Multi-Scale Modeling with Modelica: From Heat Exchanger to Smart City

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09/01/2019

University of Colorado Boulder

Outline

- **Case 1: New Finned-Tube Heat Exchangers**
- **Case 2: Comprehensive Pliant Permissive Priority Optimization (C3PO)**
- **Case 3: Multi-Infrastructure Modeling of Smart and Connected Communities**

Case 1: Finned-Tube Heat Exchanger Model

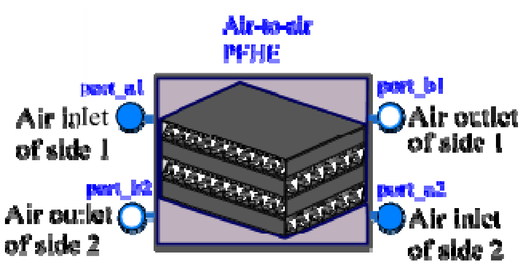
University of Colorado Boulder: Yunyang Ye, Jing Wang, Yangyang Fu, Wangda Zuo
Guangzhou University: Zhou Guang, Xiaoqing Zhou

The limitations of the existing heat exchanger models:

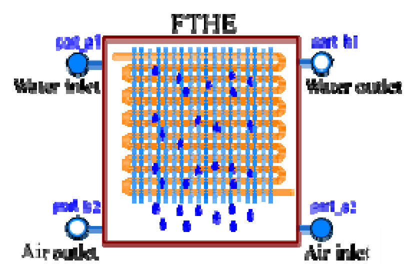
- Numerical models with finite element method: Accurate, but computationally expensive and difficult to get convergent solution.
- Analytical models: fast, but require inaccessible geometric data of the heat exchanger.
- Lumped model: relatively accurate and efficient, but still geometric data, specific heat transfer coefficients, and some operational data

Proposed new models:

computationally efficient, relatively accurate and only requires nominal data as inputs.



Air-to-Air Heat Exchanger

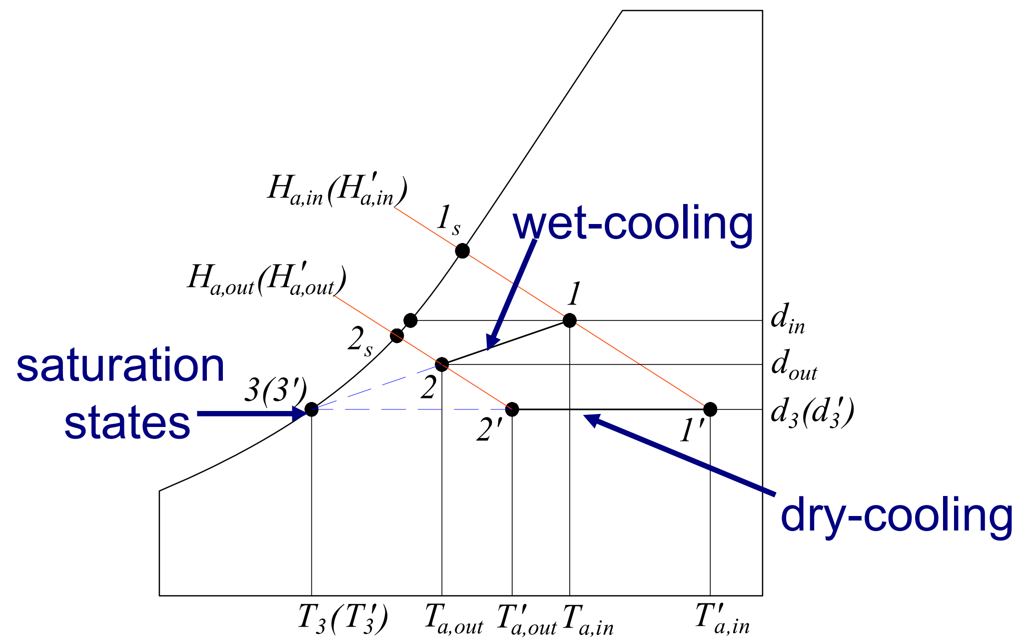


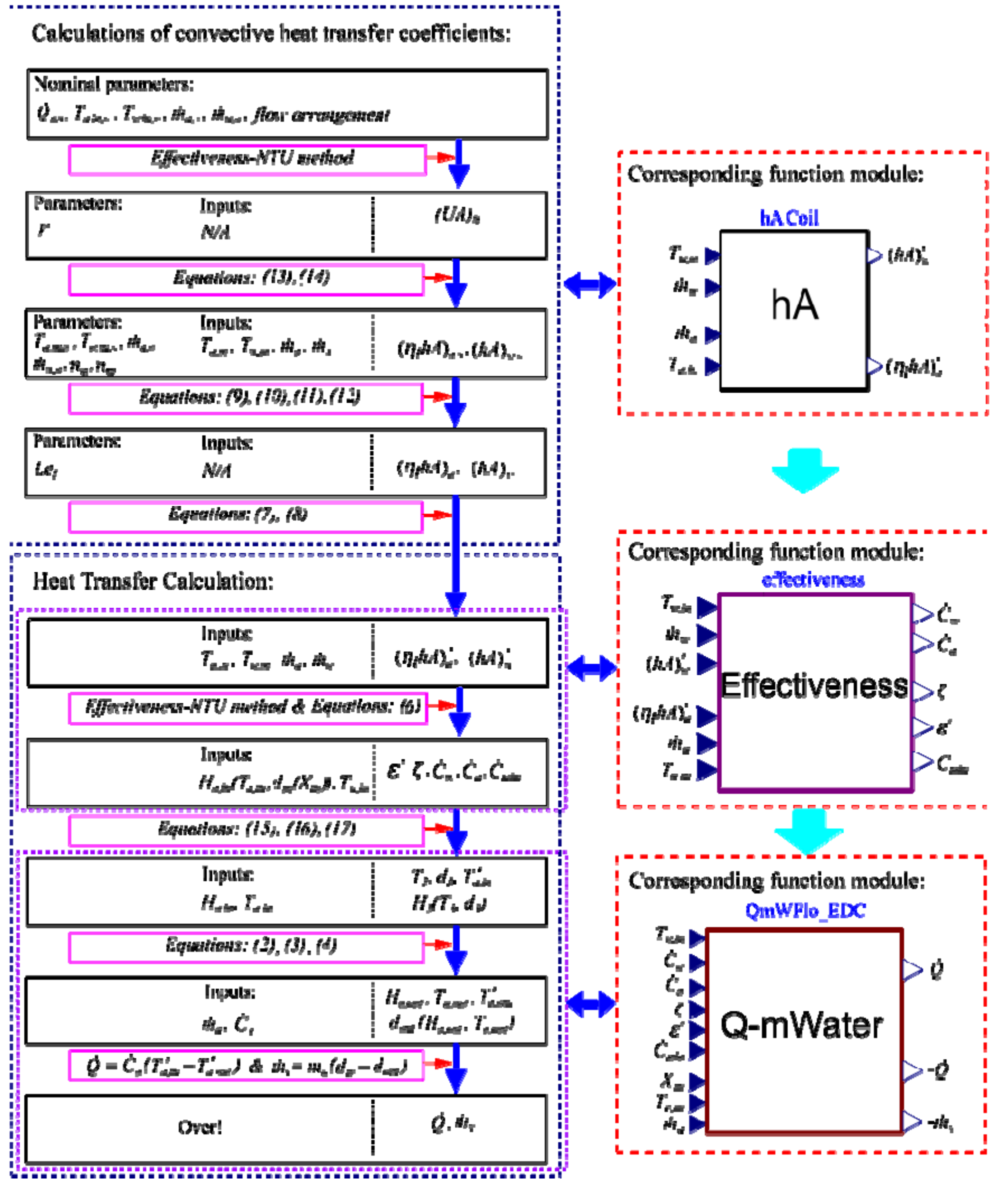
Water-to-Air Heat Exchanger

G. Zhou, Y. Ye, J. Wang, **W. Zuo**, Y. Fu, X. Zhou 2018. Applied Thermal Engineering.
G. Zhou, Y. Ye, **W. Zuo**, X. Zhou, X. Xu 2018. Applied Thermal Engineering.

Proposed New FTHE Model

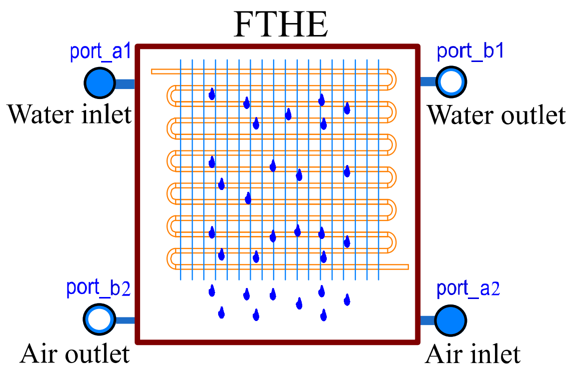
A new water-to-air Finned-Tube Heat Exchanger (FTHE) model is derived using wet-dry transformation method and the heat transfer process is calculated using the nominal data.



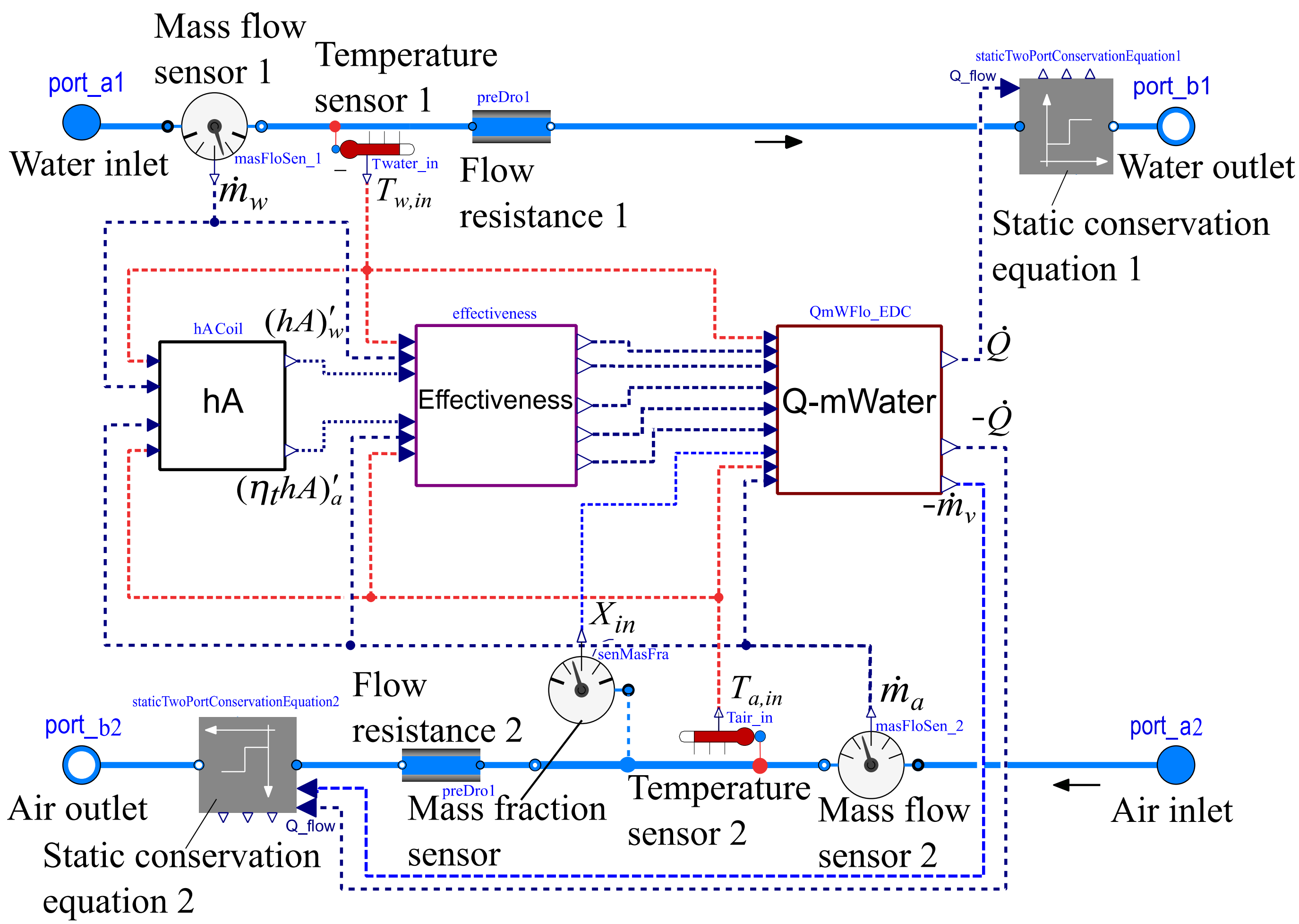


G. Zhou, Y. Ye, **W. Zuo**, X. Zhou, X. Xu 2018. Applied Thermal Engineering.

Model Implementation



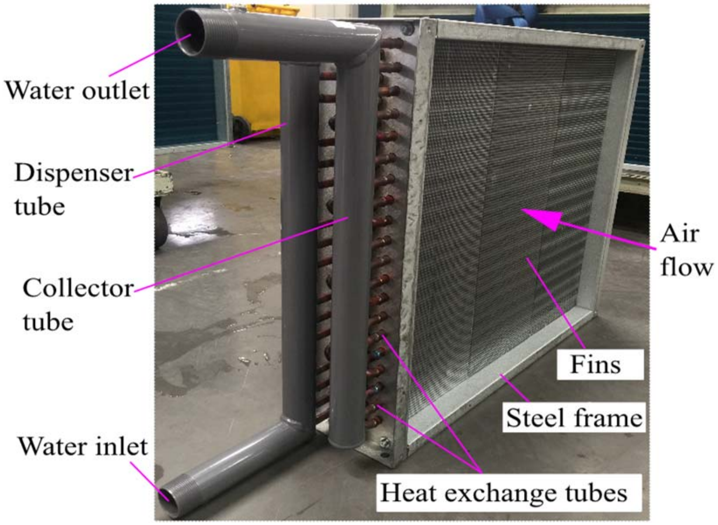
(a) Icon of FTHE model



(b) Detailed construcion of FTHE model

G. Zhou, Y. Ye, **W. Zuo**, X. Zhou, X. Xu 2018. Applied Thermal Engineering.

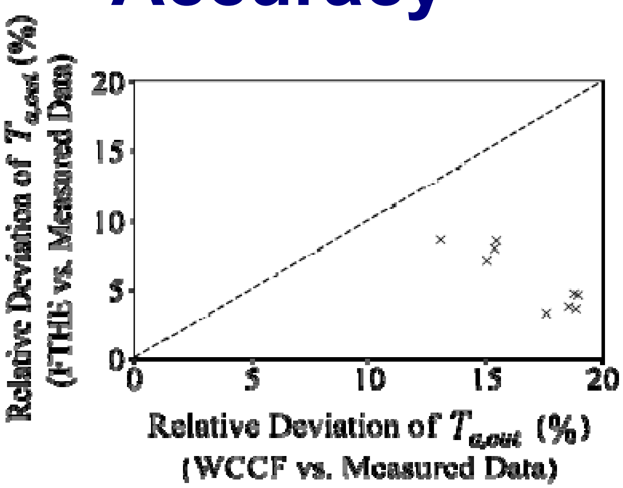
Model Validation

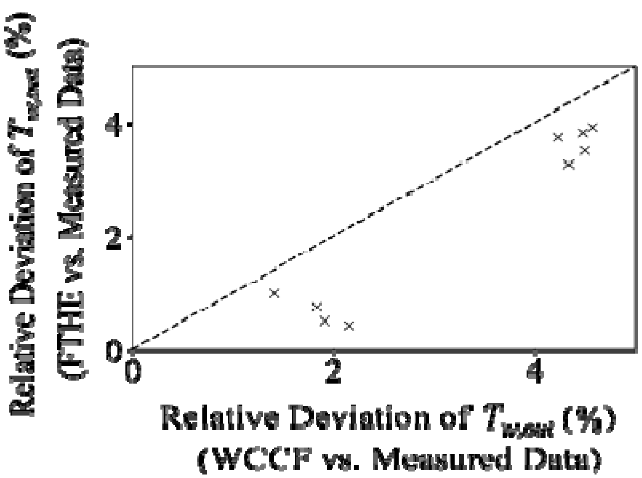


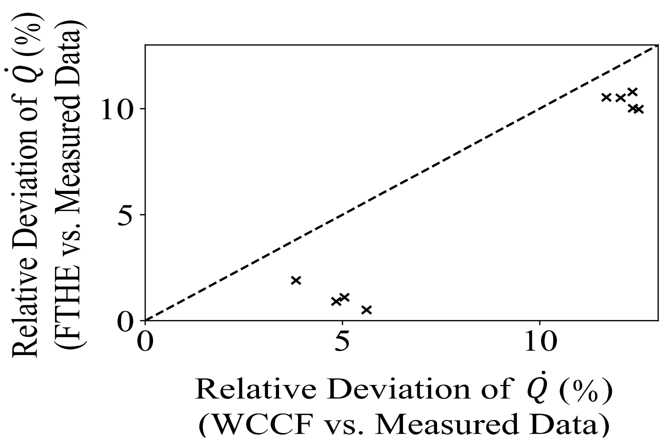
Speed

- New FTHE model: 272 equations.
- WetCoilCoutnerFlow (WCCF) model: 6,776 equations for 32 elements
- FTHE model is ~1,000 times faster than WCCF model

Accuracy



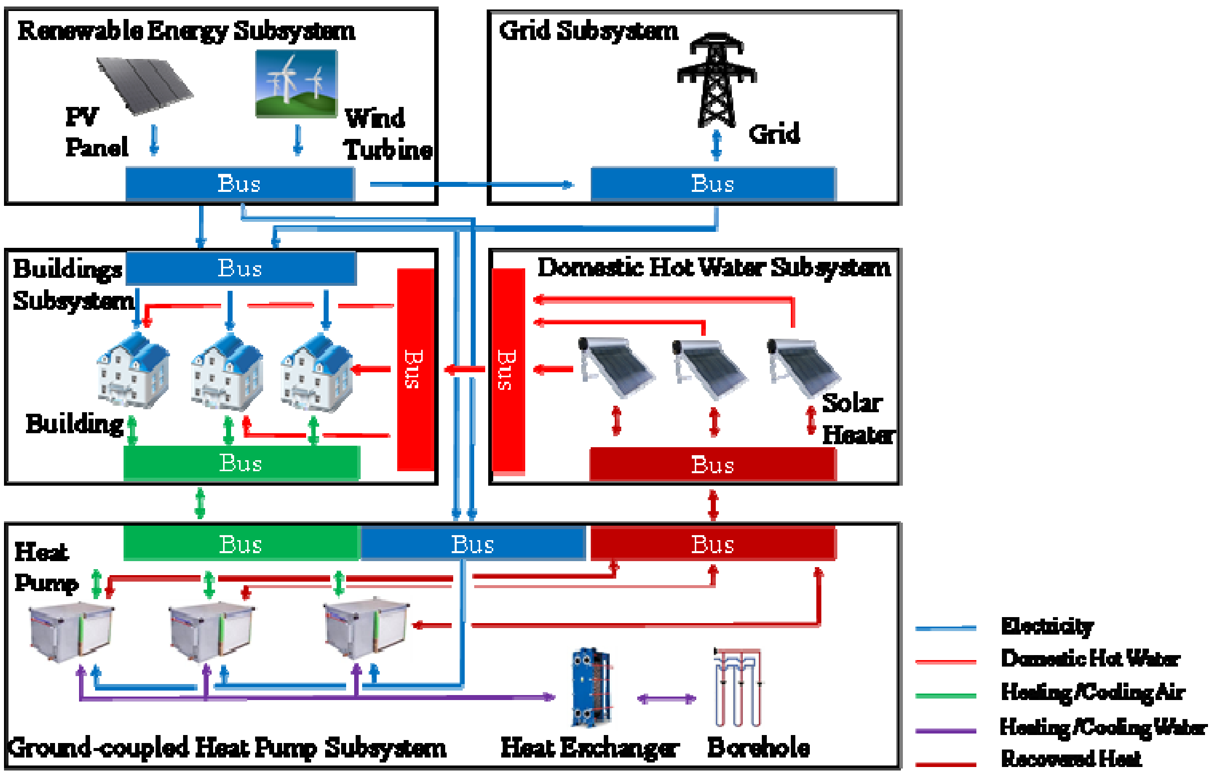




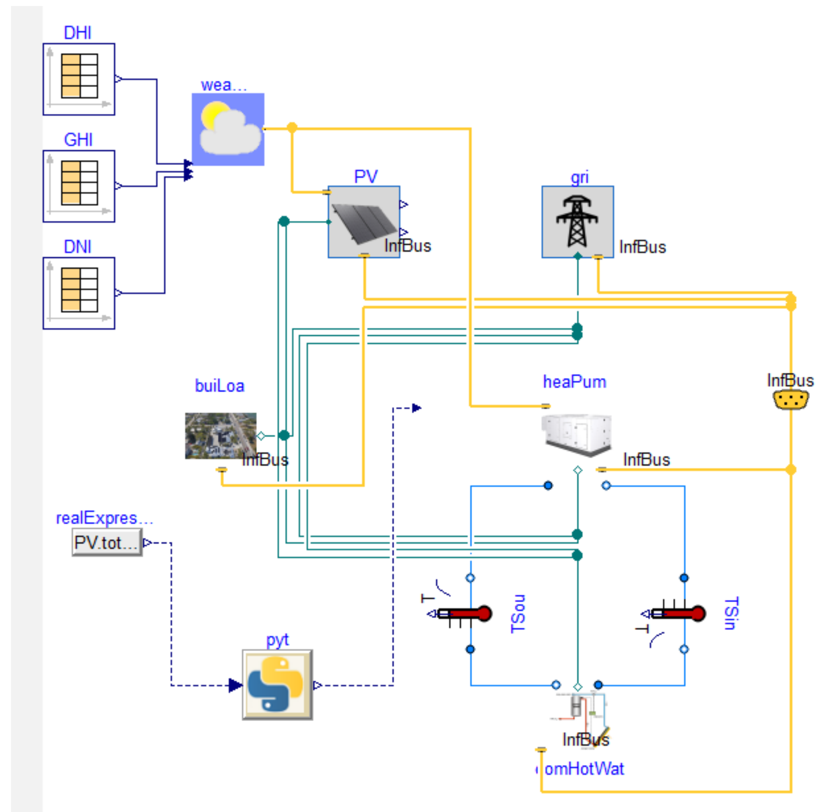
G. Zhou, Y. Ye, **W. Zuo**, X. Zhou, X. Xu 2018. Applied Thermal Engineering.

Case 2: Comprehensive Pliant Permissive Priority Optimization (C3PO)

University of Colorado Boulder: Jing Wang, Yangyang Fu, Wangda Zuo
Pacific Northwest National Laboratory: Sen Huang, Draguna Vrabie

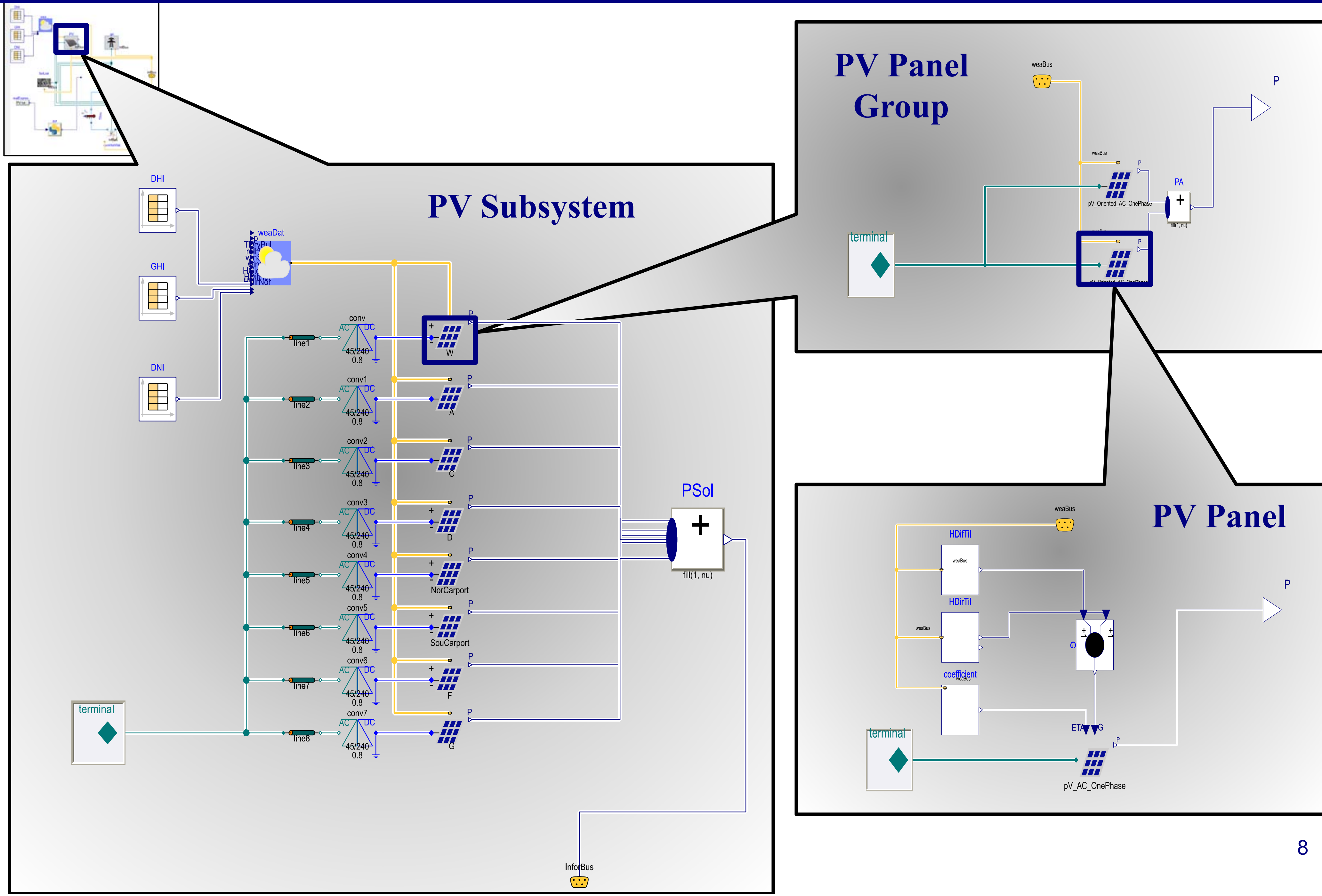


System Schematics

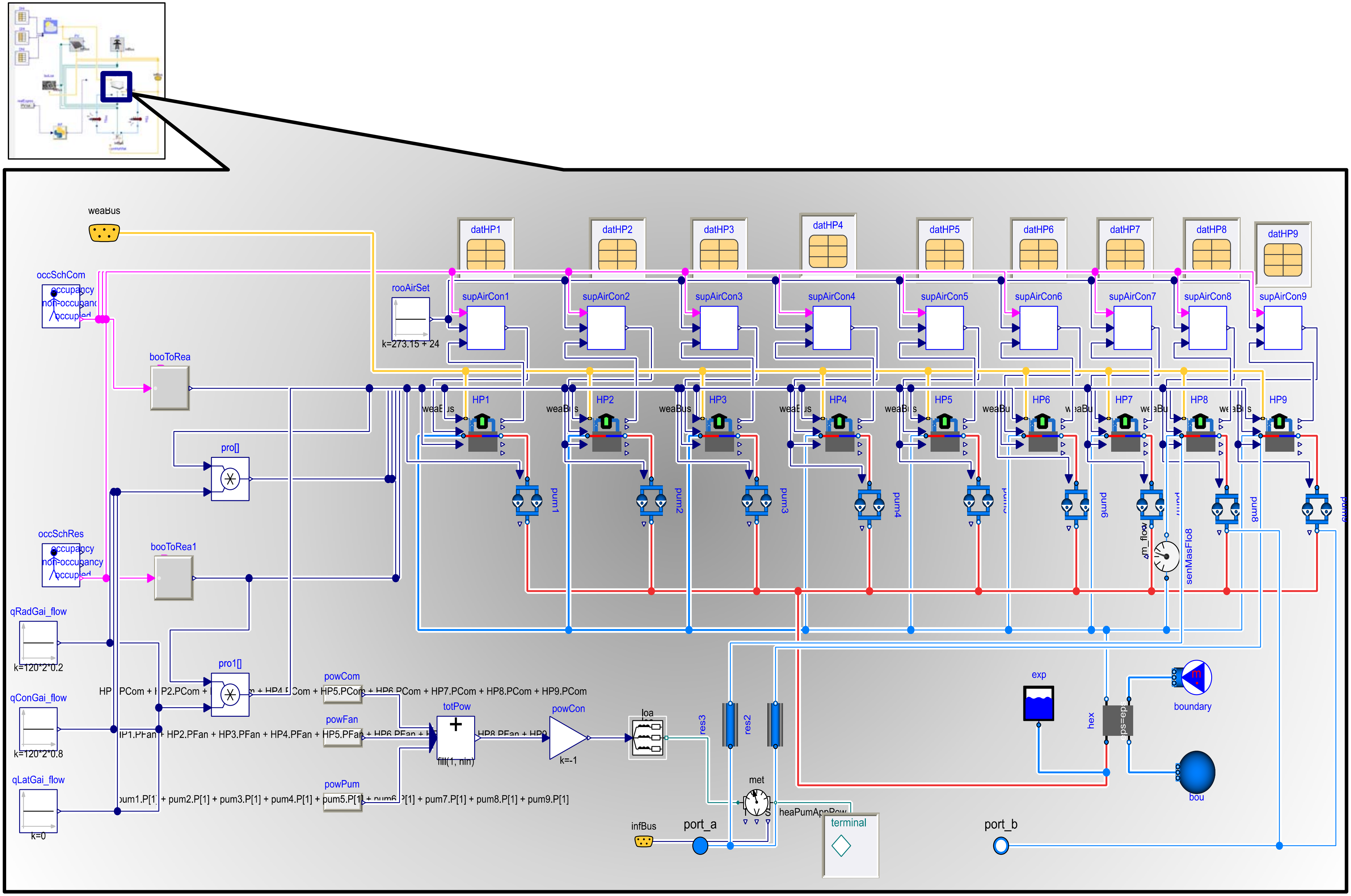


Top level model of in Modelica

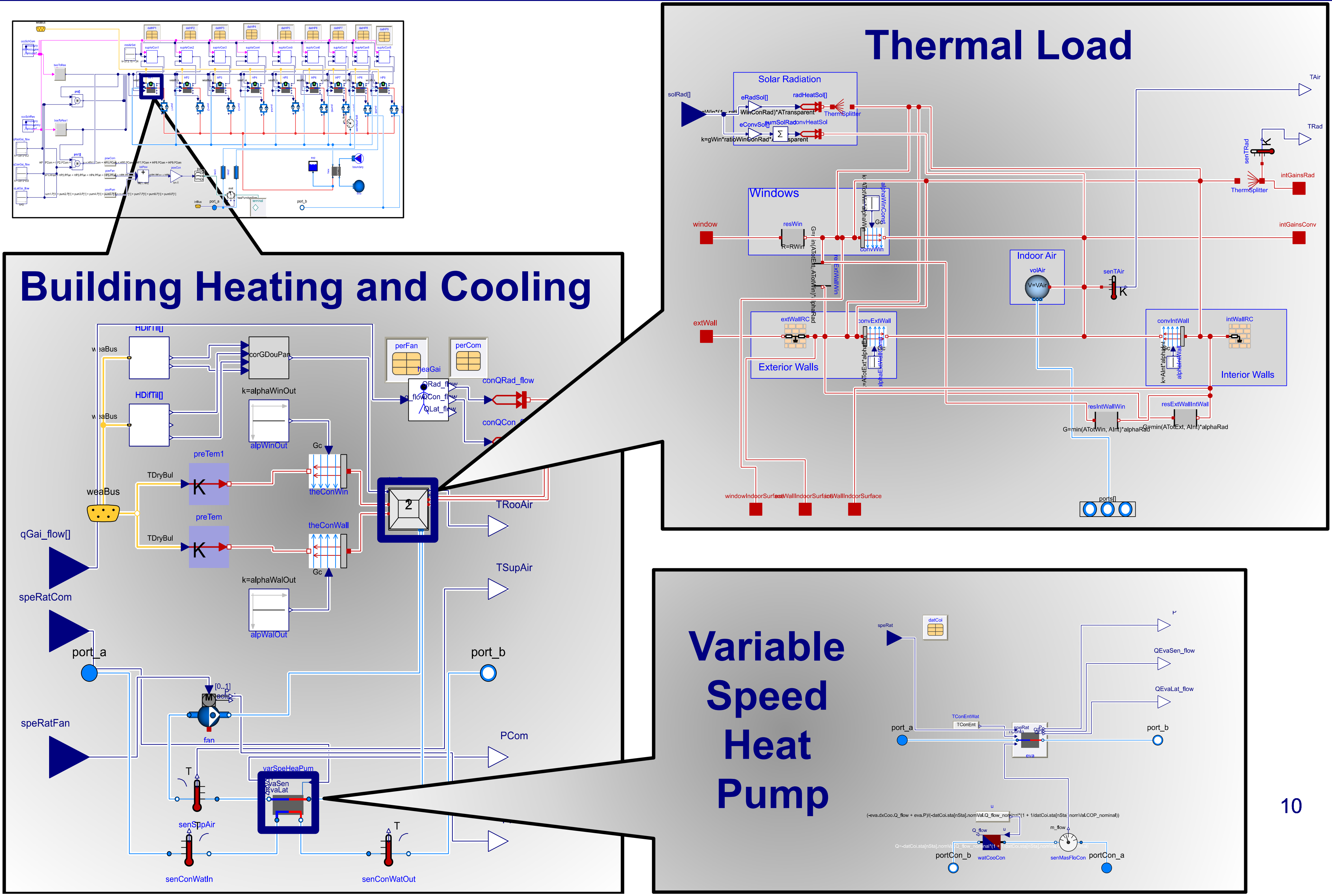
Solar PV Subsystem



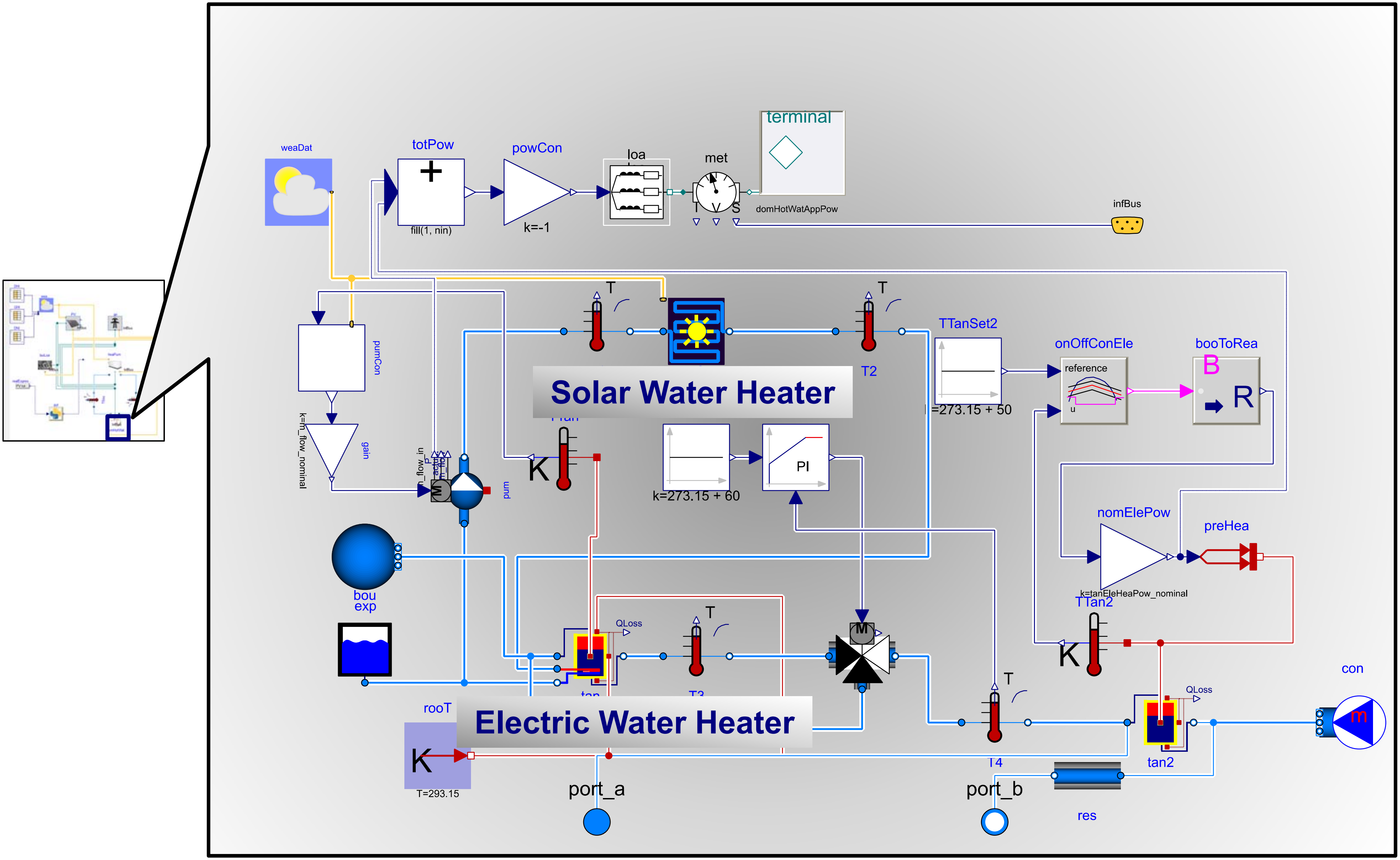
Water-Source Heat Pump Subsystem



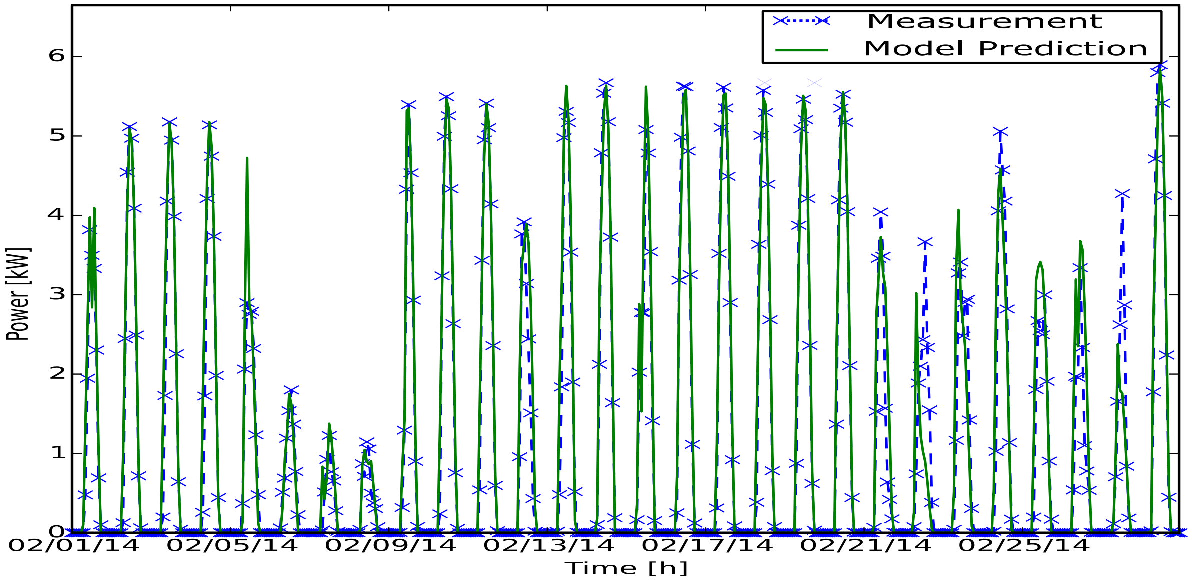
Water Source Heat Pump with Thermal Loads



Domestic Hot Water Subsystem with Solar Water Heater

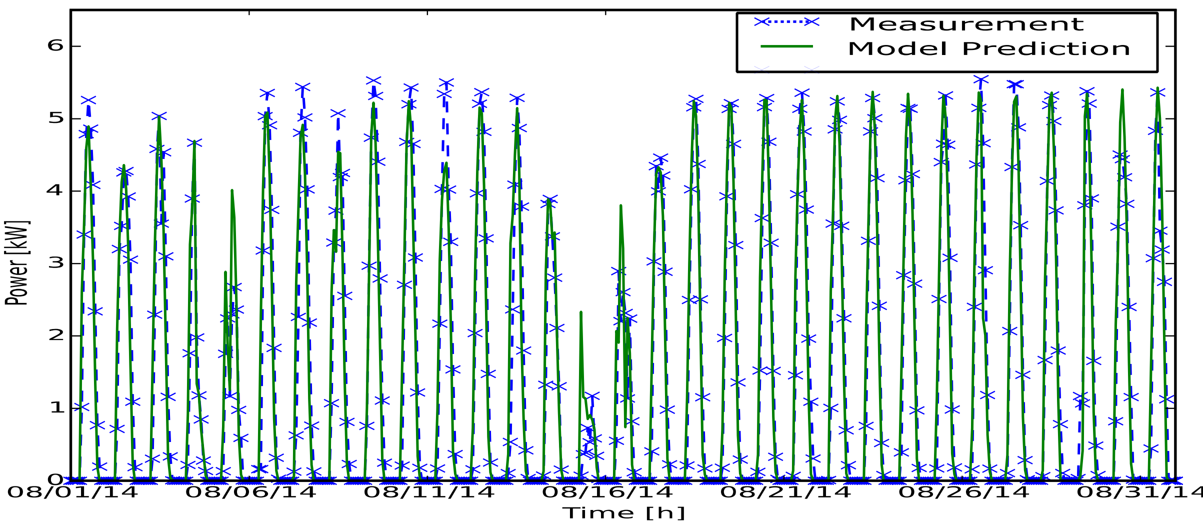


Results: Prediction of PV Power



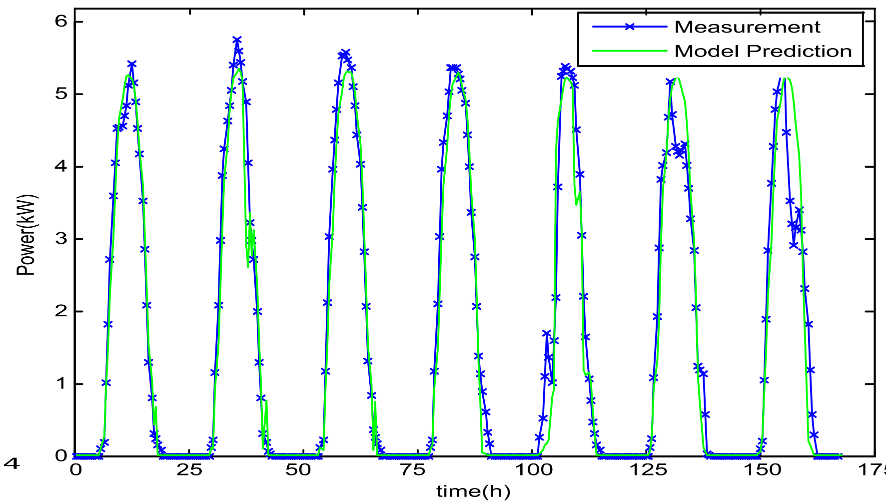
Winter

Model	R-square
Physical	0.927(winter) 0.905(summer)
Data Driven (ANN)	0.981



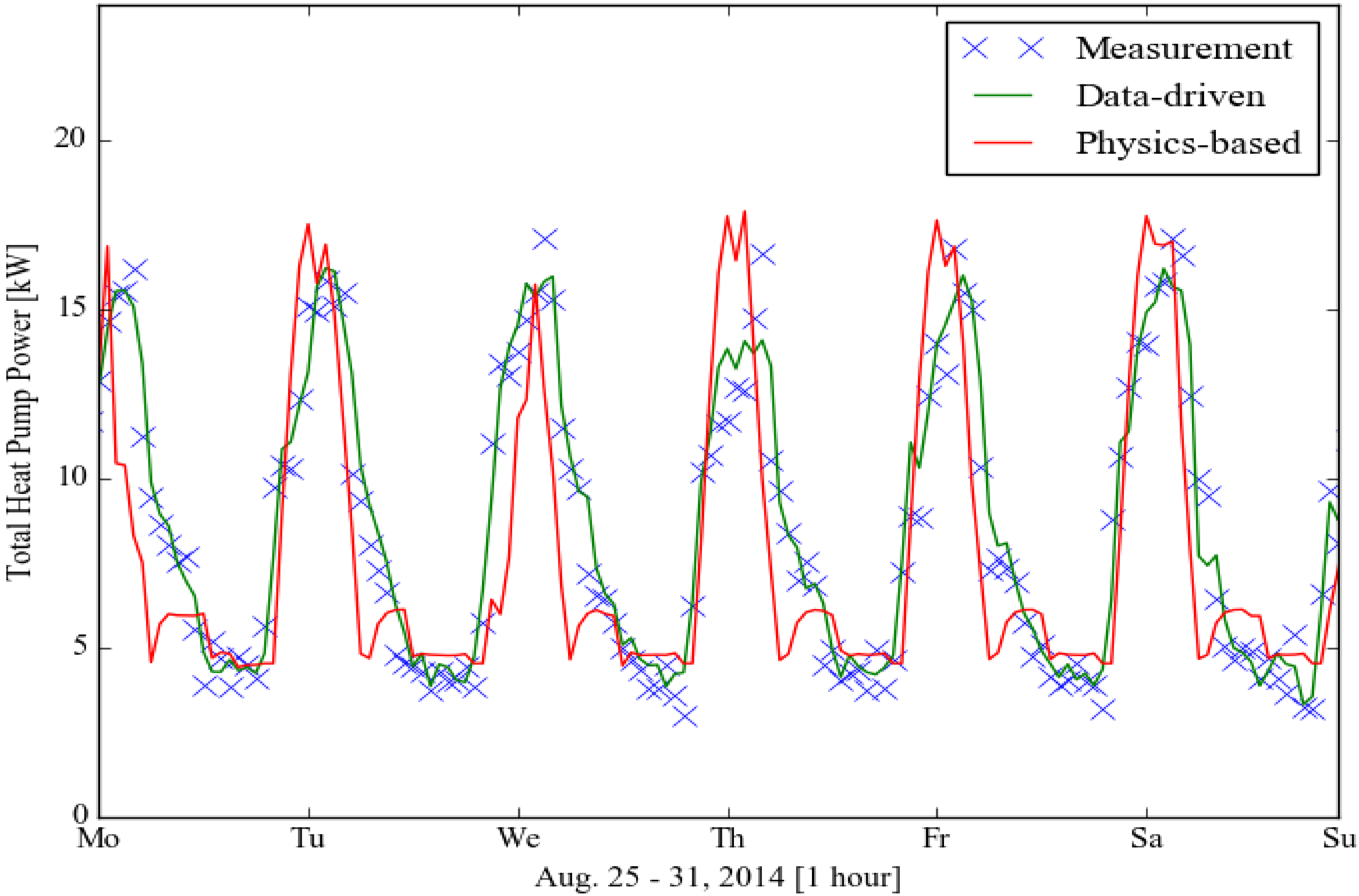
Summer

Physical Model



Data Driven Model (ANN)

Results: Heat Pumps



Open-Source Release

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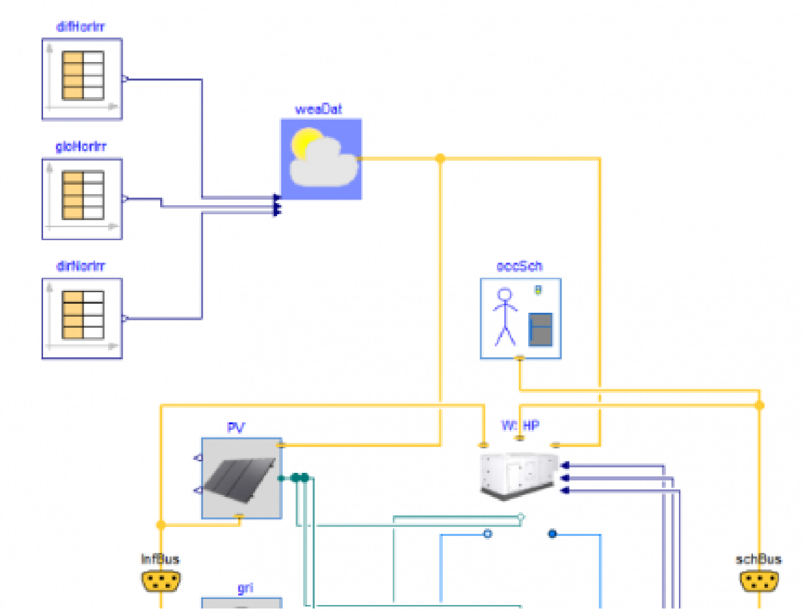
Net Zero Energy Community (NZEC) Library

March 23, 2019

A Modelica library for the NZEC is built to facilitate the design and operation of a real NZEC. Using this library, a virtual testbed is built based on a real-world NZEC in Florida. The testbed consists of a framework and system models for different subsystems, including solar photovoltaic (PV) systems, ground-coupled source heat pumps, buildings, the electric grid, and so on. The framework streamlines the process for simulation and optimization with Python; the models include both physics-based ones and data-driven ones, designed for different data availability and application contexts. The models are validated against the measurement data.



Software Download

The development site of this software is at: https://bitbucket.org/sbslab-zuo/scc-nzec.

https://www.colorado.edu/lab/sbs/nzec-library

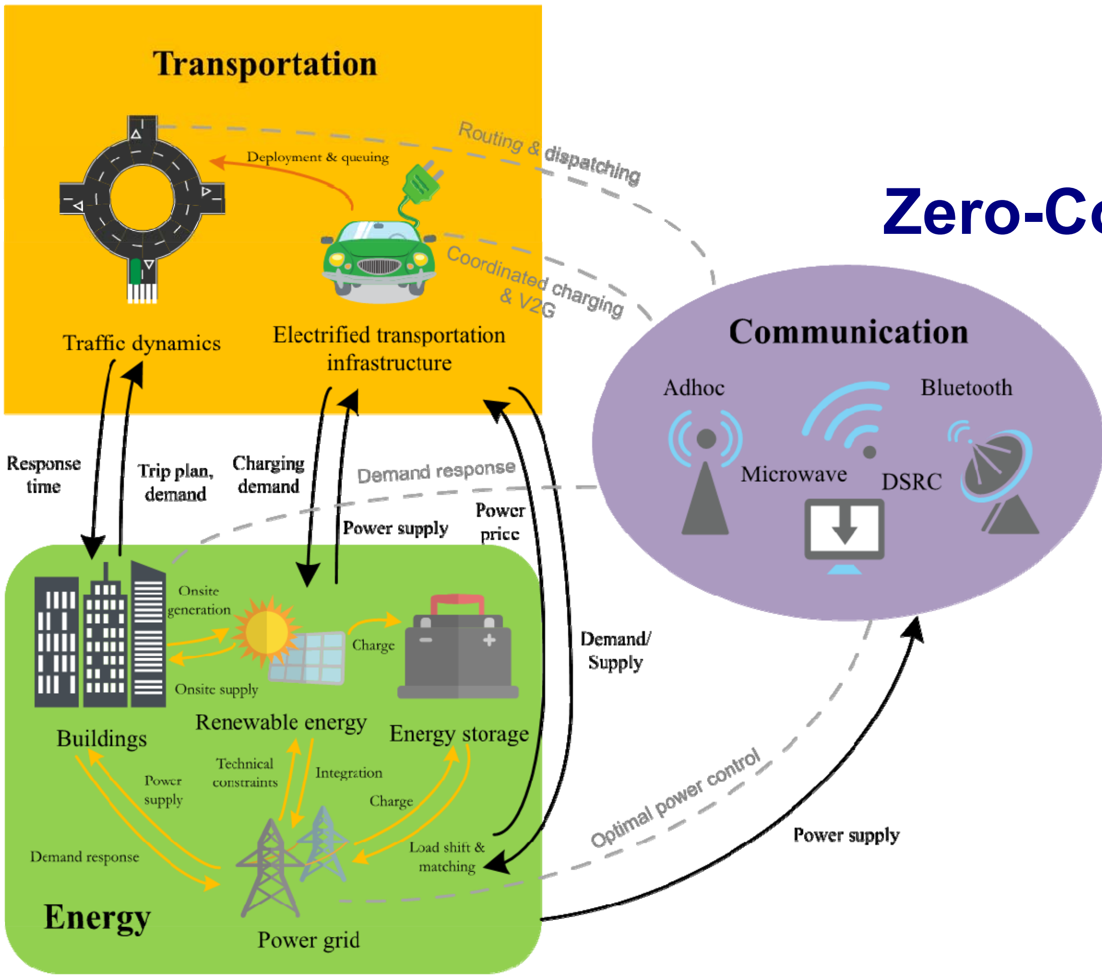
Case 3: Multi-Infrastructure Modeling of Smart and Connected Communities

University of Colorado Boulder: Xing Lu, Kathryn Hinkelman, Jing Wang, Yangyang Fu, Wangda Zuo
Virginia Tech: Qianqian Zhang, Walid Saad

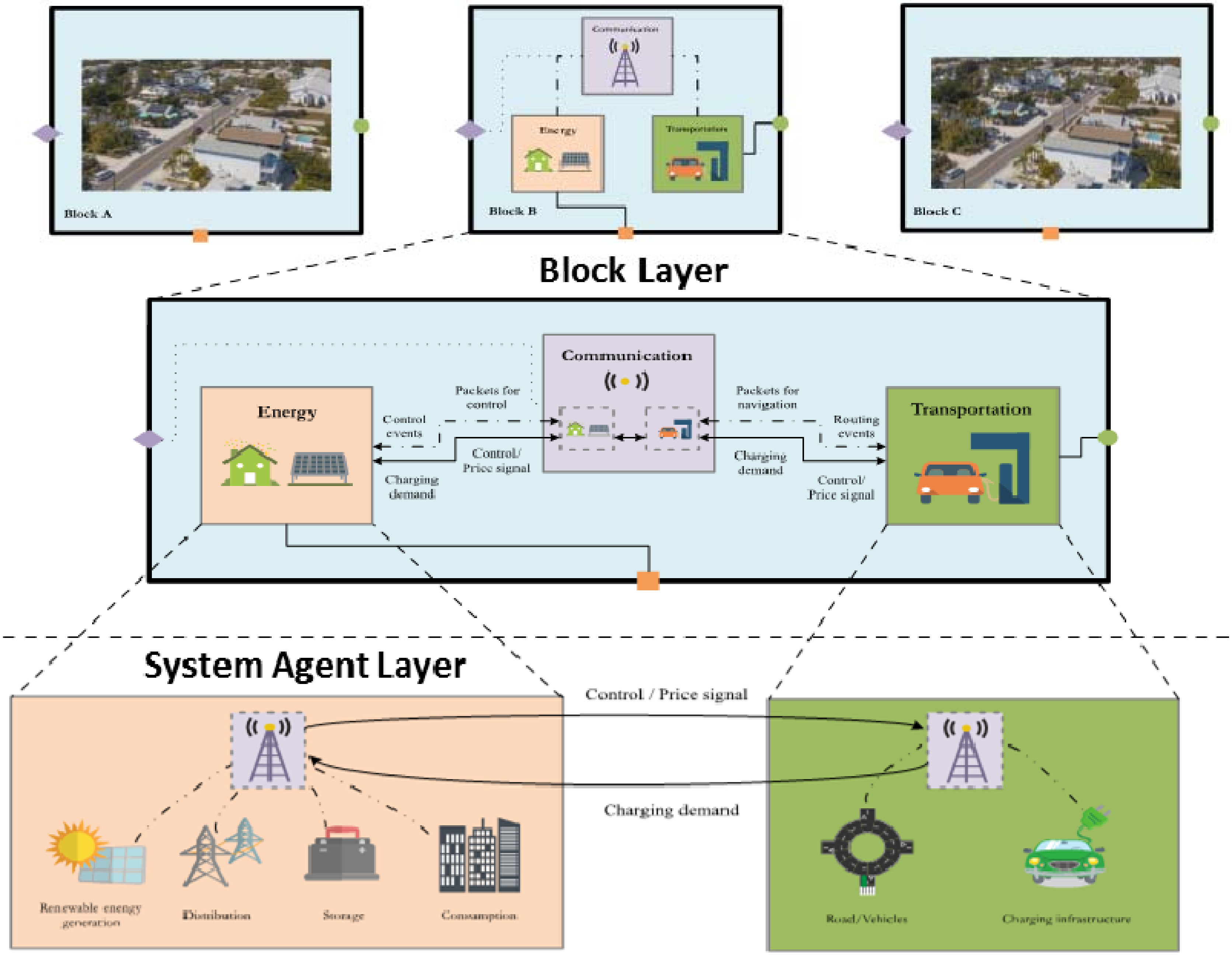
Zero-Traffic

Zero-Congestion

Zero-Outage

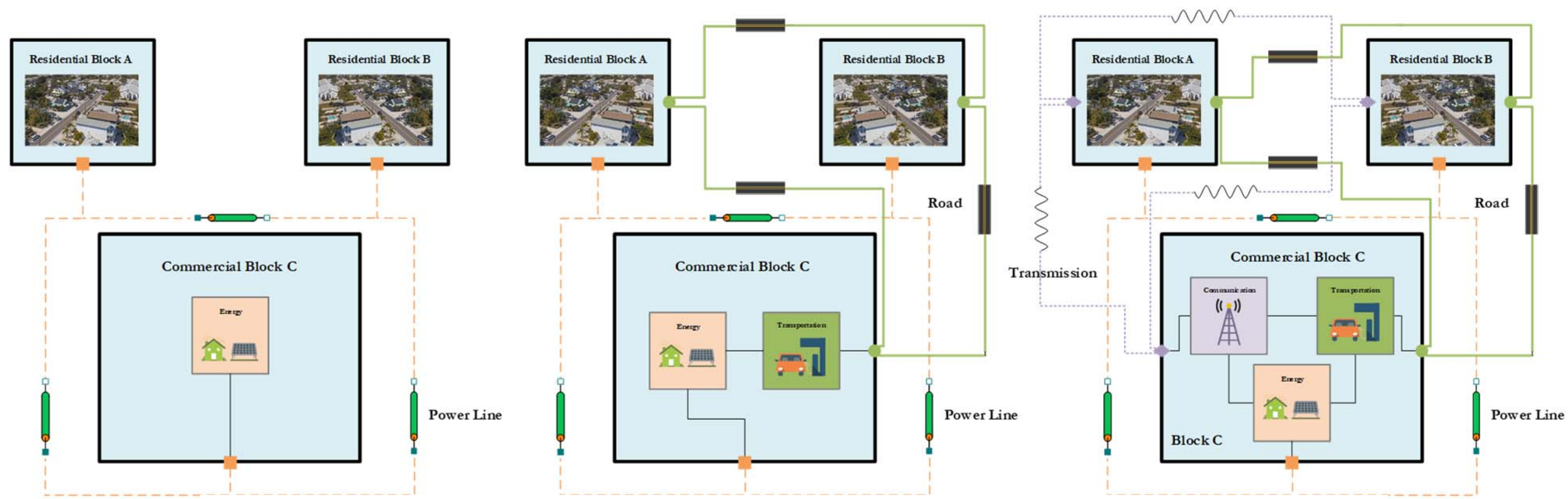


Multi-layer, Multi-block, Multi-agent (3M) Approach



Application Case Study

Energy   E + T   E + T + C



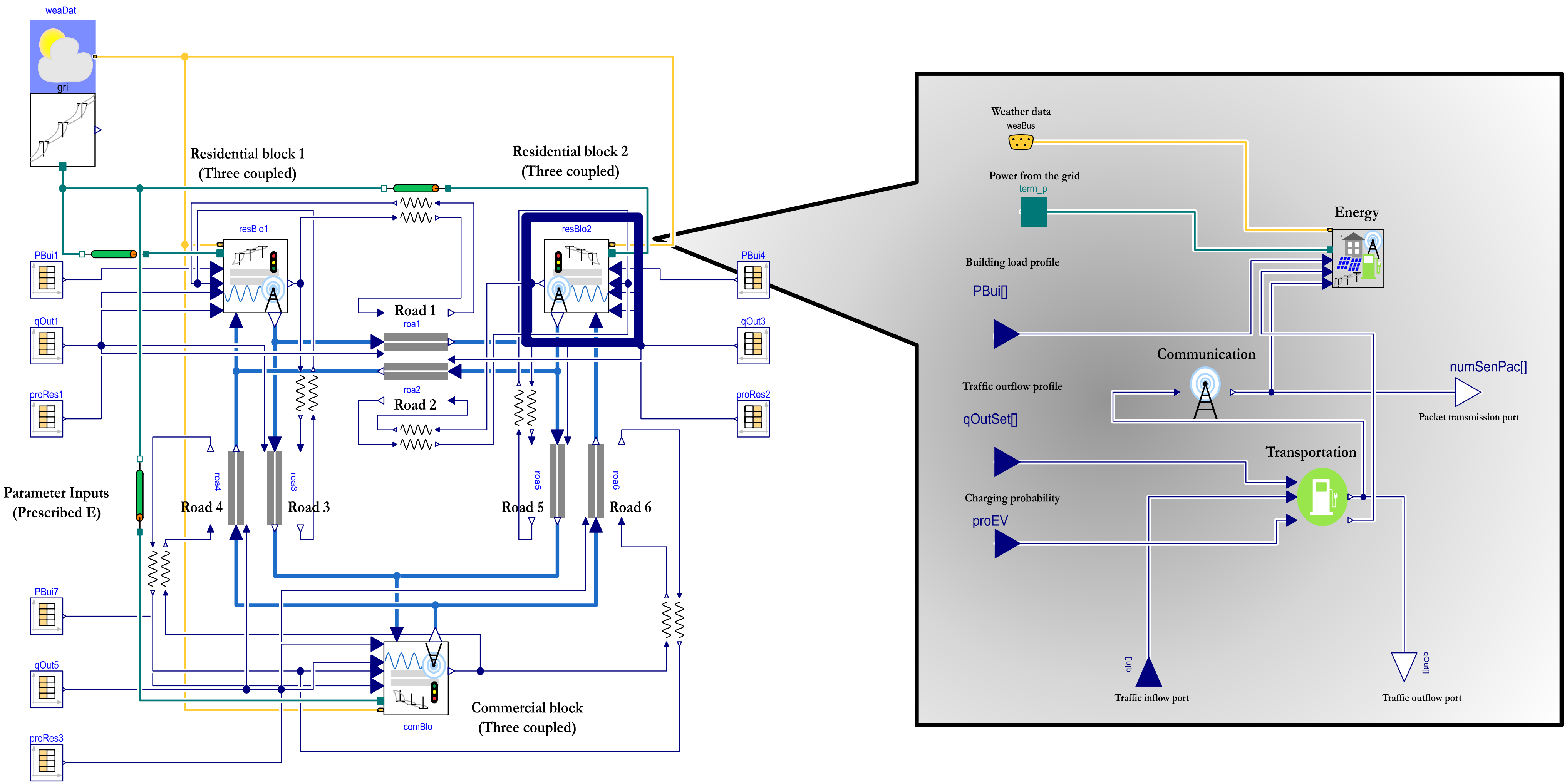
	Residential Block 1	Residential Block 2	Commercial Block
Weather profile	USA_CA_San.Francisco.Intl.AP		
Solar power farm area (m^2)	20,000	30,000	50,000
Nominal wind turbine power (MW)	1		
Battery maximum charge (kWh)	4,000	5,000	6,000
Distribution system type	IEEE 16 test feeder		
Initial EV number	800	800	200
Building type	Residential houses, Midrise apartments	Residential houses, Midrise apartments	Offices, Retails, Hotels, Schools, Restaurants

Lu, X., Hinkelman, K., Fu, Y., Wang, J., Zuo, W., Zhang, Q., Saad, W. (2019). An Open Source Modeling Framework for Interdependent Energy-Transportation-Communication Infrastructure in Smart and Connected Communities. *IEEE Access*, *7*, 55458–55476. DOI: 10.1109/ACCESS.2019.2913630.

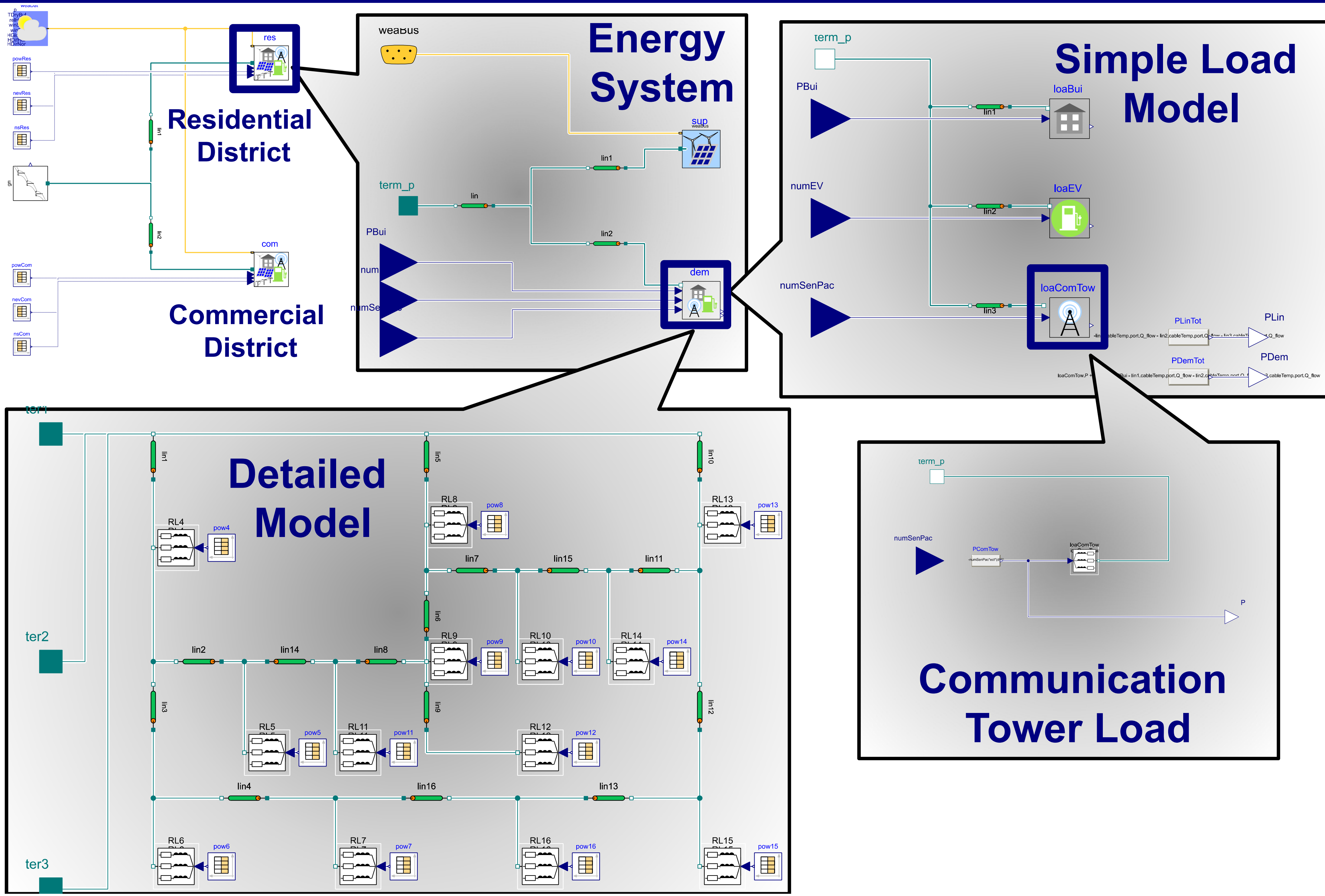
Three Coupled Systems

Community Layer

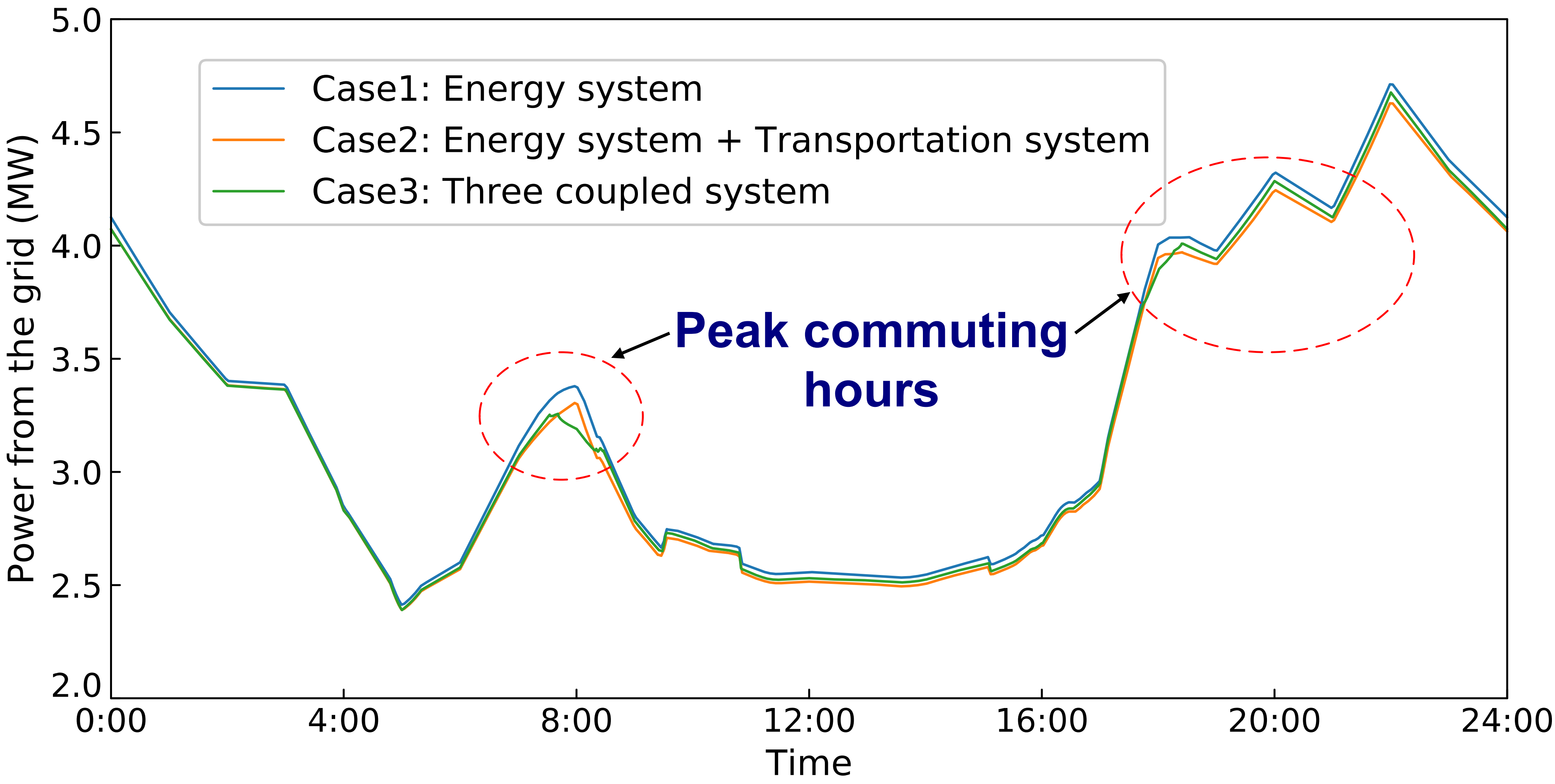
Block Layer



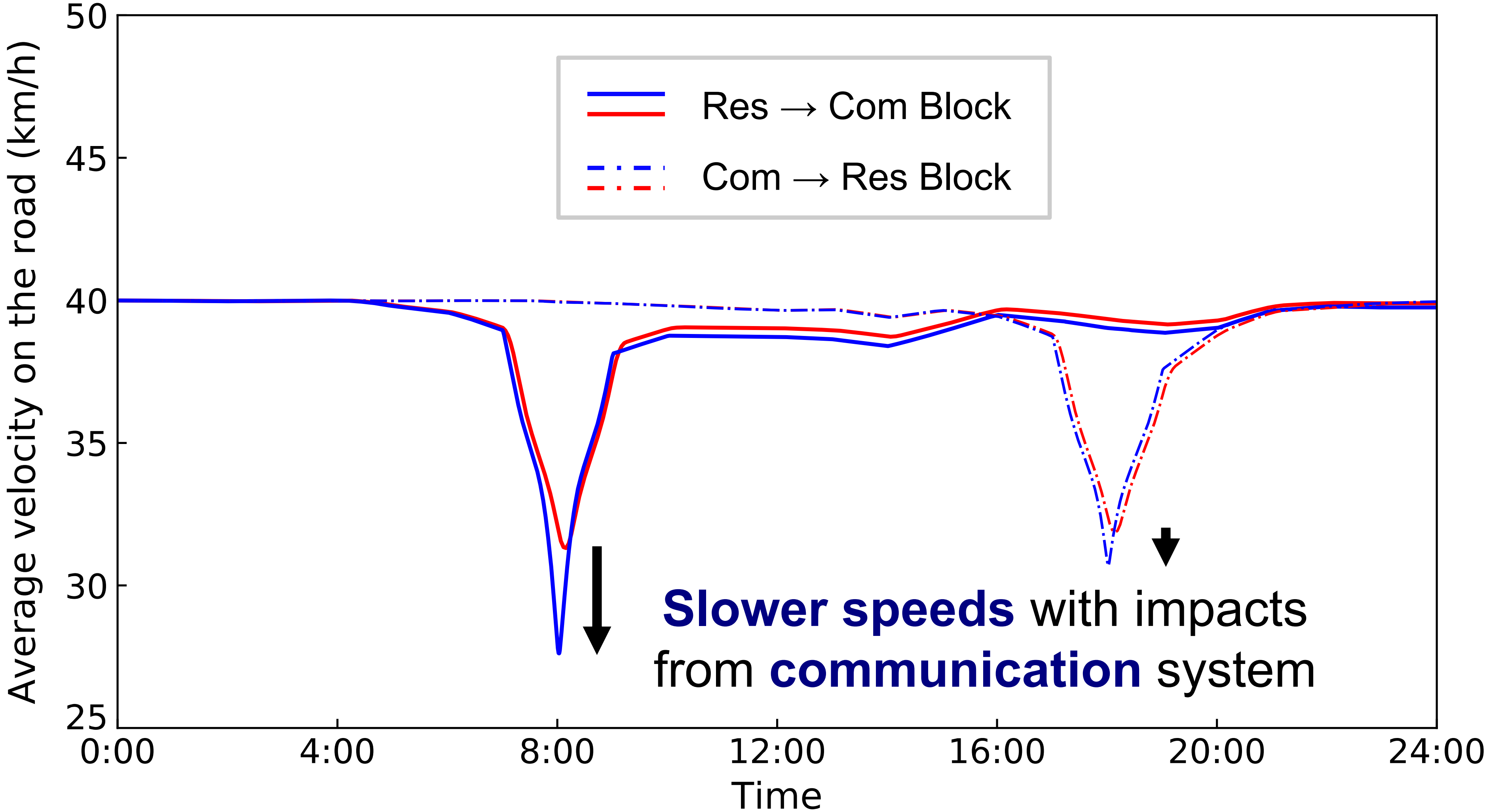
Energy Network Model



Impact on Energy Network



Impact on Transportation Network



Slower speeds with impacts from **communication** system

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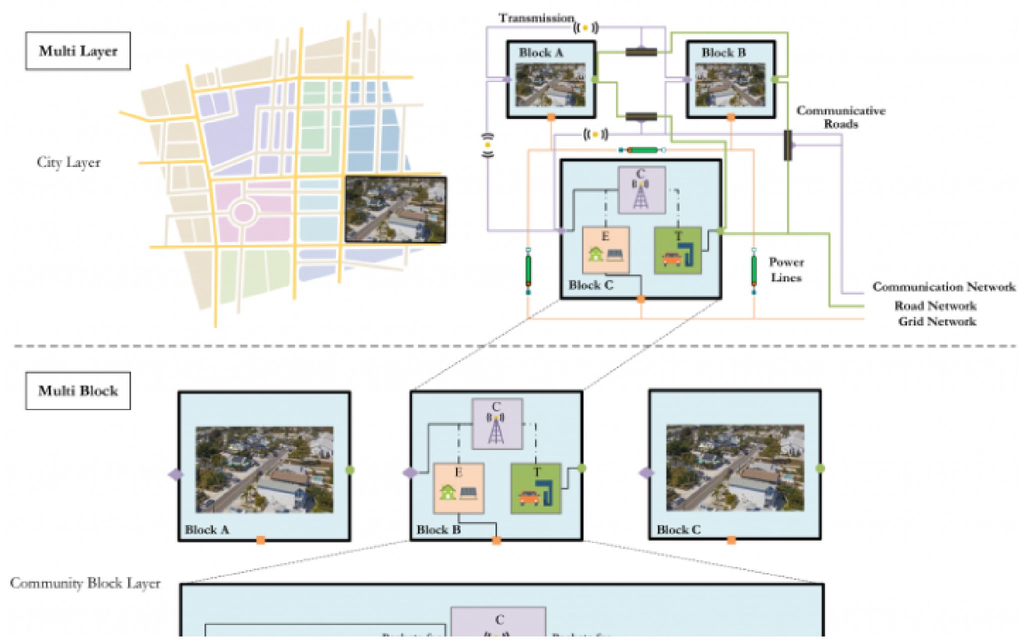
Smart and Connected Community (SCC) Library

March 23, 2019

This open source Modelica library contains an integrated modeling framework and component models for designing coupled energy, transportation, and communication systems. The framework features a multi-level, multi-layer, multi-agent (3M) approach in order to enable flexible modeling of the interconnected systems. Various component and system-level models are included as the testbed of future SCCs in order to assess the impact of infrastructure interdependencies during typical operation. This modeling framework can be further extended for various modeling purposes and use cases, such as dynamic modeling and optimization, resilience analysis, and integrated decision making in future connected communities.



Software Download

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https://www.colorado.edu/lab/sbs/scc-library