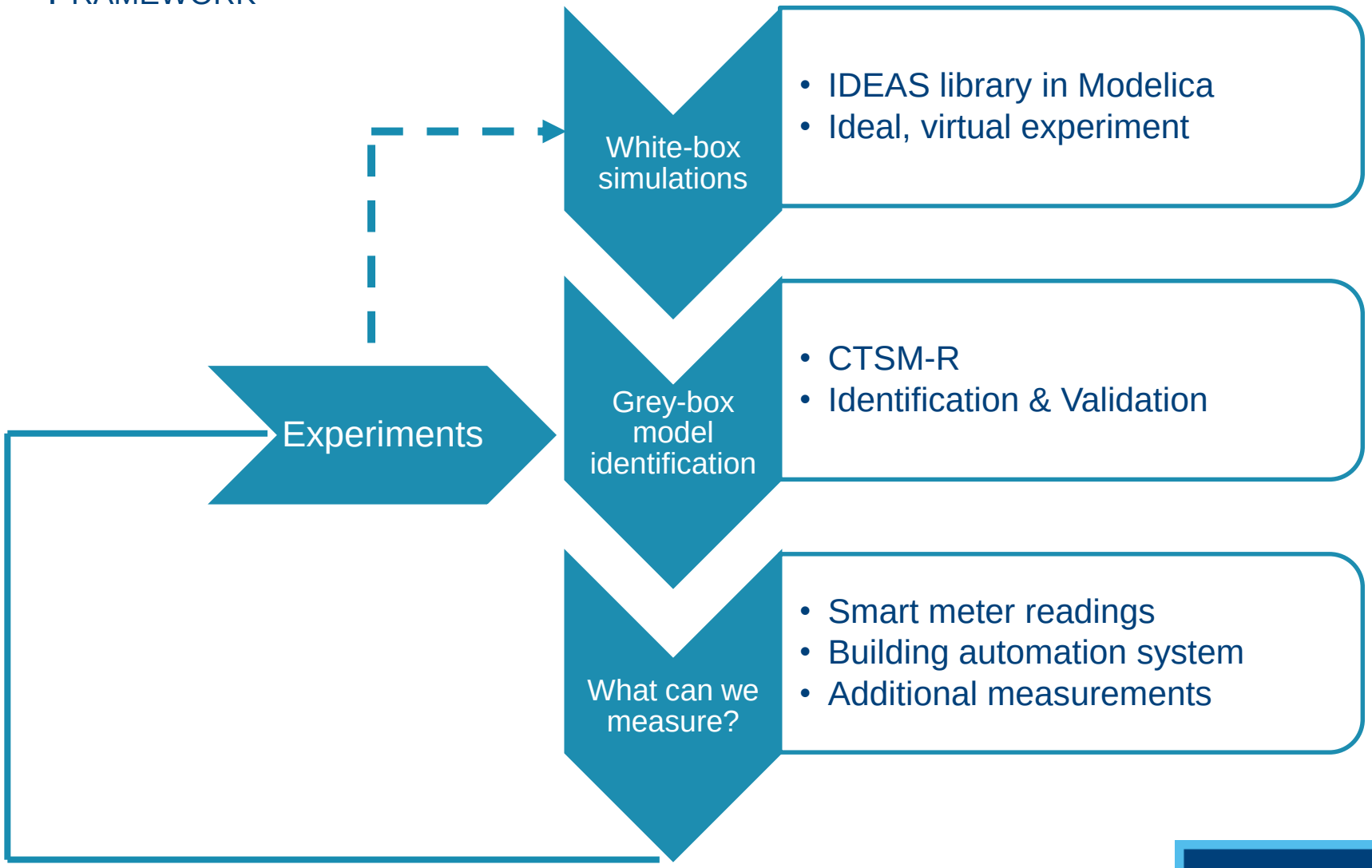


Reynders, Glenn, Jan Diriken, and Dirk Saelens. "Quality of grey-box models and identified parameters as function of the accuracy of input and observation signals." Energy and Buildings 82 (2014): 263-274.

KU LEUVEN

Reduced-order building stock model

FRAMEWORK

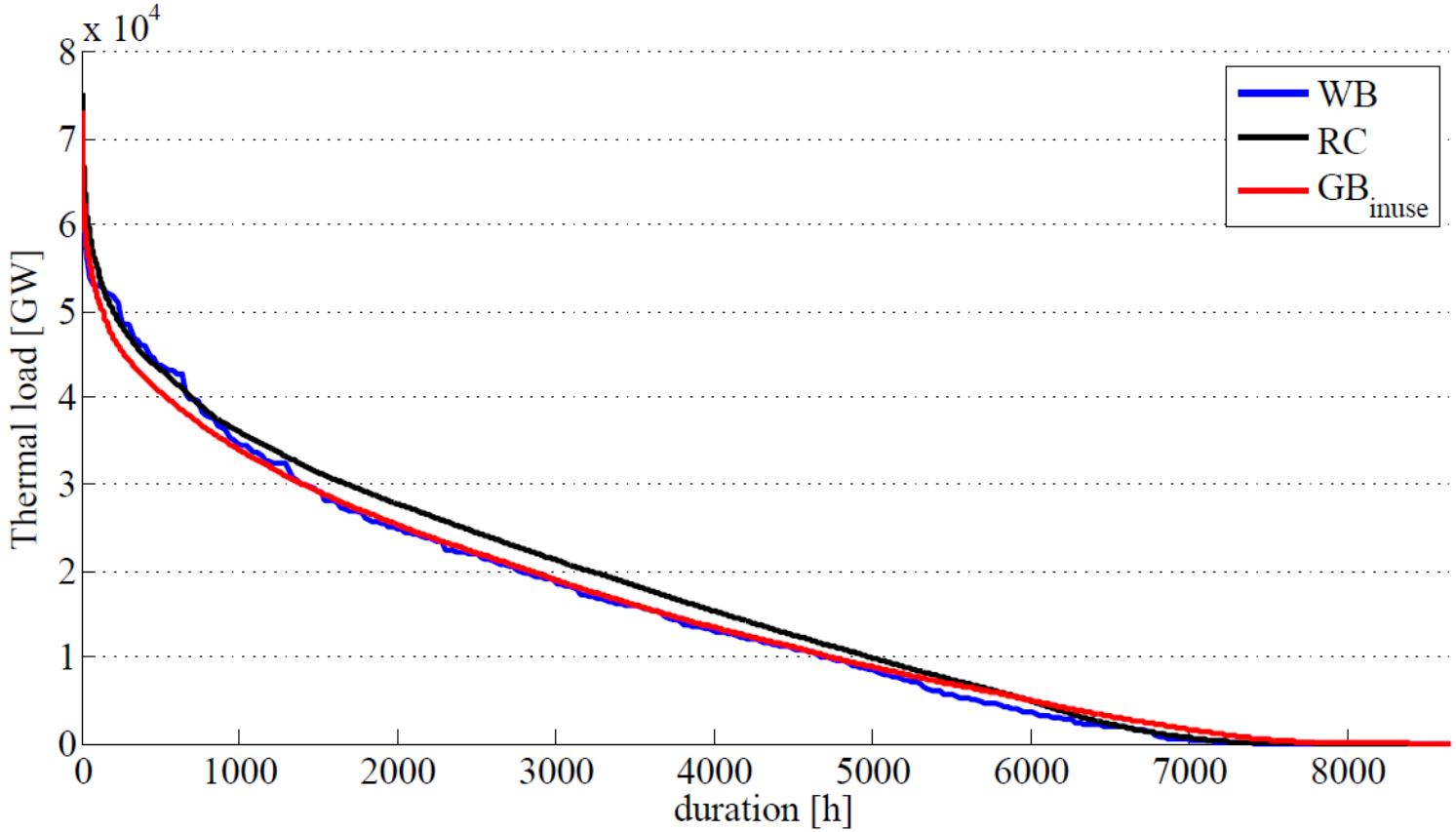


KU LEUVEN

Reduced-order building stock model

VERIFICATION IDENTIFIED MODELS

Aggregated load-duration curve

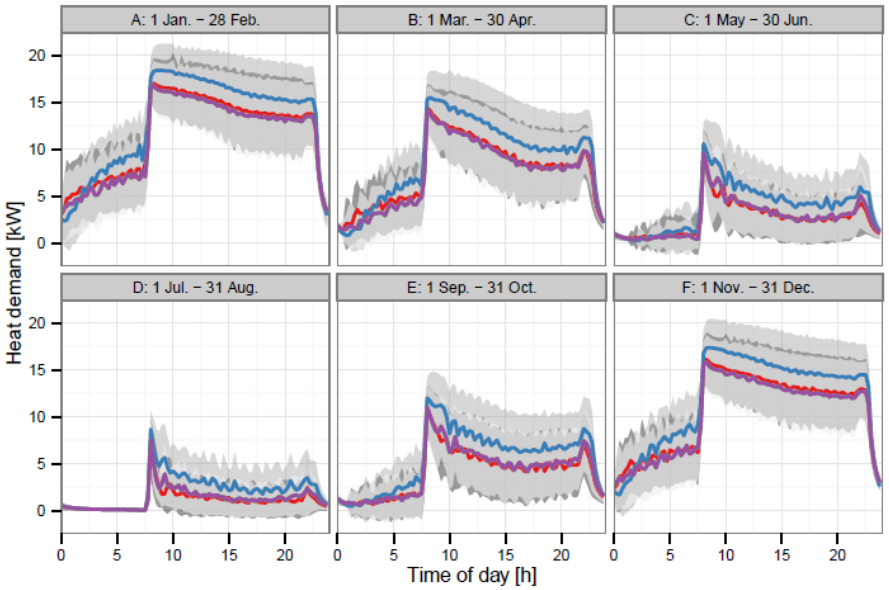


KU LEUVEN

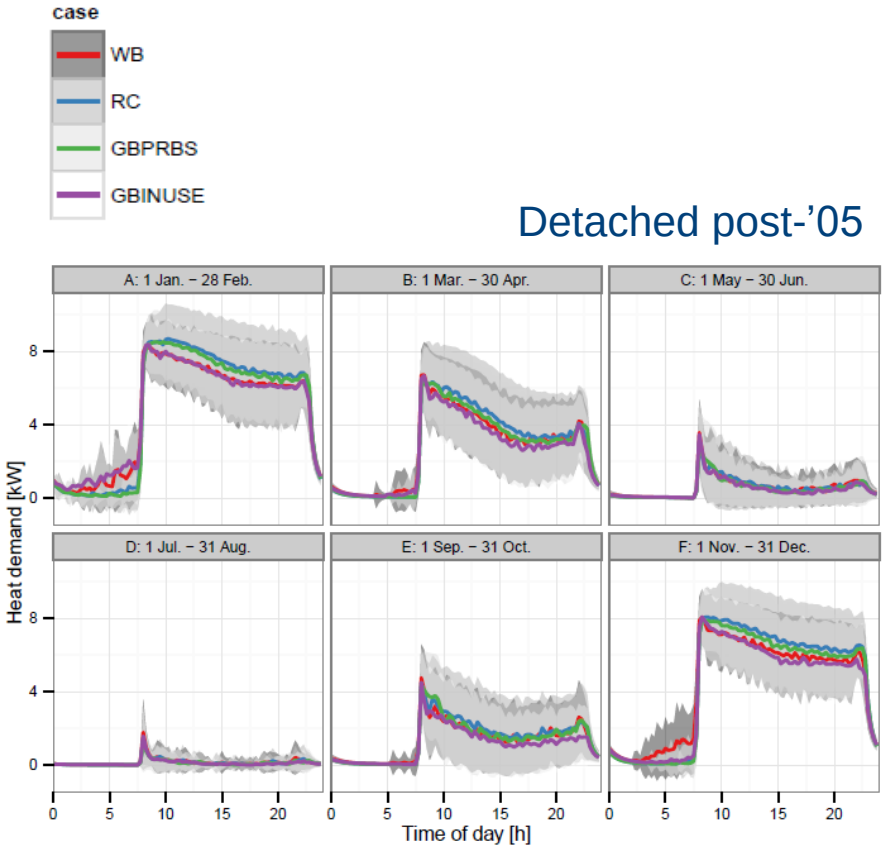
Reduced-order building stock model

VERIFICATION IDENTIFIED MODELS

Instantaneous heat demand profiles



Detached pre-'45

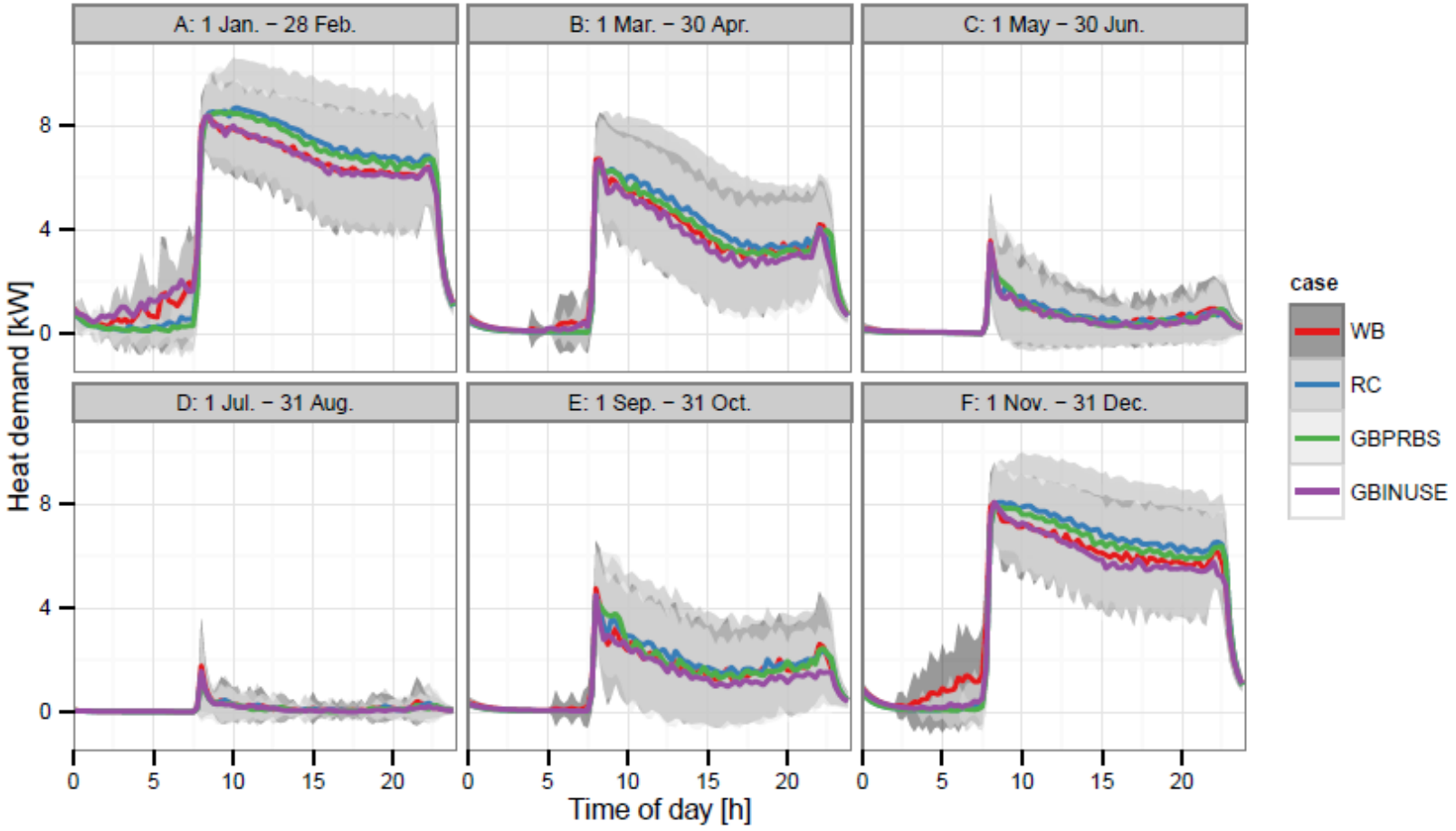


Detached post-'05

Reduced-order building stock model

VERIFICATION IDENTIFIED MODELS

Instantaneous heat demand profiles (Detached post ‘05)



Reduced-order building stock model

Lessons Learned

- Deterministic RC models tend to overestimate the accessibility of thermal mass
- 2nd Order model is absolute minimum for short-term predictions

  Especially if no floor heating or TABS
- *4rd Order model best results for:*
  - *Simulation and long-term predictions*
  - Physical interpretation of grey-box parameters

For exercise: 4th order models generated by TEASER will be used

KU LEUVEN

Content

0. Introduction

I. Case study: District Energy Assessment
   - Impact of heat pump-based building design on distribution grid level

II. Concepts for District Energy Assessment
   - Reduced-order building modelling
   - Stochastic occupant behaviour
   - Grouping of subcomponents in *partial models*

III. Workshop

KU LEUVEN

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

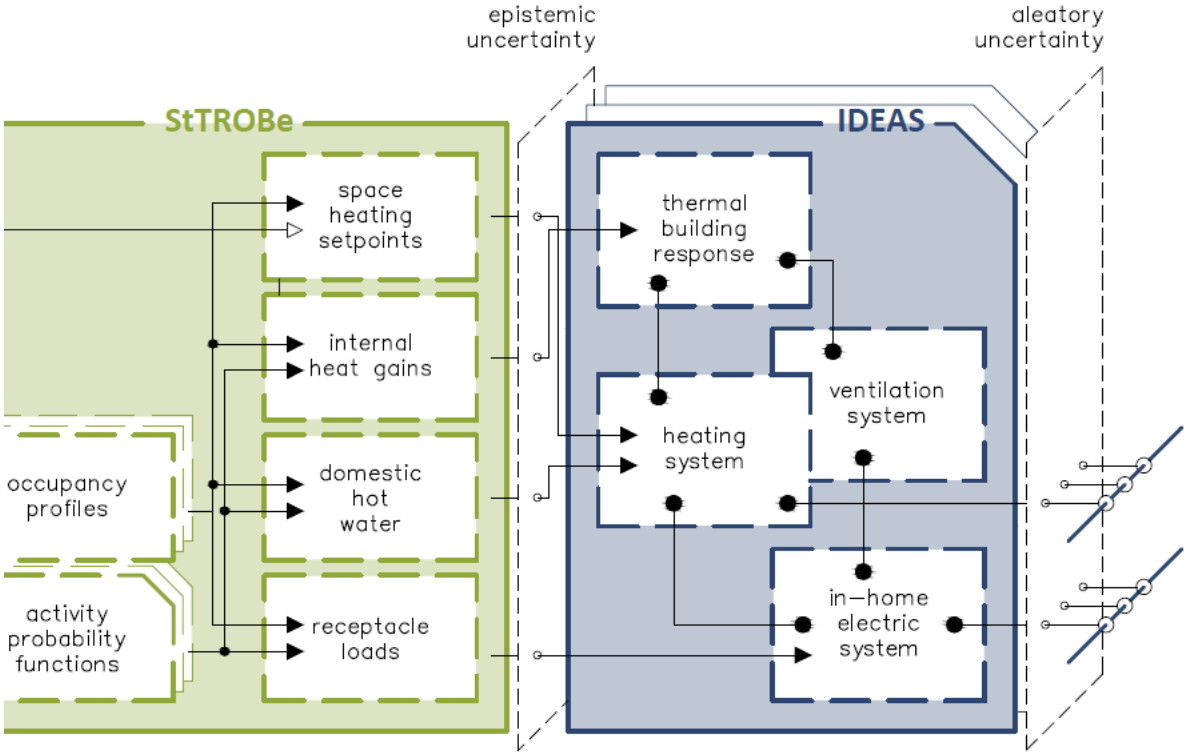


Figure 4.1

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

Baetens R. (2015) On externalities of heat pump-based low-energy dwellings at the low-voltage distribution grid. PhD Dissertation, KU Leuven

KU LEUVEN

cross-correlation
among the variables is point of attention
in the modelling approach

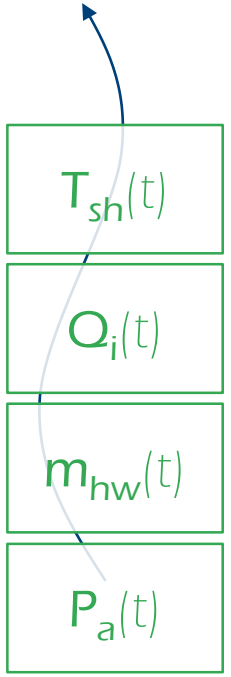


Figure 4.1

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

Figure 4.1

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

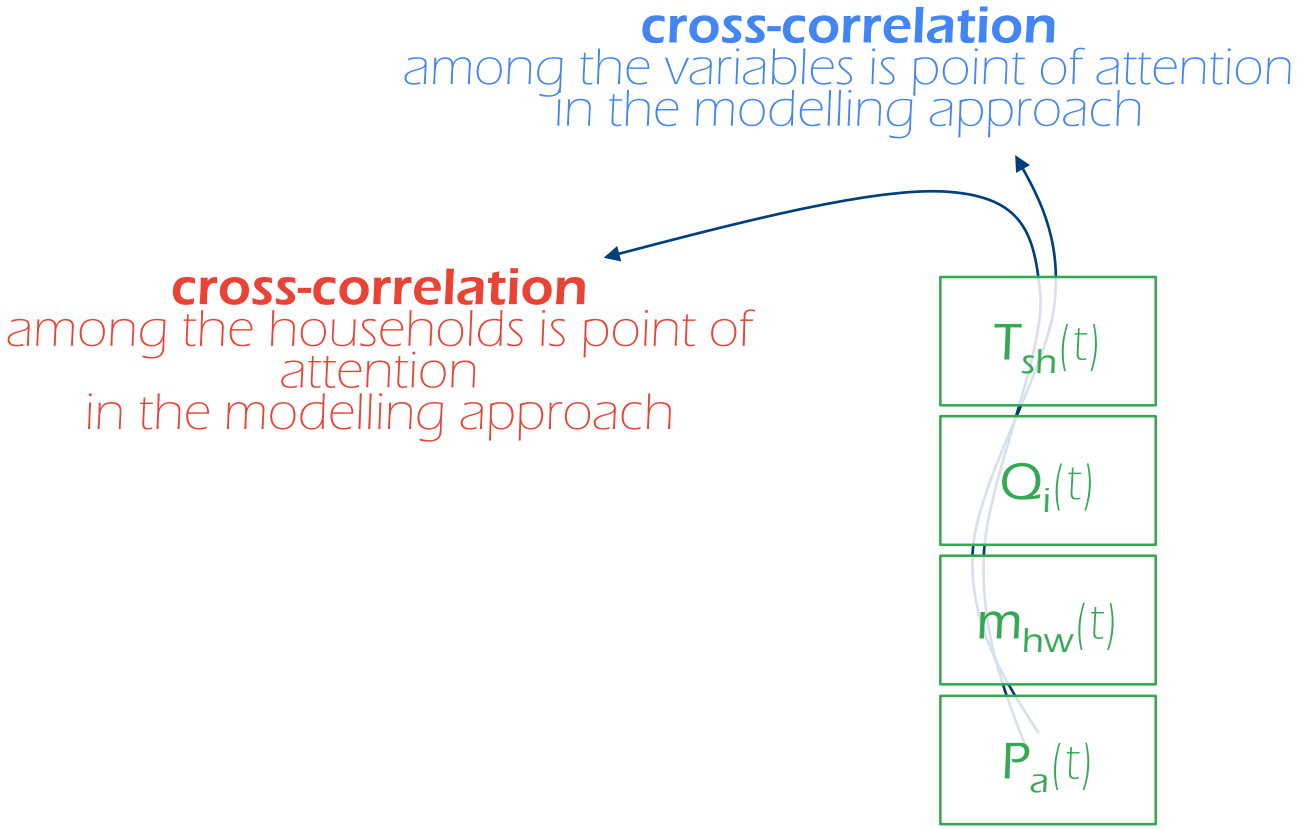
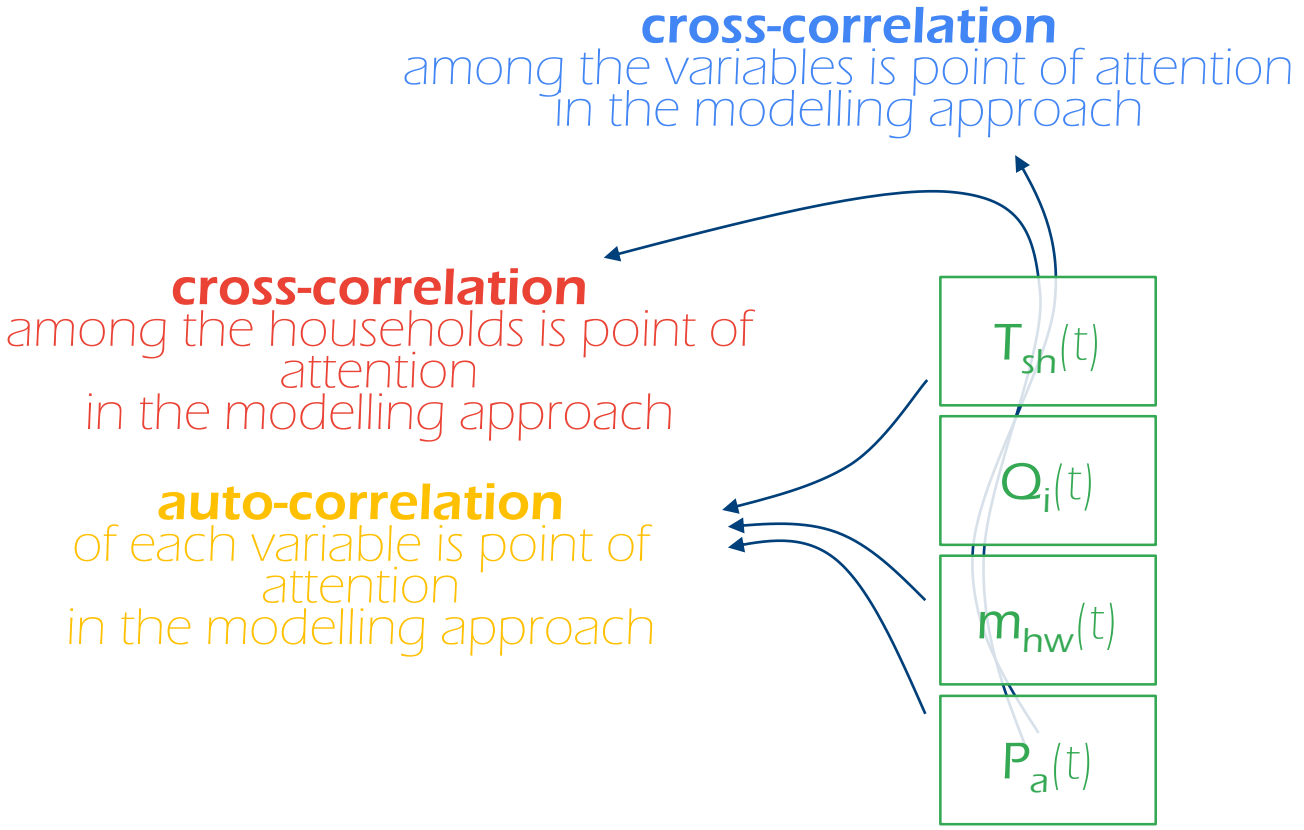


Figure 4.1

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



OpenIDEAS

An open framework for integrated building and district energy simulations

Repositories People 2

Filters ▾ Find a repository...

IDEAS

Modelica ★ 18 ⑂ 22

Modelica library allowing simultaneous transient simulation of thermal and electrical systems at both building and feeder level.

Updated 2 days ago

__CrashCourse__

Modelica ★ 3 ⑂ 3

Initiatory crash course on Modelica, its standard library and the IDEAS library for building and district energy simulations.

Updated 10 days ago

FastBuildings

★ 7 ⑂ 10

Modelica library allowing low-order grey-box modelling of buildings for model predictive controllers (MPC) or aggregators.

Updated on 11 Jan 2015

StROBe

Python ★ 3 ⑂ 3

Python module for stochastic residential occupancy behavior for both building and district energy simulations.

StROBe

Currently in beta.

StROBe (Stochastic Residential Occupancy Behaviour) is an open web tool developed at the KU Leuven Building Physics Section to model the pervasive space for residential integrated district energy assessment simulations in the open **IDEAS** modeling environment (among others). Primarily conceived as a tool for scientific researchers, **StROBe** aims at providing missing boundary conditions in integrated district energy assessment simulations related to human behavior, such as the use of appliances and lighting, space heating settings and domestic hot water redrawals.

StROBe is also highly customizable and extensible, accepting model changes or extensions defined by users. For more information on the implementation, see the GitHub Wiki.

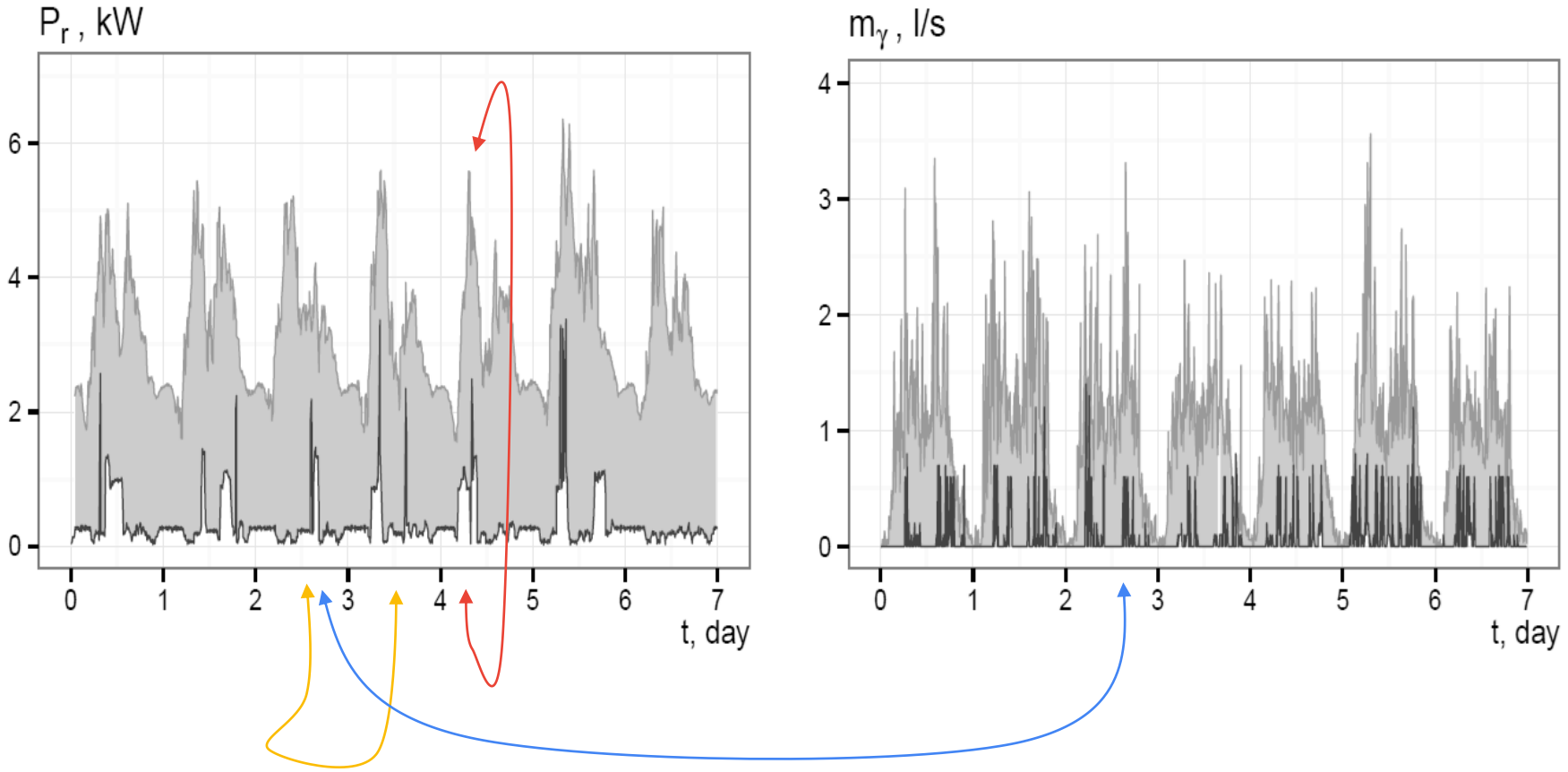
Dependencies

StROBe is implemented in Python and uses the packages Os, Numpy, Random, Time, Datetime and Ast, which are all generally available.

Examples

```
family = Household("Example family")
family.parameterize()
family.simulate()
```

KU LEUVEN



KU LEUVEN

Content

0. Introduction

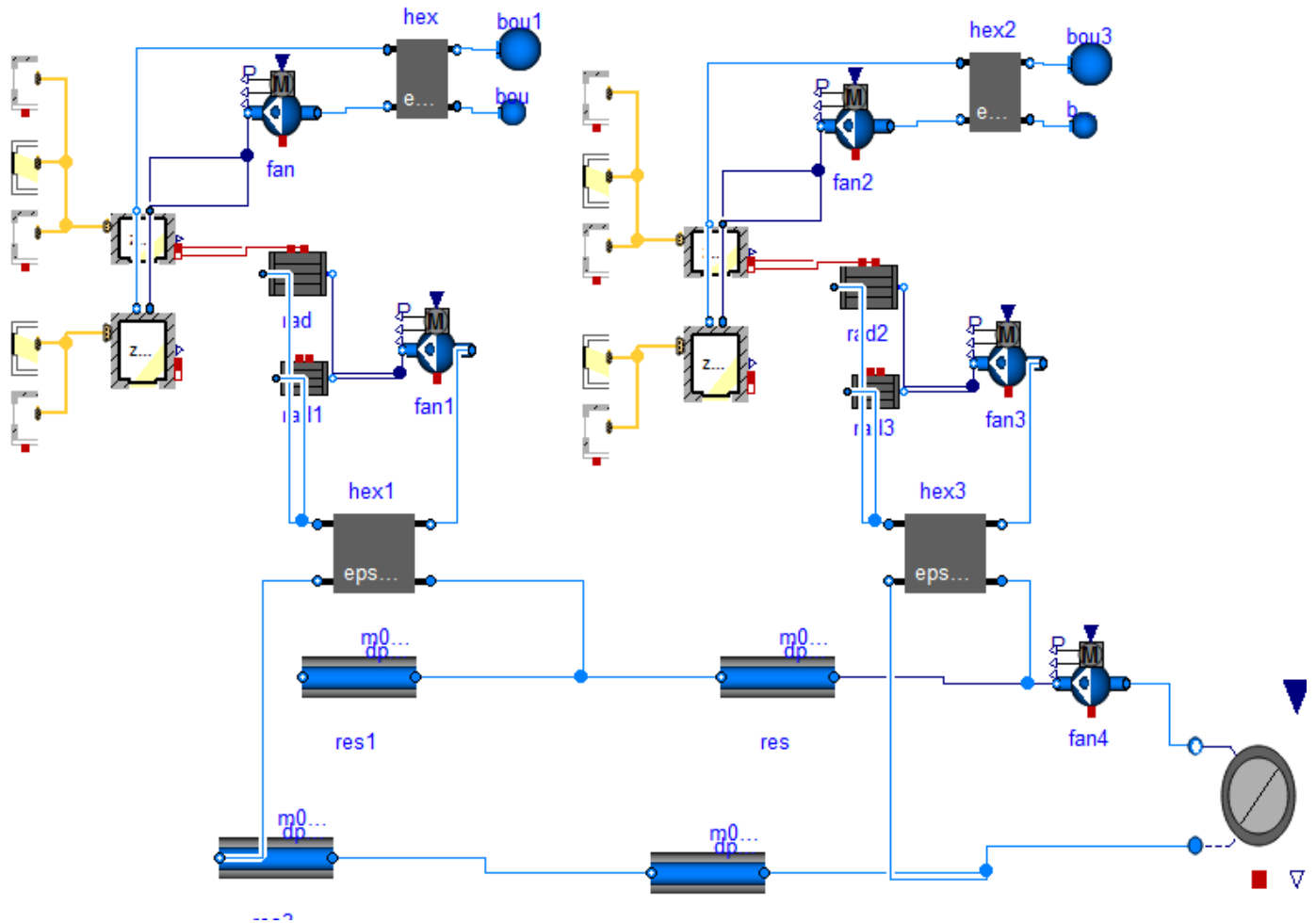
I. Case study: District Energy Assessment
   - Impact of heat pump-based building design on distribution grid level

II. Concepts for District Energy Assessment
   - Reduced-order building modelling
   - Stochastic occupant behaviour
   - Grouping of subcomponents in *partial template models*

III. Workshop

KU LEUVEN

Example: simplest 2 building network



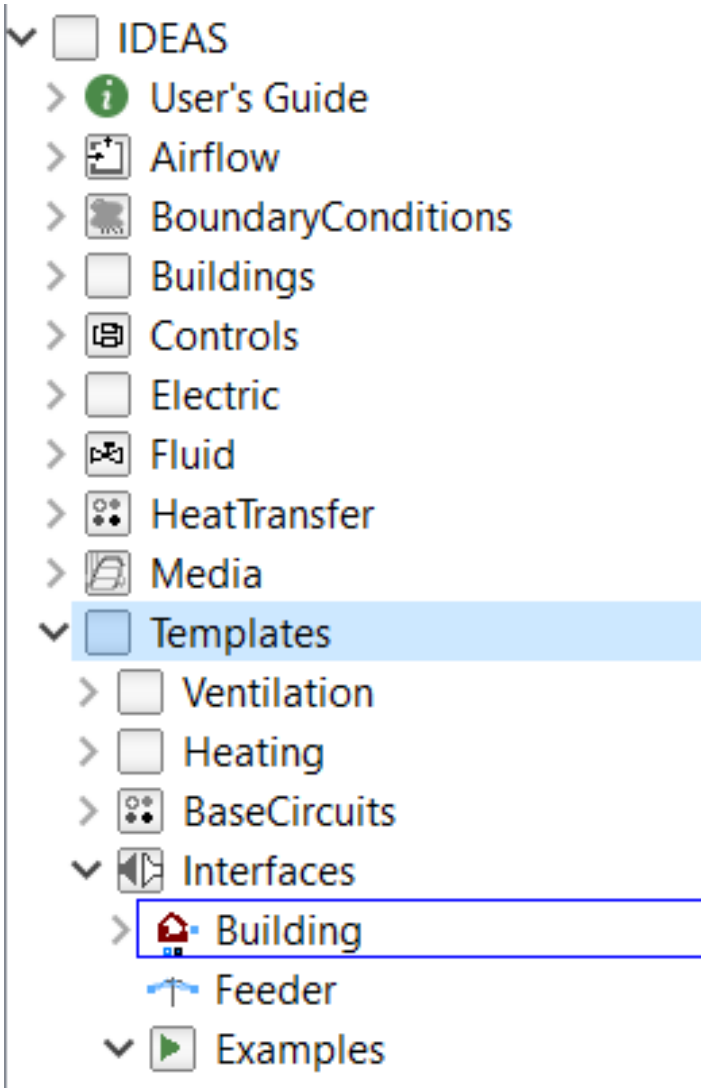
KU LEUVEN

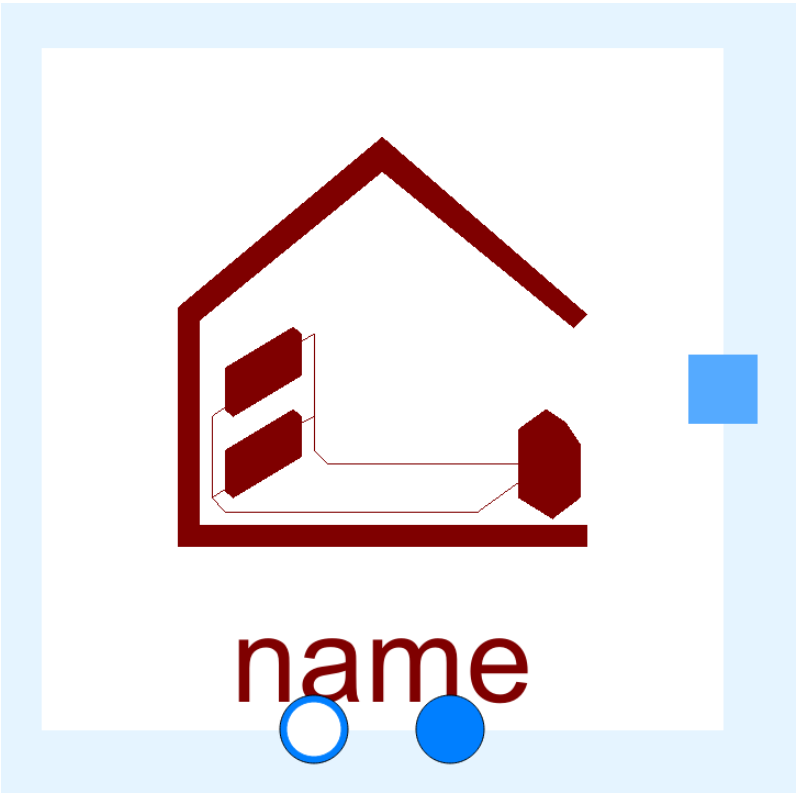
Templates

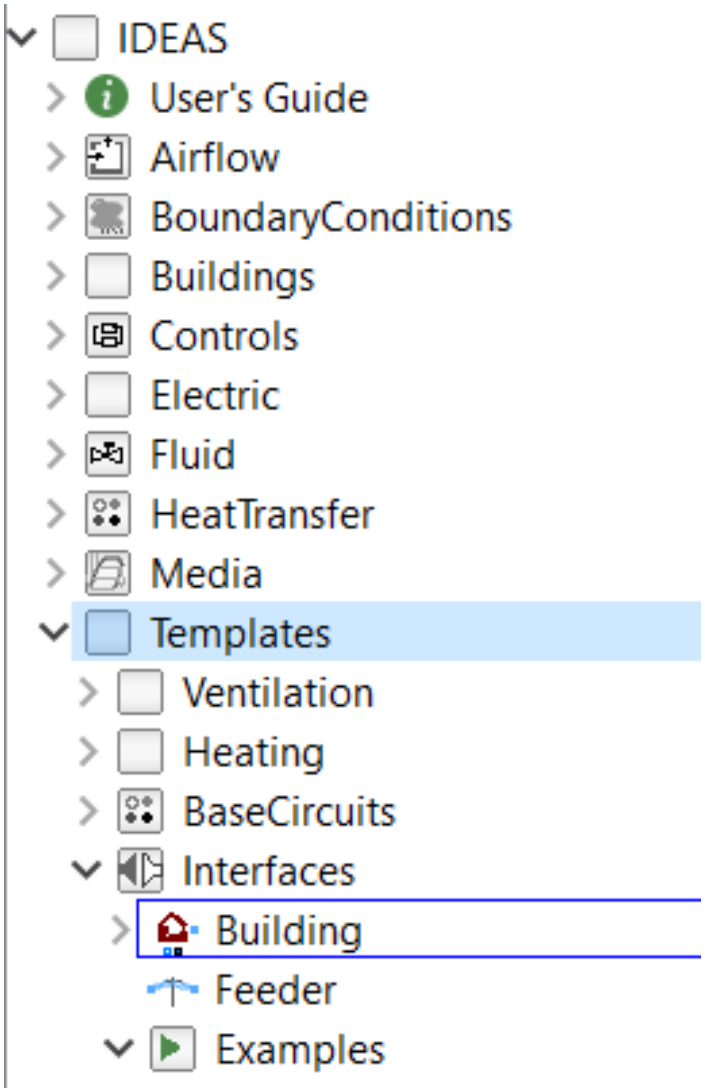
- Pre-composed
- Mostly partial models
- Standard layout

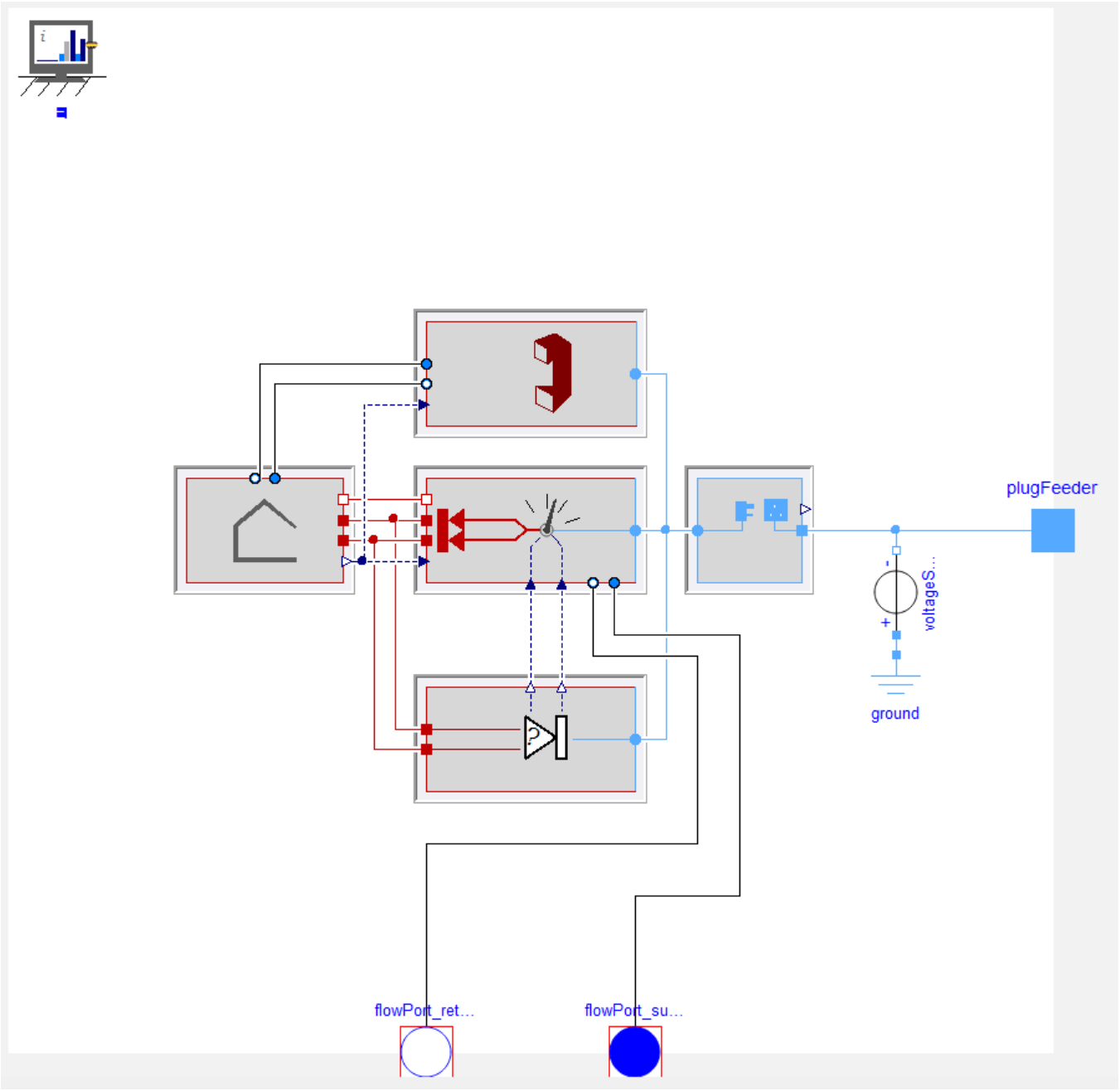
Benefits

- Workflow simplified
- Parameter inheritance
- Predefine *advanced settings*

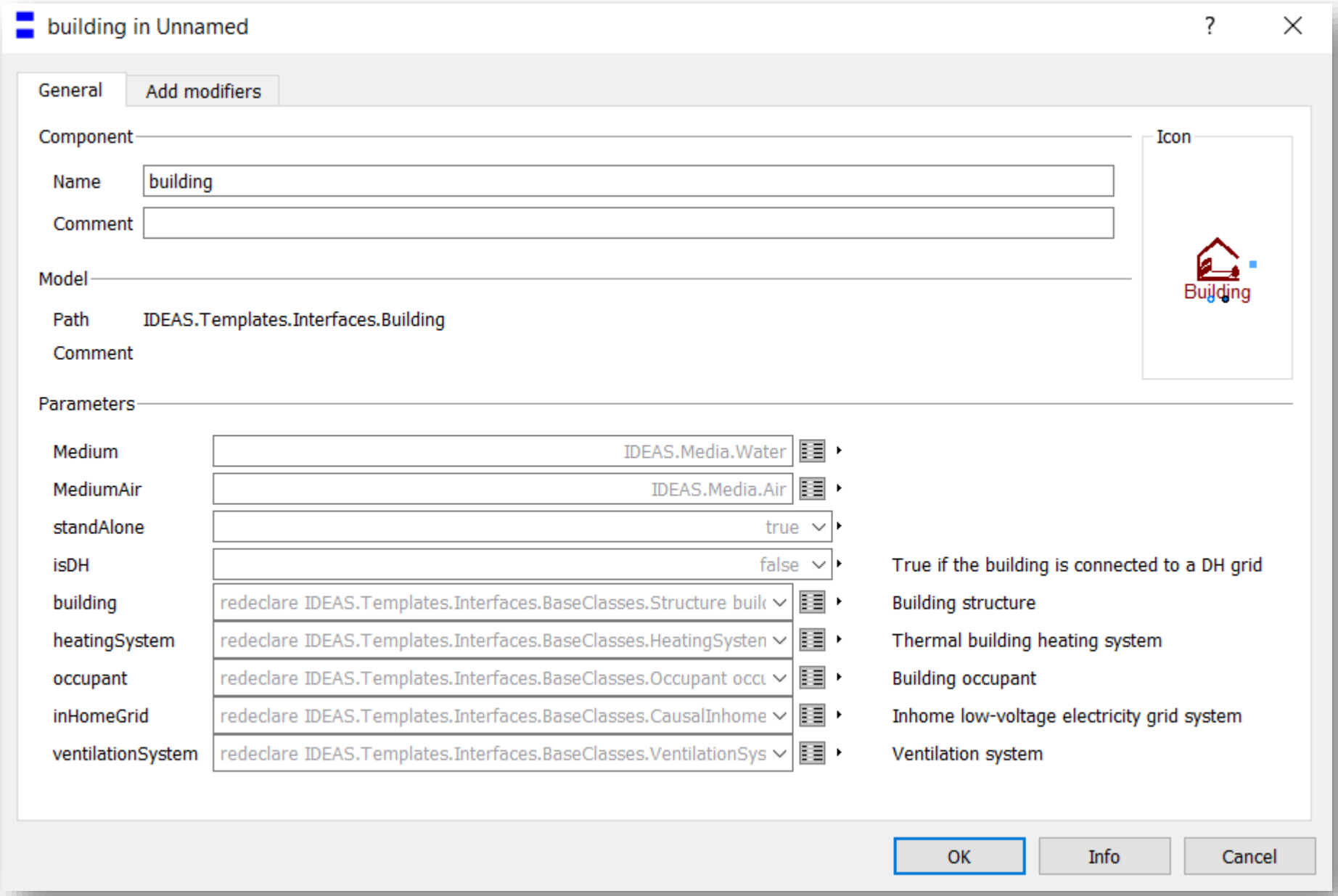



name

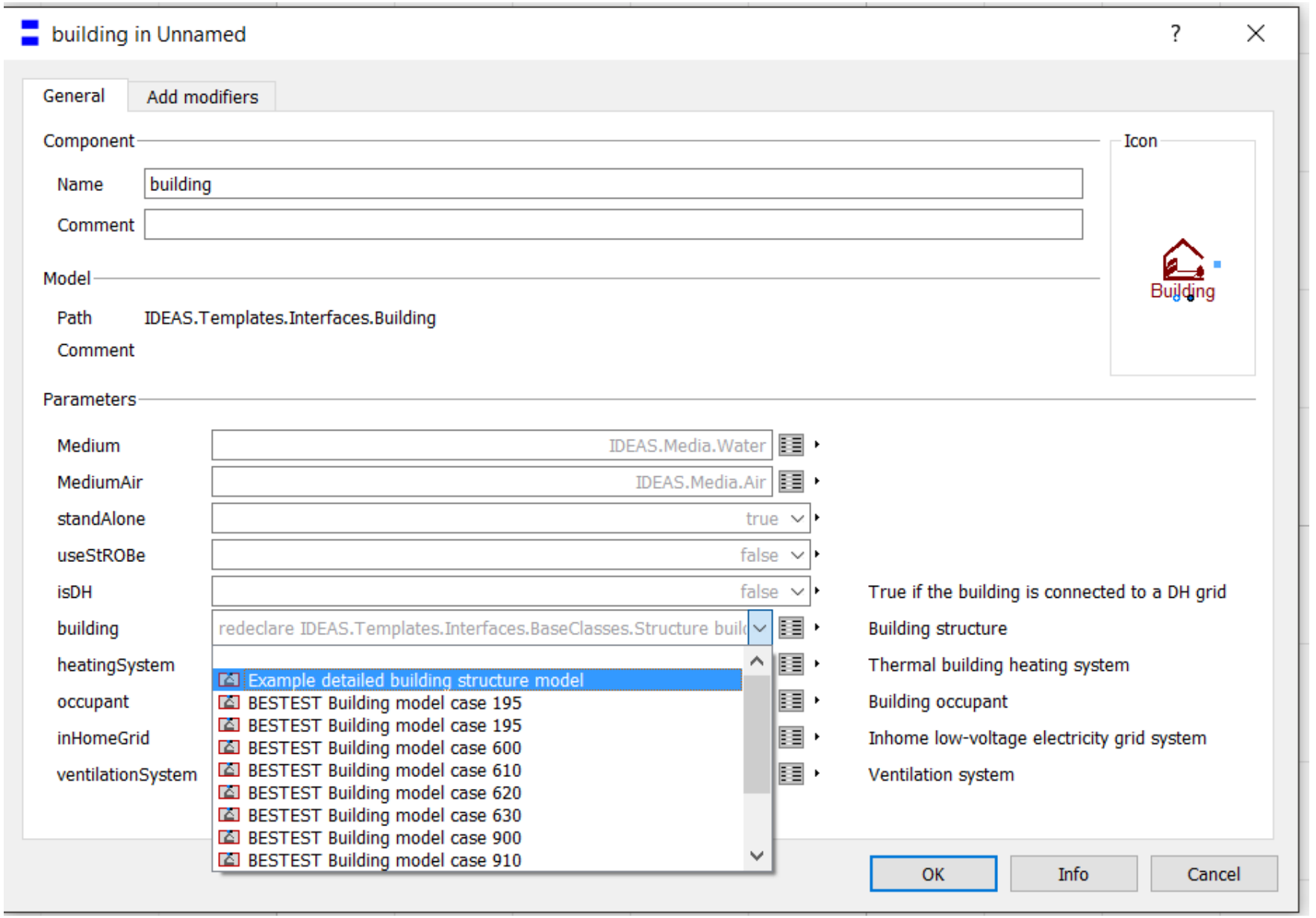

IDEAS
User's Guide
Airflow
BoundaryConditions
Buildings
Controls
Electric
Fluid
HeatTransfer
Media
Templates
Ventilation
Heating
BaseCircuits
Interfaces
Building
Feeder
Examples



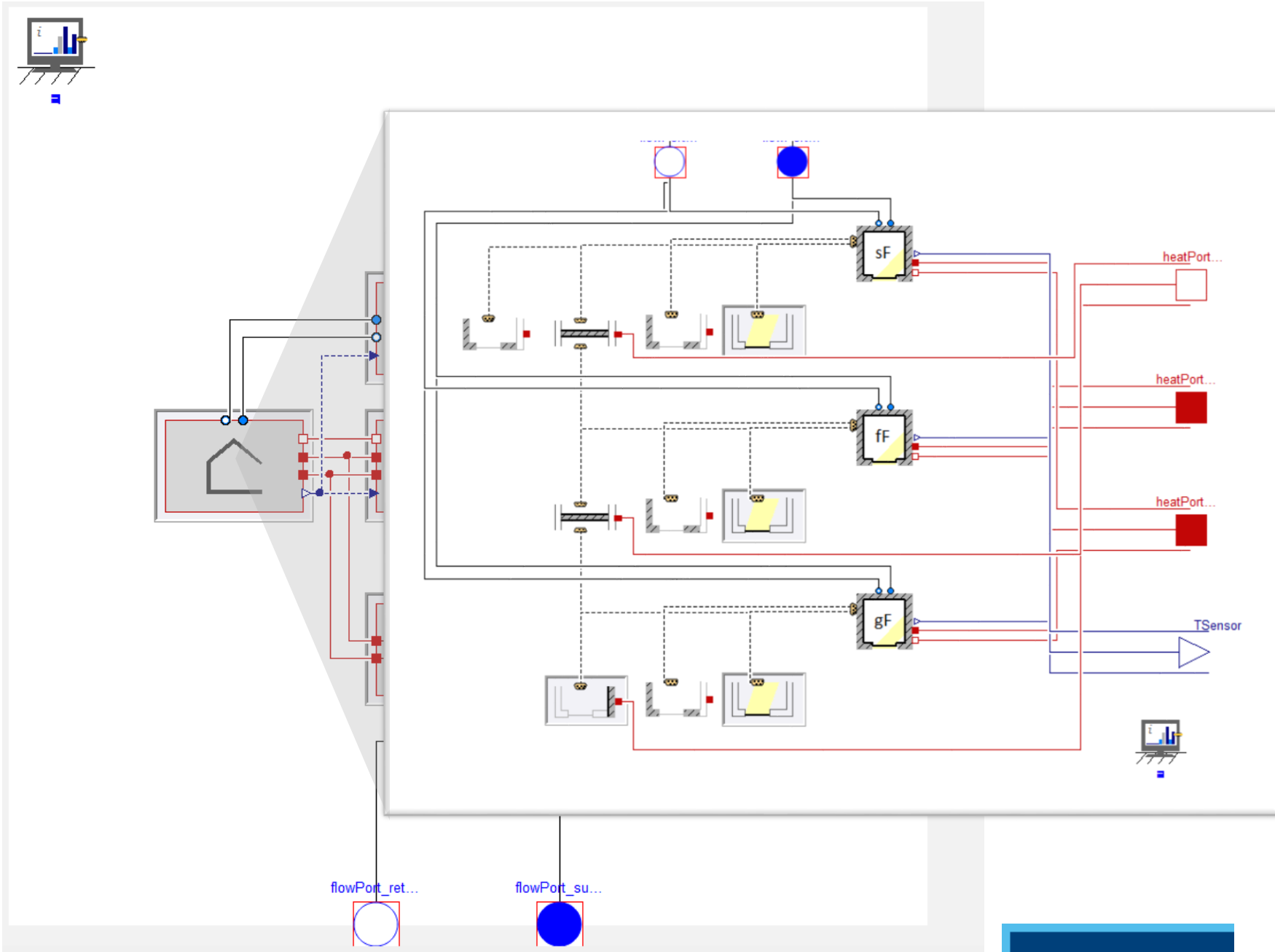
KU LEUVEN


building in Unnamed
General
Add modifiers
Component
Name
building
Comment
Icon
Building
Model
Path
IDEAS.Templates.Interfaces.Building
Comment
Parameters
Medium
IDEAS.Media.Water
MediumAir
IDEAS.Media.Air
standAlone
true
isDH
false
True if the building is connected to a DH grid
building
redeclare IDEAS.Templates.Interfaces.BaseClasses.Structure buil
Building structure
heatingSystem
redeclare IDEAS.Templates.Interfaces.BaseClasses.HeatingSysten
Thermal building heating system
occupant
redeclare IDEAS.Templates.Interfaces.BaseClasses.Occupant occ
Building occupant
inHomeGrid
redeclare IDEAS.Templates.Interfaces.BaseClasses.CausalInhome
Inhome low-voltage electricity grid system
ventilationSystem
redeclare IDEAS.Templates.Interfaces.BaseClasses.VentilationSys
Ventilation system
OK
Info
Cancel

KU LEUVEN


building in Unnamed
General
Add modifiers
Component
Name
building
Comment
Icon
Building
Model
Path
IDEAS.Templates.Interfaces.Building
Comment
Parameters
Medium
IDEAS.Media.Water
MediumAir
IDEAS.Media.Air
standAlone
true
useStROBe
false
isDH
false
True if the building is connected to a DH grid
building
redeclare IDEAS.Templates.Interfaces.BaseClasses.Structure buil
Building structure
heatingSystem
Thermal building heating system
occupant
Building occupant
inHomeGrid
Inhome low-voltage electricity grid system
ventilationSystem
Ventilation system
Example detailed building structure model
BESTEST Building model case 195
BESTEST Building model case 195
BESTEST Building model case 600
BESTEST Building model case 610
BESTEST Building model case 620
BESTEST Building model case 630
BESTEST Building model case 900
BESTEST Building model case 910
OK
Info
Cancel

KU LEUVEN


sF
fF
gF
heatPort...
heatPort...
heatPort...
TSensor
flowPort_ret...
flowPort_su...

KU LEUVEN

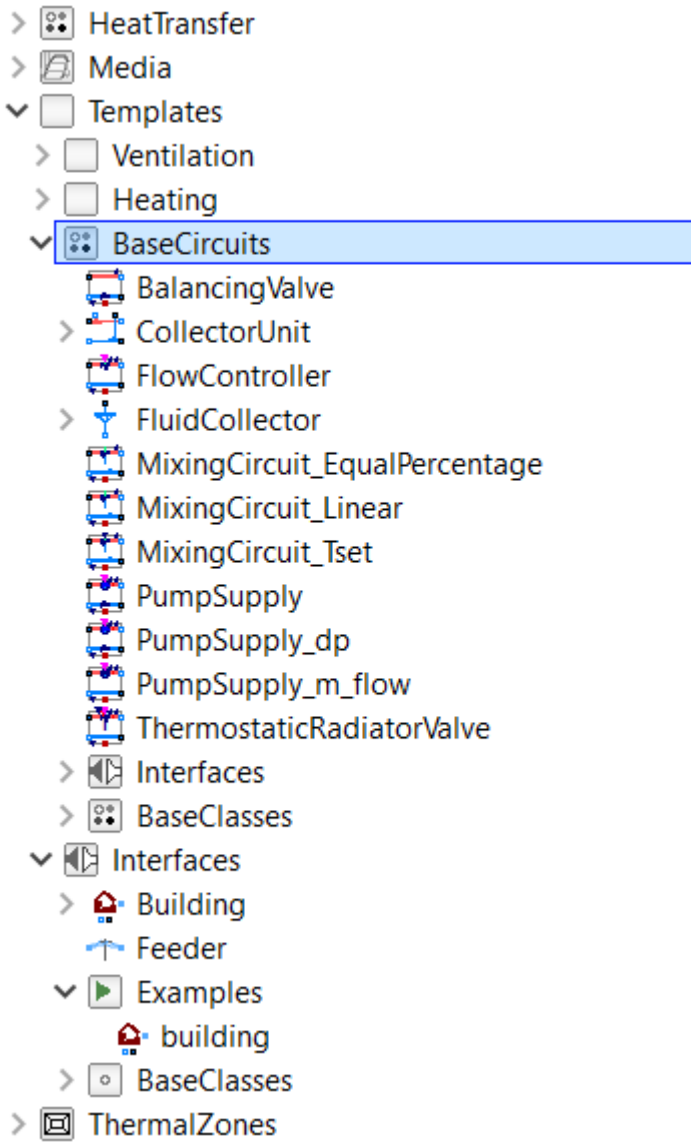
Workflow

1. Create library of building structures
2. Create (library of) heating and ventilation systems
3. Instantiate buildings

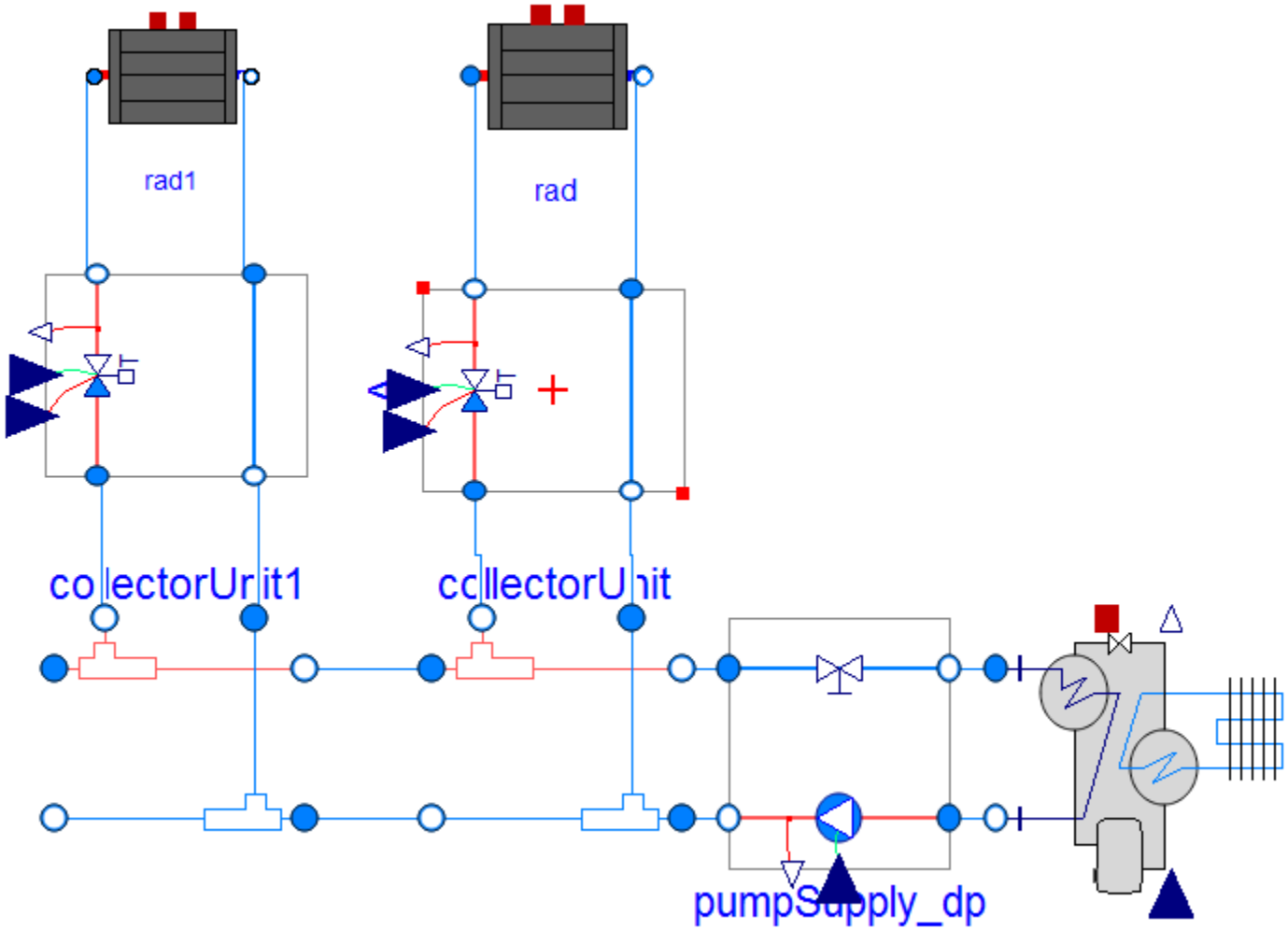
    assign structure, heating, ventilation, occupancy
4. Create district heating network

Base circuits

- Preconfigured circuits
- (District) heating systems



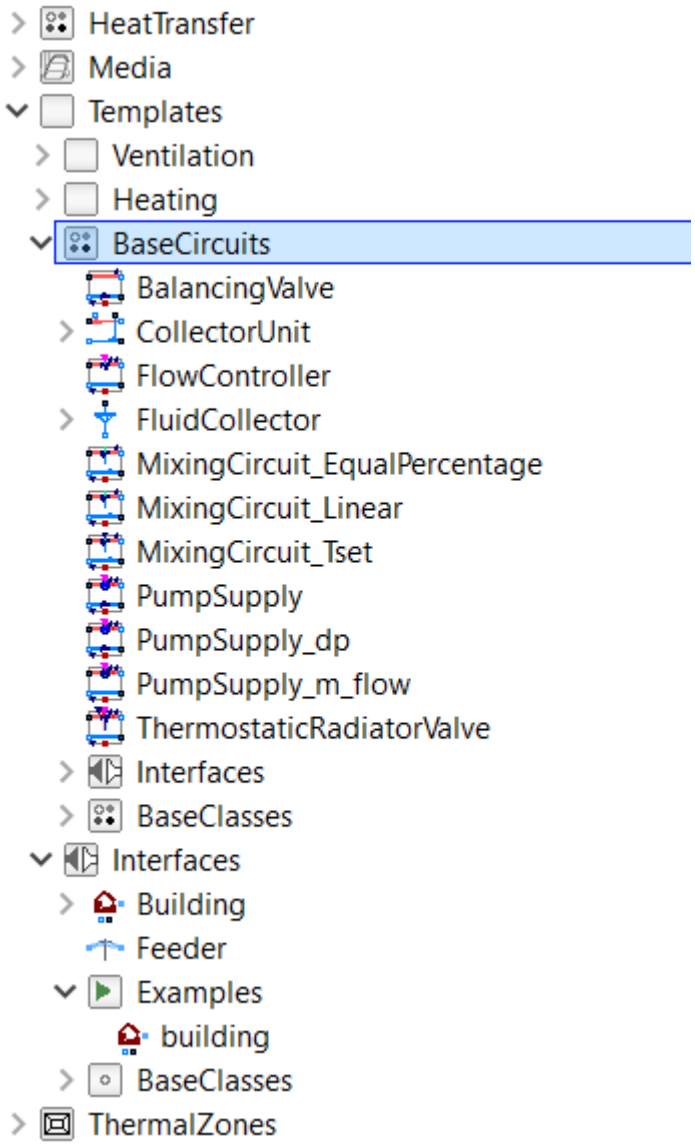
KU LEUVEN



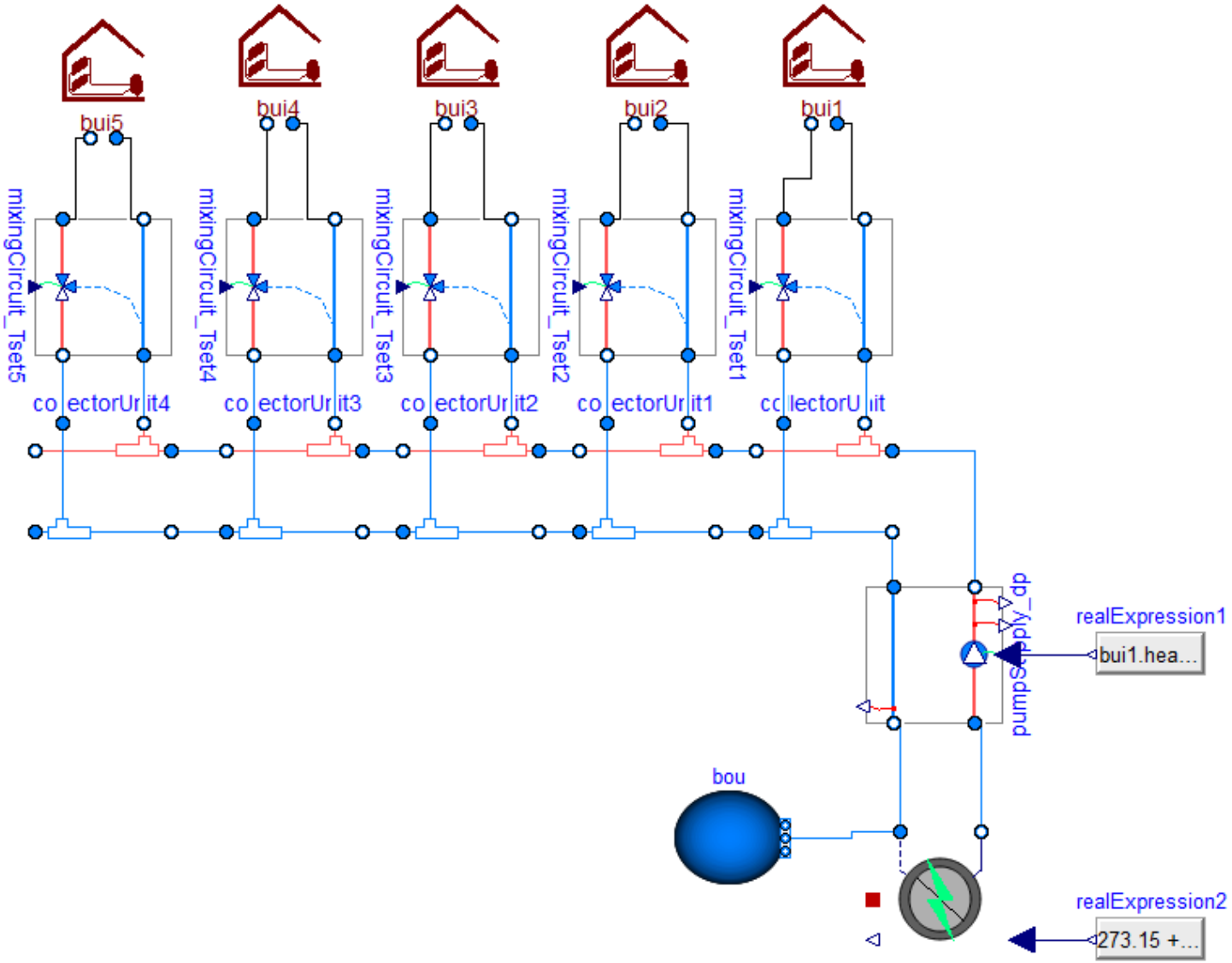
KU LEUVEN

Base circuits

- Preconfigured circuits
- (District) heating systems
- Benefits
  - Fast development
  - Predefined *advanced settings*
  - Reusability



KU LEUVEN


bui5
bui4
bui3
bui2
bui1
mixingCircuit_Tset5
mixingCircuit_Tset4
mixingCircuit_Tset3
mixingCircuit_Tset2
mixingCircuit_Tset1
realExpression1
bui1.hea...
dp_y
pumpSpeed
bou
realExpression2
273.15 +...

KU LEUVEN

IV. Work shop

KU LEUVEN

Aspects for workshop

I. Reduced-order Building model
   I. Generated using TEASER
II. Occupant data
   I. ISO 13790 vs StROBe
III. Simple district heating system
   I. Sizing based on dynamic simulation
   II. Base circuits
IV. Advanced
   I. Impact of control

Thank you!

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

dr. ir. Glenn Reynders
Glenn.Reynders@bwk.kuleuven.be
KU LEUVEN