IEA Annex 60
Computational tools for building and community energy systems

Christoph van Treeck[1], Michael Wetter[2]
(Co-operating Agents)

with contributions of Gesa Böhme, Andrea Costa, Jun Cao, Moritz Lauster, Tobias Maile, Christoph Nytsch-Geusen, Dirk Saelens, Sebastian Stratbücker and Reinhard Wimmer

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Annex 60 | Vision

- Allow engineers and scientists to quickly assemble preconfigured, modifiable and scalable **component models** of
  - electrical grids
  - buildings, district heating and cooling and
  - controls,
- **optimize the performance** of technology options and control strategies in simulation, and
- **export models and control algorithms** for
  - hardware-in-the-loop testing,
  - deployment to control systems and embedded hardware, and
  - to run as a web service for real-time operational support.
- Build software using **open-source** technology.

(Picture courtesy RWTH Aachen University)

Annex 60 | Needs

- Comprehensive, validated **tools** for
  - design and operation of new building and control **system architectures**,
  - model-based design, rapid virtual prototyping and hardware-in-the-loop of these systems,

- with **scaled scope** ranging from
  - building equipment to
  - community energy grids and
  - thermal, electrical and control systems.

- At the start of Annex 60,
  - five institutes developed their own Modelica libraries, leading to **duplicative effort**, limited scope of each library, and **incompatibility** among these implementations.

(Pictures source Nytsch-Geusen)

Annex 60 | Objectives

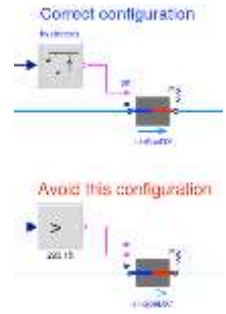
For building designers and manufacturers
→ **open-source, free library** of component and system models

For researchers and manufacturers
→ library for **rapid prototyping**

For simulation tool developers,
→ **collaborative environment**

For Annex 60 tasks,
→ library for **case studies** and demonstrations.

User guide with best practices.
Figure: model with ill-posed controller.



Annex 60 | National participation

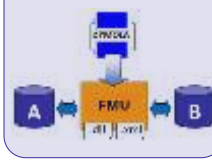
Computational Tools for Building and Community Energy Systems
based on the Modelica and Functional Mockup Unit Standard

Annex 60 | Structure

Task 1 | Technology development

Modelica
Model libraries

Co-Simulation
Model exchange



BIM
3D Data exchange

Workflow
automation

Task 2 | Validation & demonstration

Buildings
HVAC co-design

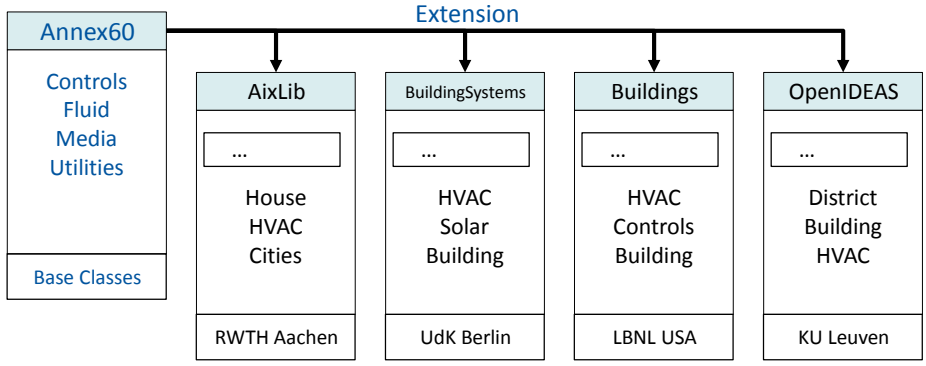
City quarters
Network interaction

Operation
Automation

Modelica model libraries | Structure

Activity 1.1 | Lead: Michael Wetter, USA

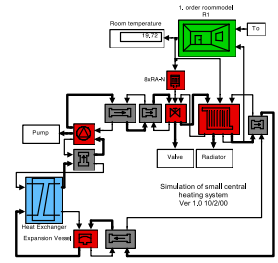
- Modelica Libraries
  - Open Source
  - Freely available
  - Linked development
- Scope
  - Energy systems for buildings and communities
  - Thermal as well as electrical applications



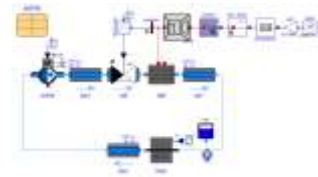
Modelica model libraries | Results

Activity 1.1 | Lead: Michael Wetter, USA

- Developed **core of an open-source library** with >100 models.
- **Successfully tested** semi-automatic integration with LBNL and KU Leuven Modelica libraries.
- Designed to allow **pre-compilation** of models to make library applicable for IDA-ICE and for the new engine design of E+.
- Ongoing: **benchmarking** numerical efficiency and robustness relative to IDA-ICE and MATLAB/Simulink.



Implementation of benchmark in Simulink (using signal flow)



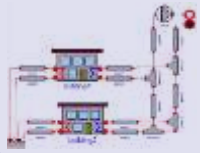
Implementation of benchmark in Modelica (using acausal models)

(Pictures courtesy LBNL Berkeley)

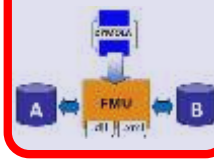
Annex 60 | Structure

Task 1 | Technology development

Modelica
Model libraries



Co-Simulation
Model exchange



BIM
3D Data exchange

Workflow
automation

Co-Simulation and model exchange | Functional Mockup Units

Activity 1.2 | Lead: Frédéric Wurtz, France

Objectives

- **Co-simulation**
  - to exploit **special-purpose numerical methods** (CFD, radiation, moisture, …)
  - to **reuse** existing code
- **Coupling** to native Modelica models for a simultaneous performance assessment

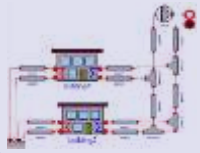
Ongoing work

- Modelica – FFD coupling (W. Zuo)
- EnergyPlus: Master algorithm and Quantized State System Integrator for FMUs for Model Exchange (T. Nouidui, M. Wetter)
- Co-simulation Agent Based Simulation – FMU (G. Plessis)
- Experiments on FMI-ME and FMI-CS, Ptolemy and Java,
  Co-simulation Agent Based approach and FMU (F. Wurtz, B. Delinchant)
- Use of FMU in TRNSYS - Return of experiment (V. Norrefeld)
- Proposal on FMI Interface Conventions for Room Models/Therakles FMI (A. Nicolai)
- …

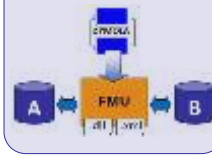
Annex 60 | Structure

Task 1 | Technology development

Modelica
Model libraries



Co-Simulation
Model exchange



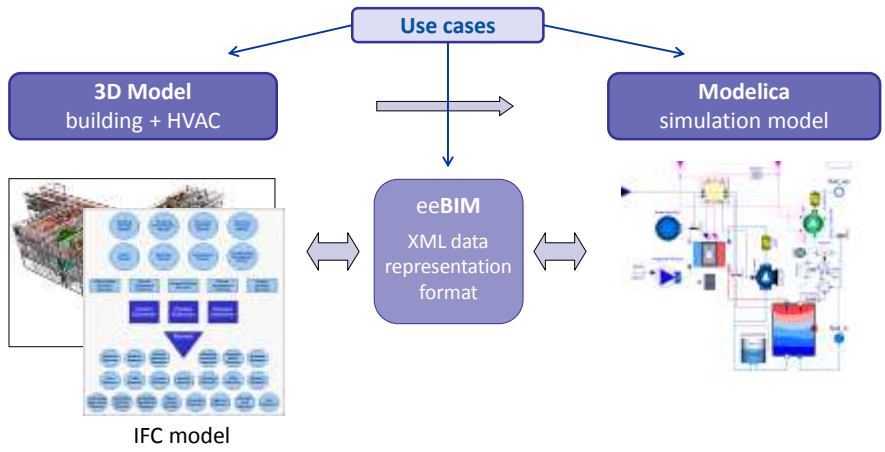
BIM
3D Data exchange

Workflow
automation

BIM | Building Information Model conversion process

Activity 1.3 | Lead: Christoph van Treeck, Germany

BIM data representation and conversion process



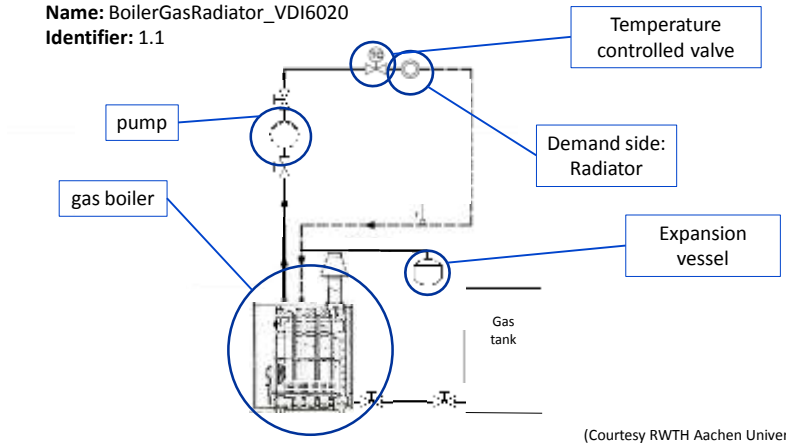
(Cao, Wimmer, Maile, O'Donnel, van Treeck; in progress)

BIM | Building Information Model conversion process

Activity 1.3 | Lead: Christoph van Treeck, Germany

Example | Use Case Definition (Boiler/Gas System)

Name: BoilerGasRadiator_VDI6020
Identifier: 1.1



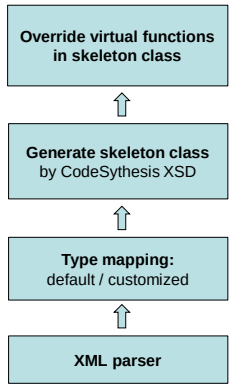
(Courtesy RWTH Aachen University)

BIM | XML Data binding / parsing

Activity 1.3 | Lead: Christoph van Treeck, Germany

Automatic XSD schema mapping to C++

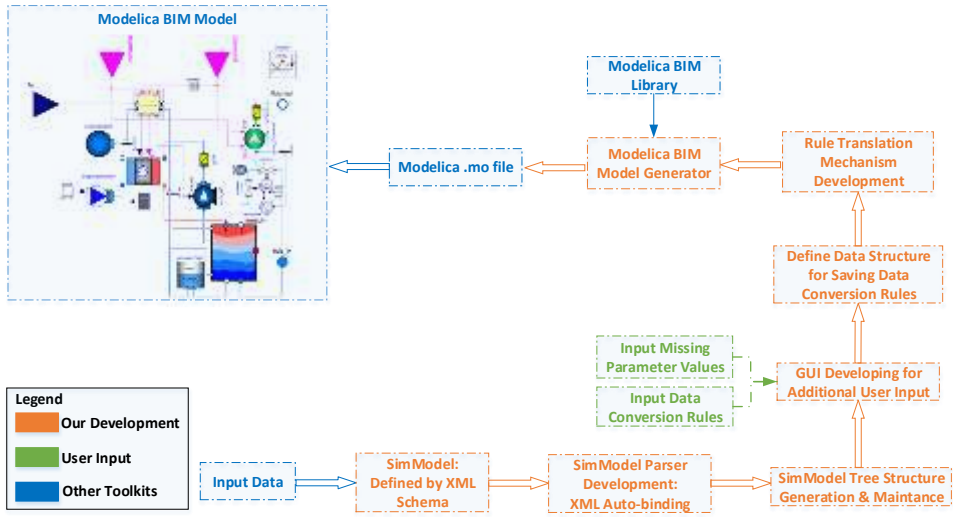
- Basis is **open-source** mapping toolkit CodeSythesis XSD
- **Model changes supported** by re-generating of skeleton classes



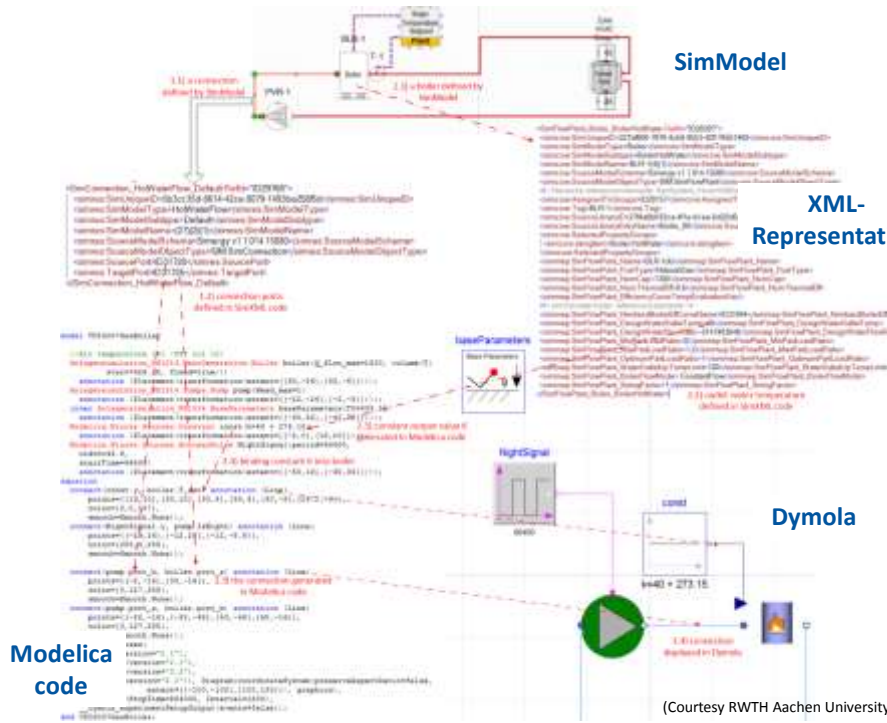
(Cao, Wimmer, Maile, van Treeck, in progress)

BIM | Workflow

Activity 1.3 | Lead: Christoph van Treeck, Germany



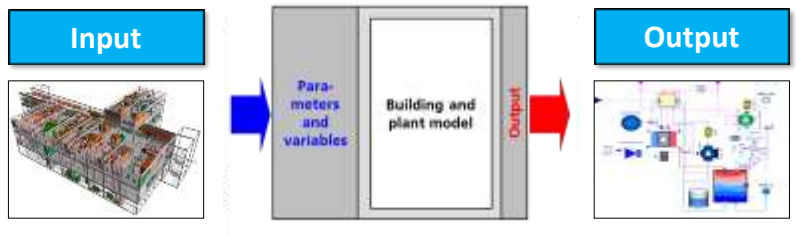
(Courtesy RWTH Aachen University)



(Courtesy RWTH Aachen University)

BIM model reduction | Sensitivity analysis

Monte Carlo Simulations and Application



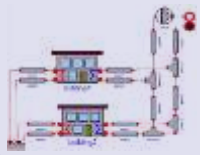
→ **Ranking of inputs** according to their influence on specific output
→ **BIM model reduction**

(Courtesy Fraunhofer ISE)

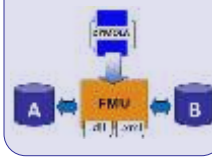
Annex 60 | Structure

Task 1 | Technology development

Modelica
Model libraries



Co-Simulation
Model exchange



BIM
3D Data exchange

Workflow
automation

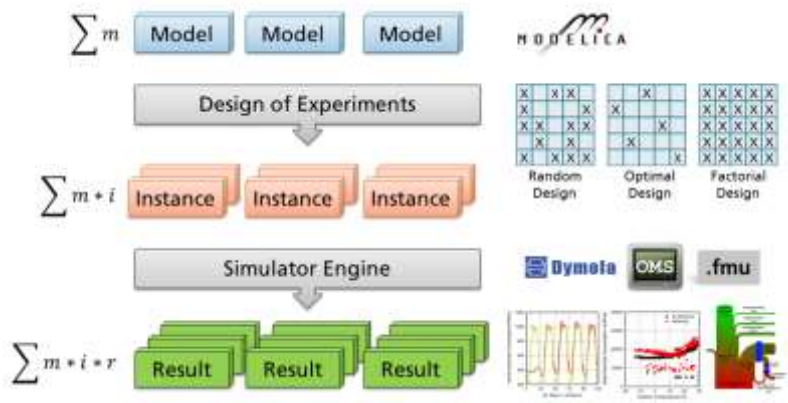
Workflow automation | Objectives

Activity 1.4 | Lead: Sebastian Stratbücker, Germany

- Compilation and assessment of existing **Python packages**
- **Harmonization** of Python based workflow automation tools
- Coordination of Python developers
- Development of a tested and documented Python package
  - for model developers
  - and for users
- Preparation of **use cases and guidelines**
- Dissemination of best practice
  - how to use Python for scientific computing
  - how to process big data with few lines of code
  - how to speed up simulation tasks

Workflow automation | Needs

Activity 1.4 | Lead: Sebastian Stratbücker, Germany

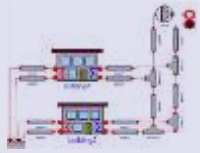


(Courtesy Fraunhofer IBP)

Annex 60 | Structure

Task 1 | Technology development

Modelica
Model libraries



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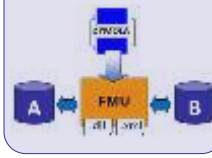

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Task 2 | Validation & demonstration

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HVAC co-design

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Detailed design of buildings | Modelica-based case studies

Activity 2.1 | Lead: Christoph Nytsch-Geusen, Germany

- **Seven case studies** set up and described by members
- Analysis of existing building and plant models for suitability of detailed design of buildings

→ Structured list of present Modelica models to **identify missing issues and gaps**

→ **Feedback** of results to technology development

Detailed design of buildings | Modelica-based case studies

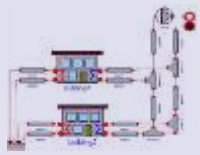
Activity 2.1 | Lead: Christoph Nytsch-Geusen, Germany

1. **Development of PV-cooling systems for residential buildings in the MENA-region**
   (TU Berlin, UdK Berlin, Germany)
2. **Control optimization of geothermal heat pump systems combined with thermally activated building systems**
   (Fraunhofer ISE, Germany)
3. **Investigation of the role of buildings in a European greenhouse gas emission free energy system**
   (KU Leuven, Belgium)
4. **Implementation of Model Predictive Control for the HVAC system of a Belgian thermally activated office building**
   (KU Leuven, Belgium)
5. **Modeling for the design of an energy and water efficient hotel**
   (University of Miami, UCI Engineering, USA)
6. **Design of an innovative two-pipe chilled beam system for both heating and cooling of office buildings**
   (Aalborg University, Denmark)
7. **Integrated optimal design and control of office buildings using renewable energy sources**
   (KU Leuven, Belgium)

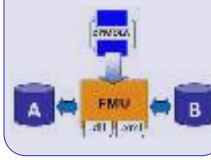
Annex 60 | Structure

Task 1 | Technology development

Modelica
Model libraries



Co-Simulation
Model exchange



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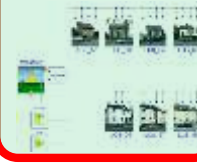
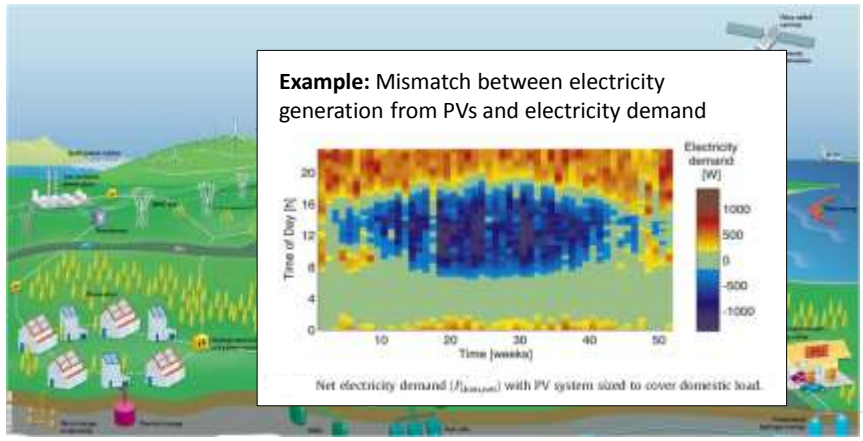


Operation
Automation

Design of district energy systems | Motivation

Activity 2.2 | Lead: Dirk Saelens, Belgium

- **Scalability:** Integration of renewable energy and zero energy buildings requires analysis on a large scale



Reynders, G., Nuytten, T., Saelens, D. (2013). Potential of structural thermal mass for demand-side management in dwellings. Building and Environment.

Design of district energy systems | Ongoing case study

Activity 2.2 | Lead: Dirk Saelens, Belgium

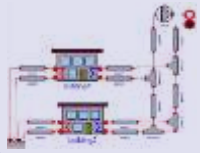
- **Demonstrate the integration of models** for thermal, electrical and control systems
  - to design and assess district energy systems
  - to develop and use control algorithms

→ Ongoing case study: **Definition of the "Annex 60 Neighborhood Case"**
  - modeling of different buildings and installations
  - connection of models on district scale with distribution system to model interplay with centralized renewable energy systems and energy exchange
  - application of control strategies

Annex 60 | Structure

Task 1 | Technology development

Modelica
Model libraries



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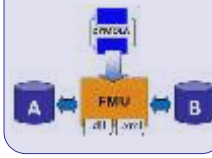

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Model use during operation | Objectives

Activity 2.3 | Lead: Ignacio Torrens and Andrea Costa, Ireland

Operation, focus on:

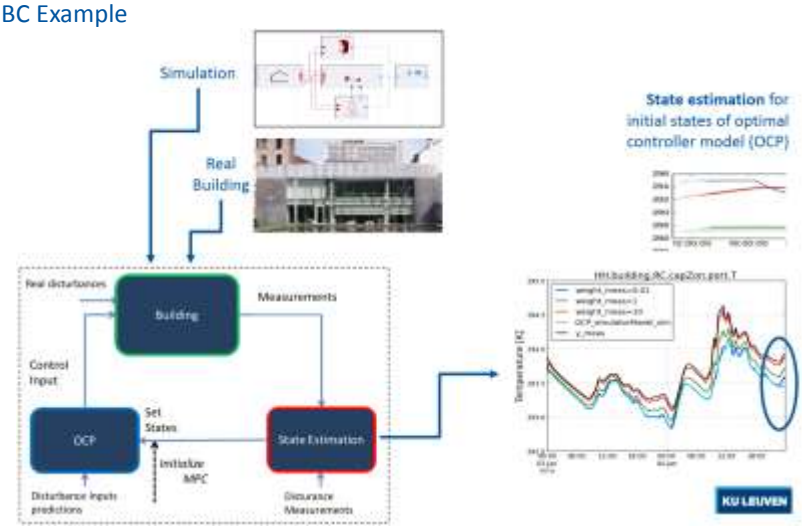
- Model Based Control (MBC)
- Hardware in Loop (HiL)
- Fault Detection and Diagnosis (FDD)

- **Real-time** use of models for verification of design intent, monitoring and optimization of **building operation**.
- **Code generators** to use Modelica models on **distributed controllers**
- Explore how to **reuse models for building operation**
- How to accommodate the situation that control vendors typically use **proprietary languages** to implement control sequences.

Model use during operation | Model Based Control

Activity 2.3 | Lead: Ignacio Torrens and Andrea Costa, Ireland

- MBC Example



(Courtesy KU Leuven)

Annex 60 | Structure

EBC

Task 1 | Technology development

Modelica
Model libraries

Co-Simulation
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IEA Annex 60

Computational tools
for building and community energy systems

Website for further information:
www.iea-annex60.org

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Bundesministerium für Wirtschaft und Energie