Cyber-physical System Modeling using Modelica for Smart and Sustainable Communities

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9/18/2020

University of Colorado Boulder

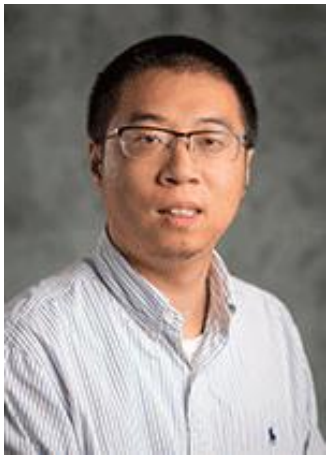
SBS LAB Sustainable Buildings and Societies Laboratory

Pacific Northwest NATIONAL LABORATORY

Introduce the Speakers

Jing Wang, Ph.D. Candidate

Jing is a PhD Candidate in Architectural Engineering at University of Colorado Boulder. Her research interests are resilient energy systems, building energy system modeling and control, building-to-grid integration. She is an ASHRAE Student Member.



Sen Huang, Ph.D.

Sen Huang joined the Pacific Northwest National Laboratory as a scientist in May 2016. Before joining PNNL, he worked as a building services engineer at Arup (2011-2012), a teaching assistant (2013) and a research assistant (2014-2016) both at the University of Miami.

Acknowledgement

- This presentation is supported by the following projects:

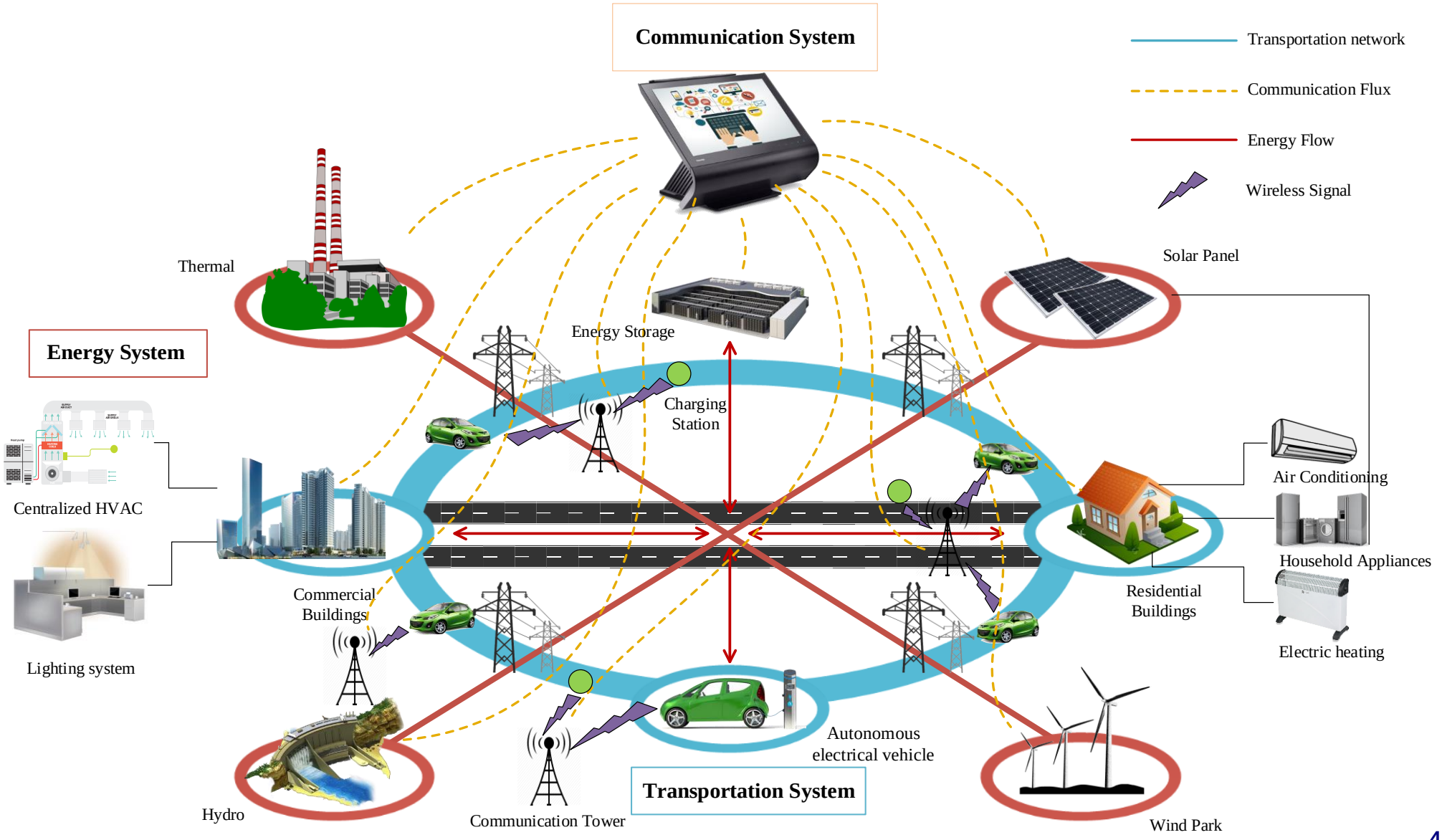
- U.S. Department of Energy, Energy Efficiency and Renewable Energy, Building Technologies Office, under Contract No. DE-AC05-76RL01830.

- National Science Foundation under Award IIS-1802017.

- Special thanks to Dassault Systèmes and Barcroft Technology for providing free Dymola licenses during the workshop!

Background

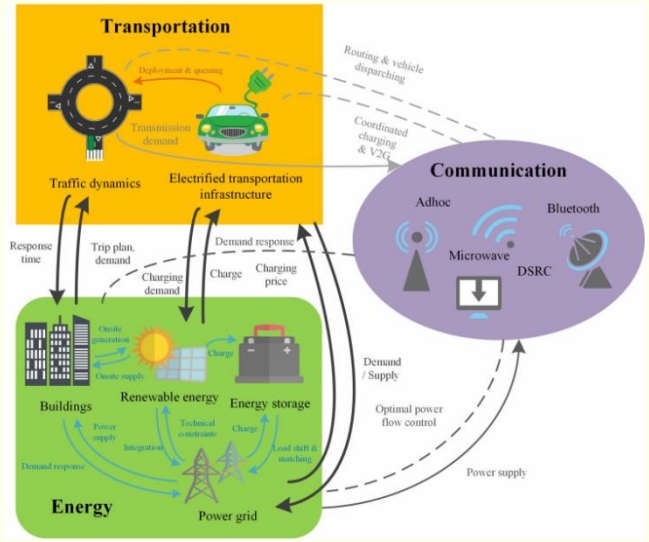
Vision of future smart cities



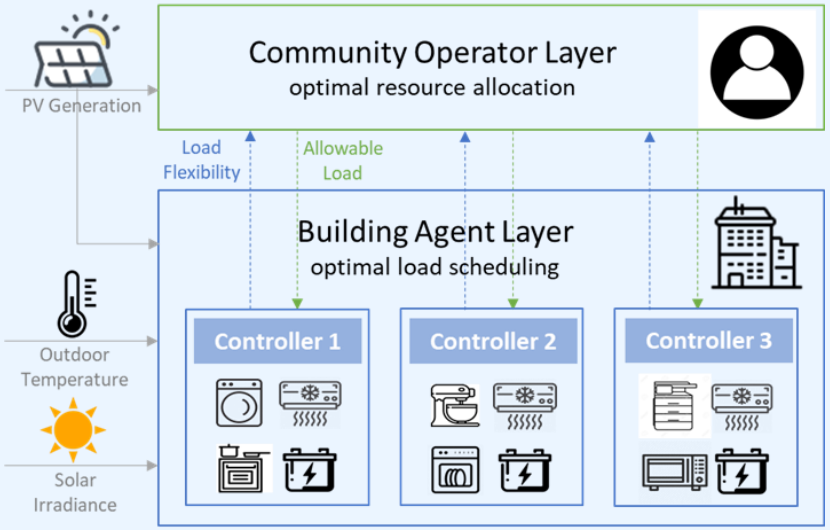
Goals and Challenges

Modeling for smart and sustainable communities

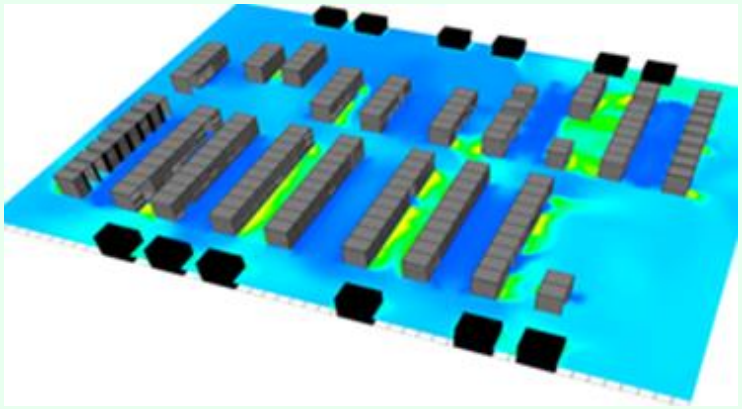
Interdependency Modeling



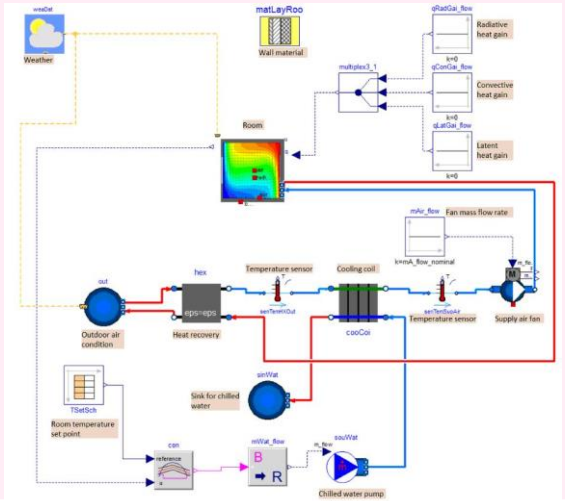
Optimal Operation



Built Environment Improving



Dynamic System Controls



Who are we?

Principal Investigator: Prof. Wangda Zuo

- 9 PhD Students
- 1 Visiting PhD Student
- 3 Graduate/Undergraduate Research Assistants

Major Research Projects

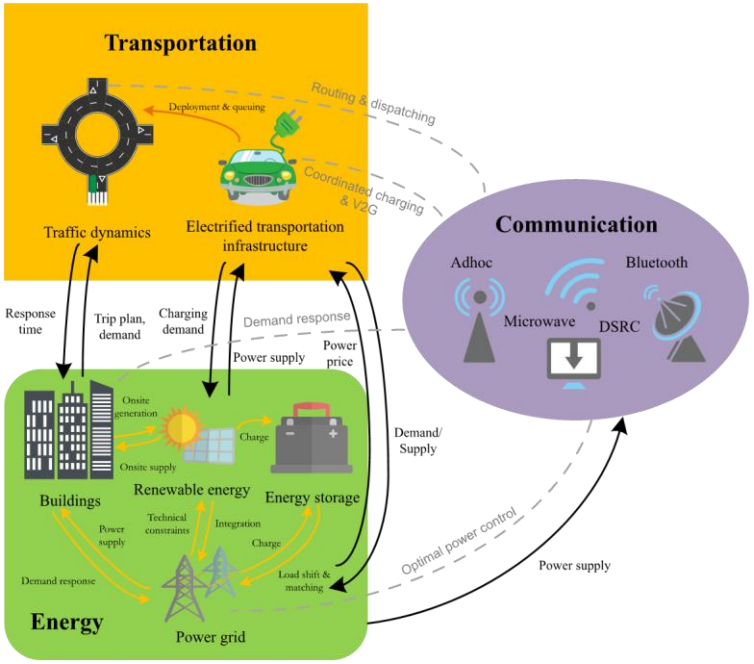
- Modelica library development
  - Modelica Buildings Library
  - Data Center package
  - District Heating & Cooling
- Modelica supported research
  - Occupancy-centric flexibility quantification
  - Building-to-grid integration

Homepage: https://www.colorado.edu/lab/sbs/

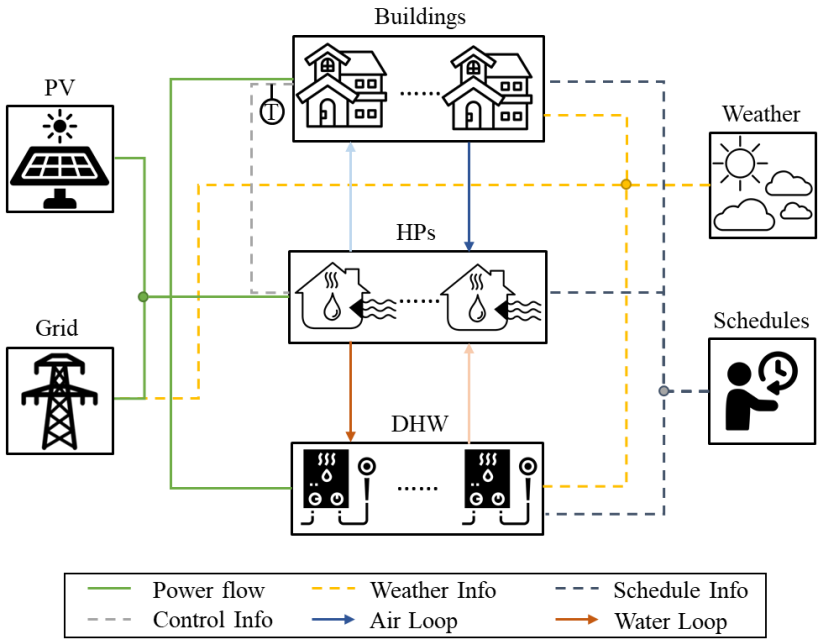
NSF Funded Development

BIGDATA: Collaborative Research: IA: Big Data Analytics for Optimized Planning of Smart, Sustainable, and Connected Communities (9/16-8/21), National Science Foundation, collaboration with Virginia Tech.

Smart and Connected Community Library



Net-Zero Energy Community Library



CU Boulder

- Dr. Wangda Zuo
- Xing Lu
- Kathryn Hinkelman
- Jessica Stershic
- Jing Wang

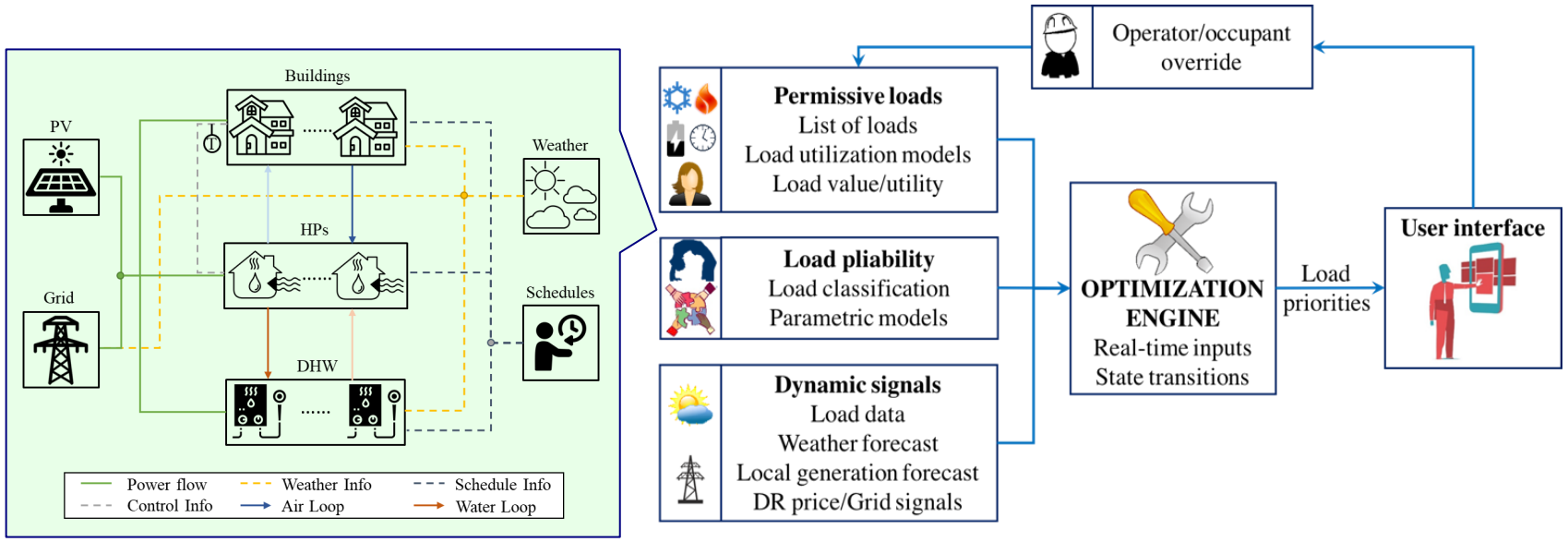
Virginia Tech

- Dr. Walid Saad
- Dr. Harpreet Dhillon

DoE Funded Application

C3PO: Comprehensive Pliant Permissive Priority Optimization (10/18-9/20), Department of Energy, collaboration with PNNL and ORNL.

- Stochastic occupancy module
- Occupancy-based control
- Occupant-centric optimization



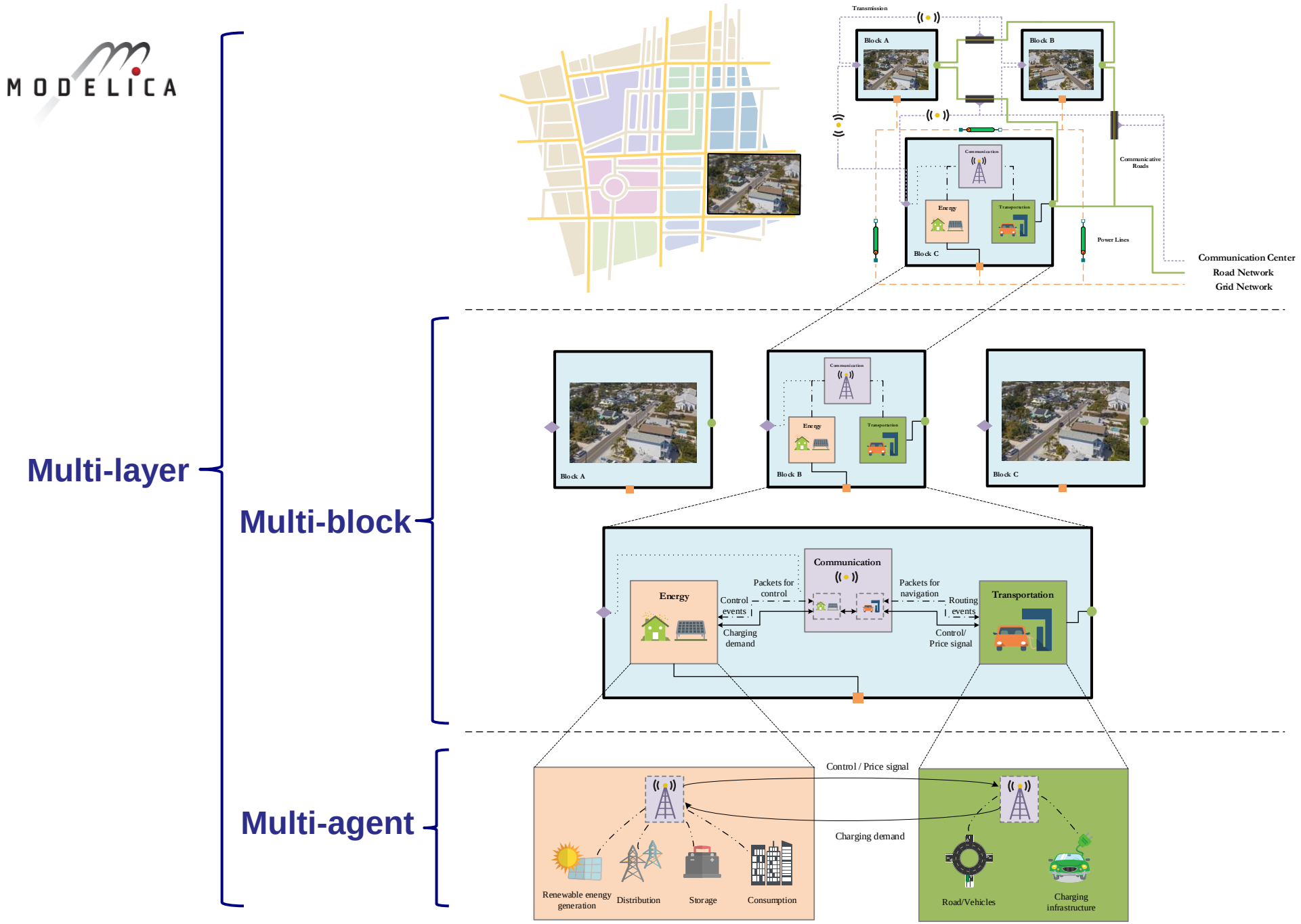
Framework to dynamically value and classify building loads

CU Boulder
- Dr. Wangda Zuo
- Jing Wang

PNNL
- Dr. Draguna Vrabie
- Dr. Sen Huang

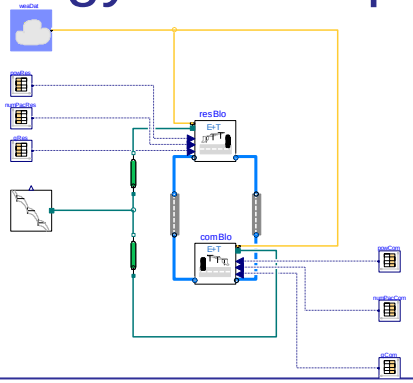
ORNL
- Dr. Piljae Im
- Dr. Yeonjin Bae
- Dr. Jian Sun

SCC Library - Proposed Framework

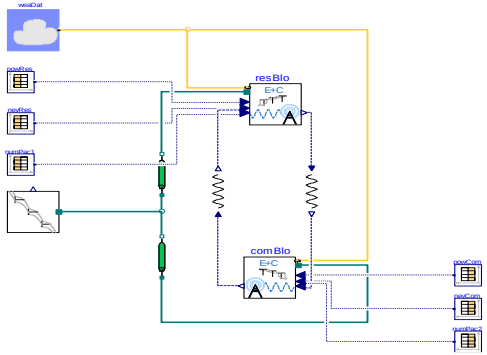


SCC Library - Models

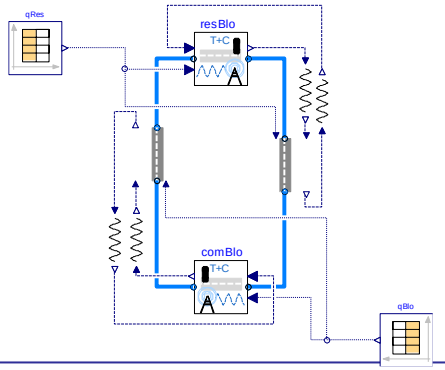
Energy + Transport



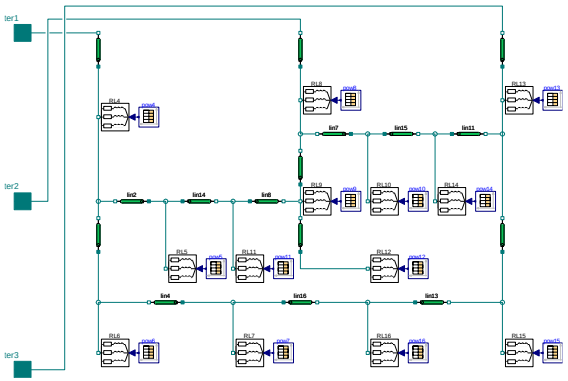
Energy + Comm.



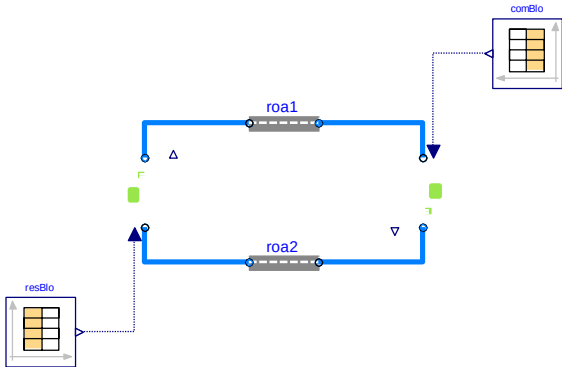
Transport + Comm.



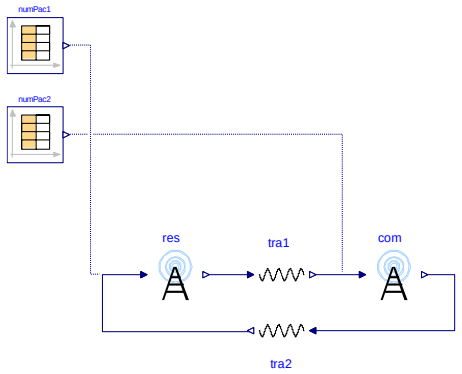
Distribution System



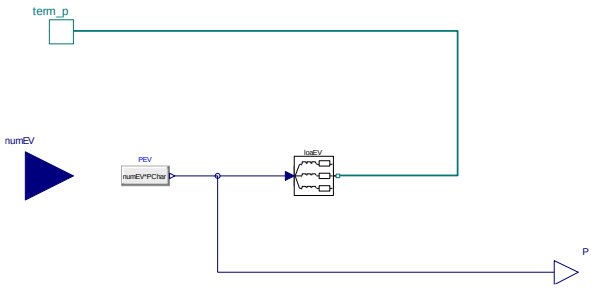
Transportation System



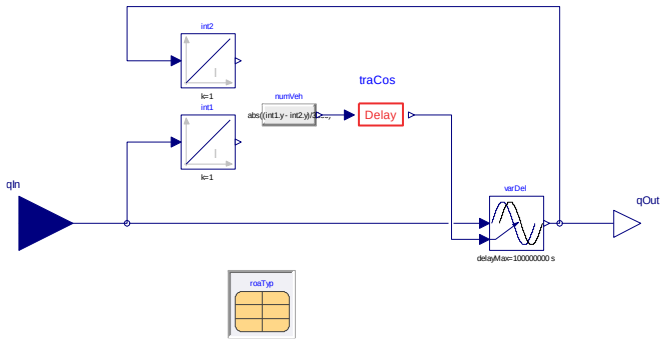
Communication System



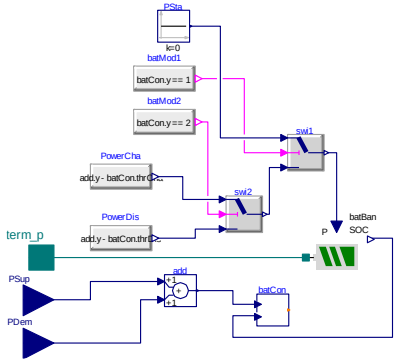
EV Charging



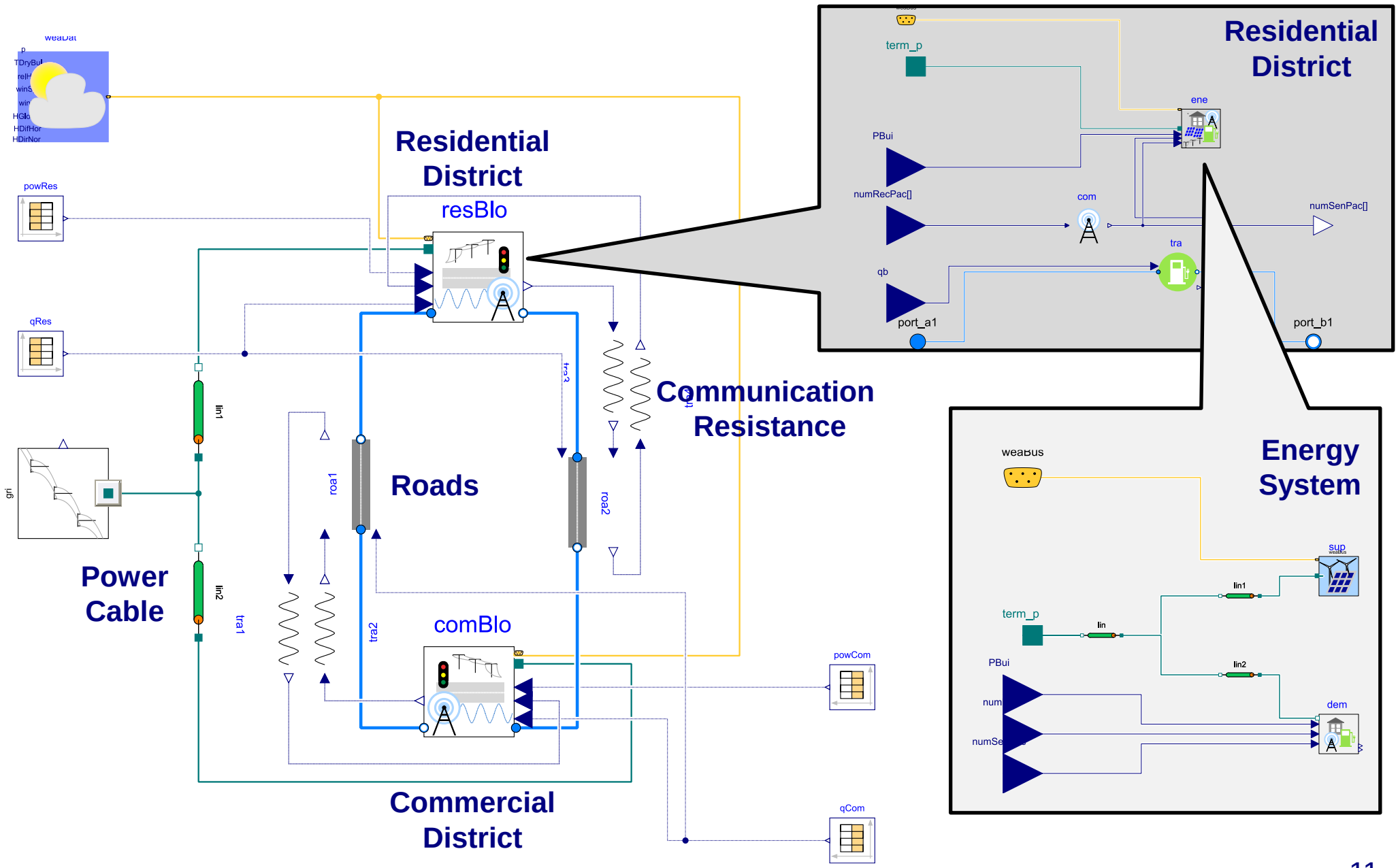
Road



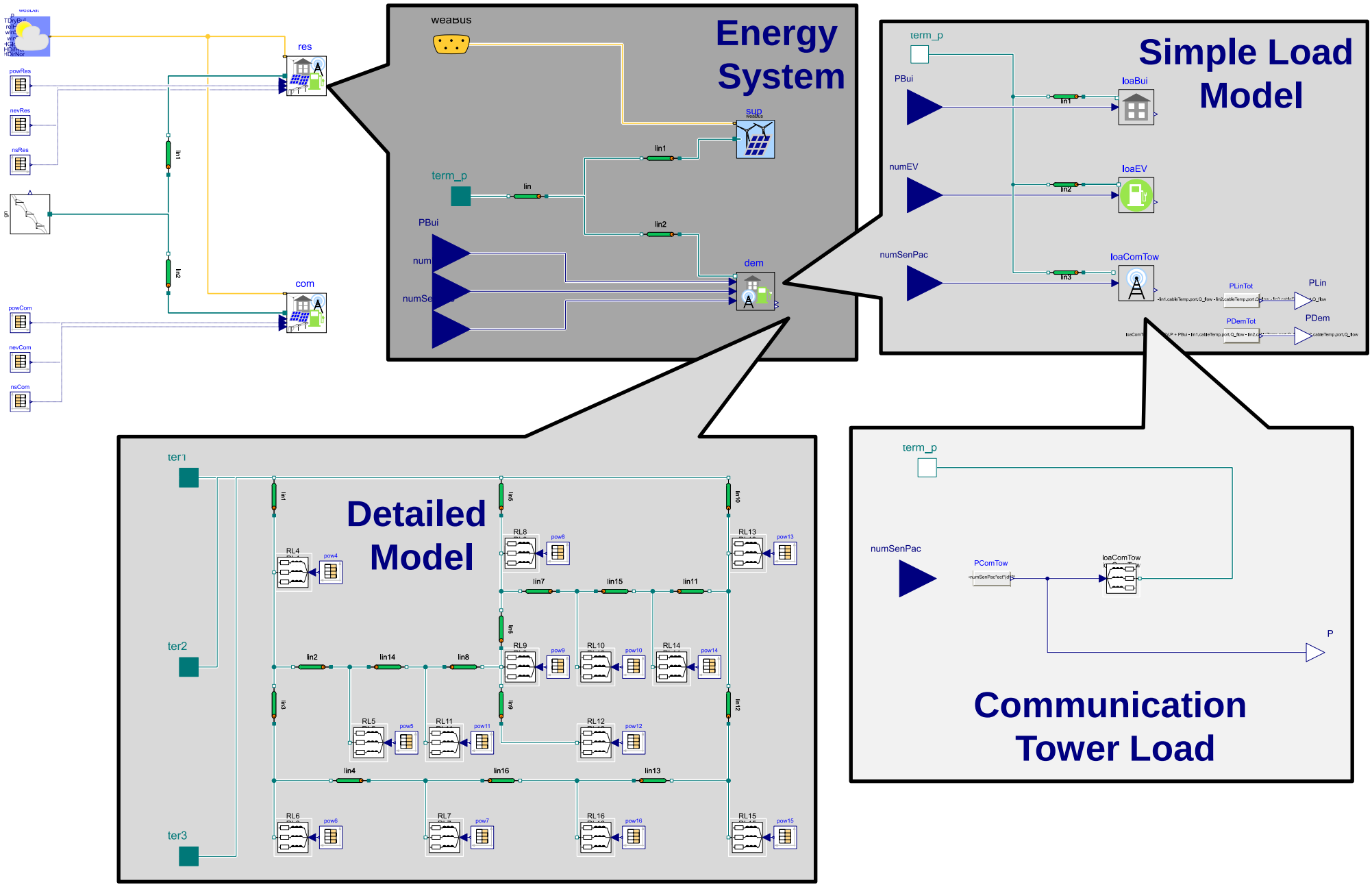
Battery



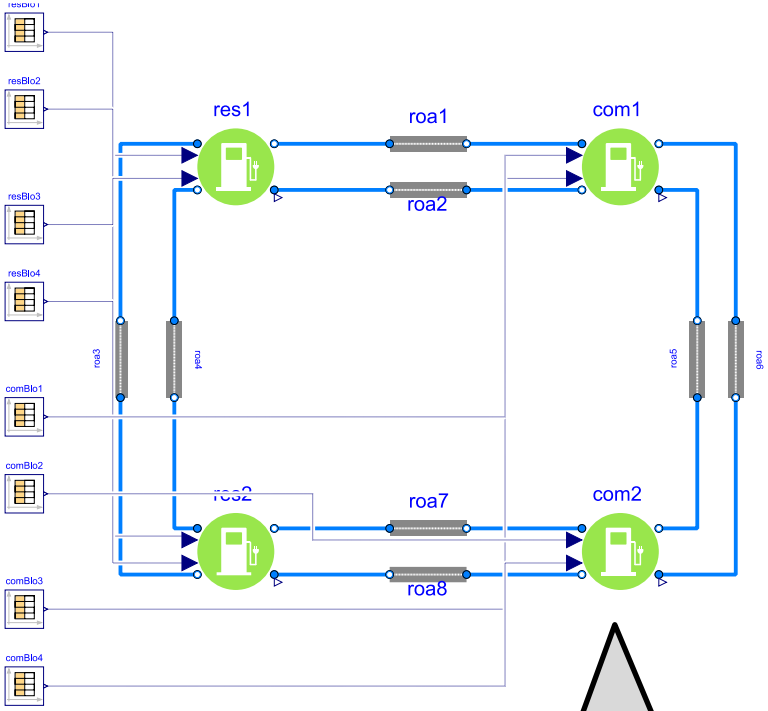
Coupled Infrastructure Networks

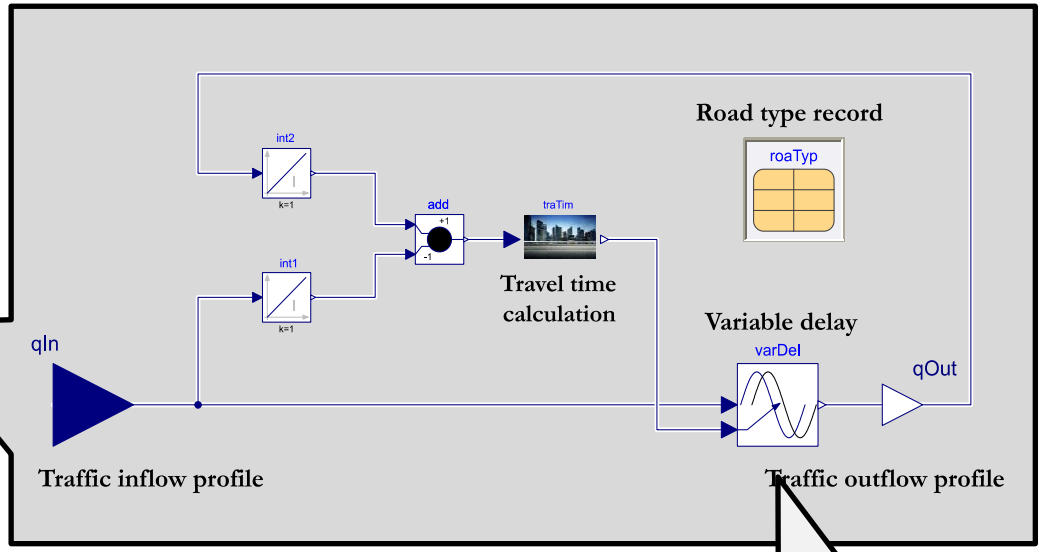


Energy Model



Transportation Model





Charging Station Model

$$\dot{N} = \sum_{i=1}^{k_{in}} q_{in} - \sum_{i=1}^{k_{out}} q_{out}$$

Road Model

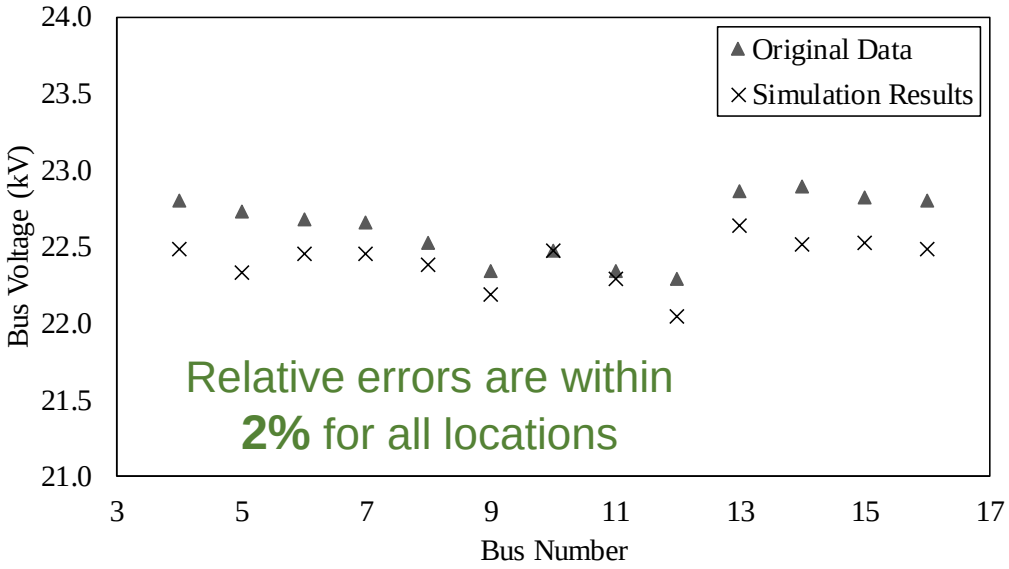
$$\begin{cases} \mathrm{U} = \dfrac{\alpha_1 U_s}{1 + \left(\dfrac{V}{C}\right)^{\beta}} \\ \beta = \alpha_2 + \alpha_3 \left(\dfrac{V}{C}\right)^3 \end{cases}$$

$$\mathrm{V} = \frac{\mathrm{U} \cdot \int (q_{out} - q_{in}) dt}{L}$$

Validation

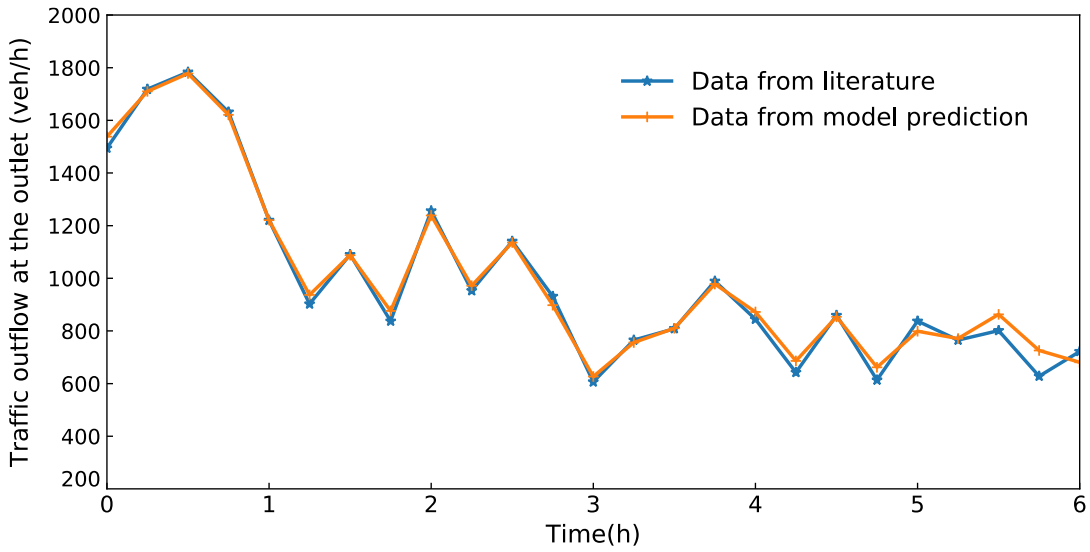
Power Distribution

Literature Comparison:
Civanlar, S., Grainger, J. J., Yin, H., & Lee, S. S. H. (1988). Distribution feeder reconfiguration for loss reduction, in IEEE Transactions on Power Delivery, 3, 3, 1217-1223.

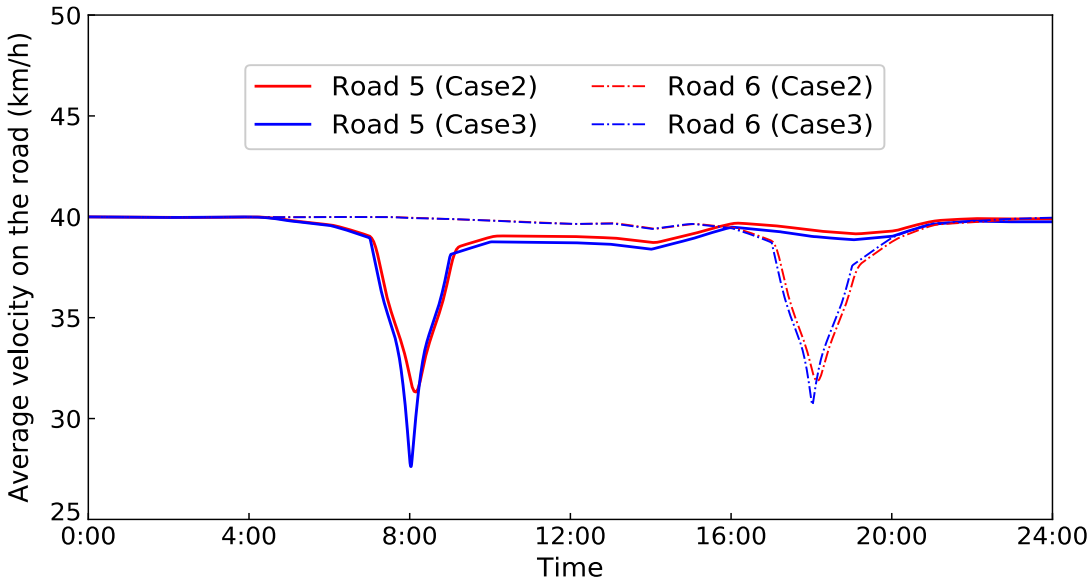


Road Model

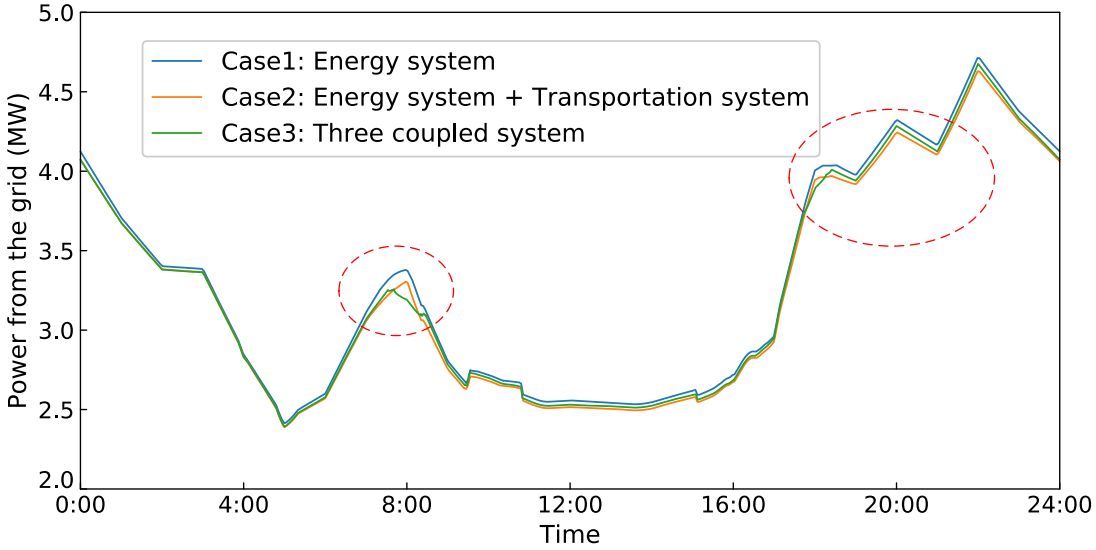
Literature Comparison:
Ang, K. C. & Neo, K. S. (2005). Real-life application of a simple continuum traffic flow model,' International Journal of Mathematical Education in Science and Technology, 36, 8, 913–922.



Case Study



(a)

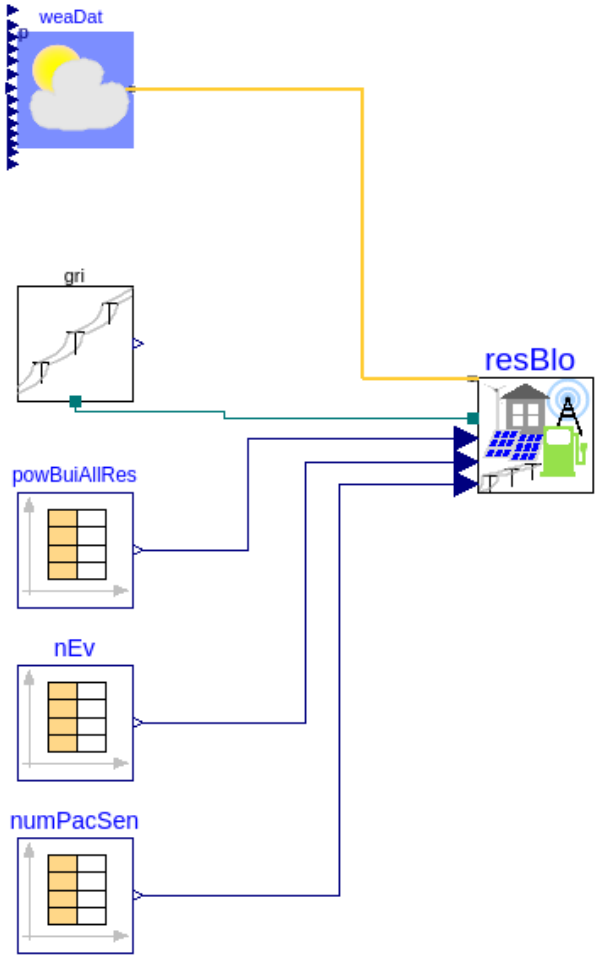


(b)

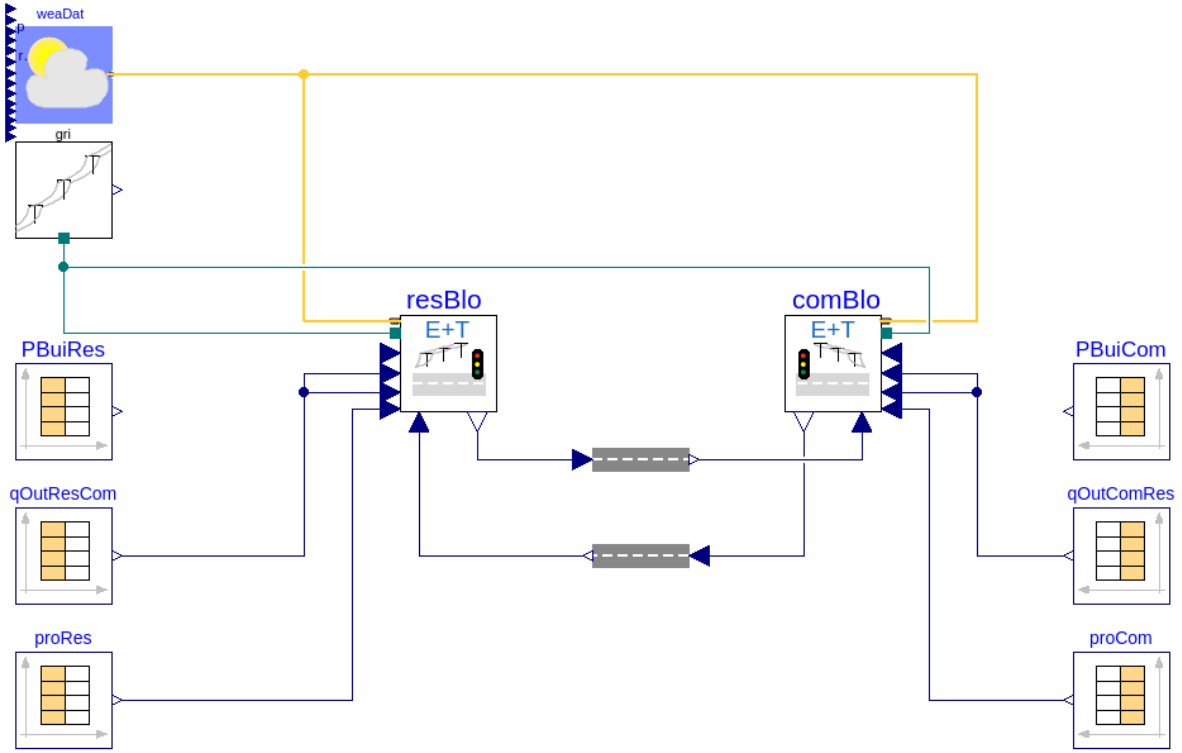
- At high traffic hours (around 8:00 and 18:00), the communication system deteriorates the traffic condition due to poor packet arrival rates.
- The deviation of power draw prediction increases during the peak commuting times (circled). The largest deviation ratio of 7% occurs around 8:00.

Workshop Tutorials

Tutorial 1: Residential District



Tutorial 2: Coupling Energy and Transportation Systems



Summary

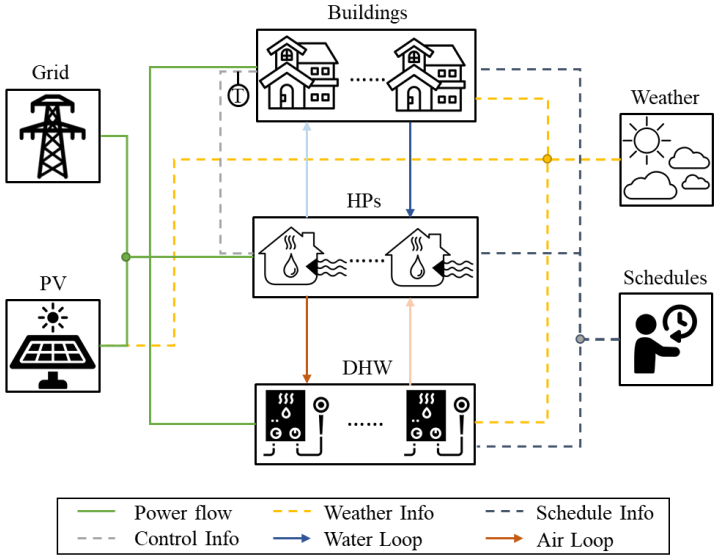
- We developed a multi-domain modeling framework, which integrates the energy, transportation, and communication systems.

- An open source Modelica Smart and Connected Community (SCC) library utilizing our 3M approach has been released.

- The workshop cases demonstrate the application of the modeling framework for studying the operation of future connected communities.

Net Zero Energy Community (NZEC) Library

- What?
  - An open source library for the NZECs
  - This library consists of
    - components for subsystem of NZECs
    - A system model for a real-world NZEC in Florida
- Who should use it?
  - Building owners who seek for economically sound design
  - Building operators who seek for optimal and resilient operation
  - Researchers who develop advanced control strategies

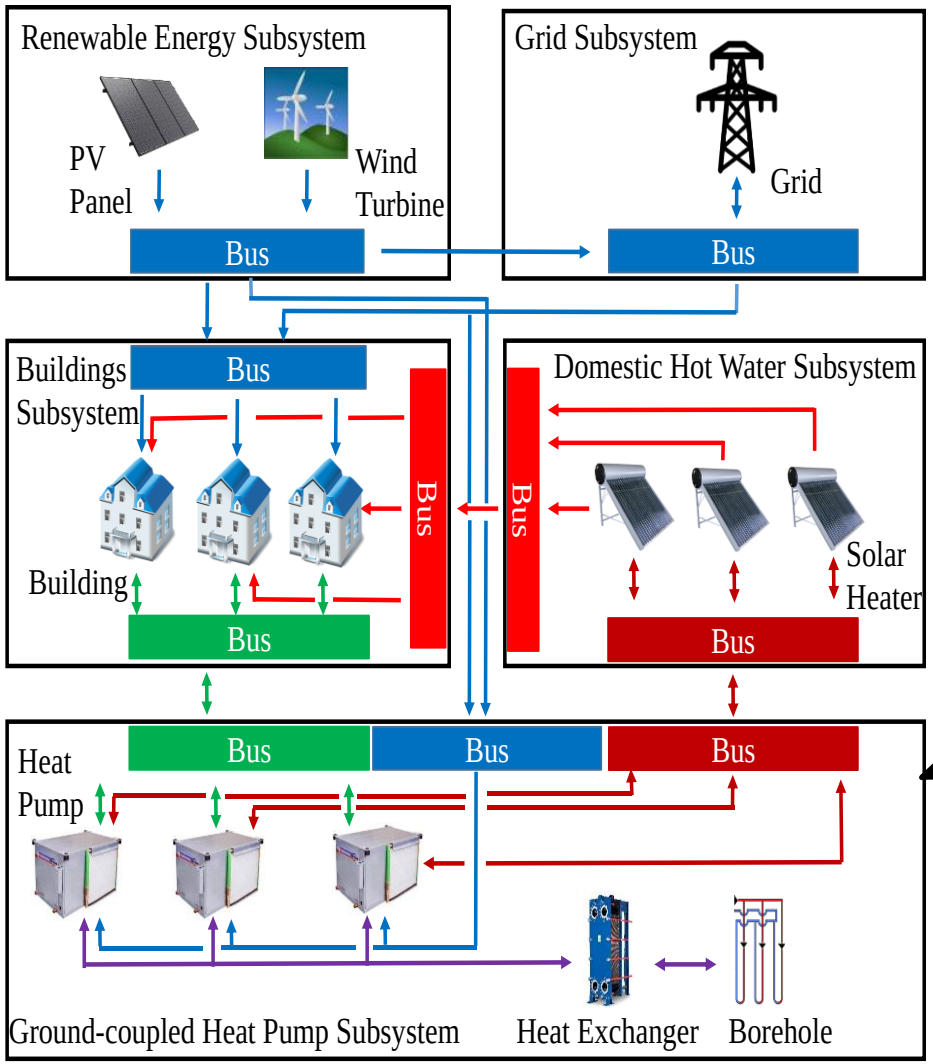


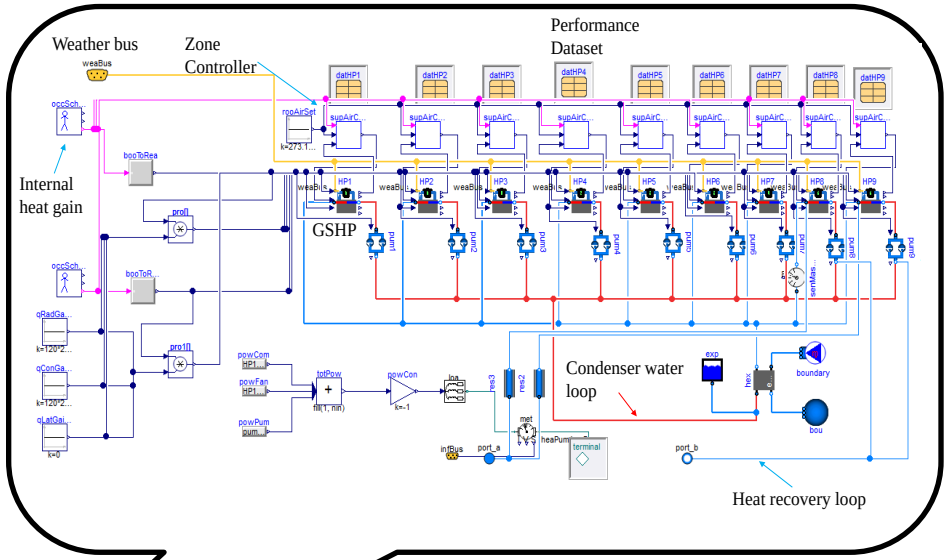
Subsystems

Historical Green Village

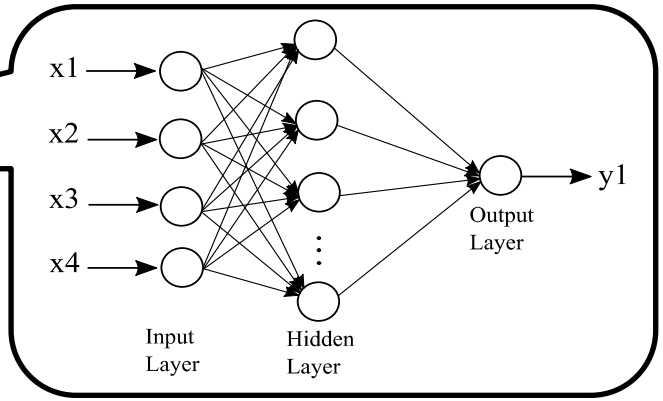
Major components

- Containing both physics-based (Modelica) and data-driven (ANN) models
- Standard interfaces for considering the interactions between subsystems





Physics-based

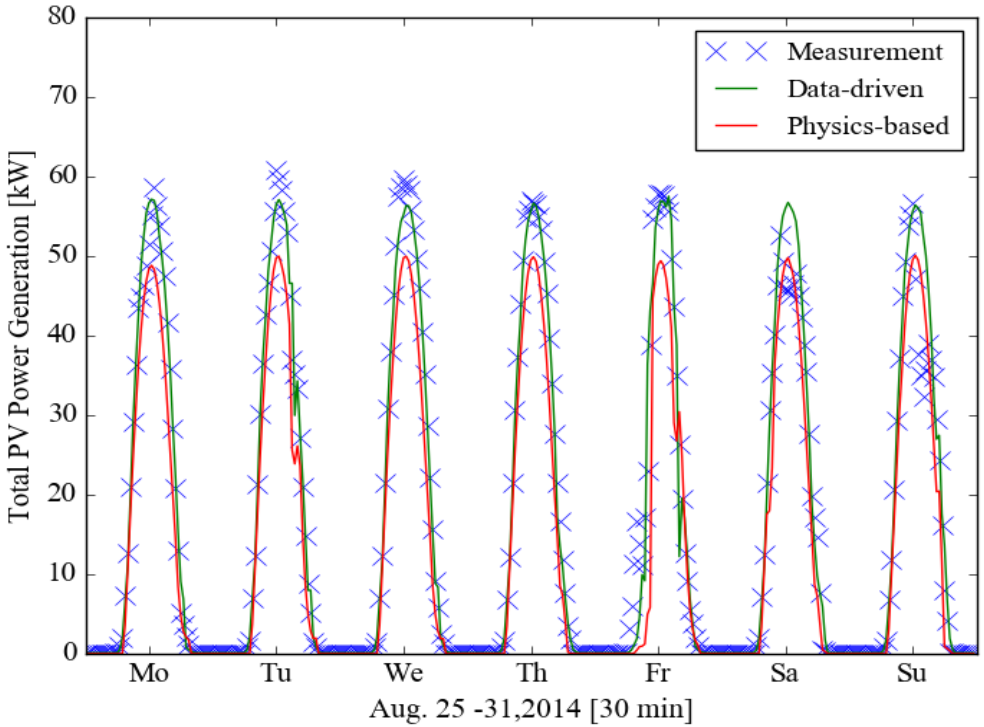


Data-driven

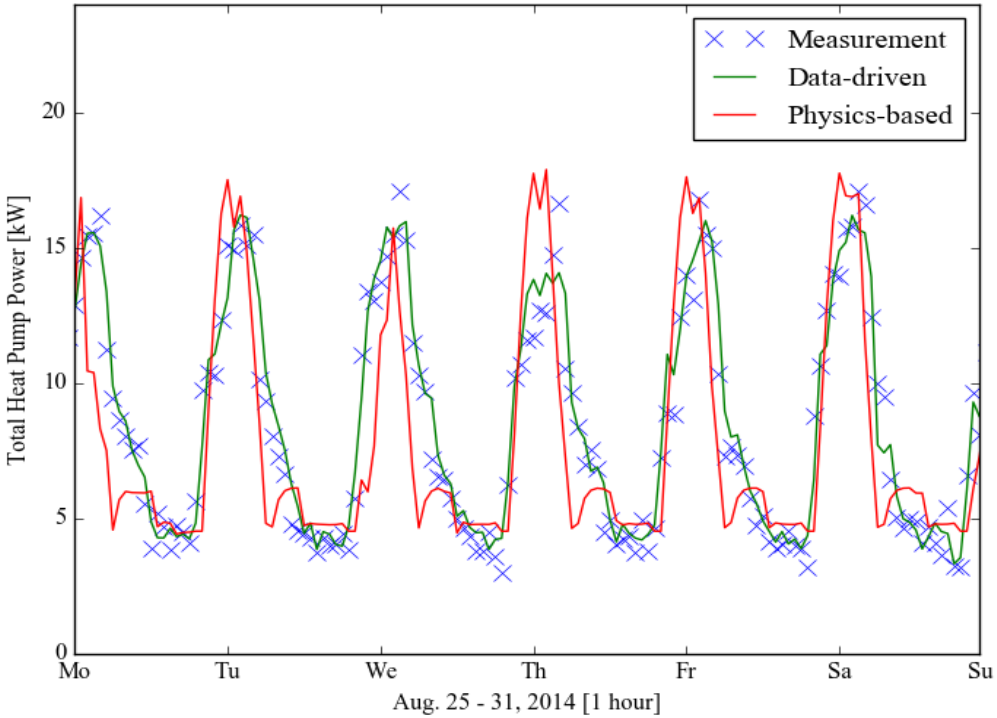
Electricity
Domestic Hot Water
Heating /Cooling Air
Heating /Cooling Water
Recovered Heat

Components - Validations

- Unit tests were performed to validate the accuracy of the components



PV



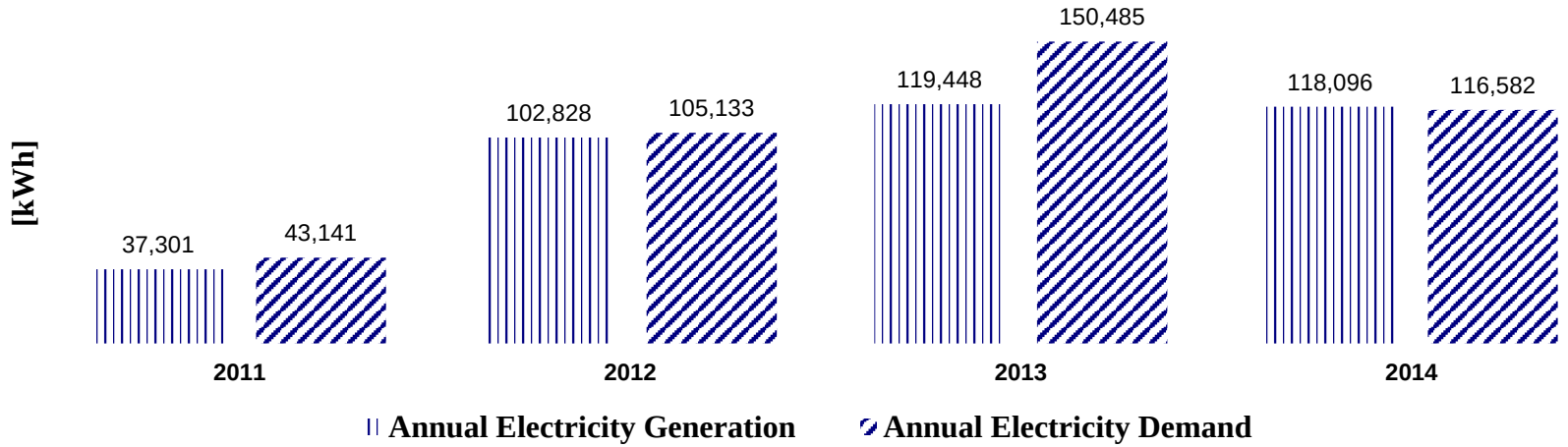
Heat Pump

Historical Green Village

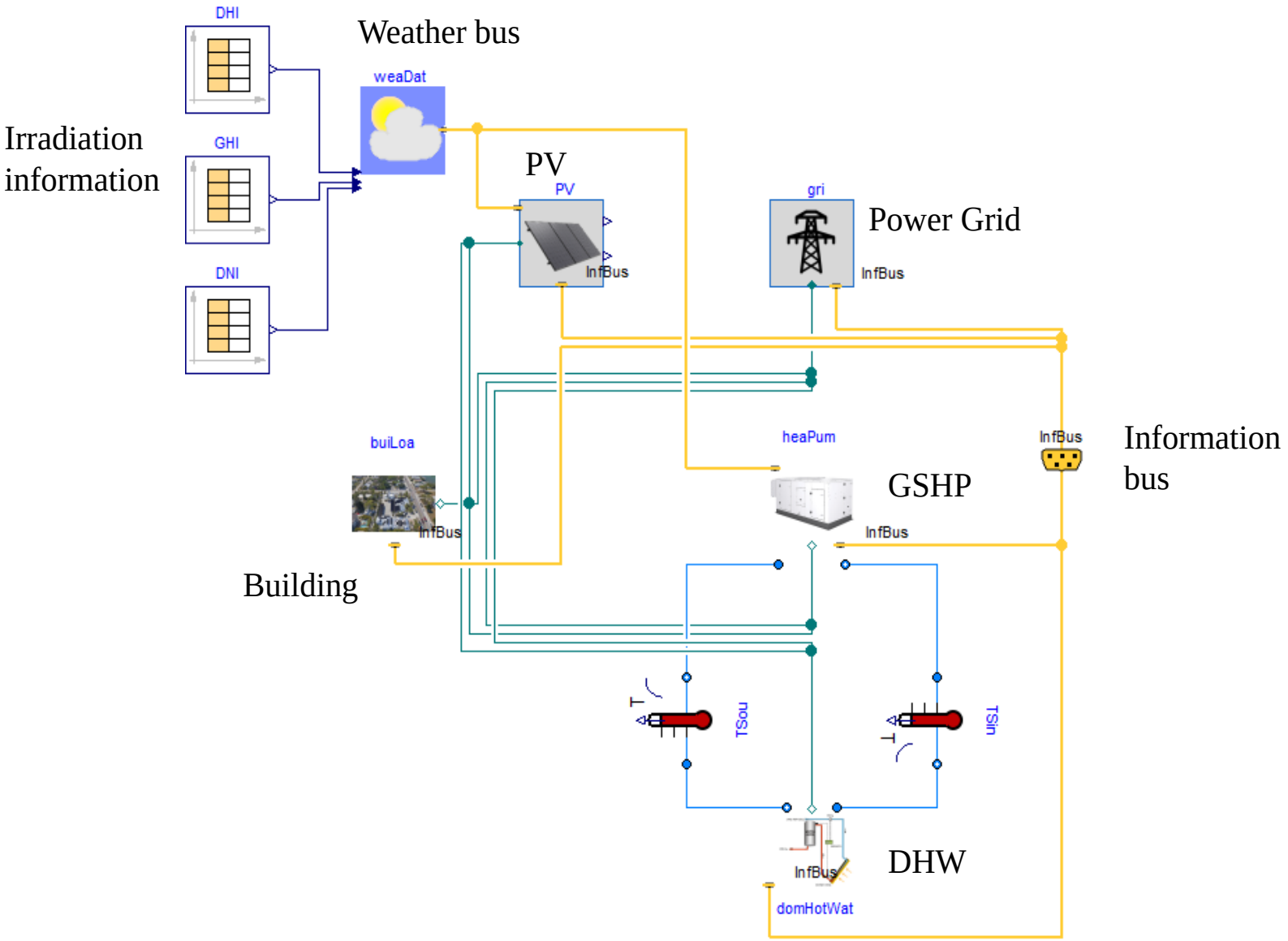
A community consisting of both residential buildings and commercial buildings

Location	Anna Maria Island, FL			
Building	**Type**	**Floor area (m^2)**	**HVAC system (kW)**	**DHW system**
F	Bakery	410	HP (19.5)	Gas heater
G1	Office	95	HP (8.22)	Gas heater
G2	Residential	95	HP (8.22)	Solar thermal water heater
A1-W	Gift shop	88	HP (8.22)	Electric heater
A1-E	Gift shop	56	HP (11.07)	
A2	Residential	94	HP (11.07)	Solar thermal water heater
D	Gift shop	95	HP (15.07)	Electric heater
C1	General store kitchen	120	HP (15.07)	Solar thermal water heater
C2	Ice cream shop	40	HP (15.07)	

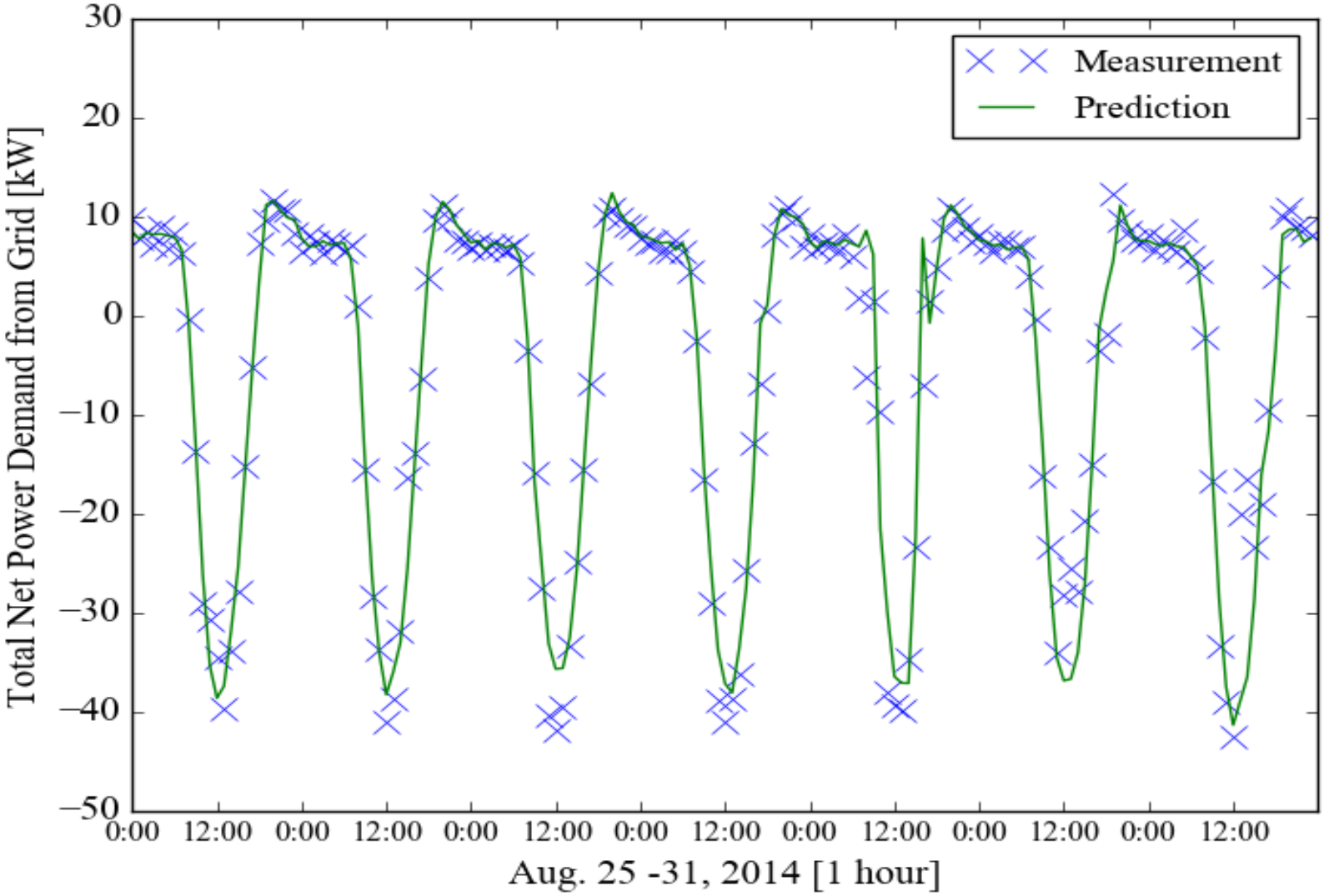
Achieved the net zero energy goal in 2014



System Model - Model Diagram

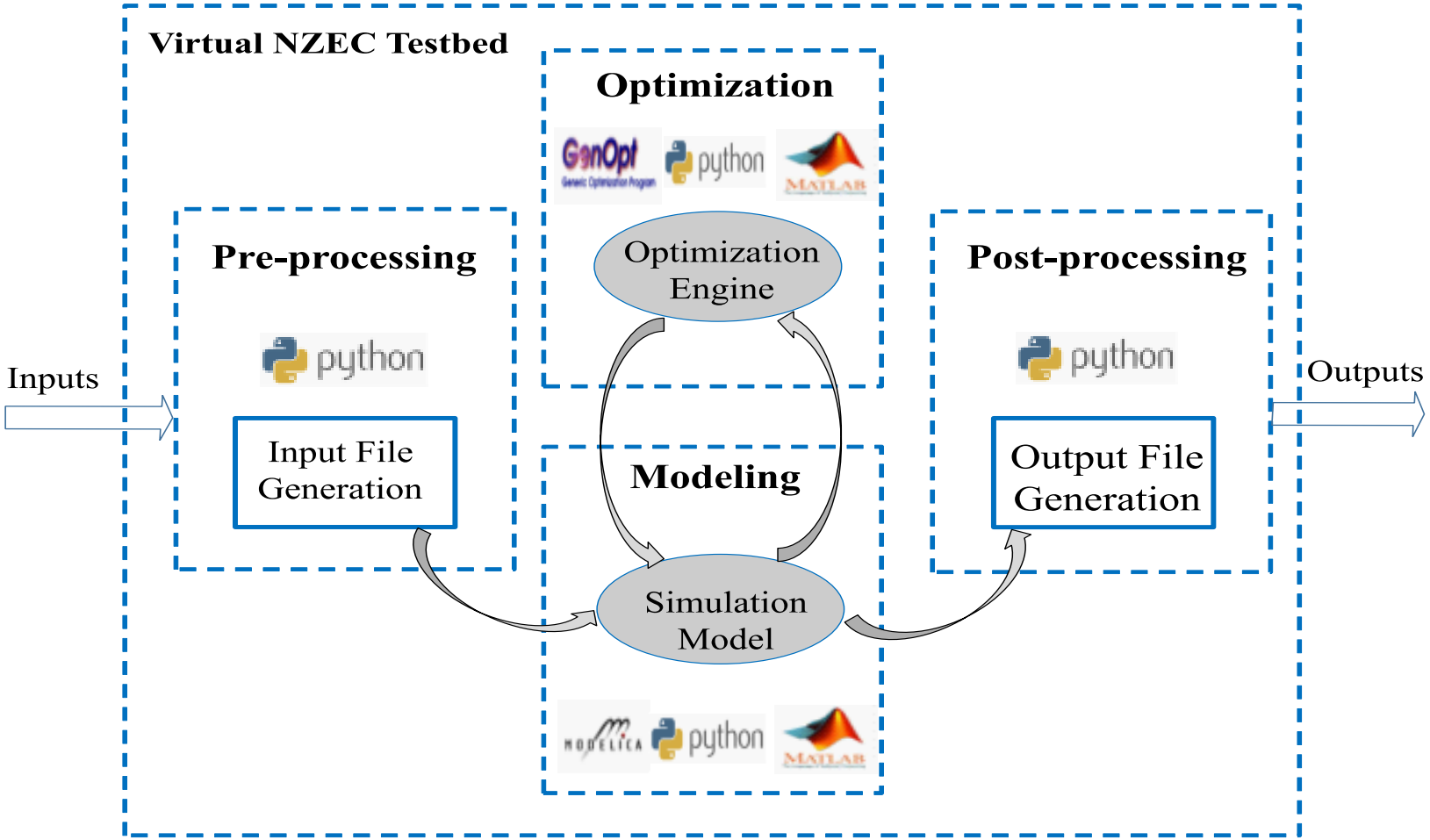


System Model - Validation



System Model - Virtual Testbed

- A software framework for facilitating the usage of the system model for design and control optimization purposes



Summary

- Basics of creating system-level models using Modelica has been introduced.
- The design purposes and contents of two Modelica libraries were introduced.
- The attendees should now be more familiar with the Modelica language and its application in cyber-physical system modeling for smart and sustainable communities.
- Future work:
  - Improvement by enabling occupant-centric control
  - Dissemination through IBPSA Project 1 WP3 Applications

References

1. X. Lu, K. Hinkelman, Y. Fu, J. Wang, W. Zuo, Q. Zhang, W. Saad 2019. “An Open Source Modeling Framework for Interdependent Energy-Transportation-Communication Infrastructure in Smart and Connected Communities.” IEEE Access, 7, pp. 55458-55476.
2. X. Lu, Y. Fu, W. Zuo 2018. “Modeling of Smart Community Infrastructure Accounting for the Interdependencies Among Energy, Transportation and Communication Networks.” 2018 ASHRAE Building Performance Analysis Conference and SimBuild (BPACS 2018), pp. 250-257, September 26-28, Chicago, IL.
3. J. Wang, K. Garifi, K. Baker, W. Zuo, Y. Zhang 2020. “Optimal Operation for Resilient Communities through A Hierarchical Load Scheduling Framework.” Accepted by 2020 Building Performance Modeling Conference and SimBuild, Chicago, USA.
4. J. Wang, W. Zuo, S. Huang, D. Vrabie 2020. "Data-driven Prediction of Occupant Presence and Lighting Power: A Case Study for Small Commercial Buildings." Accepted by the American Modelica Conference 2020, Boulder, USA.
5. D. He, S. Huang, W. Zuo, R. Kaiser 2016. “Towards to the Development of Virtual Testbed for Net Zero Energy Communities.” Proceedings of the ASHRAE and IBPSA-USA SimBuild 2016: Building Performance Modeling Conference, pp. 125-132, August 8-12, Salt Lake City, UT.

Q&A

Thank You!

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Wangda Zuo
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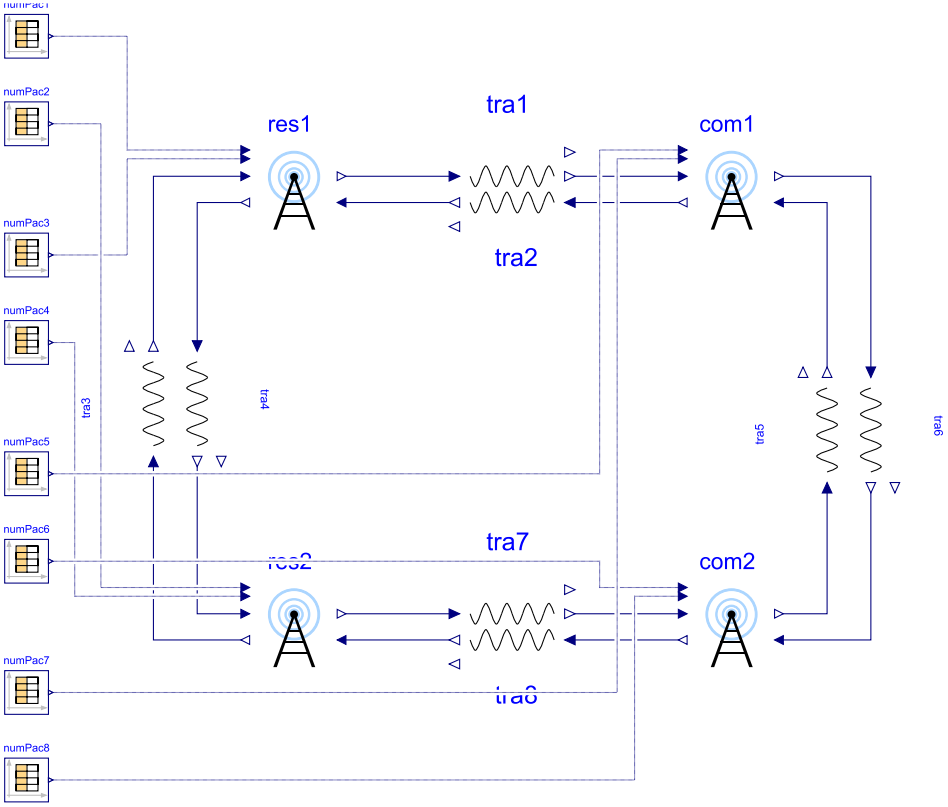
Downloading and License Information

- Download the libraries and tutorials through the following links:
  - SCC
  - https://www.colorado.edu/lab/sbs/scc-library
  - NZEC
  - https://www.colorado.edu/lab/sbs/nzec-library
- Open Dymola to open the libraries
- Open tutorials for step-by-step guide
- Questions?

Communication Model



Packet Loss Model

$$\gamma = \kappa\sqrt{Q - C}$$

Packet loss rate

Proportionality constant

Normalized throughput

Transmission threshold

Open-Source Release

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

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

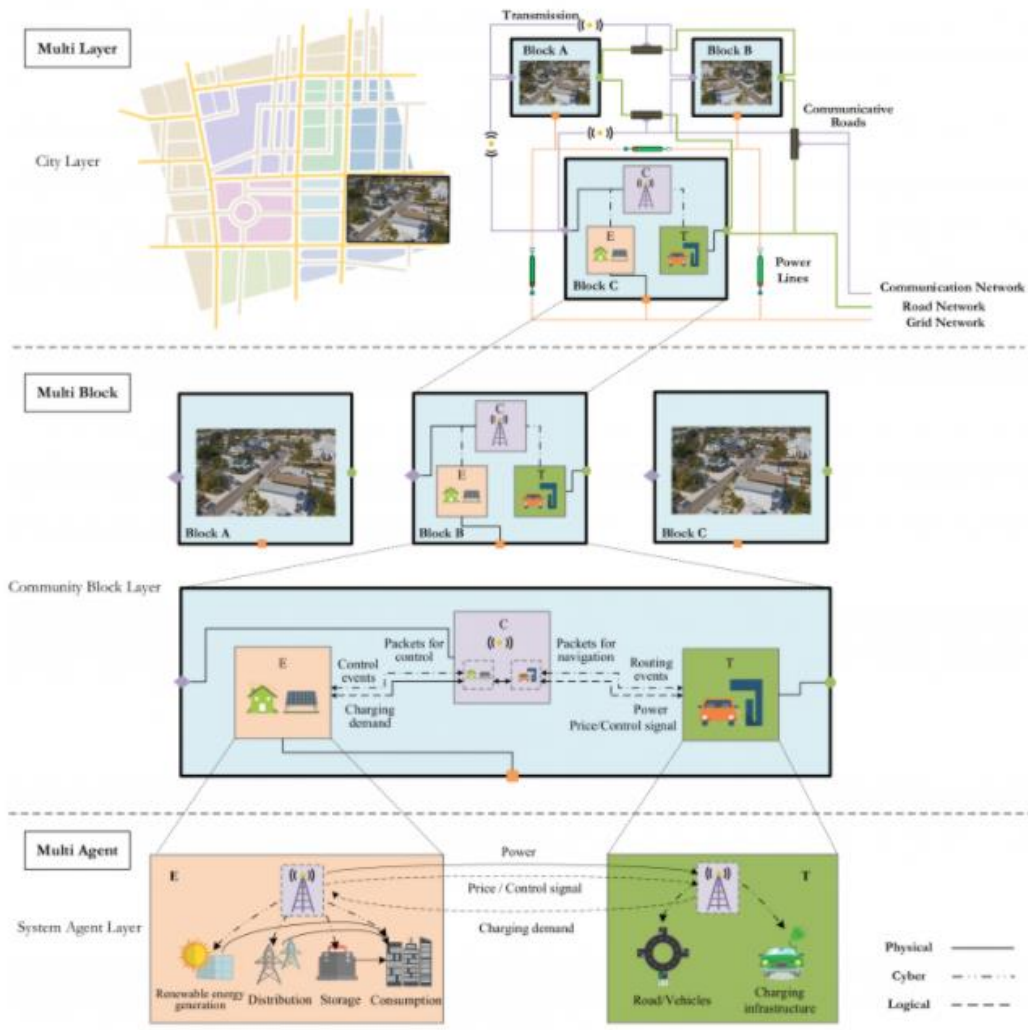
Release Notes

- **07/28/2020: SCC-Smart-City library V1.1 released.**
  - Updates the case study models and includes the tutorial models.
- **03/27/2019: SCC-Smart-City library V1.0 released.**
  - First release of the library. It contains component and system models supporting city-scale interdependent energy, transportation, and communication system modeling.

Acknowledgement

The SCC library is the outome of the project "BIGDATA: Collaborative Research: IA: Big Data Analytics for Optimized Planning of Smart, Sustainable, and Connected Communities" sponsored by the National Science Foundation (Awad No. IIS-1802017). The project website is here.

Related Publications



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