Simulation-Based Design and Optimization of Waste Heat

(URBANopt District Energy Systems)

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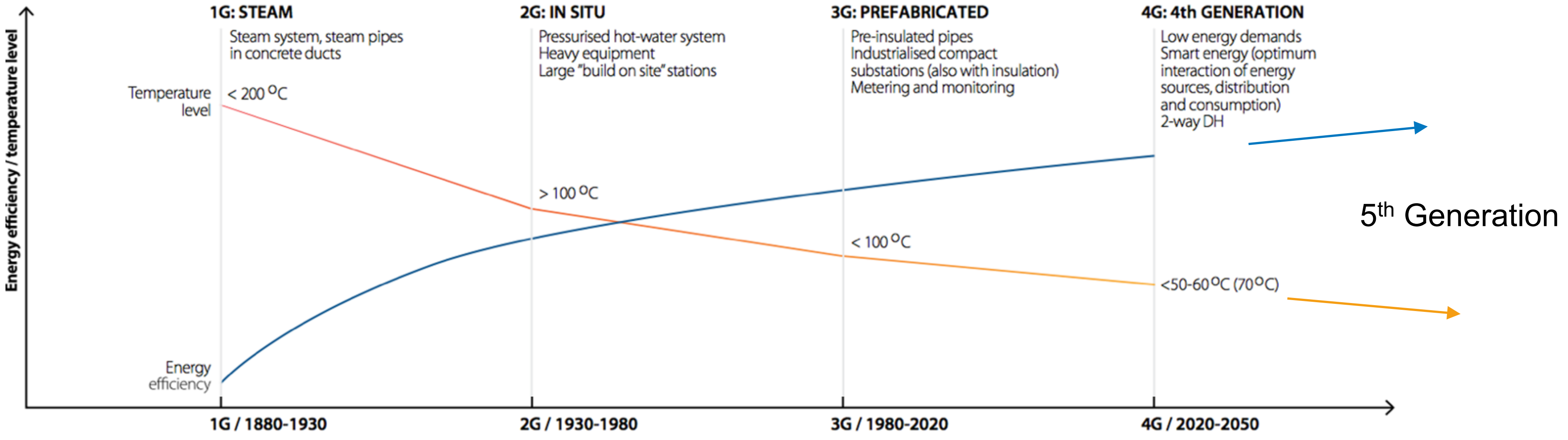
Outline

- Motivation
- Project Objectives
- Modelica Buildings Library Development
- URBANopt SDK
- GeoJSON to Modelica Translator
- Example Results / Case Studies

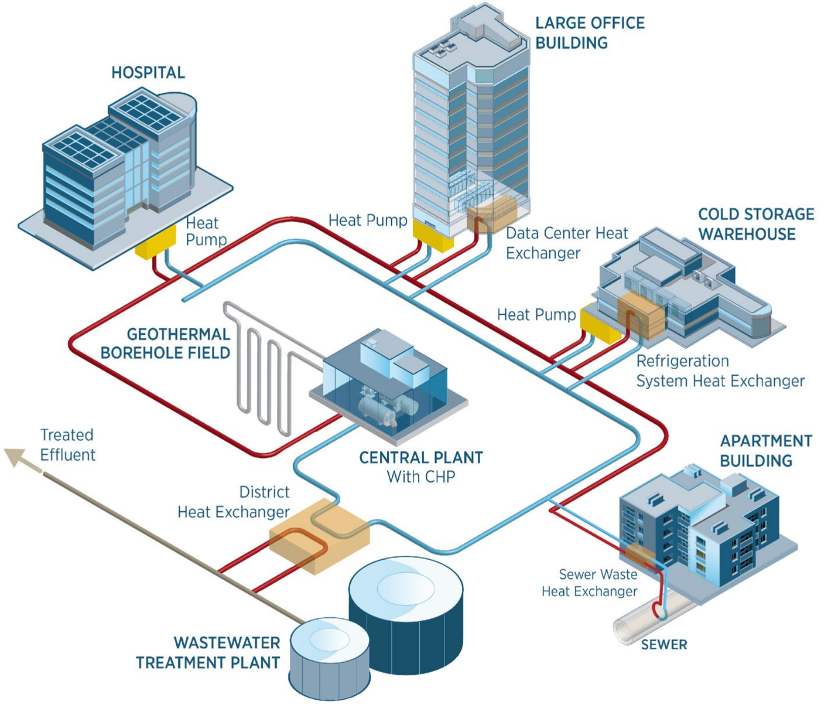
Motivation



Source:
http://ecopolis.danfoss.com

Project Objectives

- Develop analytical models for district energy systems
- Extend existing tools to enable easier modeling of district energy systems
- Integrate additional waste heat sources into analytical framework
- Work with private third-party company to integrate analysis



Source: Marjorie Schott, NREL. Adapted from http://arborus.ca/what-we-do/northern-community-energy-systems/

Modelica Buildings Library Development

Challenges of Low-Temperature Networks (LTN)

- Local boosting of temperature at buildings for heating and cooling
  → More complex Energy Transfer Station (ETS) designs

- Low-temperature lifts increase magnitude and sensitivity of mass flow to load changes
  → Greater emphasis on pump energy and control, pipe designs

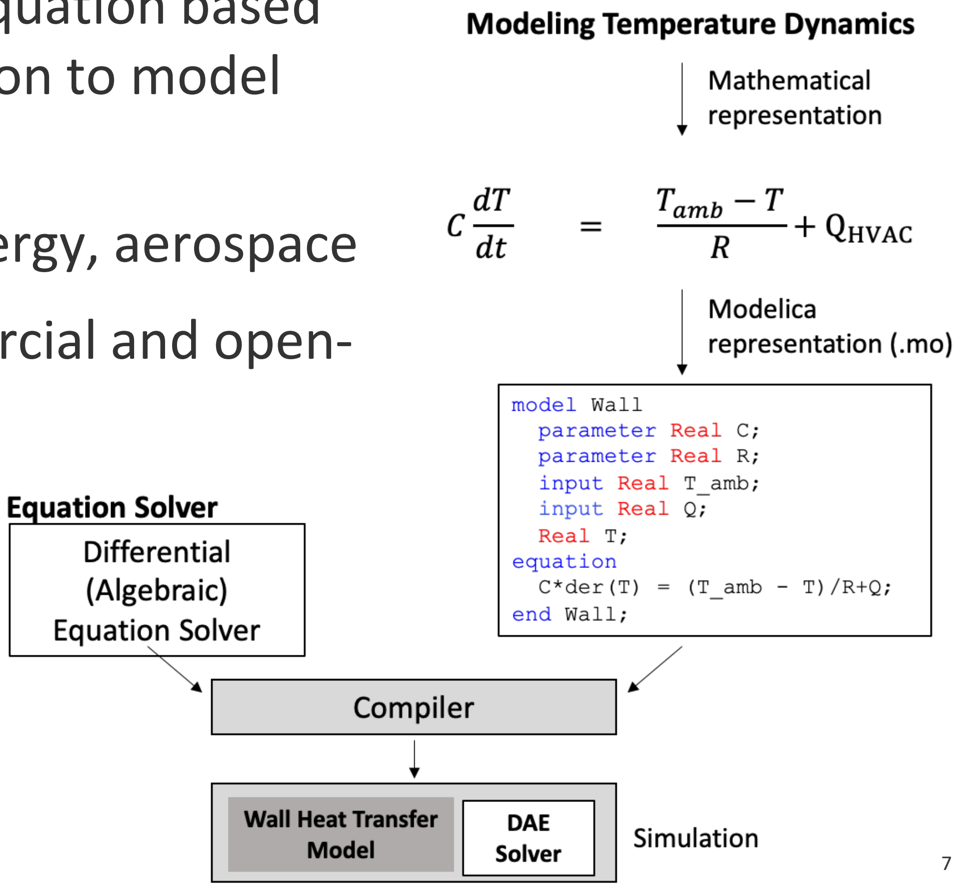
- Bidirectional mass and/or energy flow to enable network-wide heat recovery → Tighter hydronic coupling between network components

<u>Summary</u>

- Control challenges for stable and efficient operation
- Load-based modeling alone is not enough for aiding practical design and operation
- Need dynamic modeling including explicit pressure-flow and control

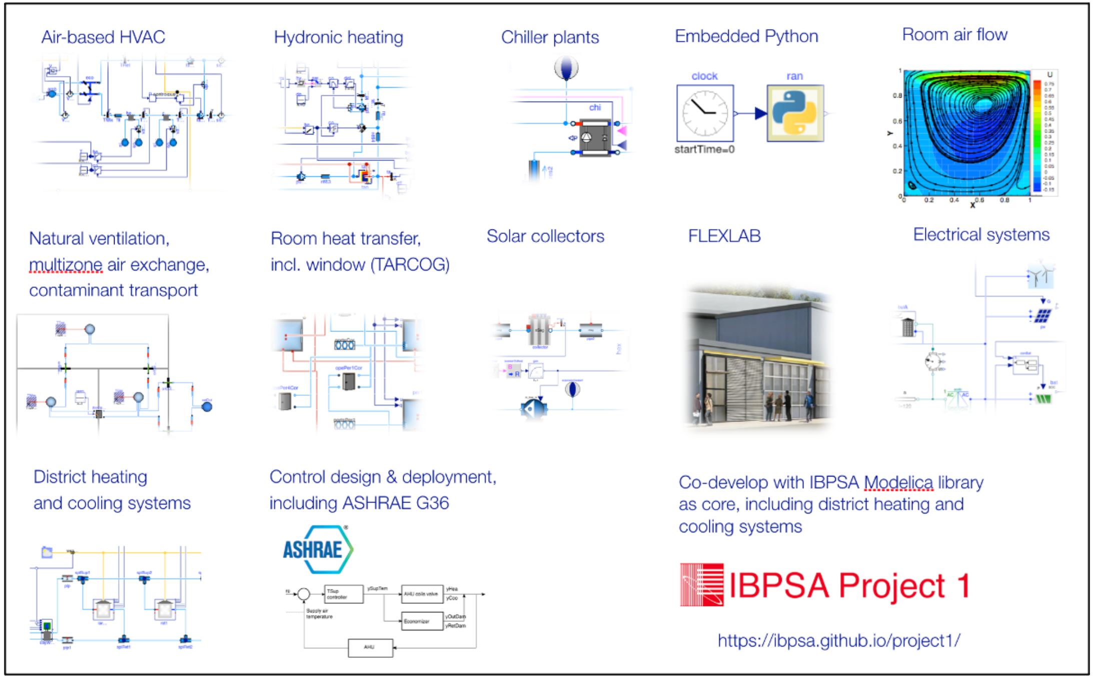
Modelica

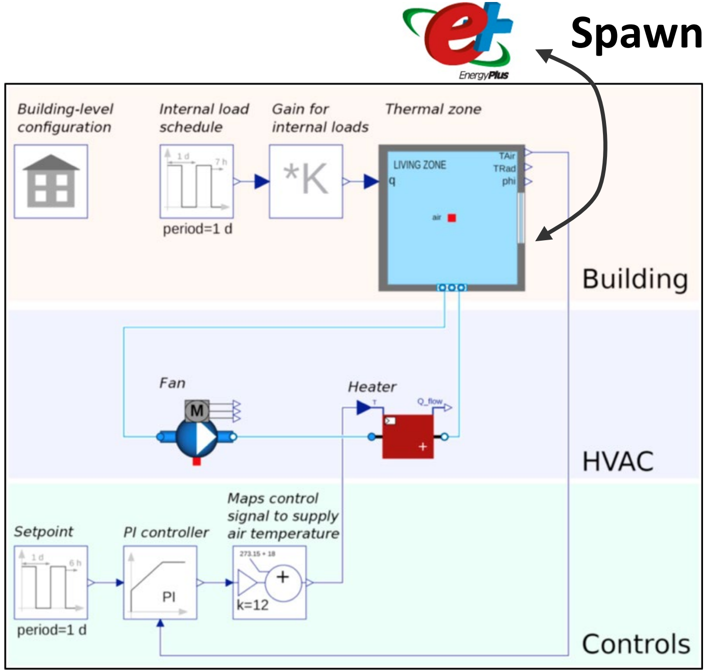
- Modelica is an object-oriented, equation based language with an open specification to model heterogeneous physical systems
- Industry usage in automotive, energy, aerospace
- Open specification allows commercial and open-source compilers
- Separates modeling from simulation to allow for different solvers as-needed, including for nonlinear, hybrid DAEs resulting from pressure-flow and control modeling



Modelica Buildings Library and Spawn

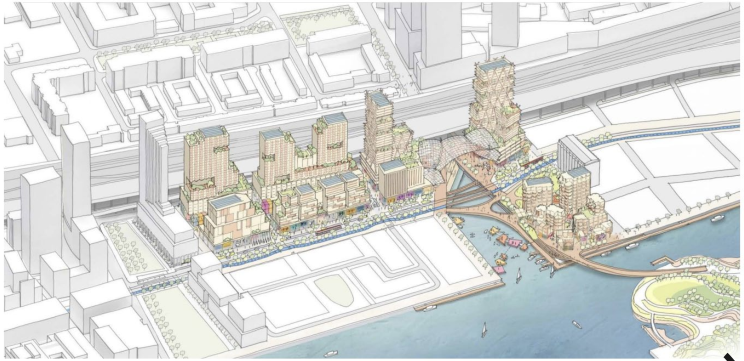
- Open-source repository of 2000+ models and functions
- For building and district energy systems and their controls (explicitly!)



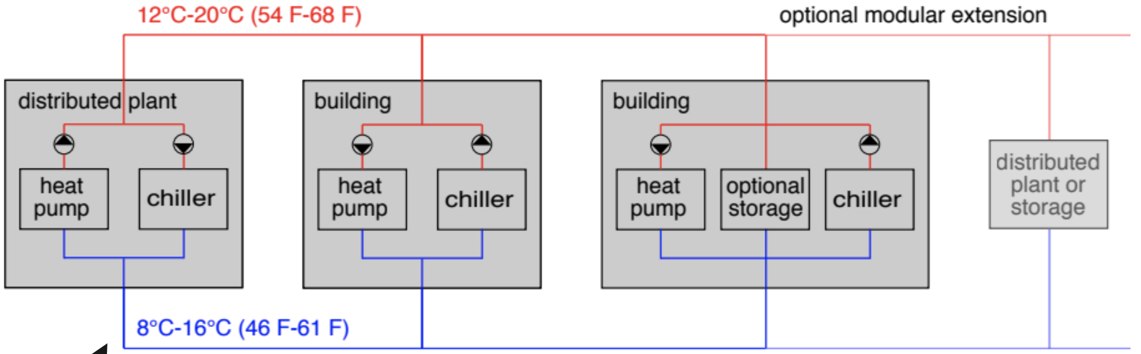


M. Wetter, W. Zuo, T.S. Nouidui, and X. Pang (2014). Modelica Buildings library. *Journal of Building Performance Simulation*, 7(4):253-270. https://doi.org/10.1080/19401493.2013.765506.
M. Wetter, K. Benne, A. Gautier, T.S. Nouidui, A. Ramle, A. Roth, H. Tummescheit, S. Mentzer and C. Winther (2020). Lifting the Garage Door on Spawn, an Open-Source BEM-Controls Engine. *Proc. of Building Performance Modeling Conference and SimBuild*, p. 518–525, Chicago, IL, USA, Sep 2020. https://simulationresearch.lbl.gov/wetter/download/2020-simBuild-spawn.pdf.

An Example Case: “Bidirectional” System Control

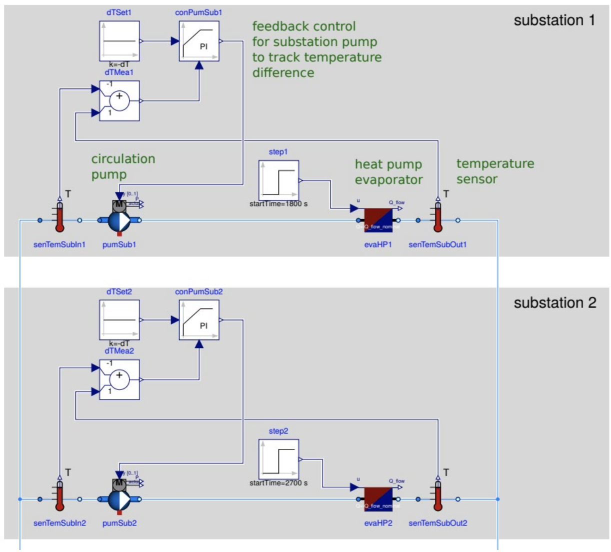


Quayside Development Project, Toronto, CN

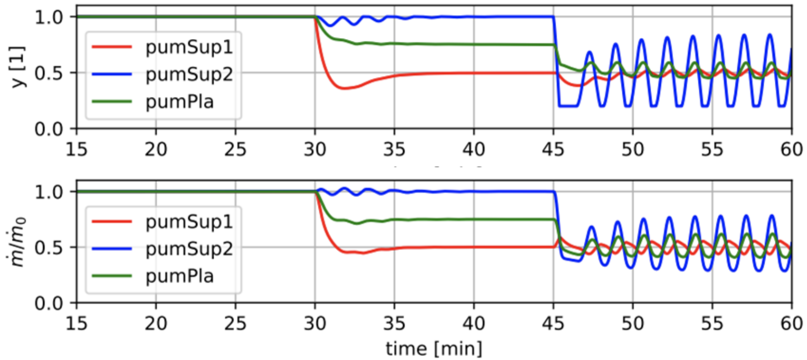


Proposed LTN
(“Parallel Bidirectional”)

Modelica Modeling



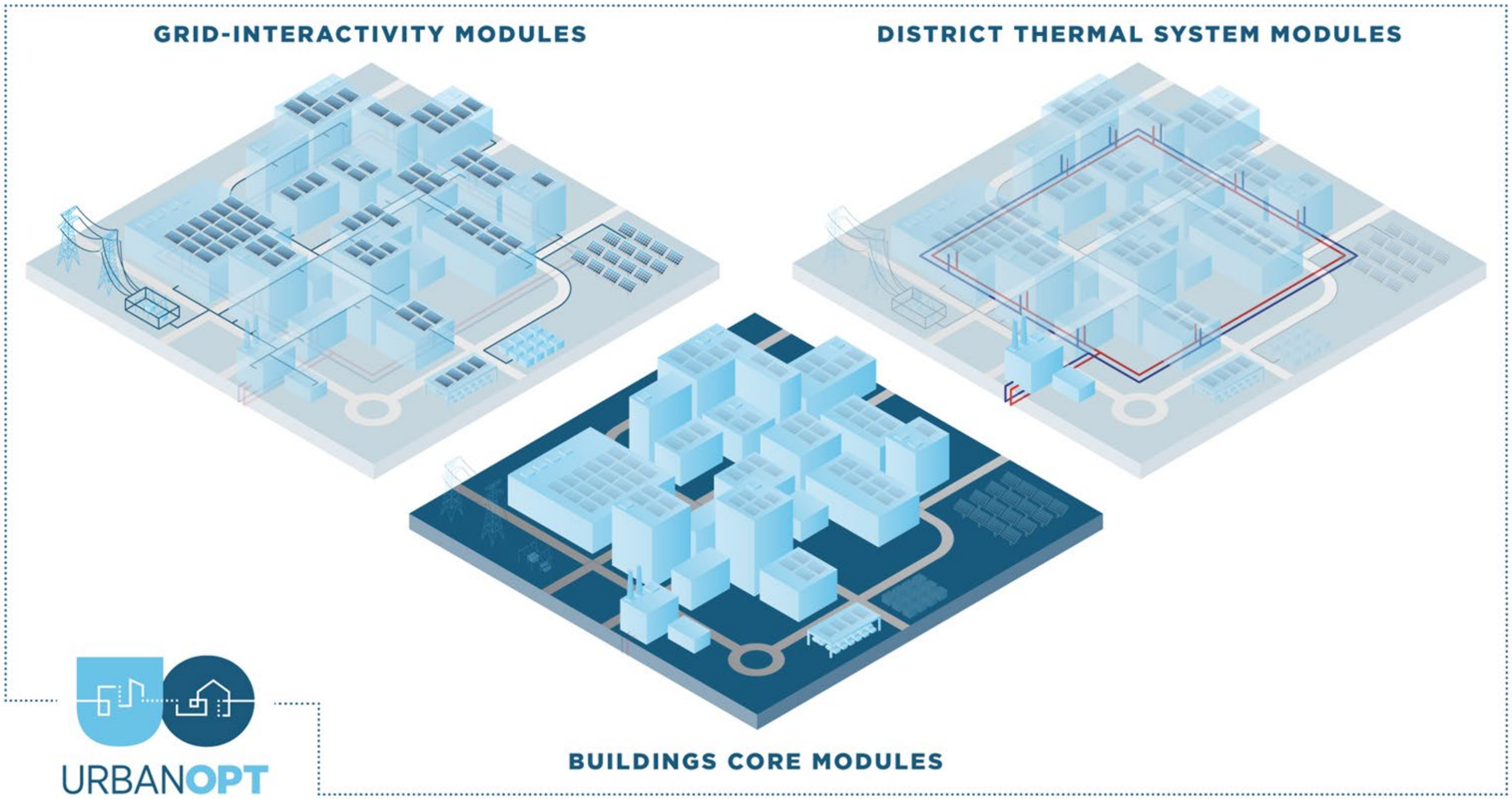
Control Instability Simulation



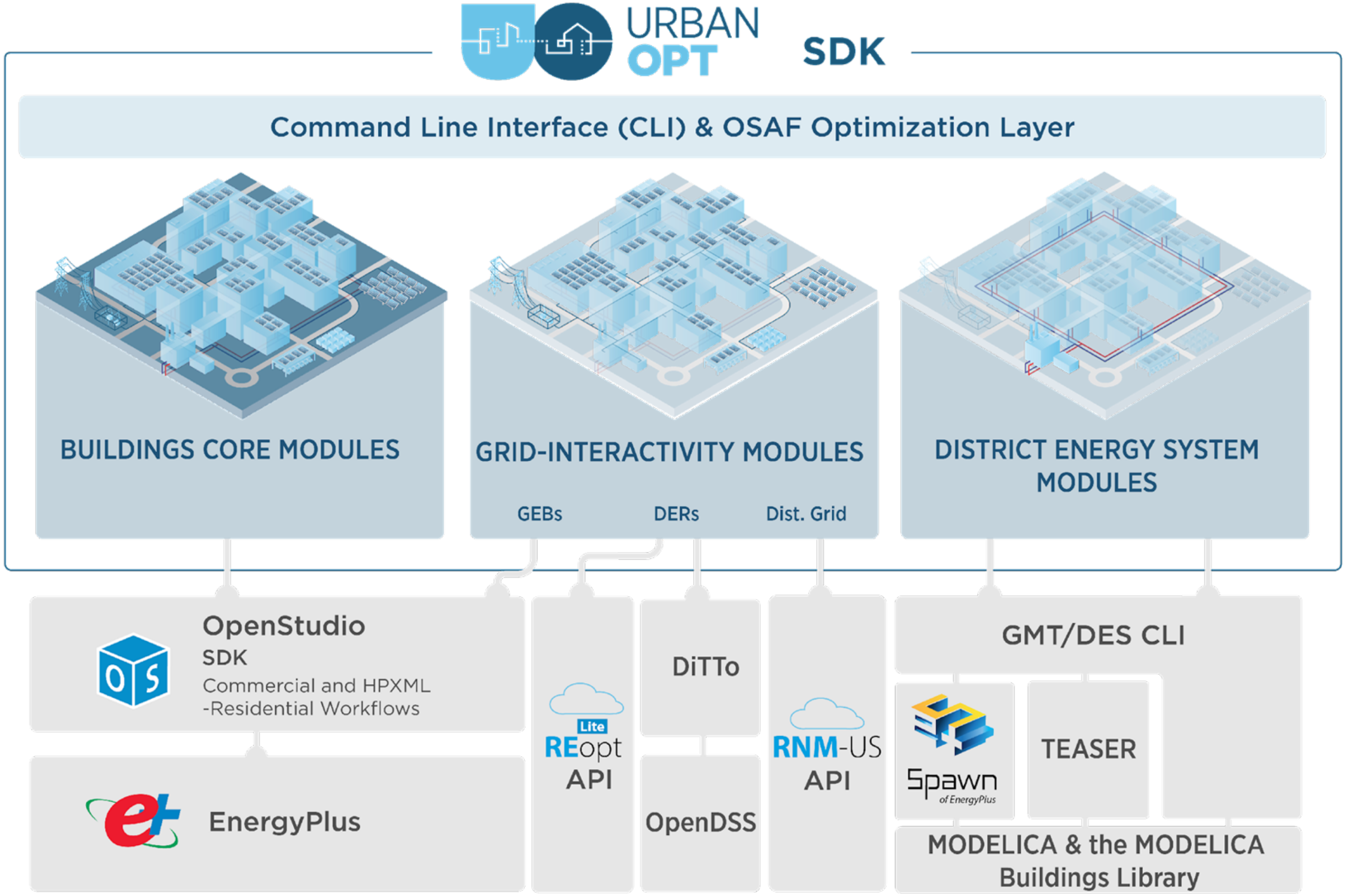
M. Wetter and J. Hu (2019). Quayside Energy System Analysis. LBNL-2001197. https://eta-publications.lbl.gov/publications/quayside-energy-systems-analysis.

URBANopt SDK

Project Focus Areas

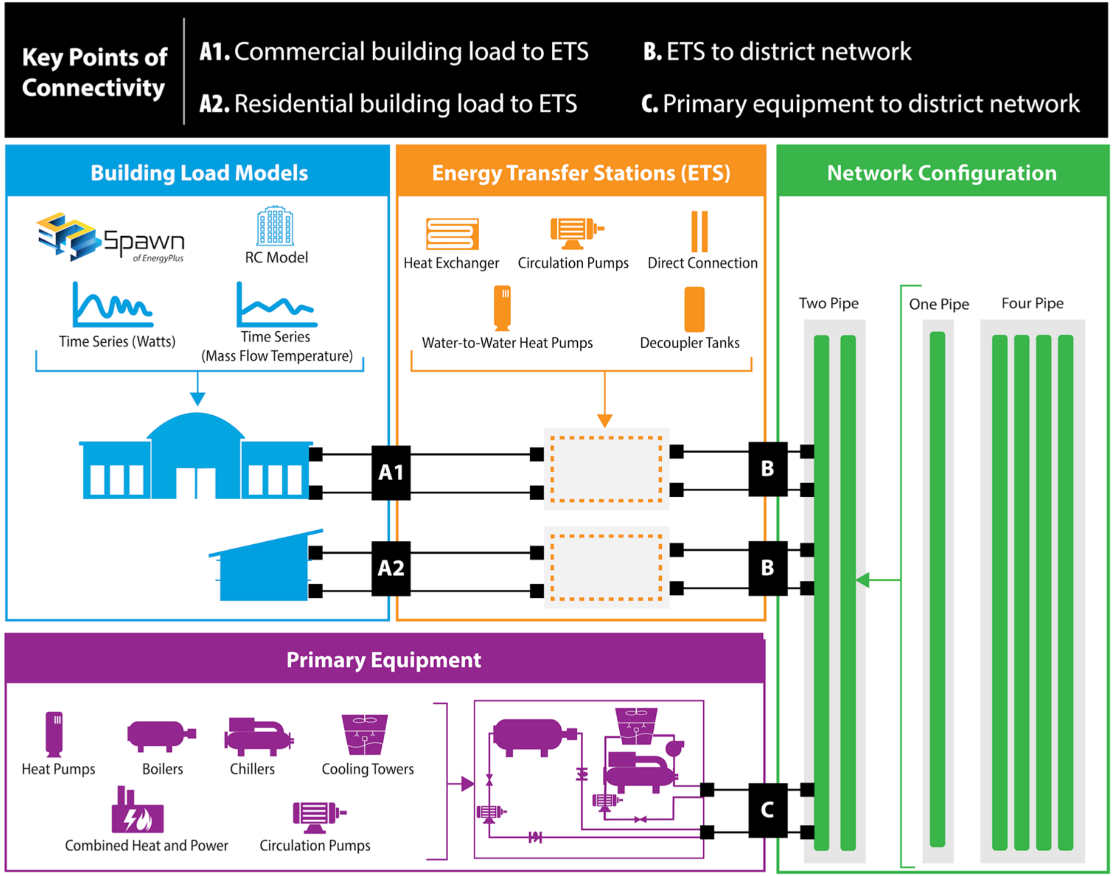


URBANopt SDK Architecture



GeoJSON to Modelica Translator

District System Architecture



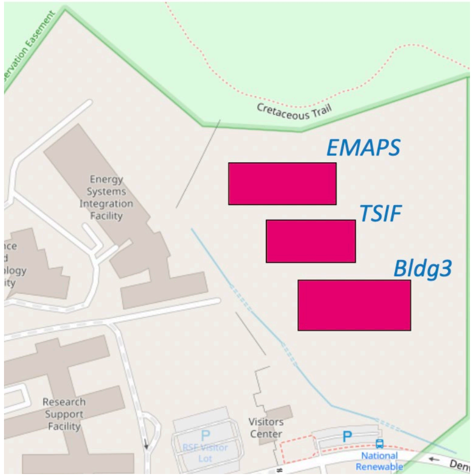
Note that the location of the primary equipment can be centralized or distributed, and that not all primary equipment component models or network configurations are represented in the diagram.

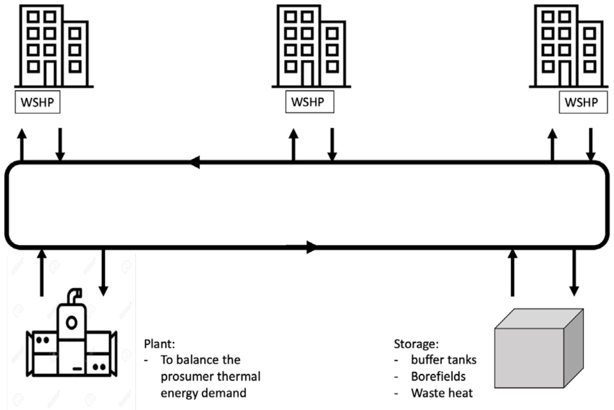
Modelica Building Load Models

- Building Load Models
  - TEASER / RC Models
  - Spawn of EnergyPlus
  - Time Series Loads
- ETS Systems
  - Indirect
  - Indirect with Heat Pump
  - Direct
- Network Topology
  - 1-Pipe
  - 2-Pipe
  - 4-Pipe
- Central Plant Configuration
  - Spatial location
  - Heating
    - Boiler(s) (temperatures)
    - Pumps
  - Cooling
    - Chiller(s) (temperatures)
    - Pumps
    - Cooling Towers

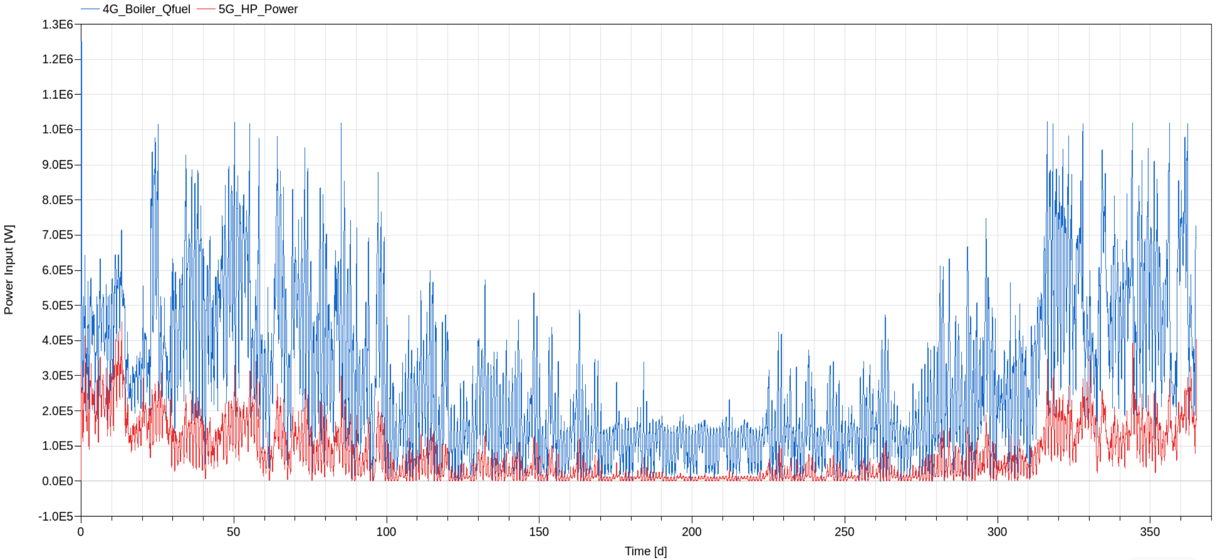
Results and Case Studies

Case Study - NREL's Campus Expansion





- Use URBANopt DES to model 4G system and MBL to model 5G system.
- 4G: 2,558,859 kWh
- 5G: 647,695 kWh (**25% of 4G heating power input**)



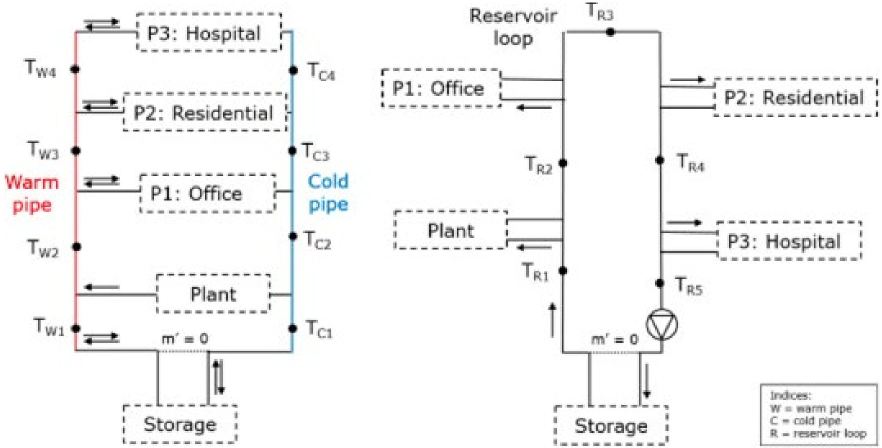
Source: Jiazhen Ling, NREL

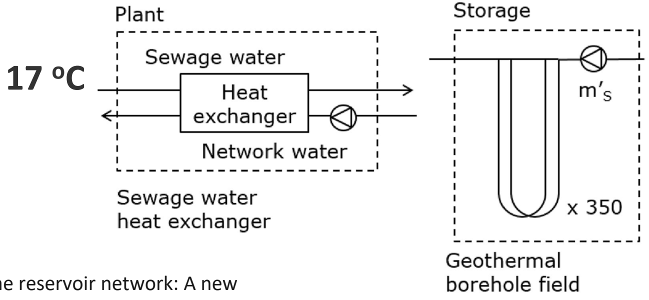
Case Study - Waste Heat Integration into LTN

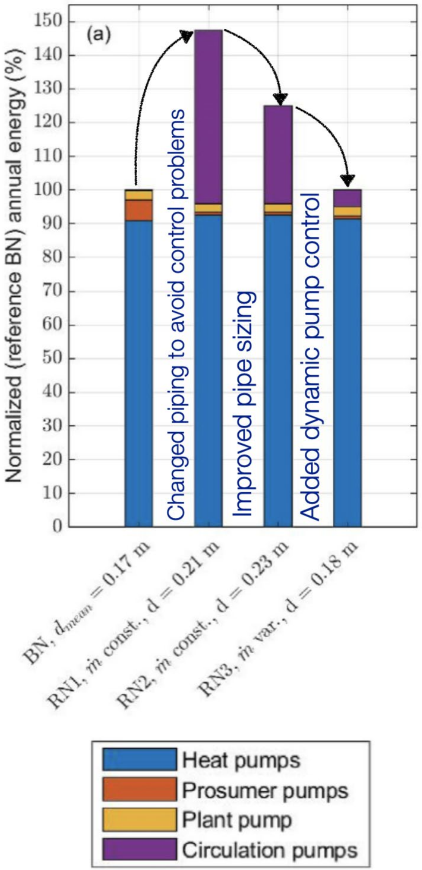
- Proposed new LTN ("Reservoir") to overcome hydronic control challenge of bidirectional
- Modeled with Modelica Buildings Library
- Similar energy performance with better control stability and opportunity for modularity

Parallel Bidirectional Network (BN)

Series Unidirectional ("Reservoir") Network (RN)





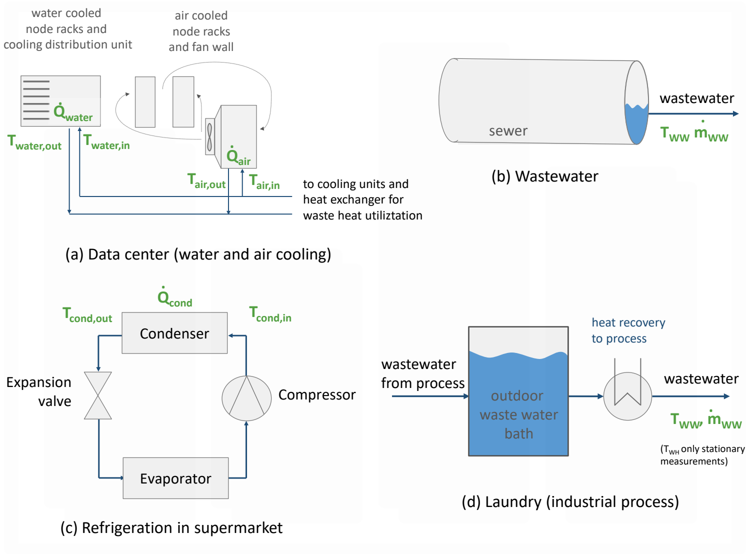


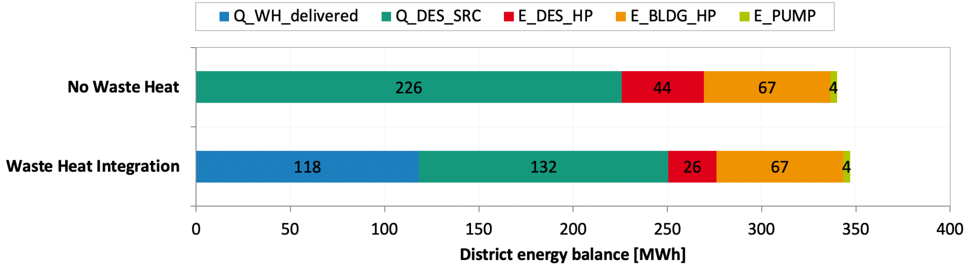
T. Sommer, M. Sulzer, M. Wetter, A. Sotnikov, S. Mennel and C. Stettler (2020). The reservoir network: A new network topology for district heating and cooling. *Energy*, 199. https://doi.org/10.1016/j.energy.2020.117418.

Case Study - Waste Heat

- Create a model to integrate waste heat loads into Modelica and URBANopt DES

	Data center water cooling	Data center air cooling	Wastewater	Refrigeration	Laundry
Supply temperature $T_{sup,mean}$	36.5 °C	30.6 °C	20.4 °C	67.0 °C	28.4 °C
Return temperature $T_{ret,mean}$	22.8 °C	20.8 °C	*10.0 °C**	27.9 °C	*10.0 °C**
Waste heat: - $\dot{Q}_{flow,nom}$ - $\dot{Q}_{flow,mean}$ - Annual waste heat Q_{WH}	839 kW 723 kW 6330 MWh/a	199 kW 169 kW 1483 MWh/a	97.5 MW 46.0 MW 402 GWh/a	193 kW 114 kW 1002 MWh/a	292 kW 89.8 kW 786 MWh/a
Fluid/media	Water	Water	Wastewater	Refrigerant	Wastewater
Open/closed loop	Closed	Closed	Open	Closed	Open
Location	Golden, CO, USA		Denver, USA		Germany
Measurement period	09/2016 - 08.2017		11.2018 - 10.2019		
Number of hourly data points					
Process description	930 m² floor area, 2.5 MW of total MW of total				





Source: Manuel Lämmle, Fraunhofer ISE, CU Boulder, NREL

Thank you!

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