BuildingSystems – A modular hierarchical Modelica library for building & plant simulation

Christoph Nytsch-Geusen[1,2]
Christoph Banhardt[2]
Alexander Inderfurth[1]
Katharina Mucha[1]
Jens Möckel[1]
Jörg Rädler[1]
Matthis Thorade[1]
Carles R. Tugores[1]

Universität der Künste Berlin[1]
Technische Universität Berlin, Campus El Gouna[2]

Annex 60/GENSIM Meeting, 22.-28.10.2016, Corsica

Outline

- **Room scales in building simulation**
- **Model library BuildingSystems**
  - Annex 60 library core
  - Building simulation
  - Plant simulation
  - System simulation
  - 3D visualization
- **Cases studies**
  - Single room simulation
  - Multi-zone building simulation
  - District simulation

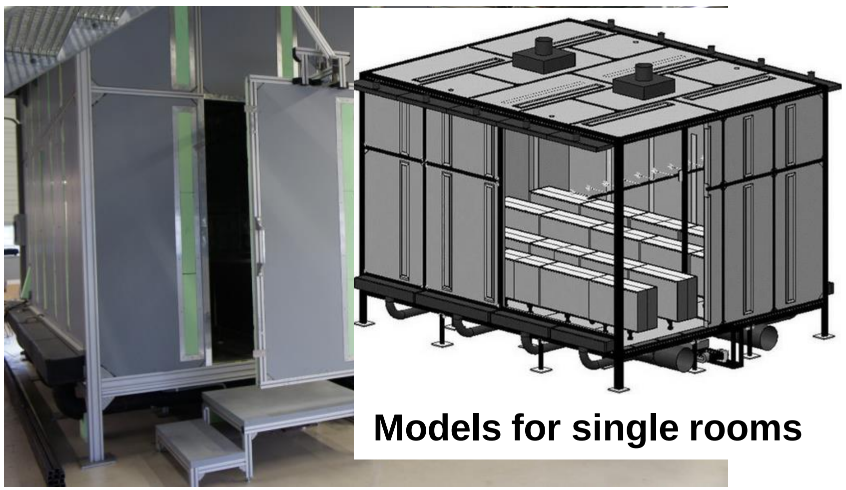
Room scales in building simulation

Model room AMoR from RWTH Aachen (Source: RWTH Aachen)

Rooftop building, Solar Decathlon 2014 (Source: UdK Berlin)

University campus Berlin-Charlottenburg (Source: Apple maps)

Room scales in building simulation

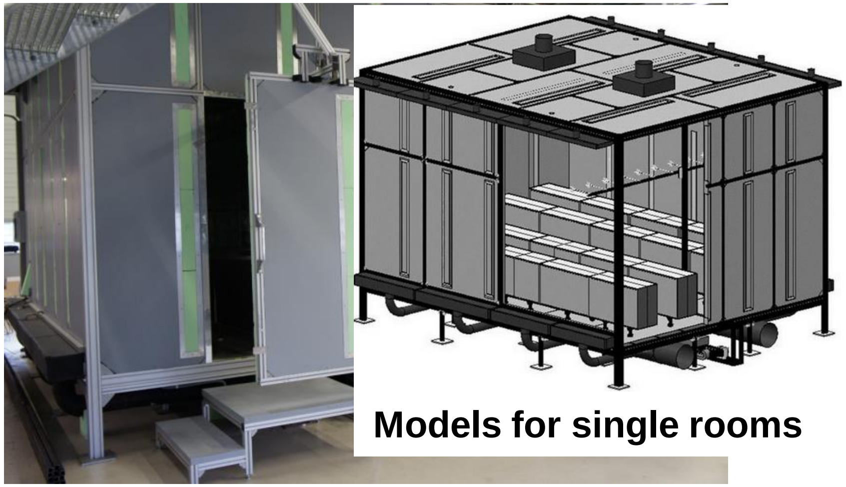


Model room AMoR from RWTH Aachen (Source: RWTH Aachen)

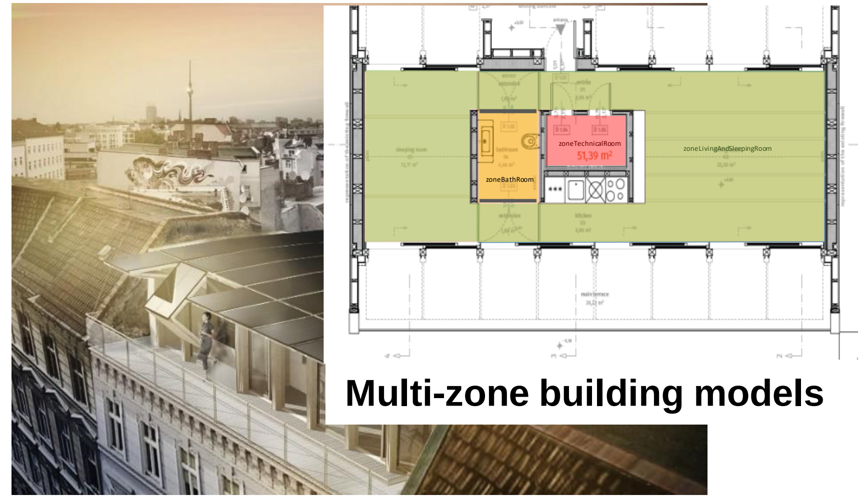
Rooftop building, Solar Decathlon 2014 (Source: UdK Berlin)

University campus Berlin-Charlottenburg (Source: Apple maps)

Room scales in building simulation



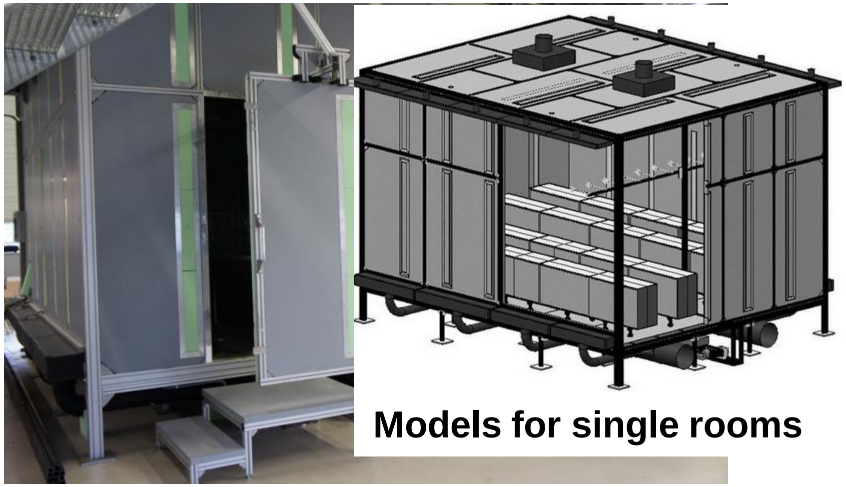
Model room AMoR from RWTH Aachen (Source: RWTH Aachen)



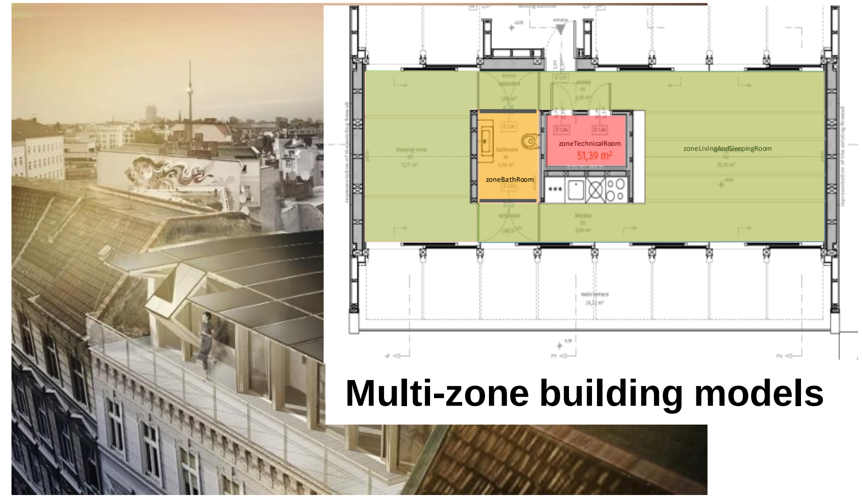
Rooftop building, Solar Decathlon 2014 (Source: UdK Berlin)

University campus Berlin-Charlottenburg (Source: Apple maps)

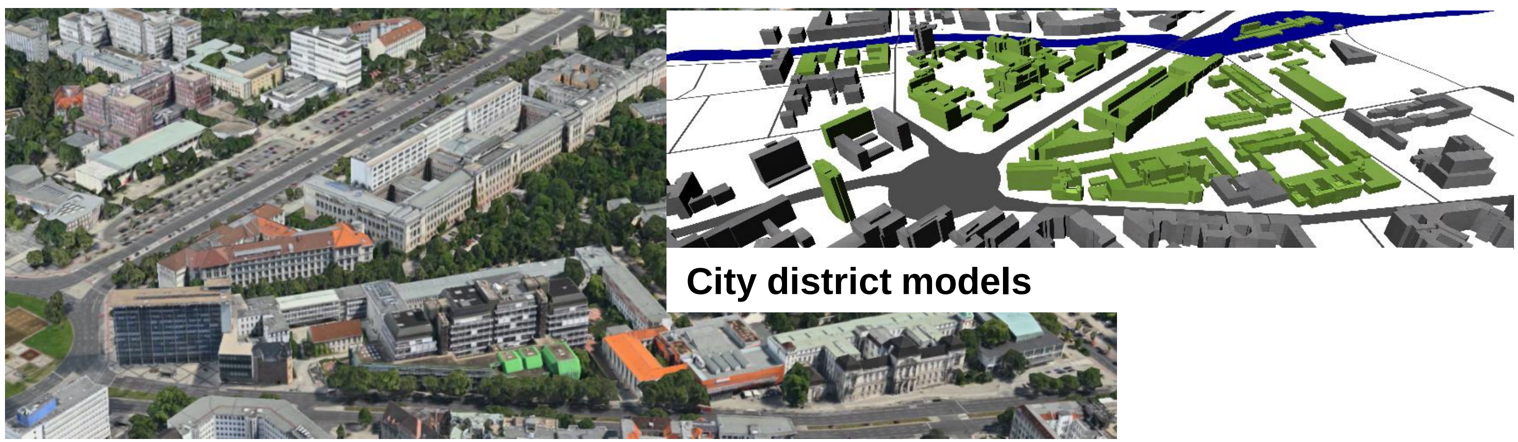
Room scales in building simulation



Model room AMoR from RWTH Aachen (Source: RWTH Aachen)



Rooftop building, Solar Decathlon 2014 (Source: UdK Berlin)

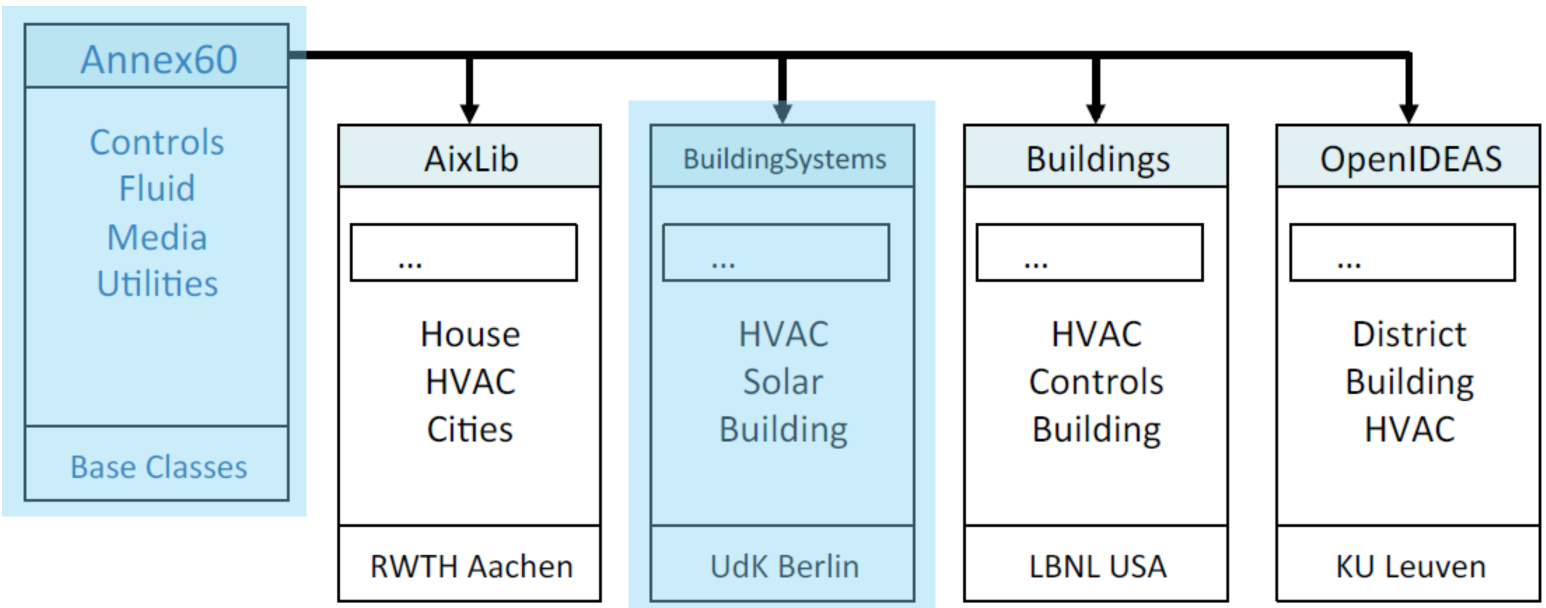


University campus Berlin-Charlottenburg (Source: Apple maps)

BuildingSystems – Annex 60 library core

Integrated Annex 60 core library

- GitHub: https://github.com/iea-annex60/modelica-annex60
- Compatibility with other Modelica building energy simulation libraries (common interfaces, standard functions and standard model classes)
- Focus on new model development
- International cooperation & exchange of experience



Annex60 core library and its use within four Model libraries for building energy simulation (Source: Annex60.org)

BuildingSystems – Building simulation

Example: Configuration of a building model with four thermal zones

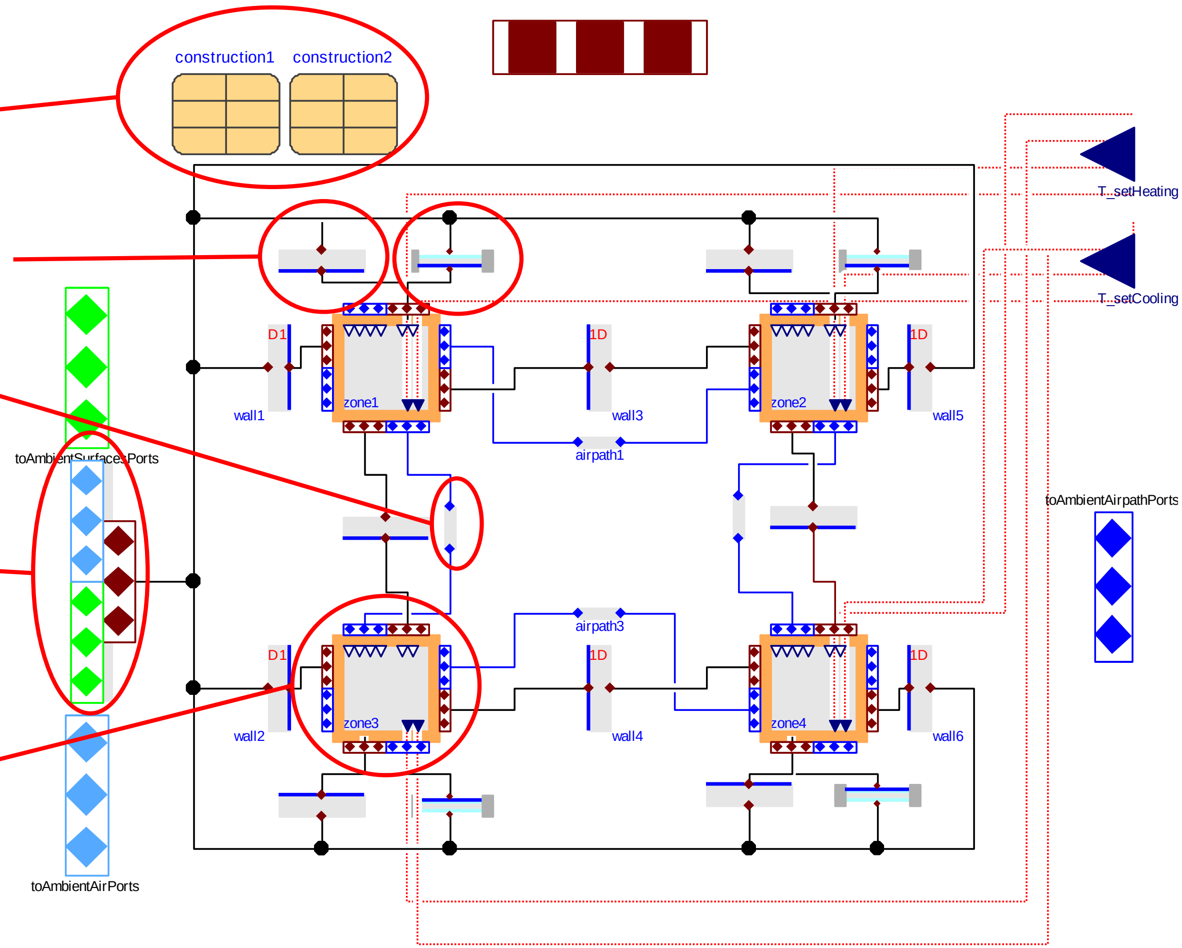
Construction types
(walls, windows, …)

Building element models

Air path models

Surface models with
contact to the
building ambient

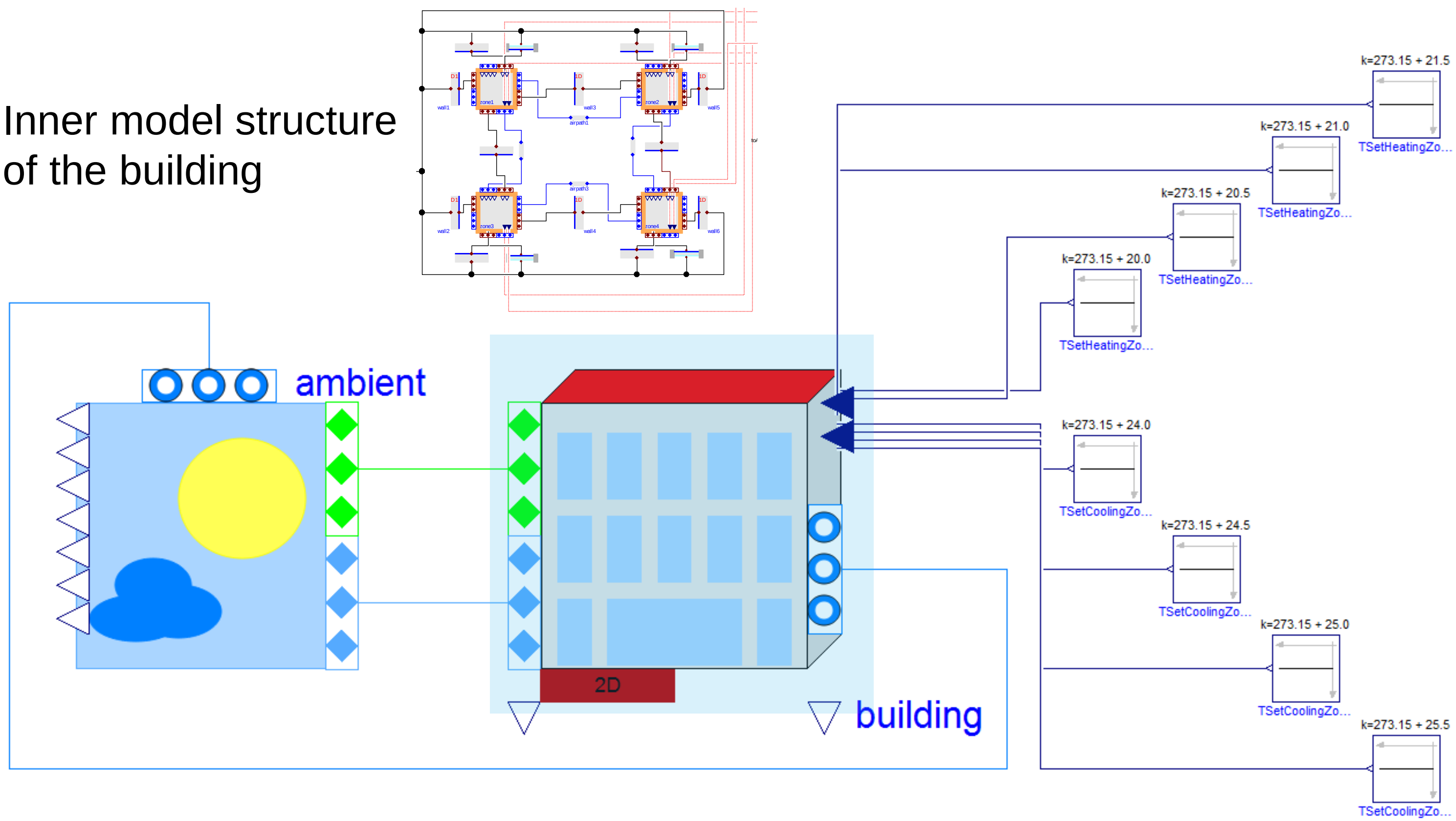
Zone models



BuildingSystems – Building simulation

Example: Configuration of a building model with four thermal zones

Inner model structure of the building



Ambient model

Building model

User behavior

BuildingSystems – Building simulation

Building model with three levels of detail

- 3-dim. space resolved „zonal model“
- Energy, mass & momentum balance with friction
- Detailed radiation model
- Results: locale (x,y,z) room climate: T_A, T_R, x, u, v, w

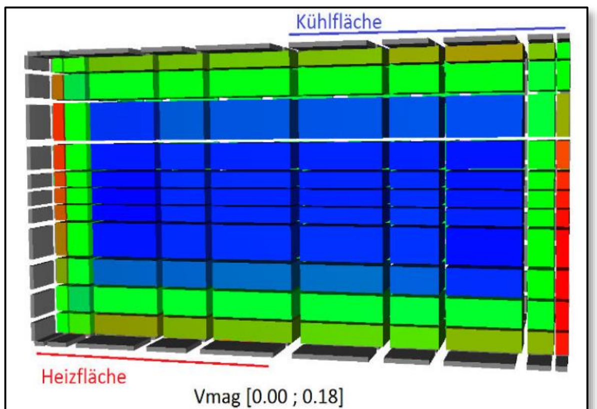
3D room model

- „Multi-zonal model“ with zone averaged values
- 1-dim. discretized elements
- Energy- & mass balance
- Inter-zonal air exchange
- Results: averaged room climate: T_A, T_R, x

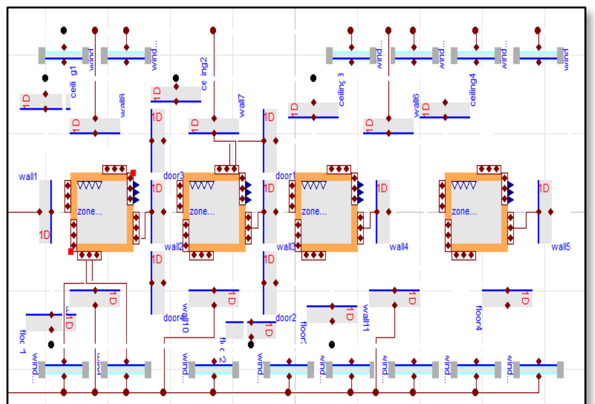
1D building model

- „Low-order model“ with building averaged values
- concentrated parameters for several elements
- Energy & mass balance
- Results: averaged building climate: T_A, T_R, x

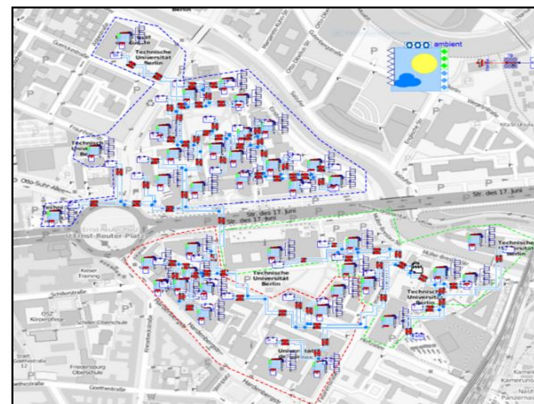
0D building model



Room simulation

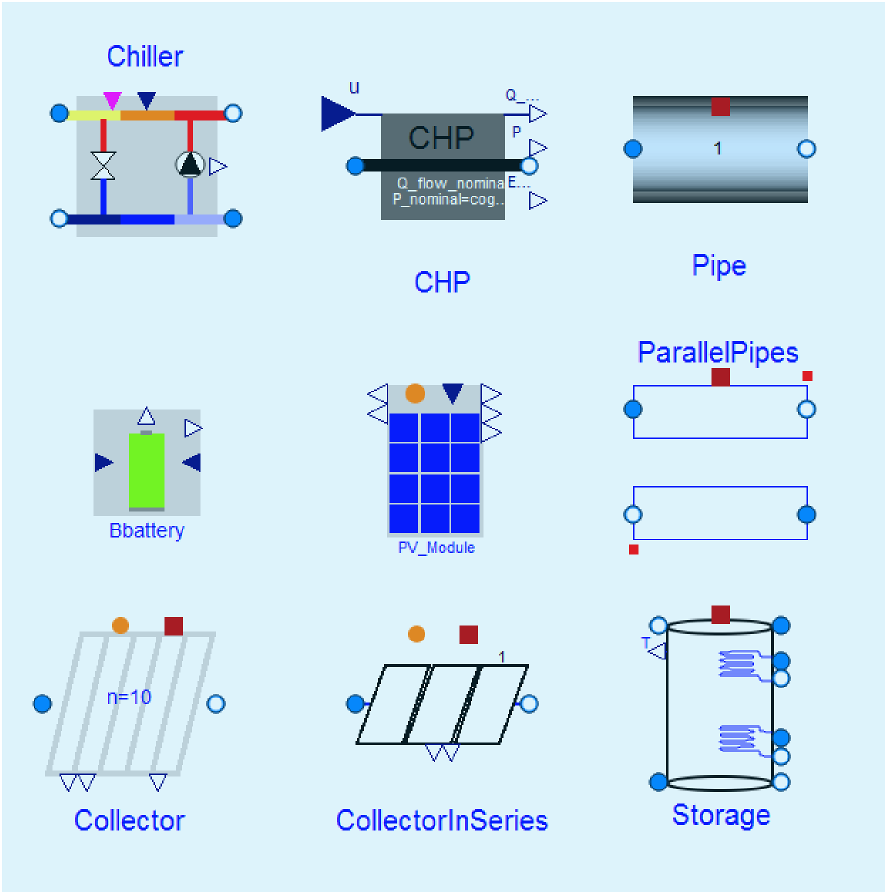


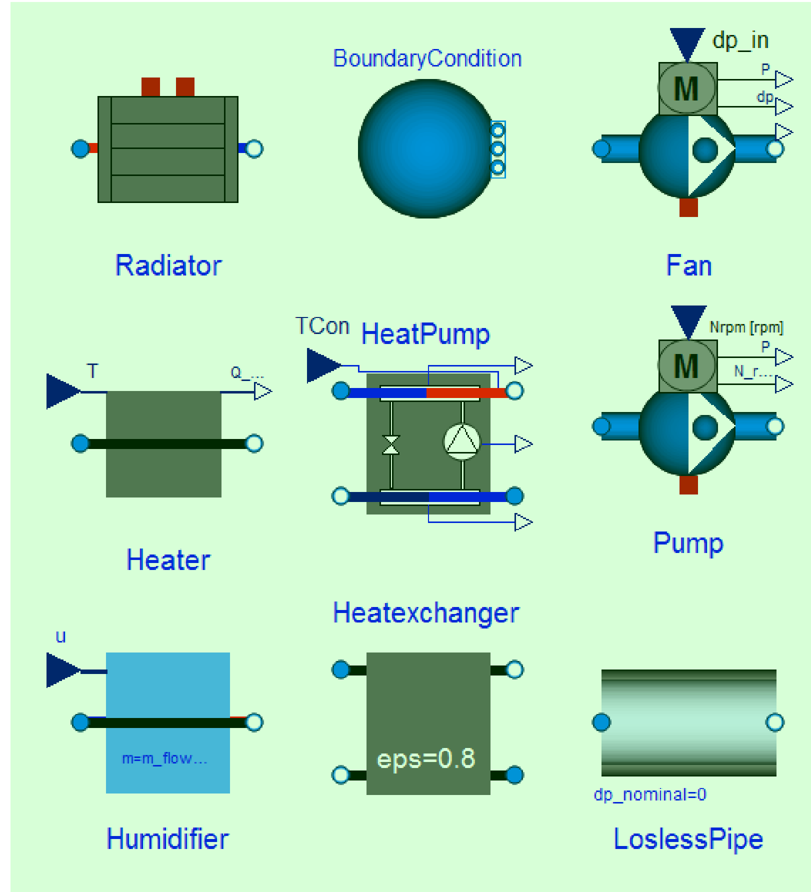
Multi-zone building simulation



City district simulation

BuildingSystems – Plant simulation



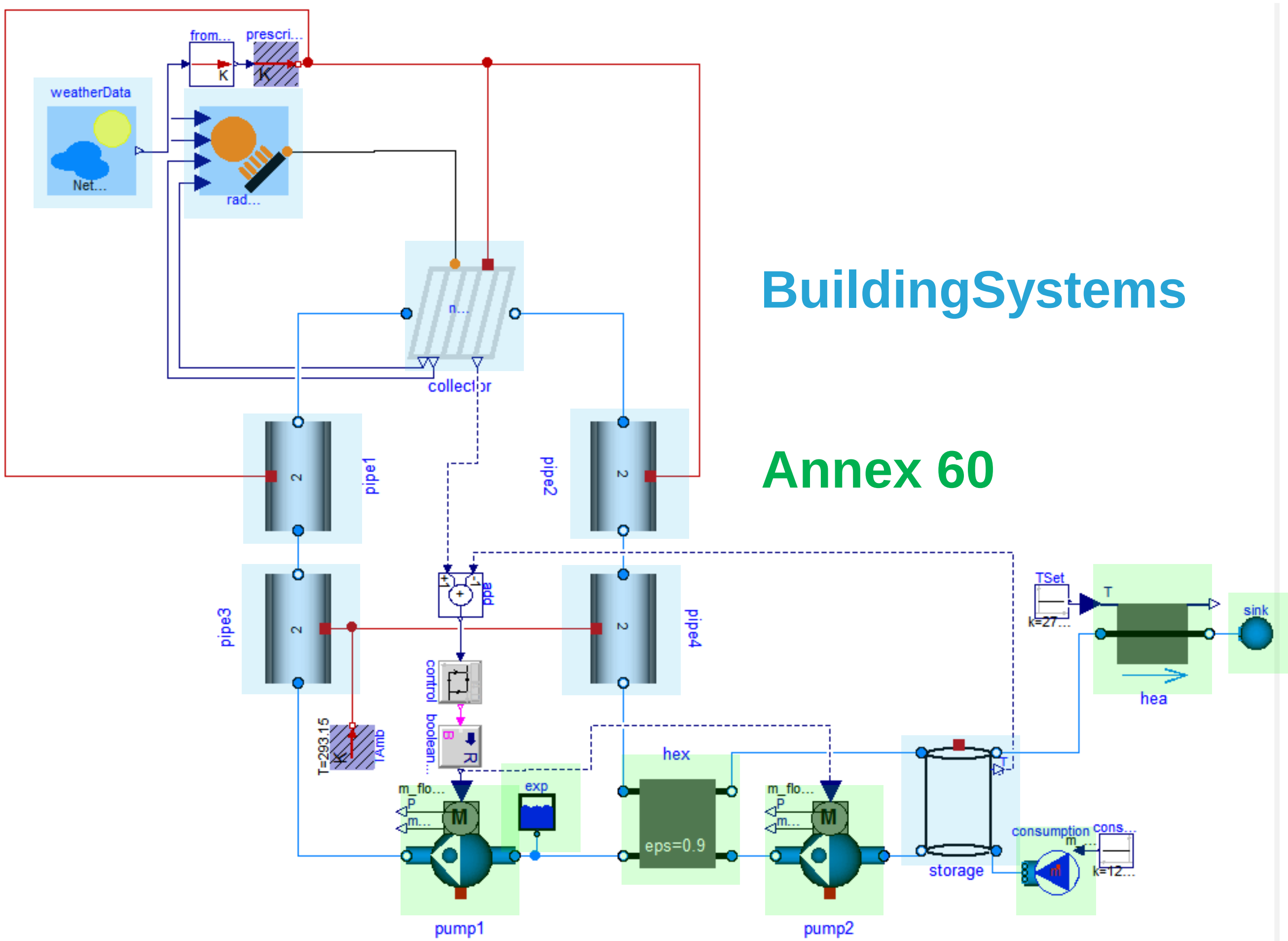


BuildingSystems

Annex 60

BuildingSystems – Plant simulation

Example: Model of a solar thermal system

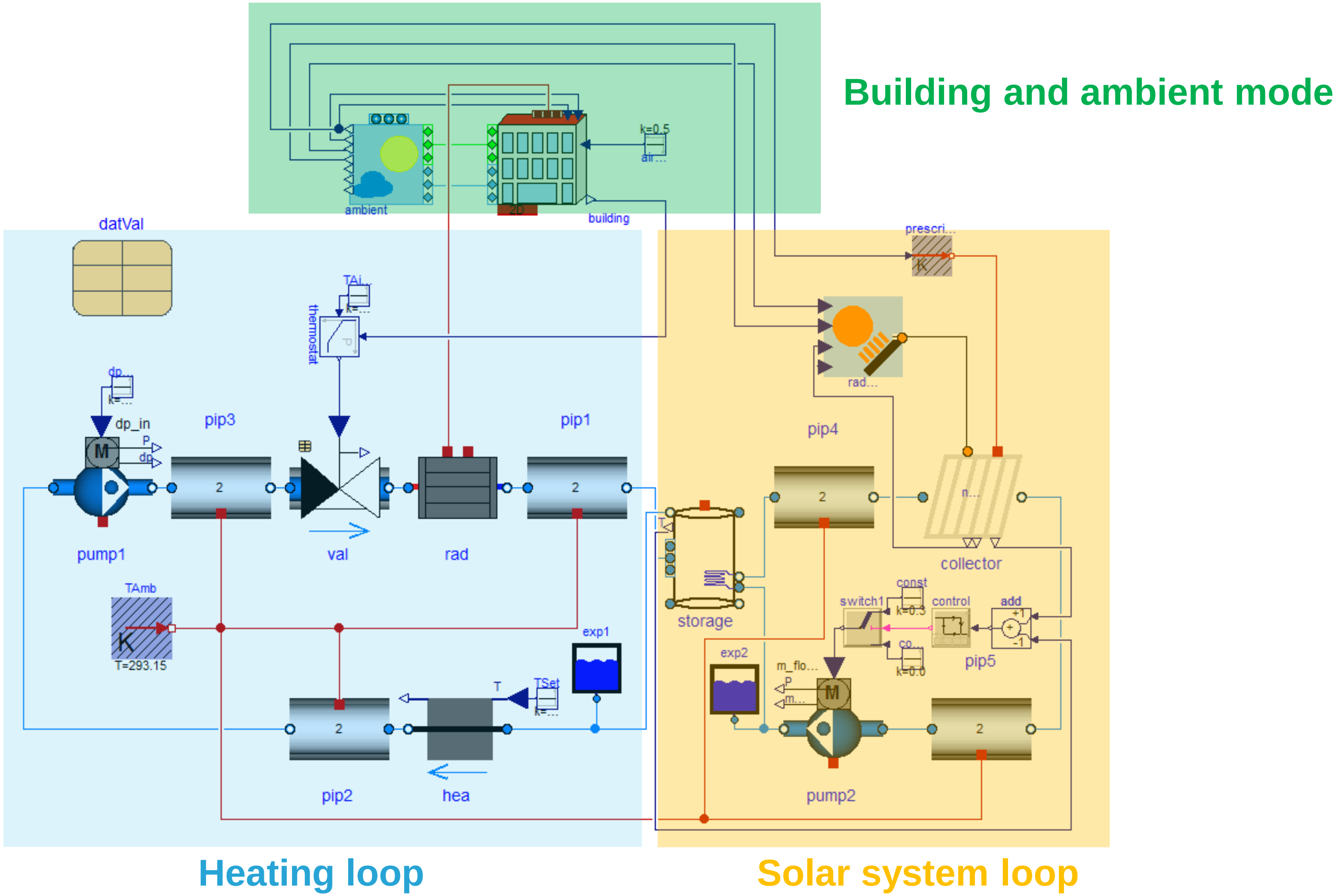


BuildingSystems

Annex 60

BuildingSystems – System simulation

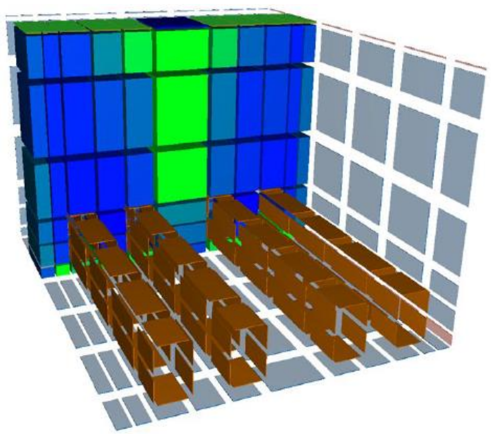
Example: Model of a solar heated building



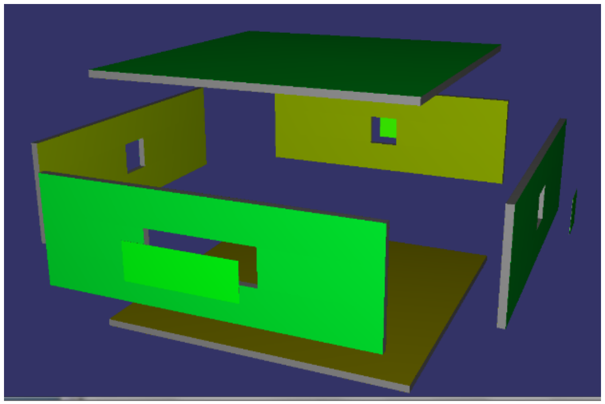
BuildingSystems – 3D Visualization

BuildingSystems_Vis

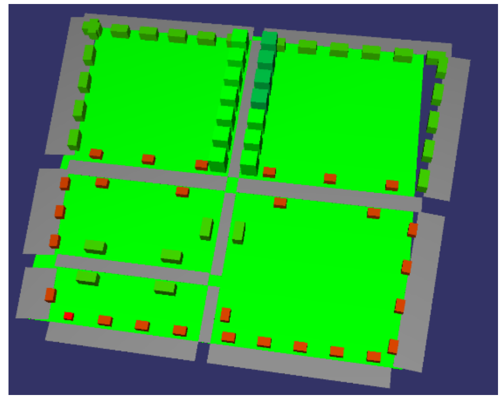
- Modelica base library for visualization and animation of graphical primitives: sphere, cube, cylinder (Höger et al. 2012)
- Coupling to external visualization systems (Open Scene Graph, Blender, …)
- 3D visualization of time dependent model variables (e.g. temperatures, moistures, pressures, mass flow rates)



Room model



Building model



City district model

BuildingSystems – Free Open Source library

- **Modelica library, based on the Annex60 core library:**

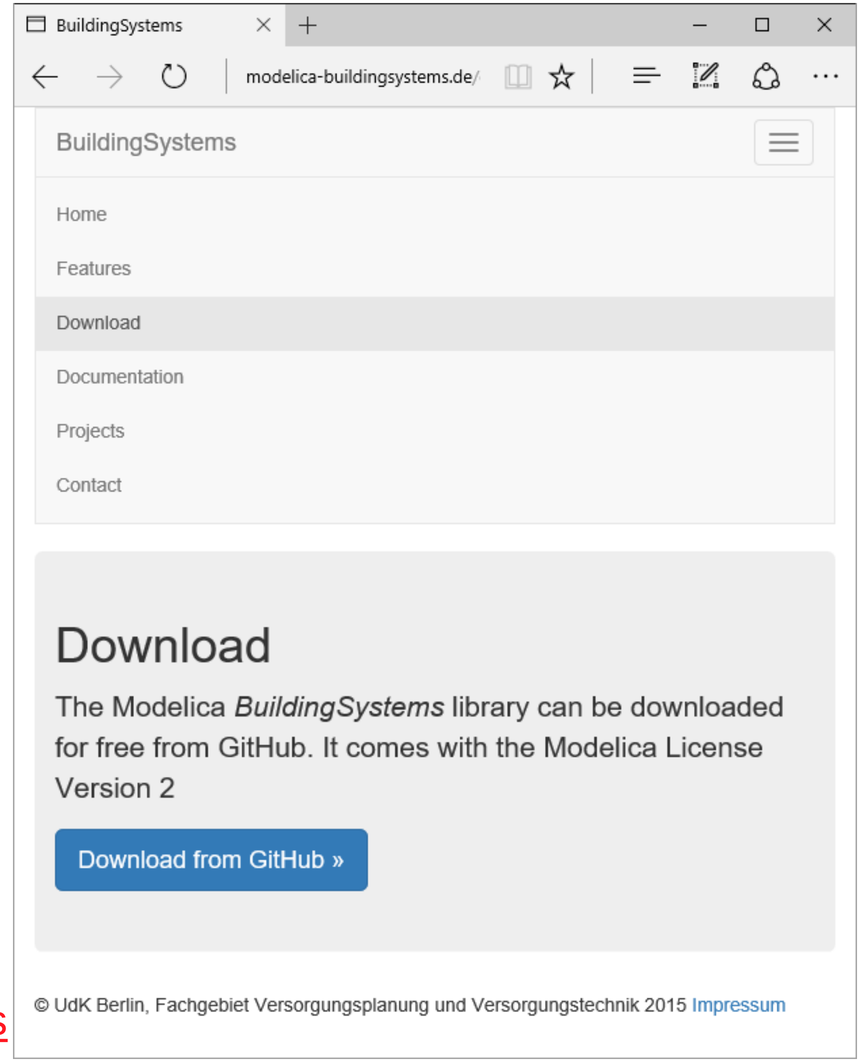
  http://www.modelica-buildingsystems.de

  - Modelica License 2
  - Development of UdK Berlin and research partners

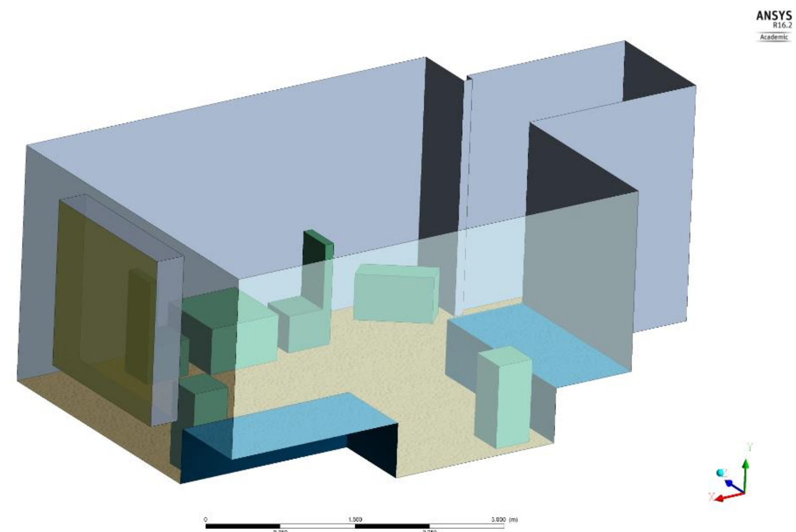
- **Model spectrum**
  - Building simulation
  - Solar technologies
  - HVAC systems
  - thermo-hydraulic net works

- **Download from GitHub:**

  https://github.com/UdK-VPT/BuildingSystems



Case study “Single room simulation”



Left: Care facility in Berlin; right: Single room of the care facility (Source: UCaHS - DFG Forschergruppe 1736)

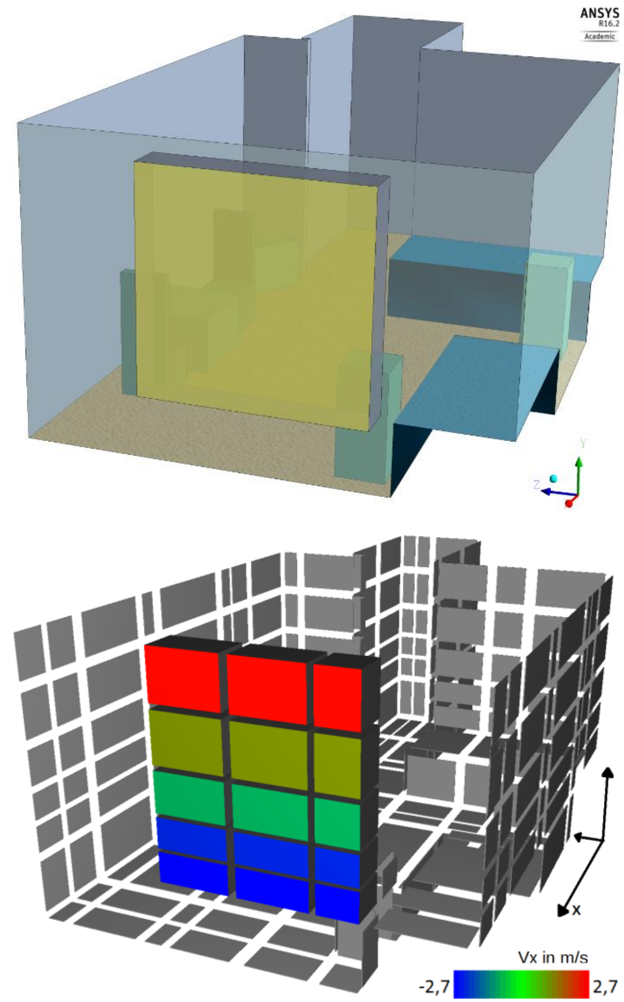
Case study "Single room simulation"

– Objective

- Space and time resolved analysis of the indoor climate of a single room of a care facility
- Local air temperatures and flow velocities for the closed window and the opened window (90° opening angle after10 minutes)

– Simulation model

- Zonal room model (Mucha et al., 2015)
- Space discretized representation with 303 air volume elements (3D modelling approach)
- Consideration of the furniture (beds, table/bedside cabinets, chairs) by the modelling of the air space
- Air and surface temperatures of the inner space: 30 °C (initial value)
- Air temperature of the building ambient: 25 °C (constant over the simulation time period)

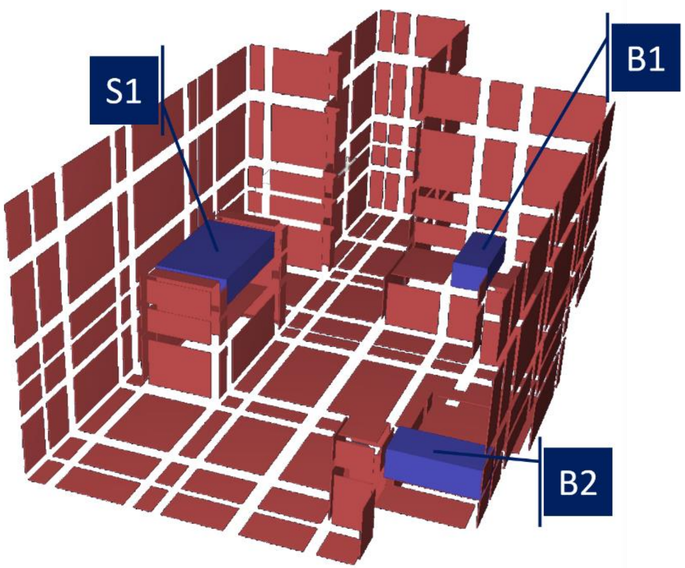


3D-discretized room and window model

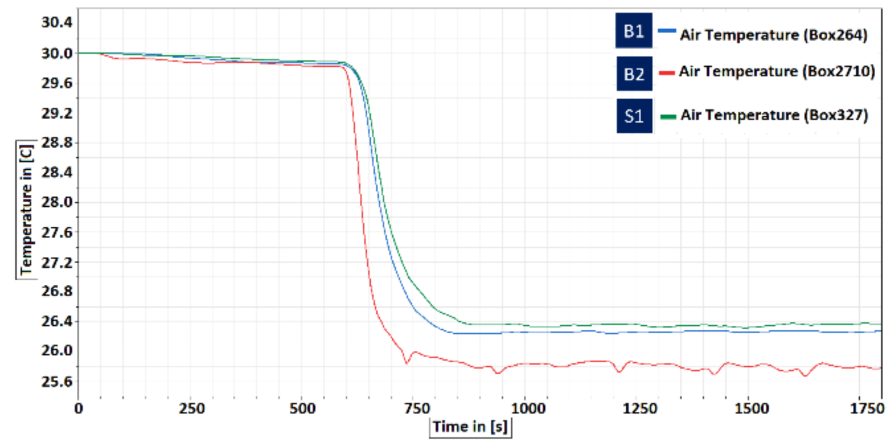
Case study “Single room simulation”

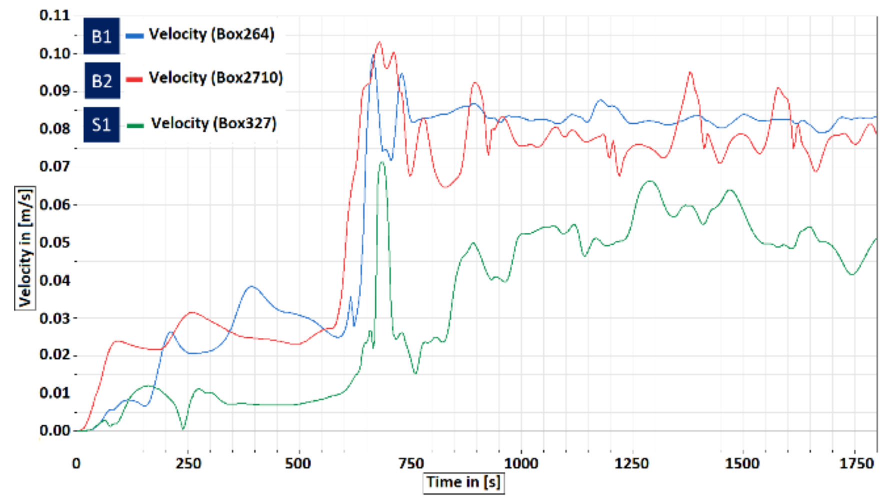
– **Simulation analysis:**

- Opening process of the window
- Typical temperature distribution by free window ventilation
- Reasonable increase of the air flow velocities



Selected monitor points S1, B1 and B2 representing the local room climate





Air temperatures (above) and air flow velocities (below) at three selected room positions with closed and opened window in the single room

Universität der Künste Berlin, Institut für Architektur und Städtebau
Fachgebiet Versorgungsplanung und Versorgungstechnik

Case study “Multi-zone building simulation”

Model of a office storey with 13 thermal zones (modelled in Unity 5)

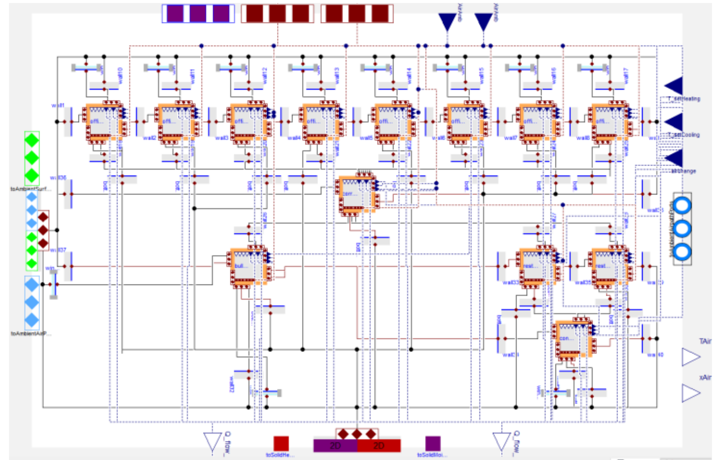
Case study “Multi-zone building simulation”

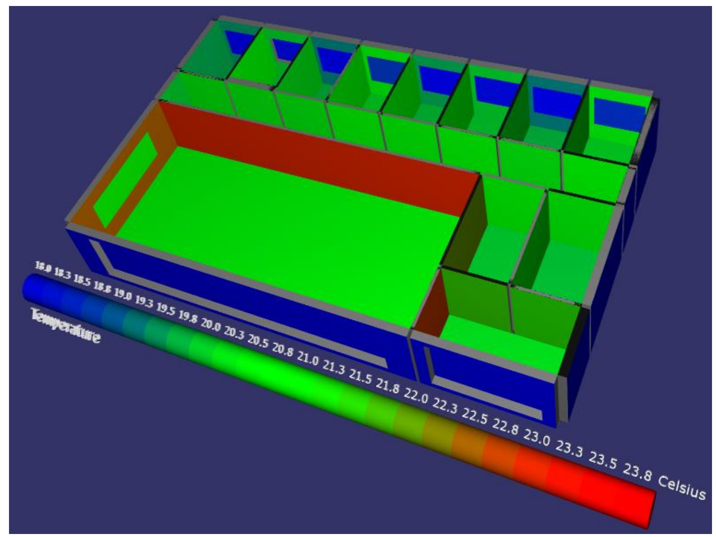
– Objective

- Calculation of the heating and cooling demand of a storey of an office building
- dynamical behavior of a bullpen and meeting room during three days in August (cooling load curve)

– Simulation model

- Building model with 13 thermal zones (1D-modelling approach)
- Different room uses:
  - Office rooms & sanitary rooms (heating and cooling),
  - Bullpen & meeting room (additional cooling),
  - Corridor (buffer zone)
- Climate data Berlin (Meteonorm)





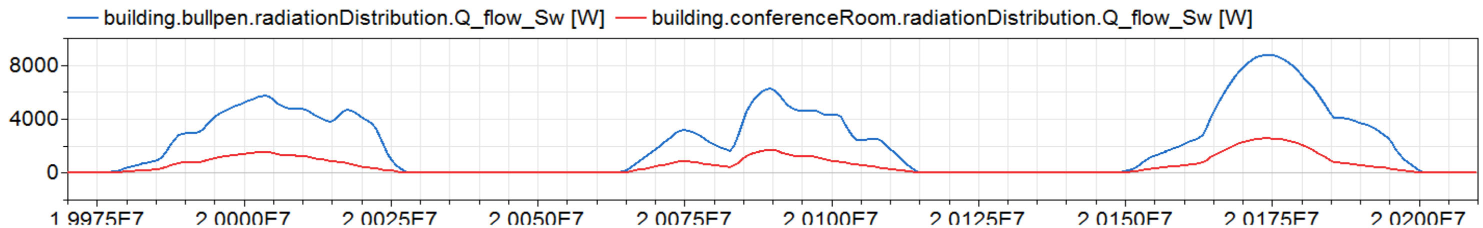
Multi-zone Modelica-Model (above) and Visualization of the surface temperatures (below)

Case study "Multi-zone building simulation"

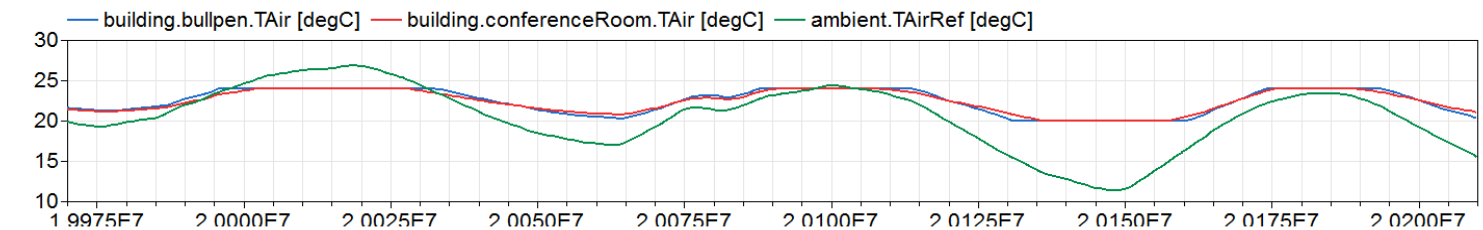
– Simulation analysis:

- Passive solar gains of both zones are increasing during the simulation period, the ambient air temperature is decreasing at the same time.
- The level of the cooling load is decreasing over the three days:
  1st day: the transmission gains through the building envelope are dominating.
  2nd and 3rd day: the passive gains become relevant.

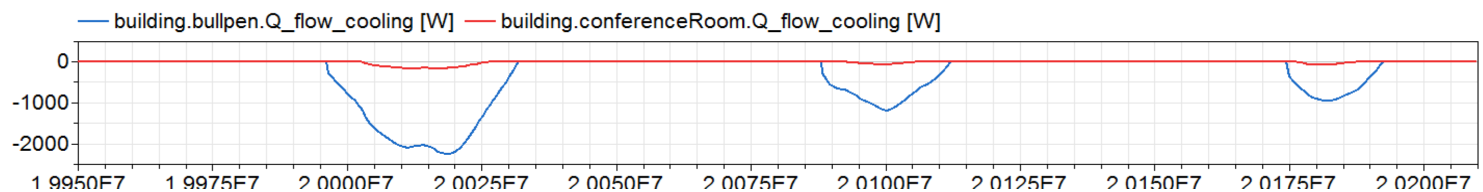
Passive solar gains



Room air and ambient air temperatures



Cooling loads



Case study “City district simulation”

City model of the University campus Berlin-Charlottenburg (Source: Apple maps)

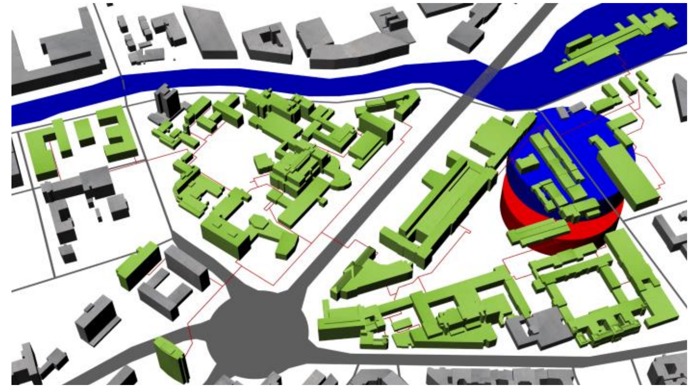
Case study "City district simulation"

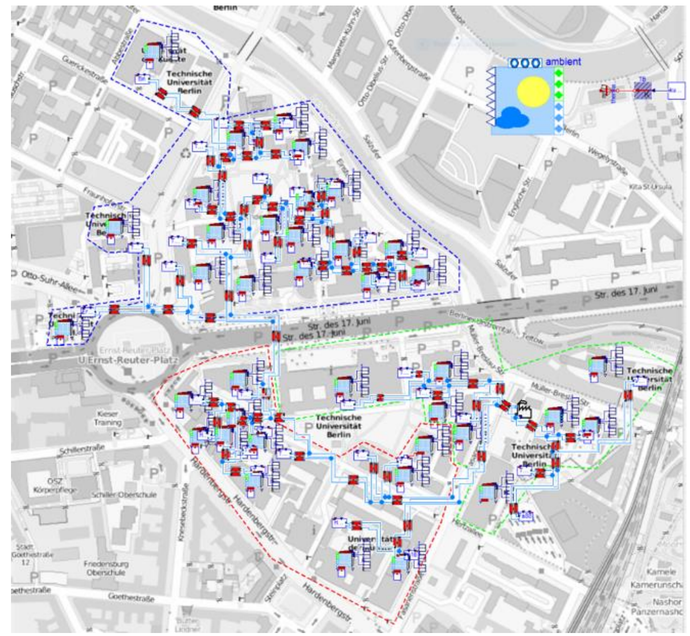
– Objective

- Calculation of the local distributed heat and cooling energy demand for the building stock of the university campus Berlin-Charlottenburg
- Present state and variants of refurbishment

– Simulation model

- Strong simplified building model with only a few thermal capacities (Low-Order-Model)
- Determination of the model parameters of each single building model (U-values of the facades, roofs, base plates, thermal capacities, set-heating temperatures etc.) through parameter identification (Inderfurth et al., 2015)
- Data base for the parameter identification are monthly values of the heating and electricity demand as well as measured weather data
- 39 building models represent together the building stock of the campus





Modelica-Modell of the university campus with 39 low-order building models (Source: project ATES)

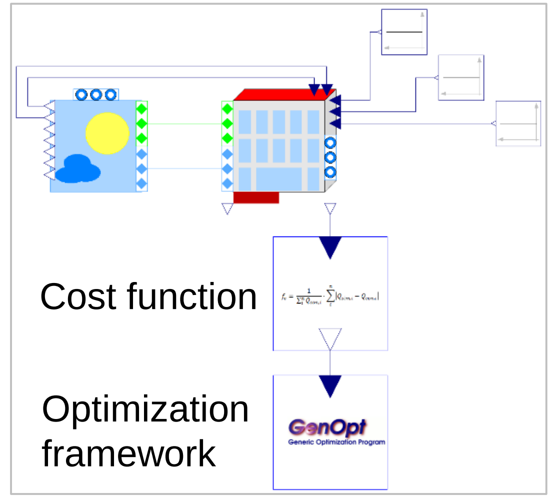
Case study "City district simulation"

Parameter identification

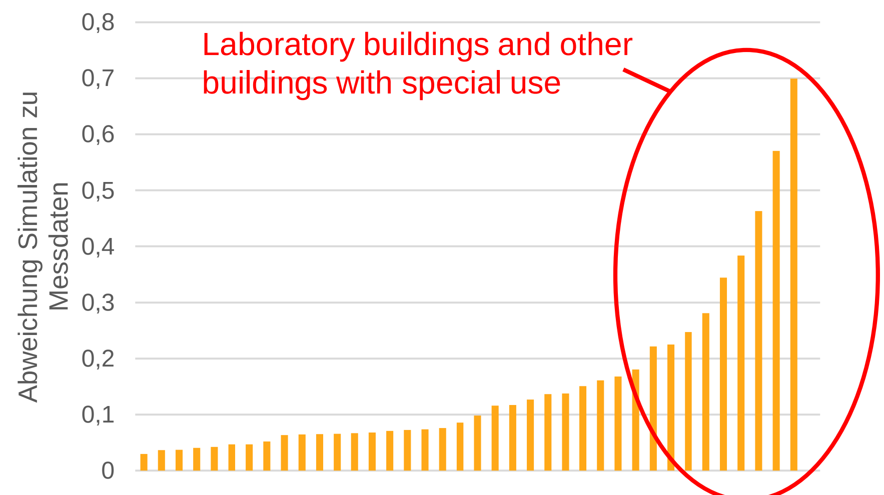
- **Optimization parameter:**
  - (U-values, heat capacities, set-temperatures heating, …)
- **Cost fuction:**

$$f_c = \frac{1}{\sum_i^n Q_{con,i}} \cdot \sum_i^n |Q_{sim,i} - Q_{con,i}|$$

  - Sum of the absolute differences of the monthly simulated demand and the measured consumption (normalized)
- **Excellence of the Optimization**
  - 50 percent of the buildings show a deviation smaller than 10 percent regarding the heating demand
  - Validation of the method with information from the follow-on project HCBC (more detailed data exploration of the building stock of the campus)



Parameter identification with GenOpt

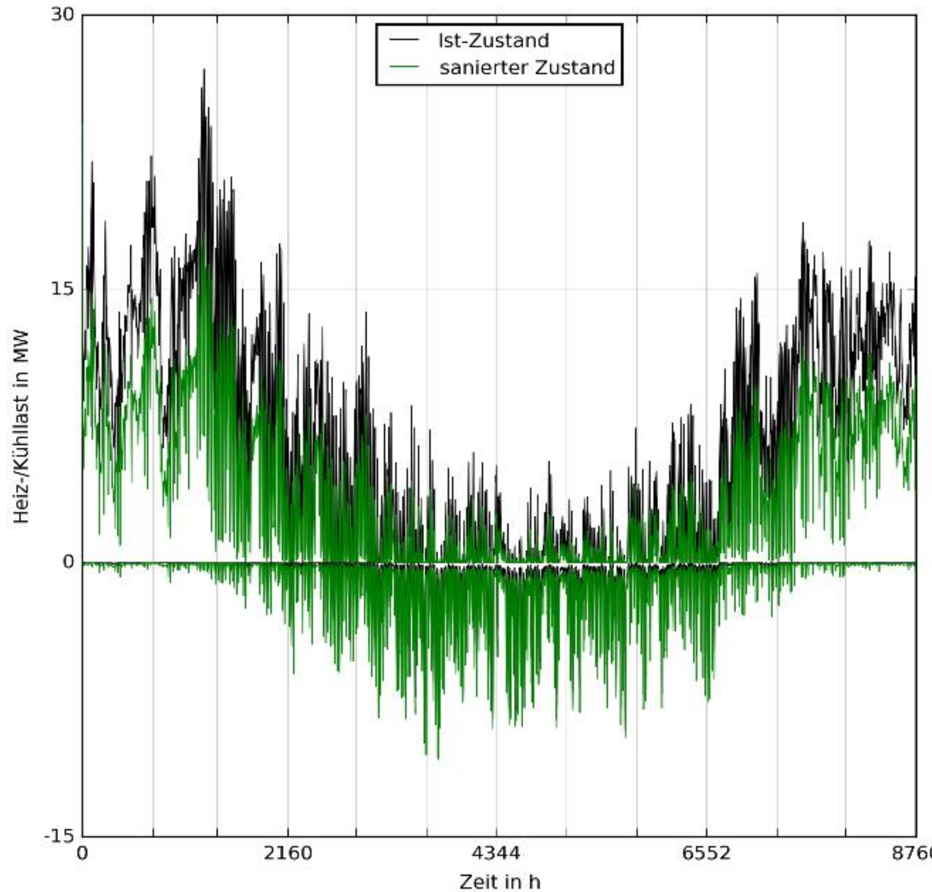


Excellence of the 39 building models after the parameter identification

Case study "City district simulation"

– Simulation analysis

- All building models are refurbished with windows with an unique U-value of 1.1 W/(m2K).
- All facades and roofs are equipped with an additional insulation of 10 cm.
- Slight increase of the peak cooling load from 10.6 MW to 10.7 MW.
- Reduction of the peak heating load from 27.0 MW to 24.1 MW.
- Heating energy reduction per year about 25 percent.



Yearly time line of the total heat and cooling load of the city district before (black) and after (green) energetic renovation (Source: project ATES)

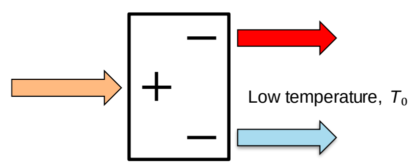
Complexity and numerical effort of the case studies

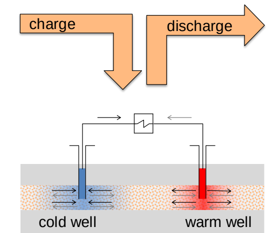
Case study	Single room,	Multi-zone building	City district
Equations (Modelica)	96,490	30,853	115,575
Time dependent variables (relevant for the solver)	21,733	3,815	9,437
State variables (relevant for the solver)	1,347	266	494
Simulation time period	30 minutes	1 year	1 year
CPU time in s (solver)	46 (cVode)	370 (Dassl)	3,600 (Dassl)
Relation SR: Simulation time to CPU time	39	85,232	8,760
SR per state variable	0.03	320.40	17.73

BuildingSystems library - Present and planned work

– Integration of new models

- BuildingSystems.Applications
- BuildingSystems.Buildings
- BuildingSystems.Technologies



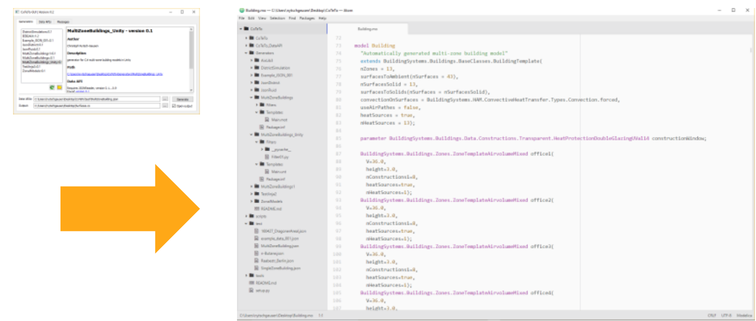


Absorption heat transformer (left) and ATES (right)

– Code generation of simulation experiments

→ Tool CoTeTo (EnEff BIM-project)

- Complex building models
- Structure variations of energy plant models



Code generation with CoTeTo

– Evaluation of the library with real buildings

- Rooftop Building
- Elementary school
- Campus Buildings

Rooftop building (Source: UdK Berlin)

Universität der Künste Berlin, Institut für Architektur und Städtebau
Fachgebiet Versorgungsplanung und Versorgungstechnik

Summary

- **BuildingSystems library**
  - Annex 60 core library
  - Adaptive building model (3D, 1D, 0D)
  - Building, plant and system simulations
  - Open source library on GitHub

- **Case studies**
  - Single room simulations (local room climate)
  - Multi-zone building simulations (complex building energy balances)
  - City district simulations (simulation of building groups)
  - Numerical comparison (number and correlation of state variables)