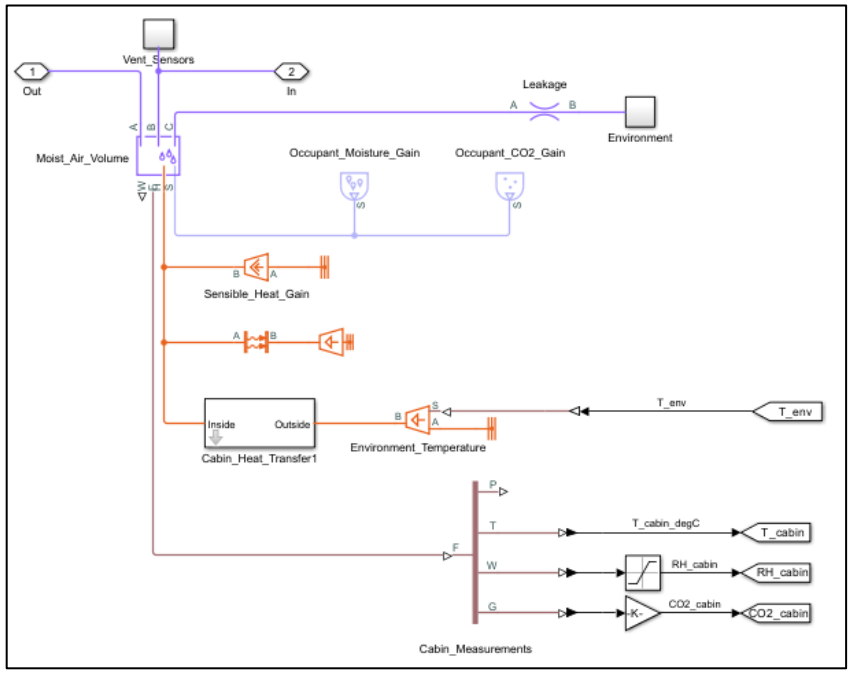
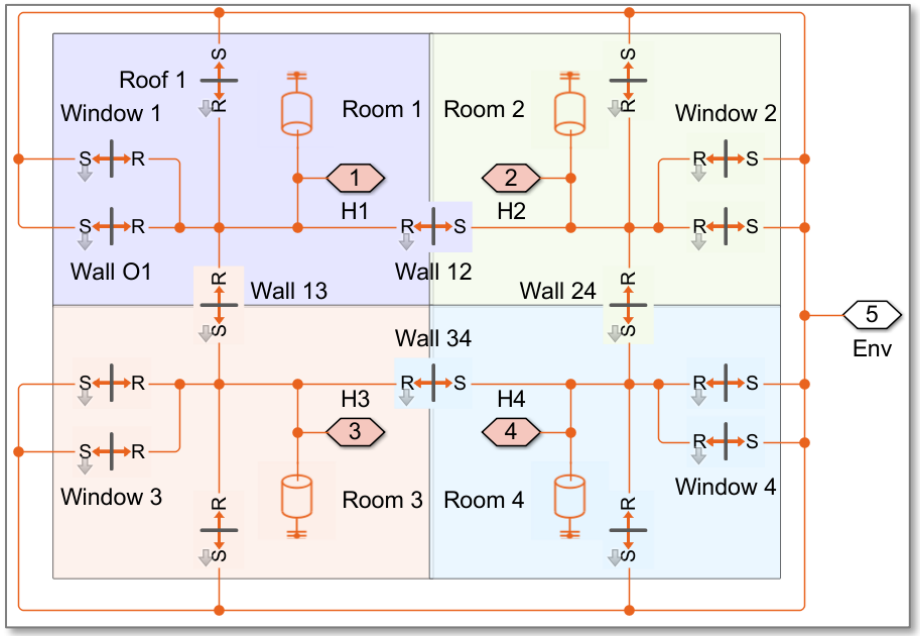




Modeling the Physics of HVAC systems with Simscape

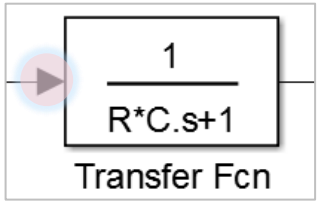
Aldo Caraceto

Application Engineering Group - MathWorks

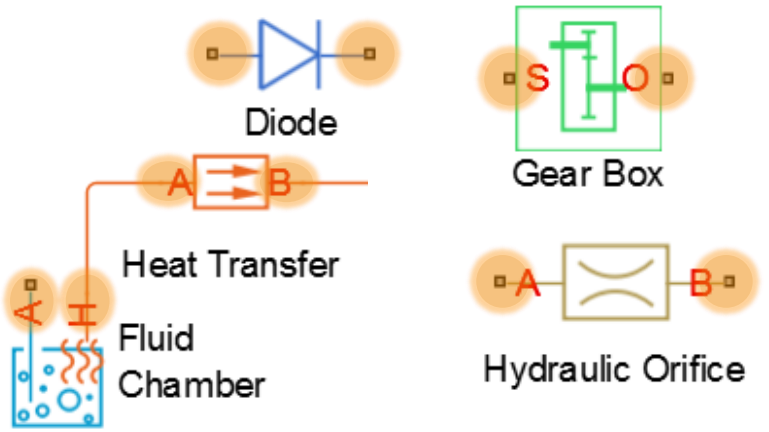
Key Messages

- Simscape offers a modeling method that is well-suited to thermal, fluid, and other types of physical systems
- Combining CARNOT Blockset content with Simscape capabilities could offer big benefits to CARNOT users
- CARNOT Blockset could tackle a wider range of problems if it leveraged Simscape

Signal-Based

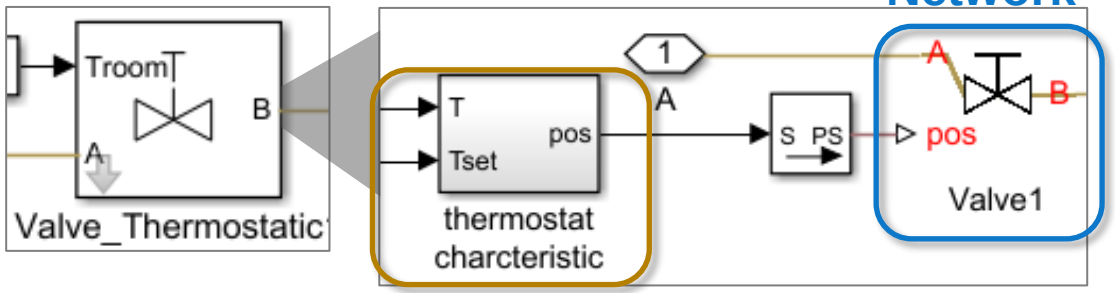


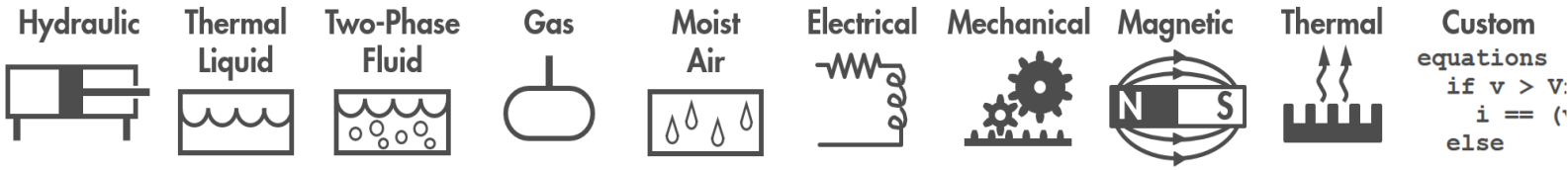
Simscape (physical networks)



CARNOT Content

Simscape Network



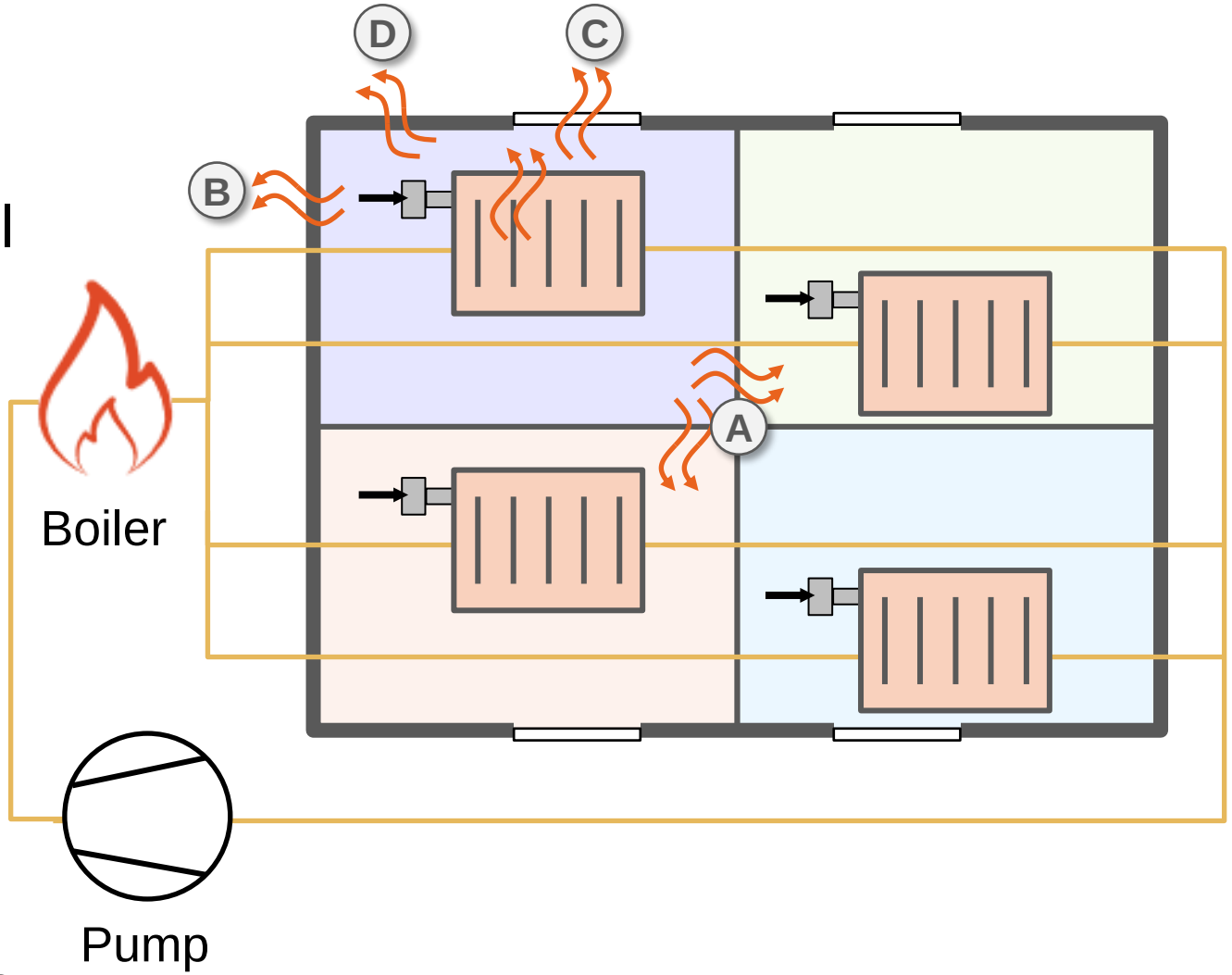


Agenda

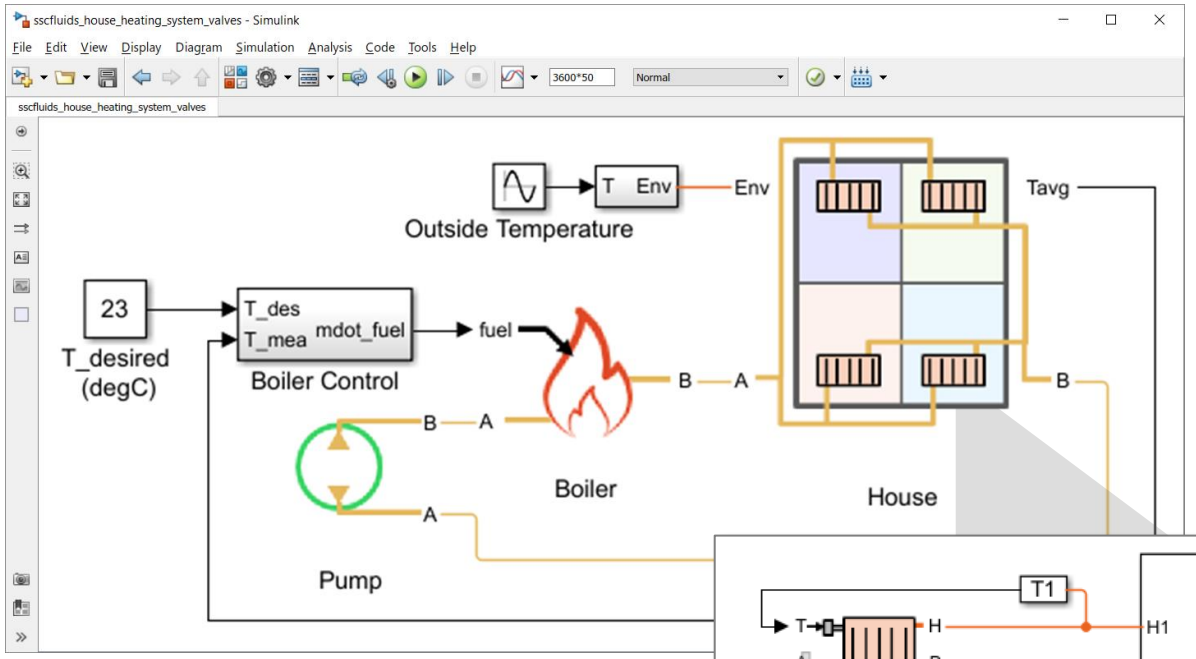
- Primary Example: House Heating Model
- Comparing Modeling Methods (signals, networks)
- Combining Simscape and CARNOT Blockset
  - Standard components
  - Custom components
- Extending CARNOT using Simscape
  - Range of fluid domains (phase change, gas, moist air)
  - Electrical, mechanical, energy storage (batteries, etc.)

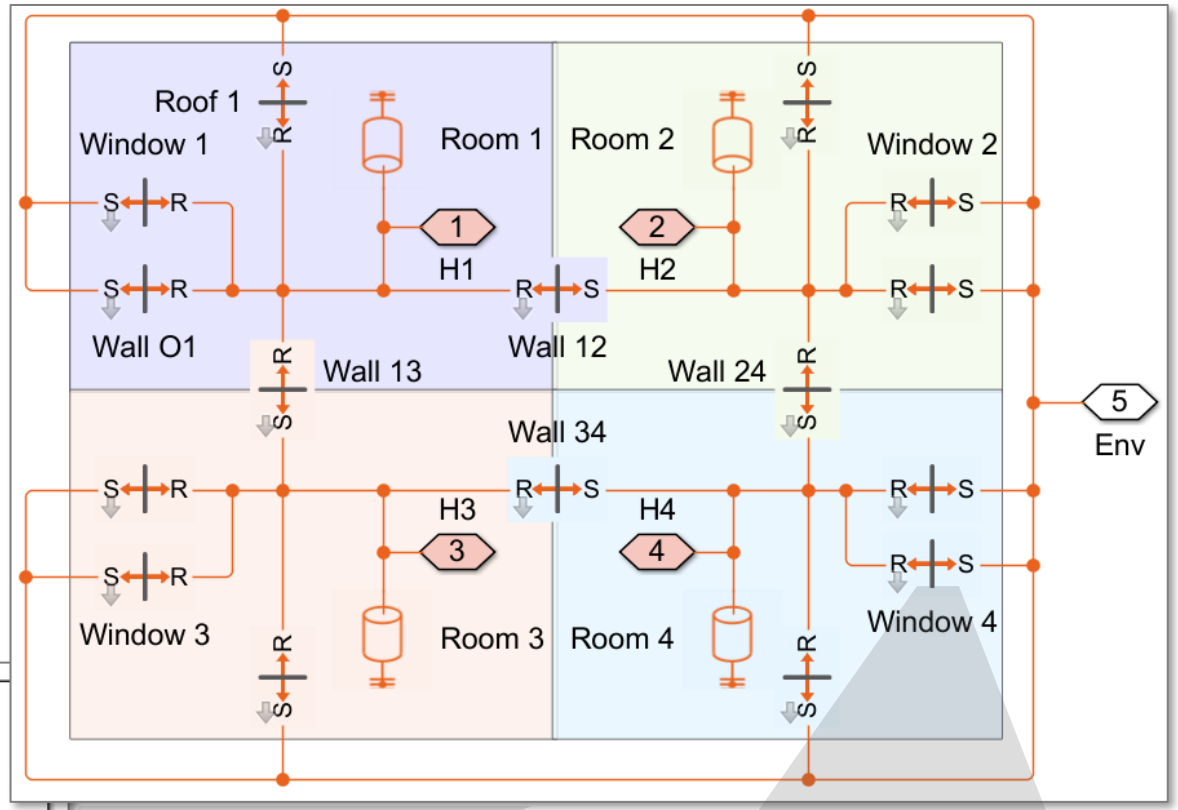
Example: House Heating System

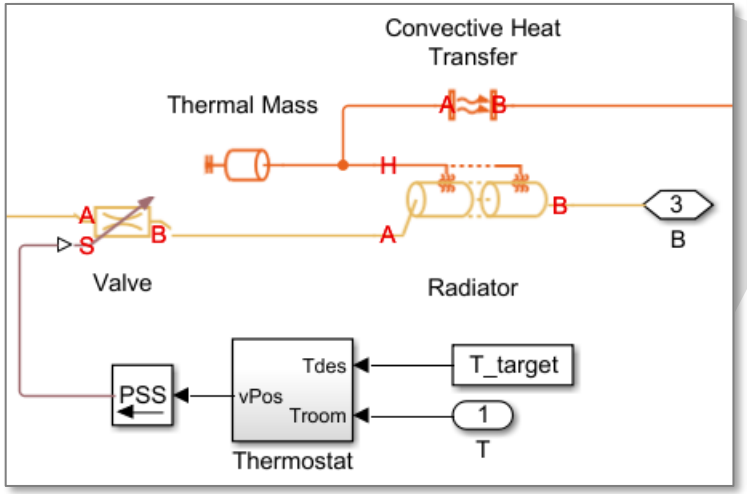
- Single pump and boiler
- Four radiators connected in parallel
  - Thermostat on each radiator
- Four rooms in 2x2 grid each with heat transfer
  - (A) Through wall to 2 rooms
  - (B) Through wall to outside
  - (C) Through window to outside
  - (D) Through roof to outside
- Water transports heat through network, and water properties vary with temperature and pressure

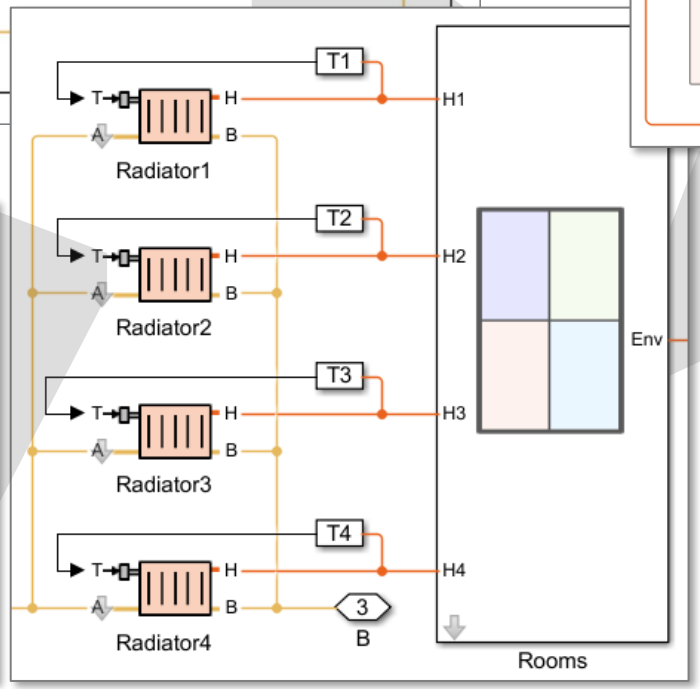


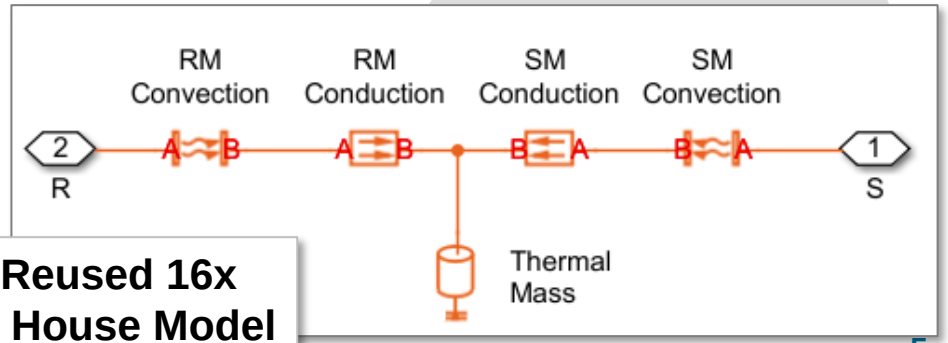
Example: House Heating System











Reused 16x in House Model

Agenda

- Primary Example: House Heating Model
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  - Custom components
- Extending CARNOT using Simscape
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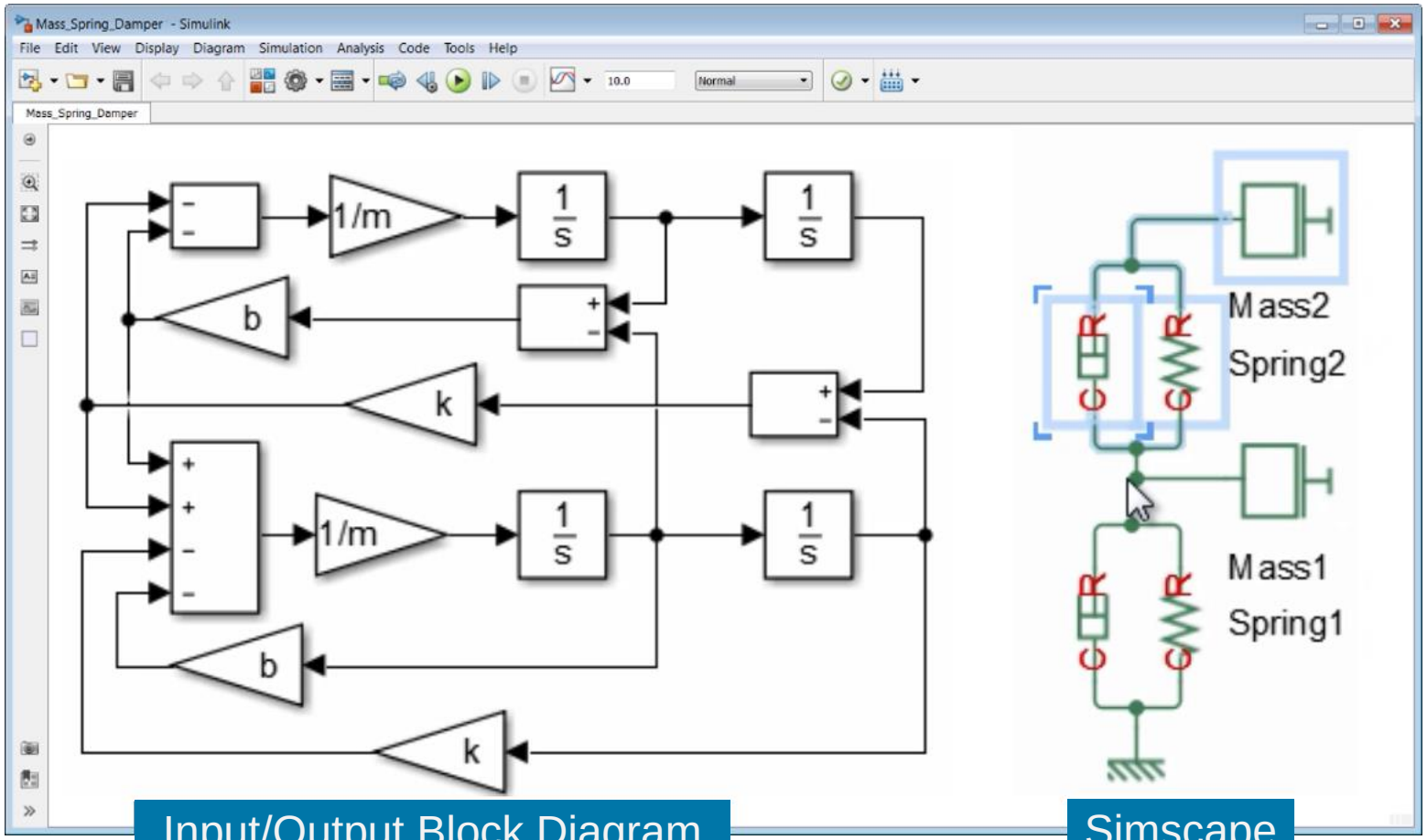
  - Electrical, mechanical, energy storage (batteries, etc.)

Physical Modeling Method

- Physical connections makes modeling physical systems quicker and easier
  - Intuitive
  - Easy to modify
  - Easy to maintain
- Automatic formulation of system equations
  - ODEs and DAEs



Input/Output Block Diagram

Simscape

Agenda

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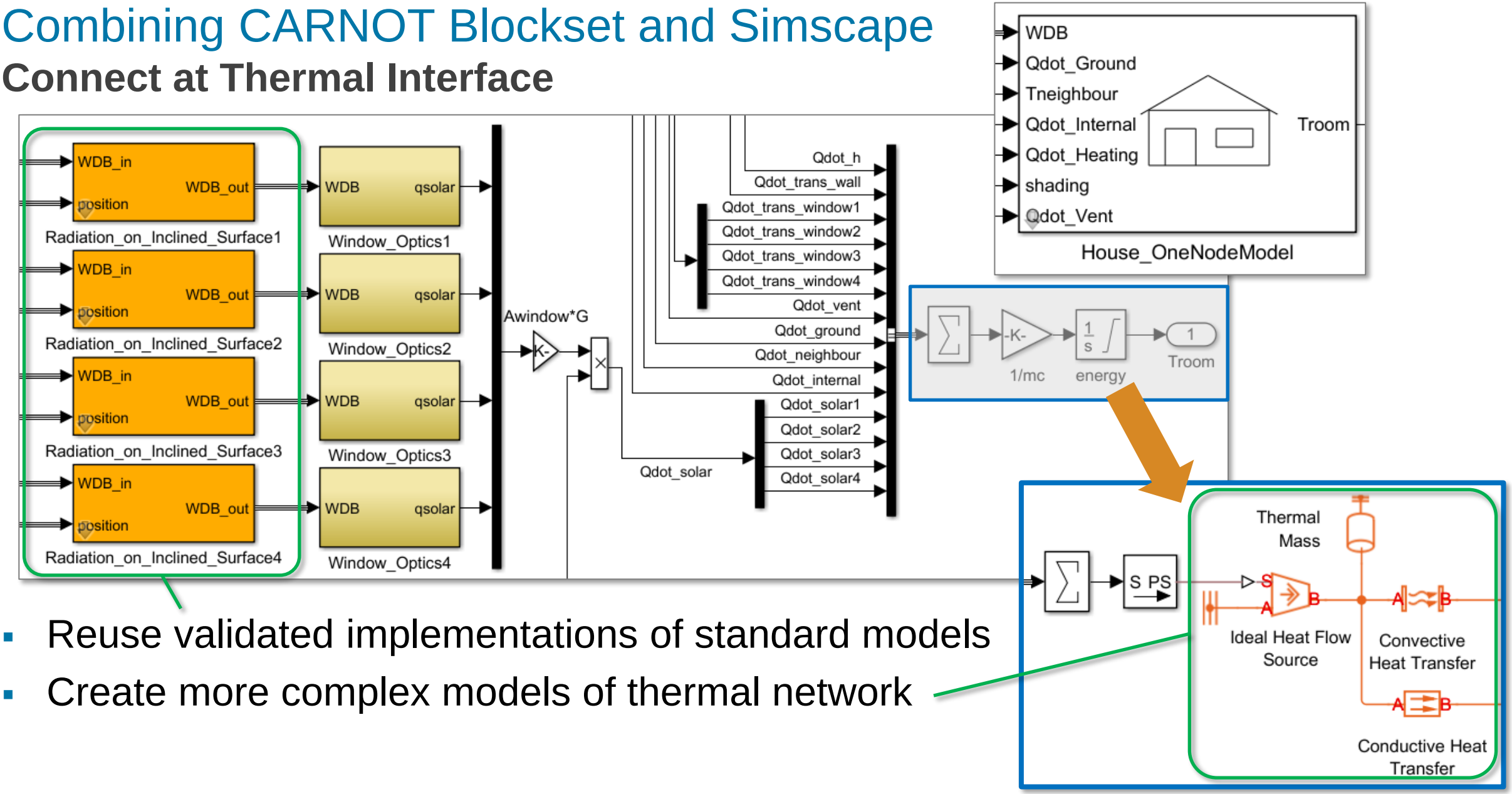
Strengths of CARNOT Blockset and Simscape

- CARNOT Blockset
  - Application-specific blocks
  - Extensive set of application examples
  - Many person-years of research
  - Validation against specific test cases
- Simscape
  - Modeling approach (physical networks)
  - Advanced effects (phase change, condensation, flow reversal)
  - Generic, multi-purpose components

Combining CARNOT Blockset and Simscape

Connect at Thermal Interface



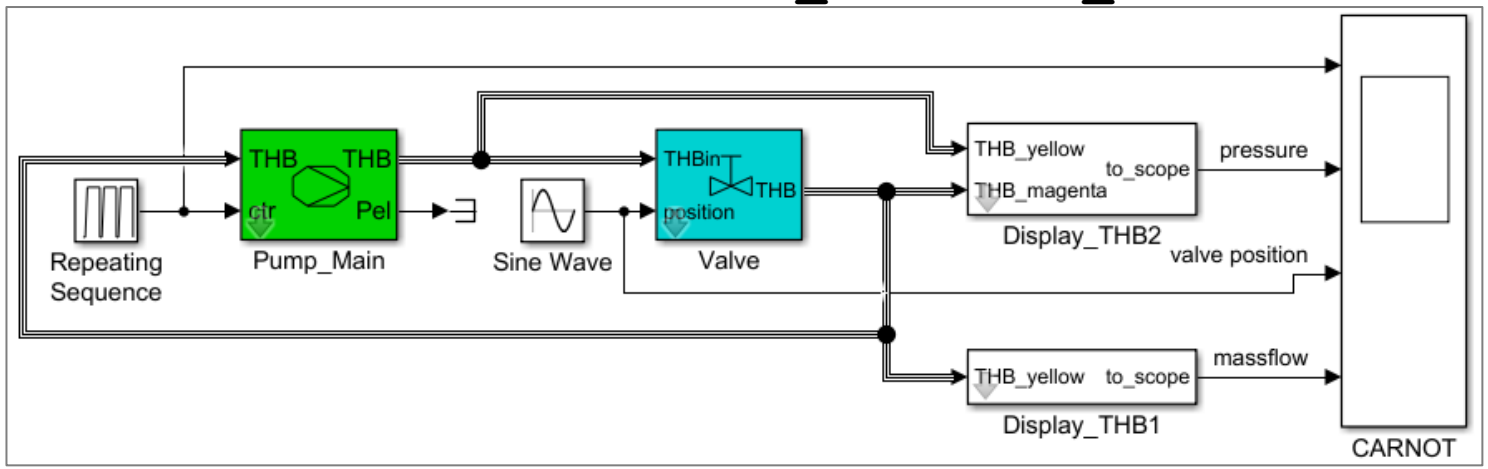
- Reuse validated implementations of standard models
- Create more complex models of thermal network

Combining CARNOT Blockset and Simscape

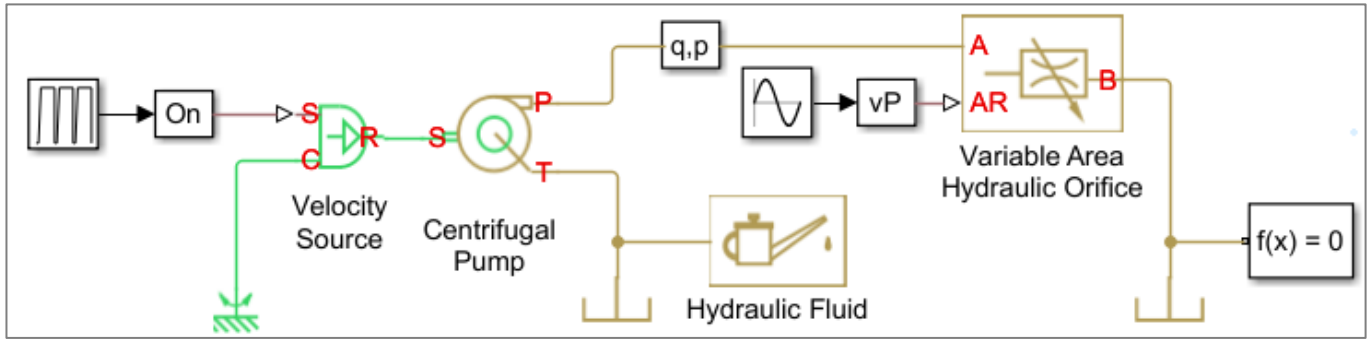
Use Blocks from Simscape Libraries

- Simscape libraries have many components that could be a close match
  - Review parameterization and assumptions in equations
- Benefits:
  - Blocks fully documented
  - Maintained by MathWorks (code, documentation)
  - Parameterization tools

CARNOT Blockset Model `Example_Hydraulic_Valve.slx`



Implementation Using Standard Simscape Blocks

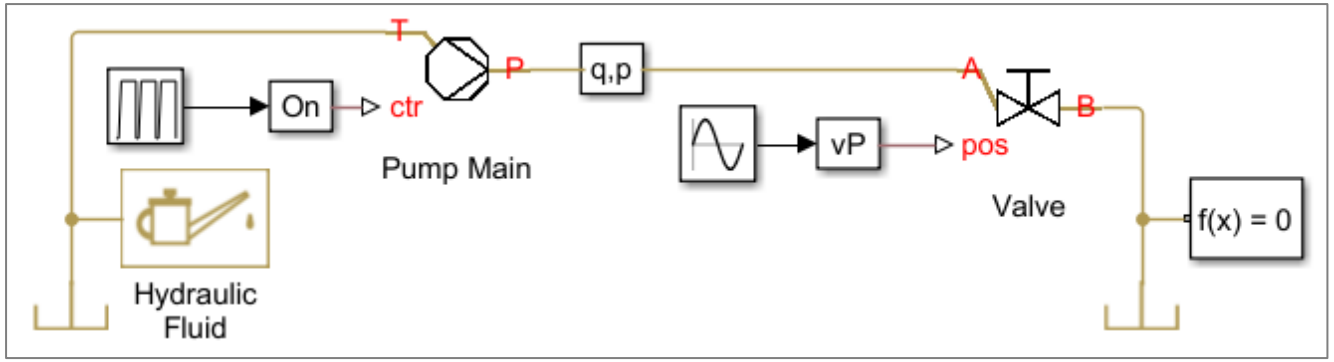


Combining CARNOT Blockset and Simscape

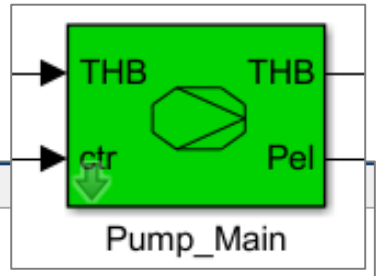
Reuse Equations in Simscape Language

- Custom Simscape blocks can use the same equations as CARNOT Blockset blocks
  - Simscape language (extension of MATLAB)

Implementation Using Custom Simscape Blocks



Equations S-Function



pump.c

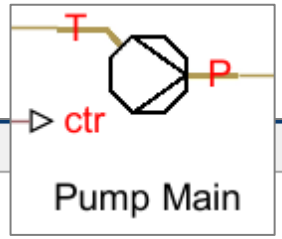
```
166  a = PUQUA - DPQUA;
167  b = PULIN - DPLIN;
168  c = PUCON - DPCON;
169  solve_quadratic_equation(x12, a, b, c);
```

Calculate massflow by solving the equations:

pressure_drop = c + l*mdot + q*(mdot)²

pump_pressure = a0 + a1*mdot +a2*(mdot)²

Equations in Simscape language



carnot_pump_main.ssc

```
38  equations
39      p == P.p - T.p;
40      p == ctr*a0 + a1*q*P.density + a2*(q*P.density)^2;
41  end
```

Agenda

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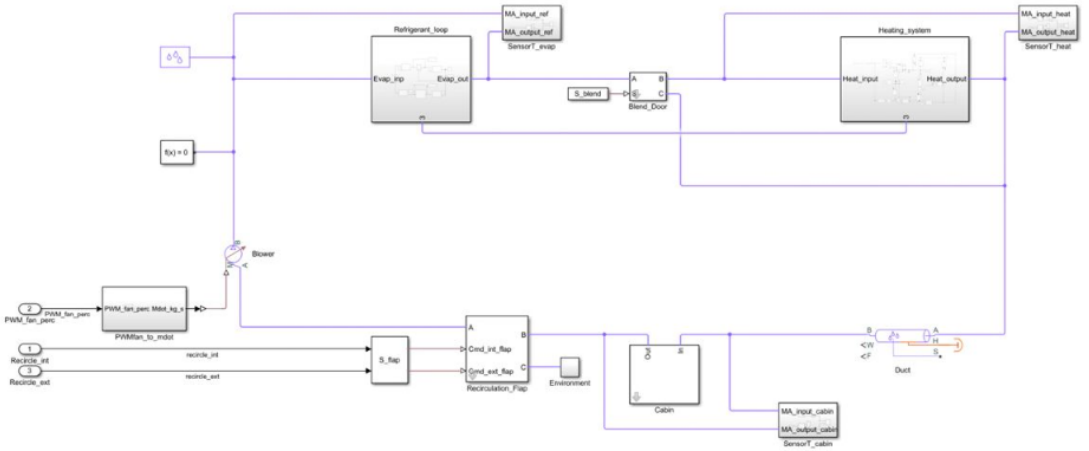
Politecnico di Torino and EMA Global Develop a Multidomain Hypercar HVAC System Through Industry-Academia Collaboration

Using MATLAB and Simulink, EMA Global partnered closely with Politecnico di Torino to develop an HVAC system for a custom-built, multimillion dollar car

Results

- Developed detailed HVAC system modeled across six different physical domains using Simulink and Simscape
- Calibrated, optimized, and tested an accurate HVAC system controller without relying on hardware
- Shortened the overall development time for the controller using Model-Based Design



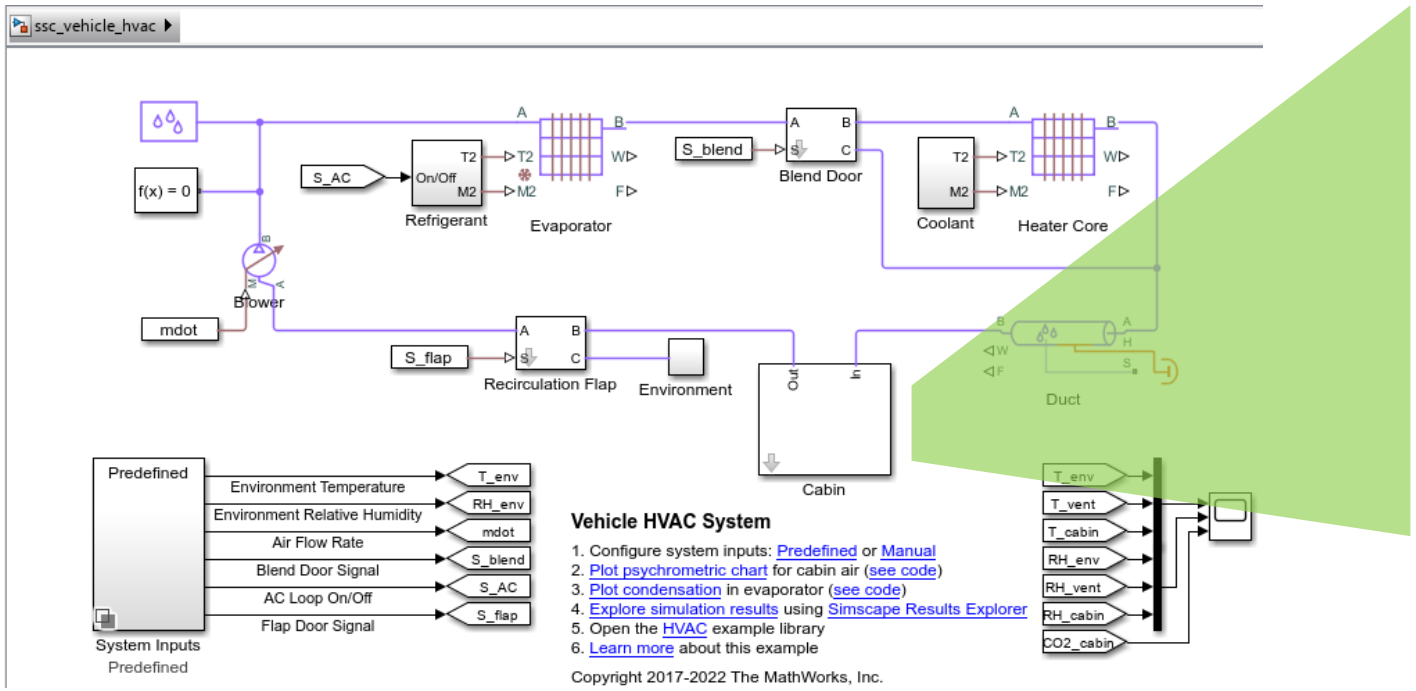
Top-level vehicle HVAC model.

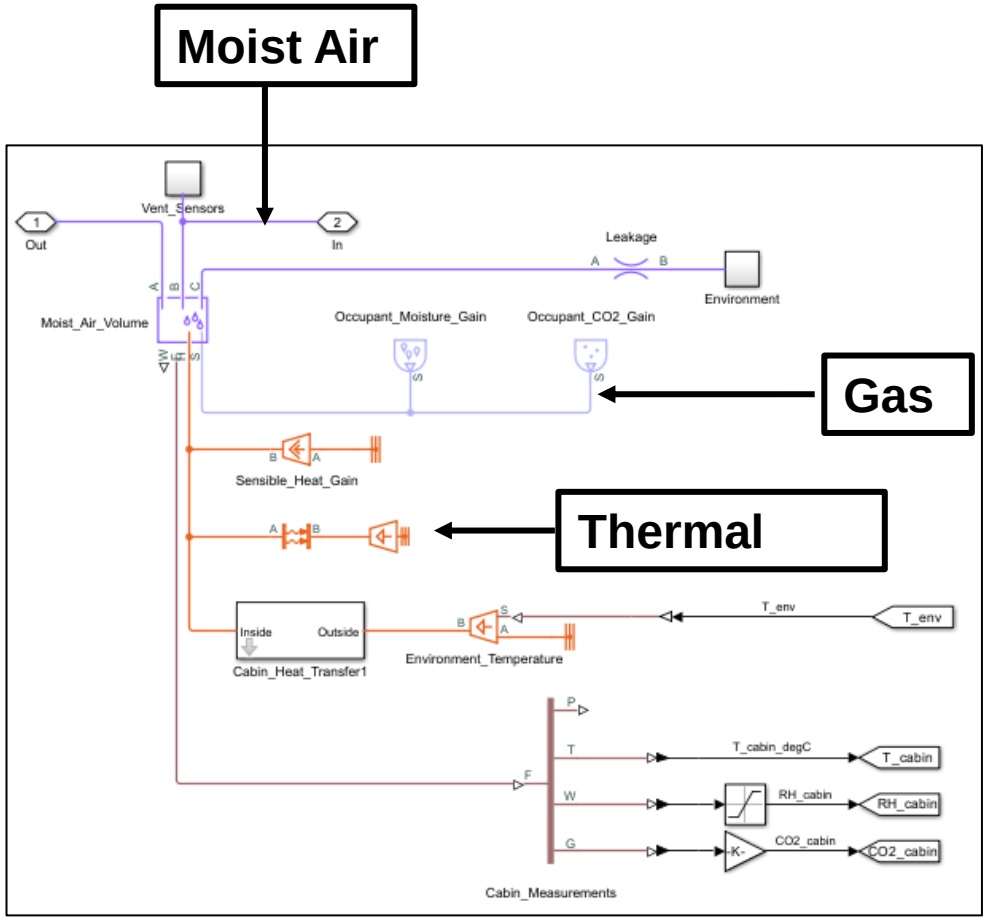
"This project was a great opportunity for EMA Global to collaborate with both MathWorks and Politecnico di Torino in applying a state-of-the-art automotive engineering approach that we can now continue to use moving forward."

- Mirko Zanotel, EMA Global Engineering

Link to article

HVAC System – Details - Cabin

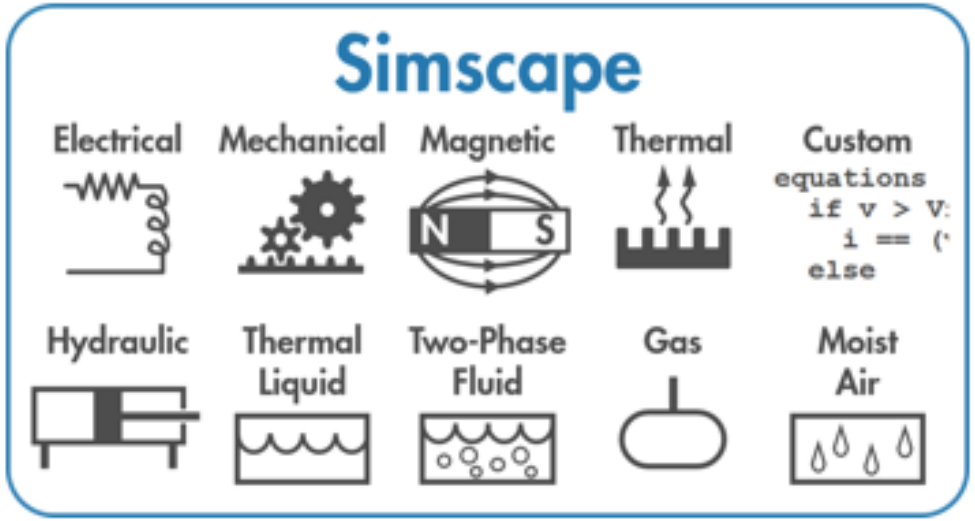




[Vehicle HVAC System]

Model Fluid Systems Using Simscape

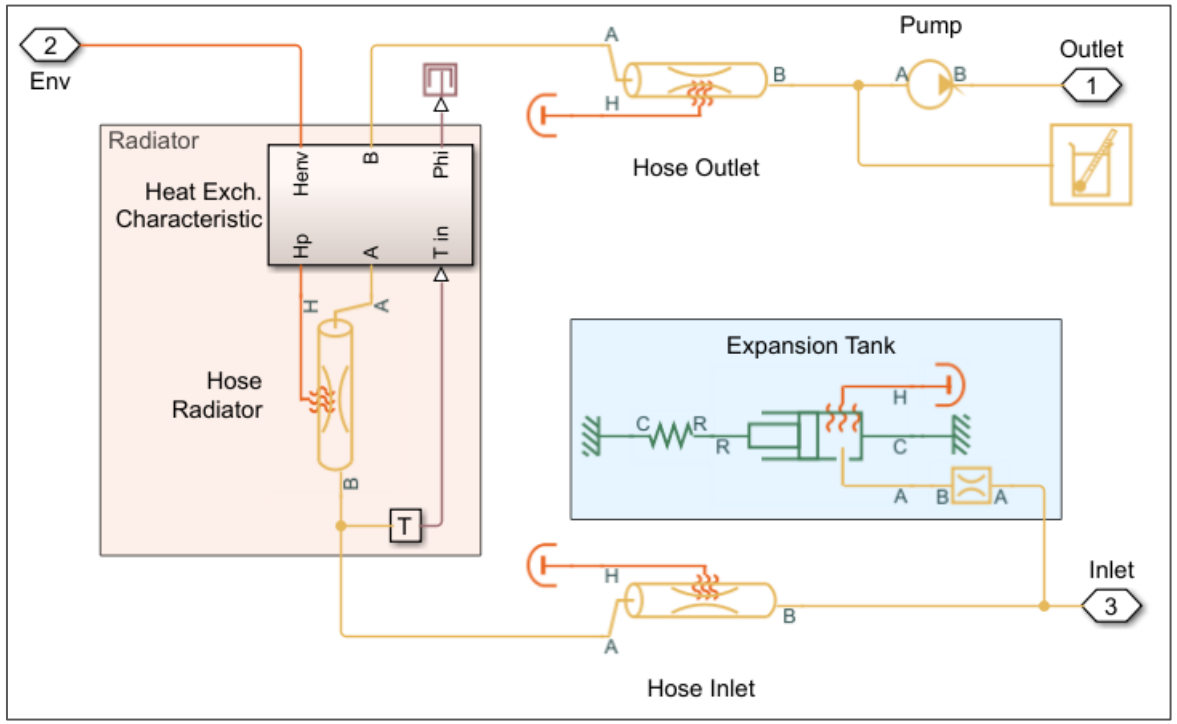
- Set of domains to accommodate range of assumptions for fluid systems
- Libraries with source code for each domain
  - Extend as needed
  - Wide range of examples to get you started

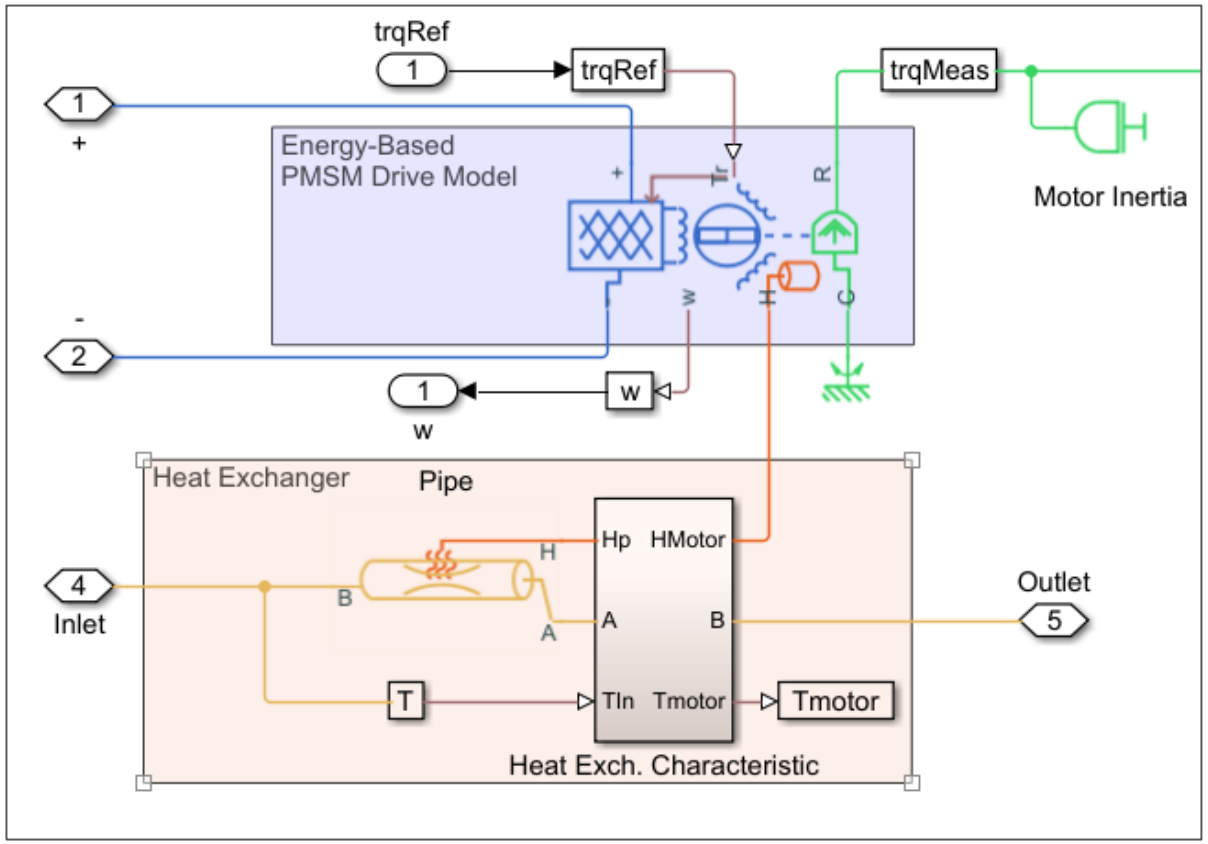


Assumption	Simscape Domain
Constant heat transfer coefficient	Thermal
Liquid properties do not vary with temperature	Hydraulic (Isothermal Liquid)
Liquid properties vary with temperature	Thermal Liquid
Gas	Gas
Fluid that changes phase	Two-Phase Fluid
Mixture of 3 species with condensation	Moist Air

Integrate Additional Domains Using Physical Network Method

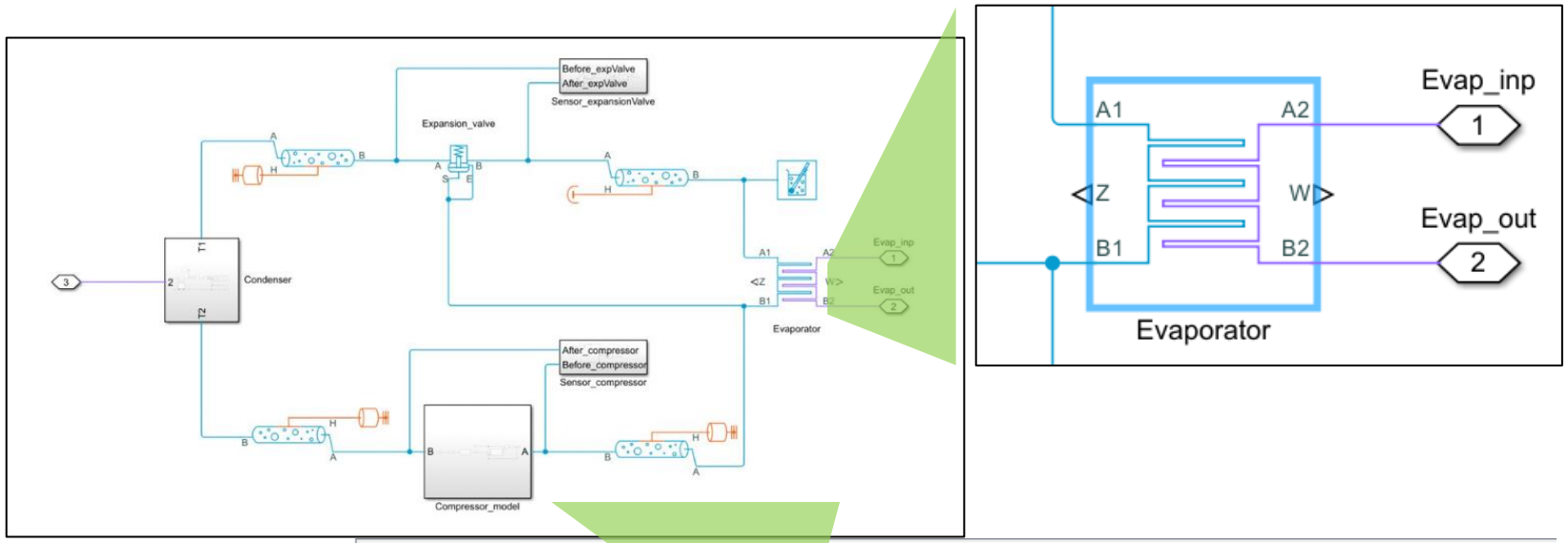
- Integrate electrical, mechanical, and other systems
- Example applications: Cooling systems for electric motors and batteries





[Electric Vehicle Configured for HIL]

HVAC System – Details - Refrigerant



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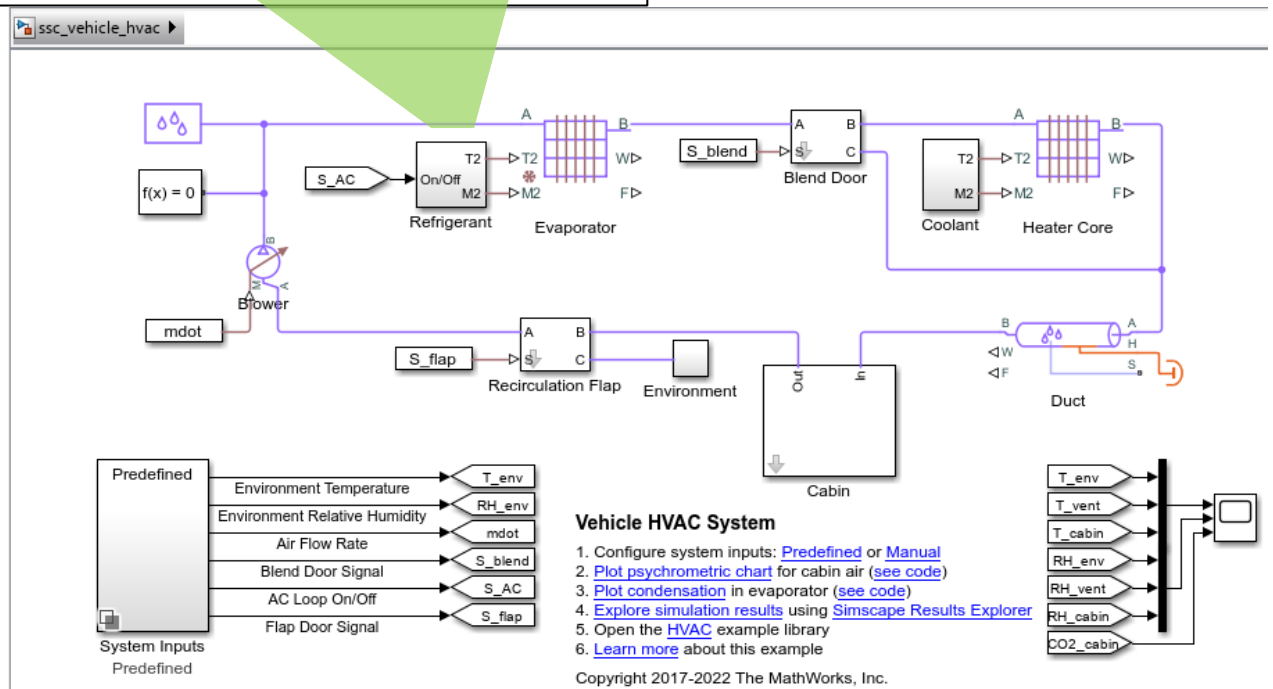
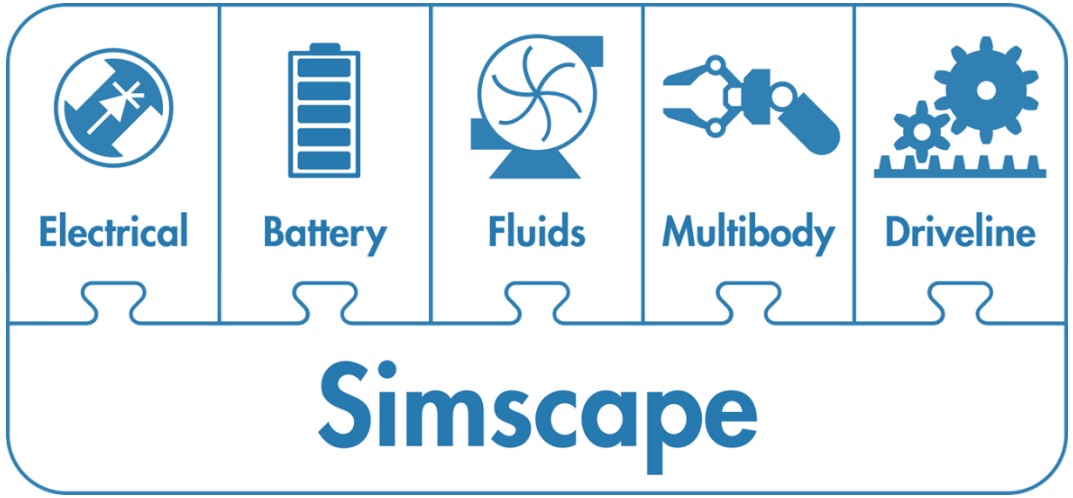


* Available in Simscape Fluids

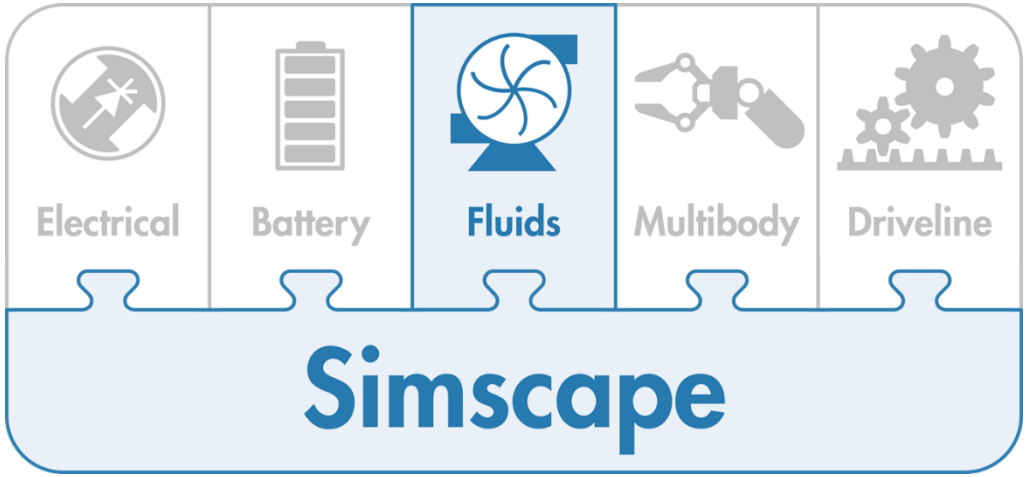
Simscape Add-On Libraries

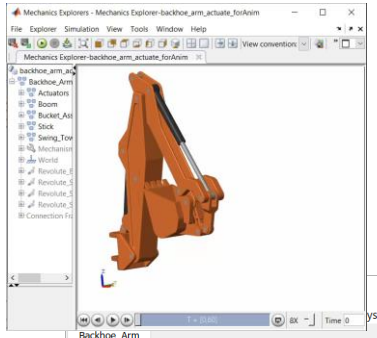
- Extend foundation domains with components, effects, parameterizations
- Multibody simulation
- Editing Mode permits use of add-ons with Simscape license only
- Models can be converted to C code

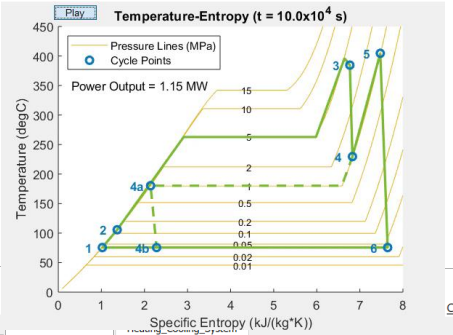


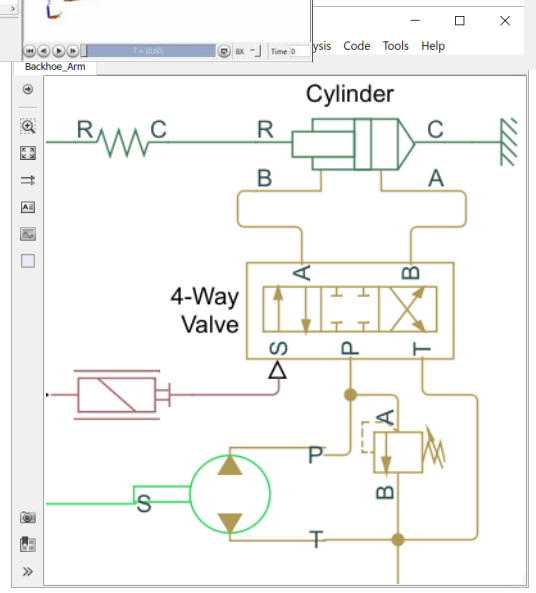
Simscape Fluids
Overview

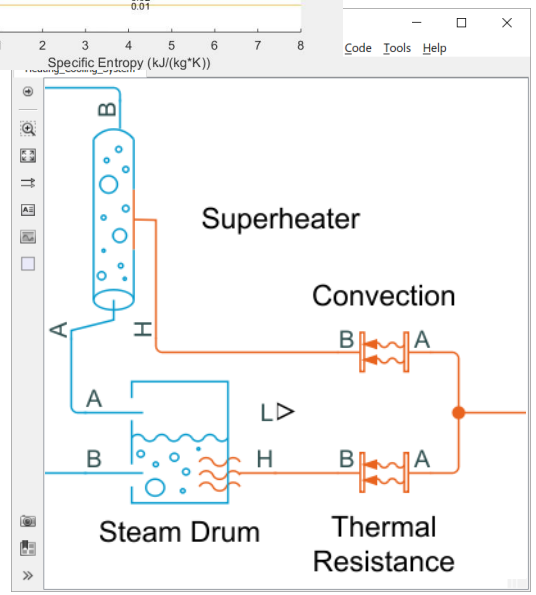
- Enables physical modeling (acausal) of fluid systems
  - Fluid power, heating, cooling, and fluid transportation
  - Liquids, gases, and multiphase fluids
- With Simscape Fluids you can
  - Refine requirements for fluid systems
  - Discover integration issues early
  - Design control algorithms and logic within the Simulink environment
  - Test embedded software without hardware prototypes







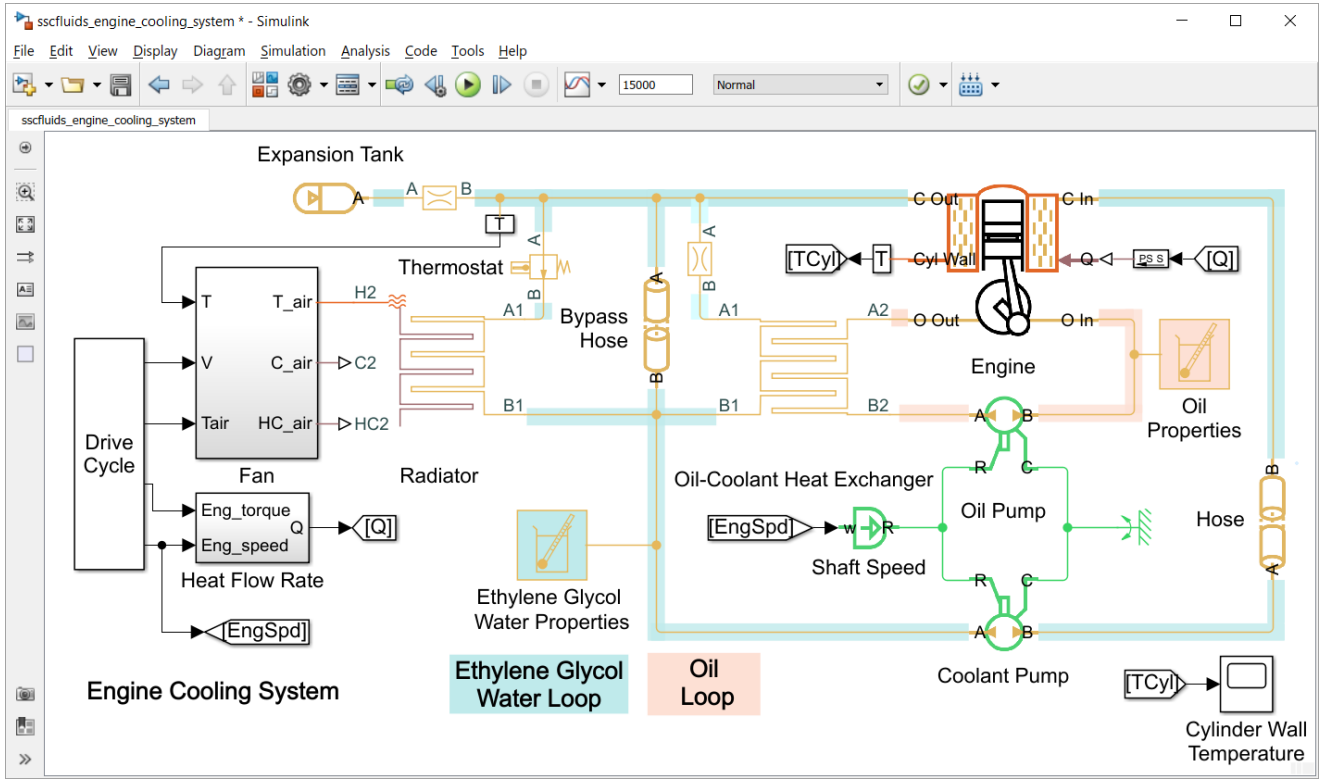


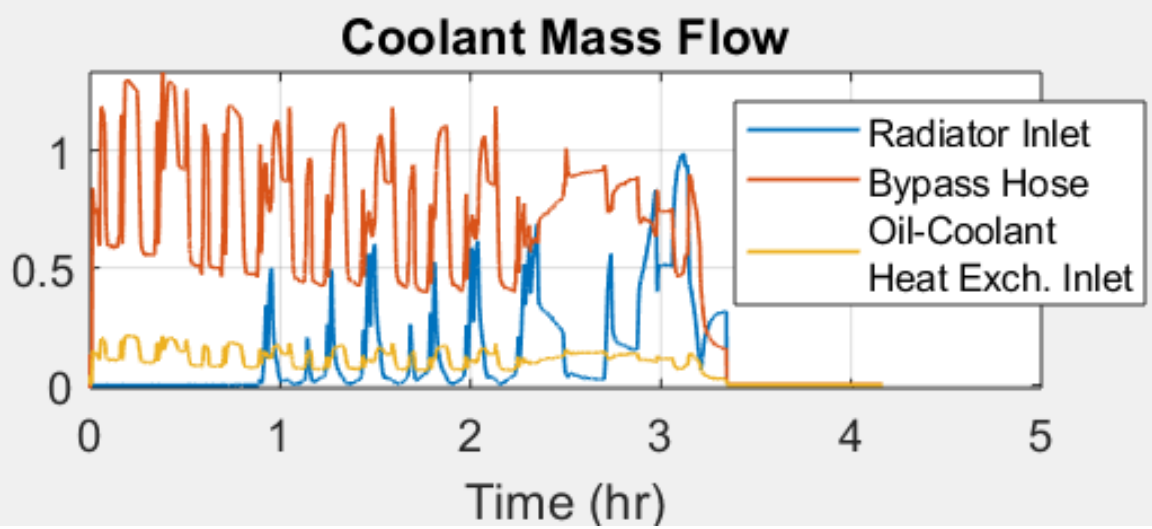


Simscape Fluids Applications

Heating and Cooling Systems

- Engine cooling system
  - Coolant loop, oil loop
  - Pump drives cooling circuit
  - Thermostat diverts flow to the radiator when temperature is too high
- Simscape Fluids is used to:
  - Refine system-level requirements
  - Select components (pumps, valves)
  - Test system integration
  - Design control systems, including HIL testing



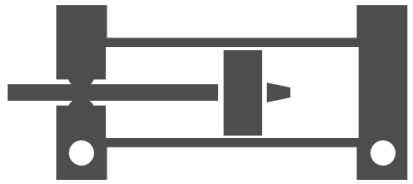



```
>> sscfluids_engine_cooling_system
```

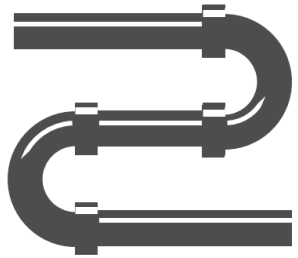
Simscape Fluid Component Models

Pumps

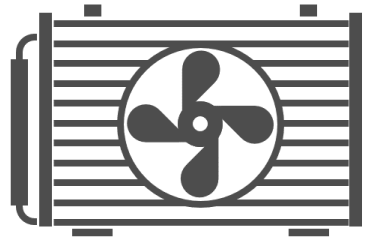
Valves



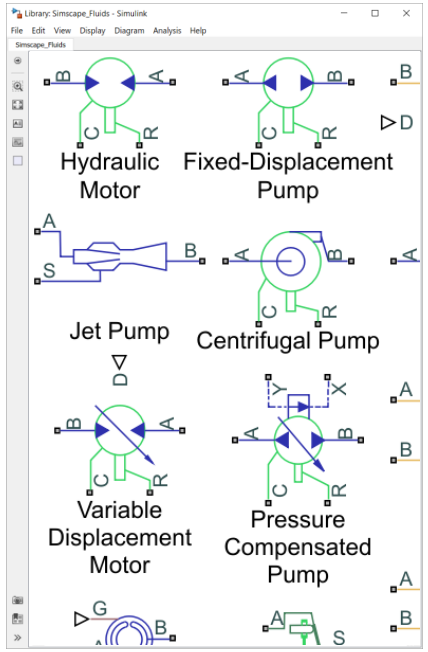
Actuators

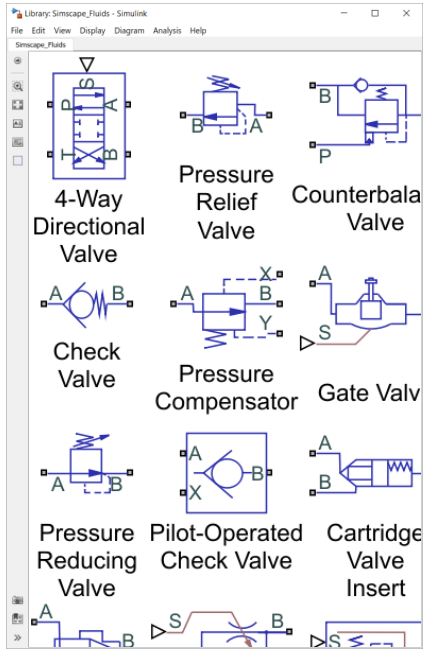


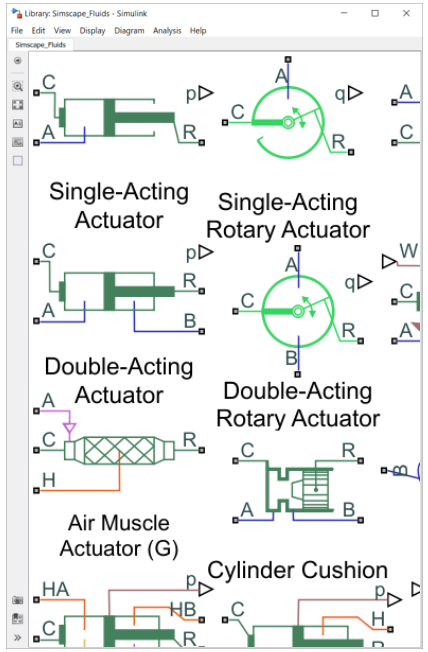
Pipes, Tanks

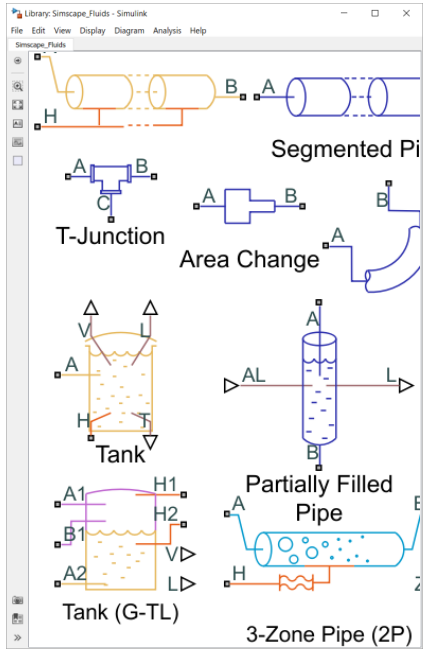


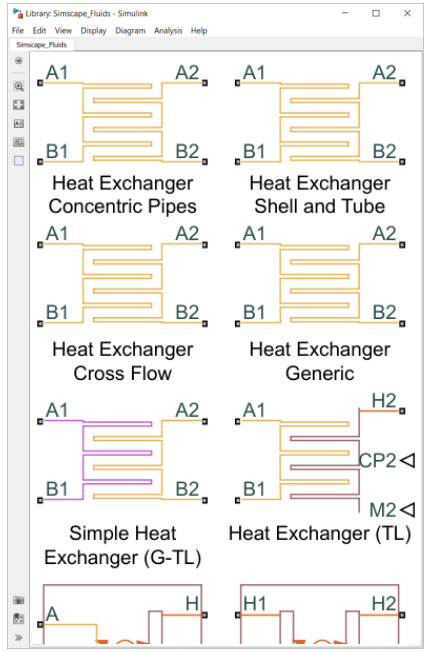
Heat Exchangers







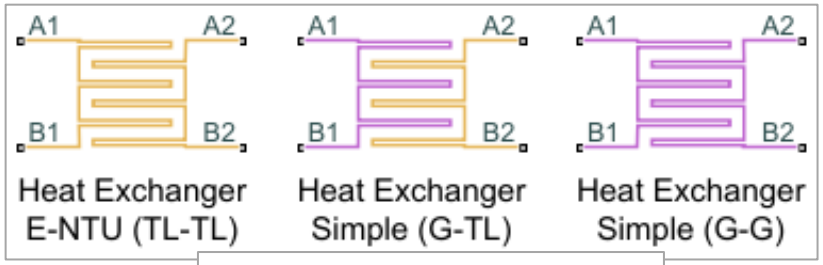


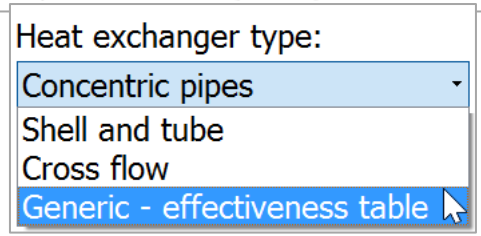


Simscape Fluids Component Models

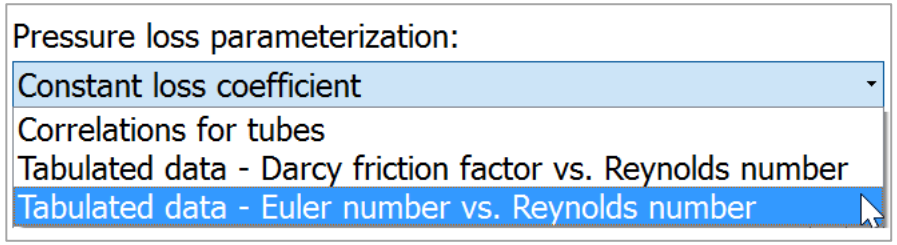
Pumps and Motors, Valves, Actuators, Pipes and Tanks, Heat Exchangers

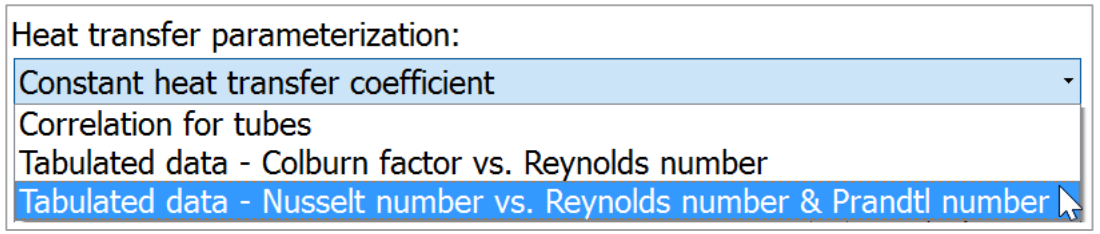
- Standard and custom types
  - Parallel or counter flow
  - Single or multiple shell passes
  - Mixed or unmixed flow



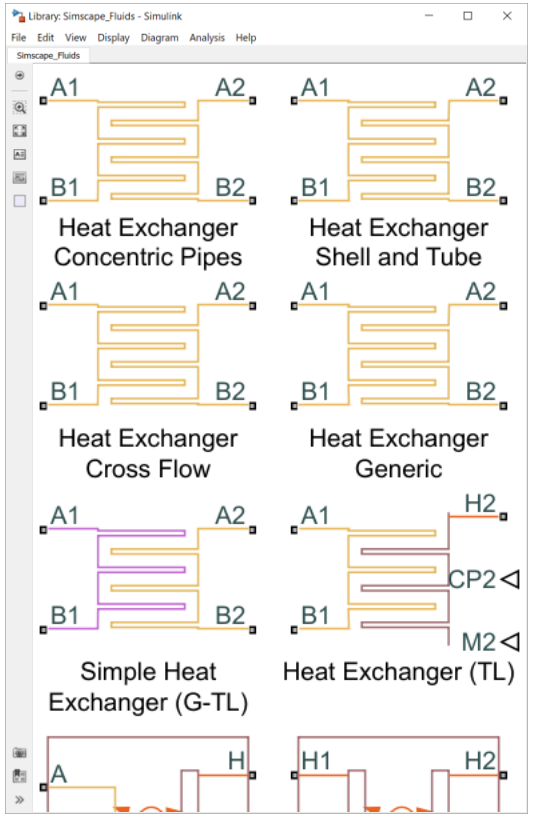


- Parameterization options
  - Pressure losses
  - Heat transfer
  - Compressibility





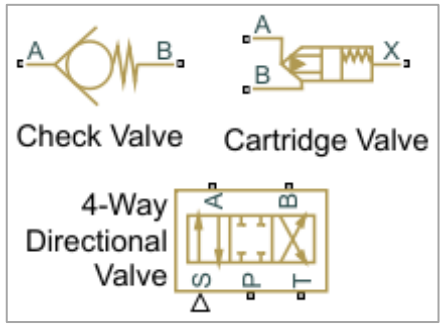
Subset of libraries

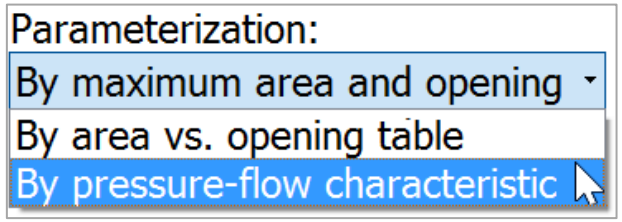


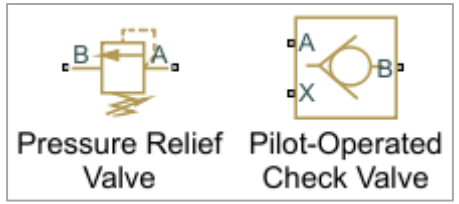
Simscape Fluids Component Models

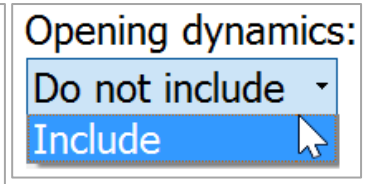
Pumps and Motors, Valves, Actuators, Pipes and Tanks, Heat Exchangers

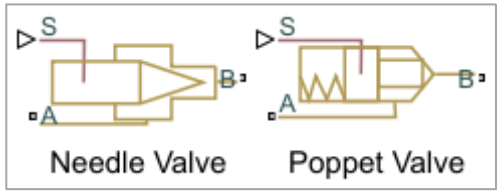
- Directional
  - Spool, check, cartridge
  - Parameterization options
- Pressure control
  - Control tasks (variable)
  - Switching tasks (fixed)
- Flow control
  - Pressure dependent
  - Pressure independent

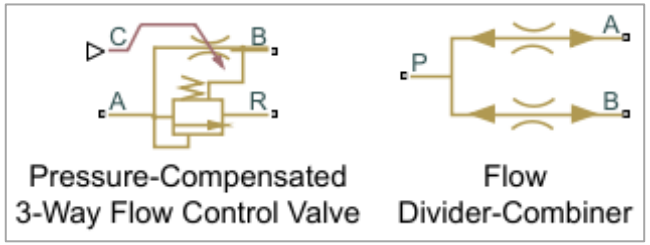




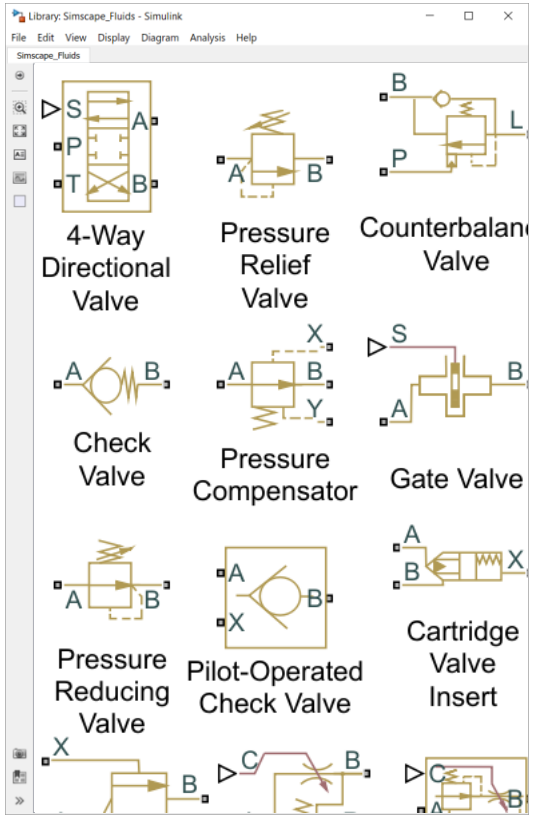






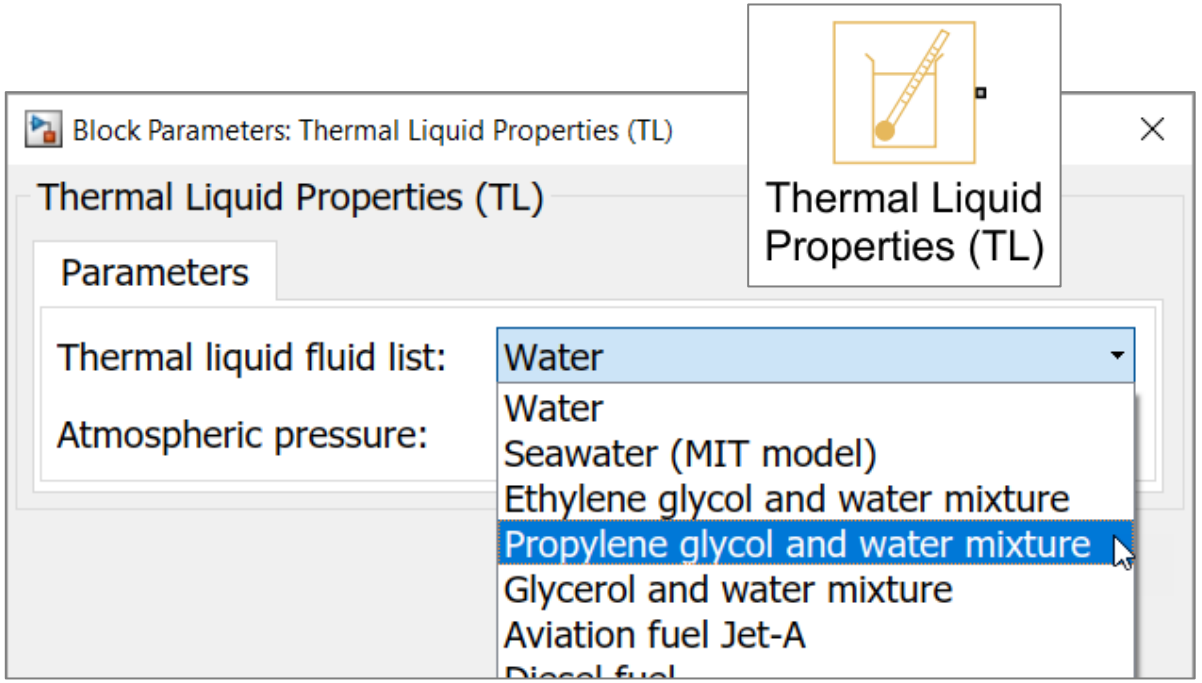


Subset of libraries

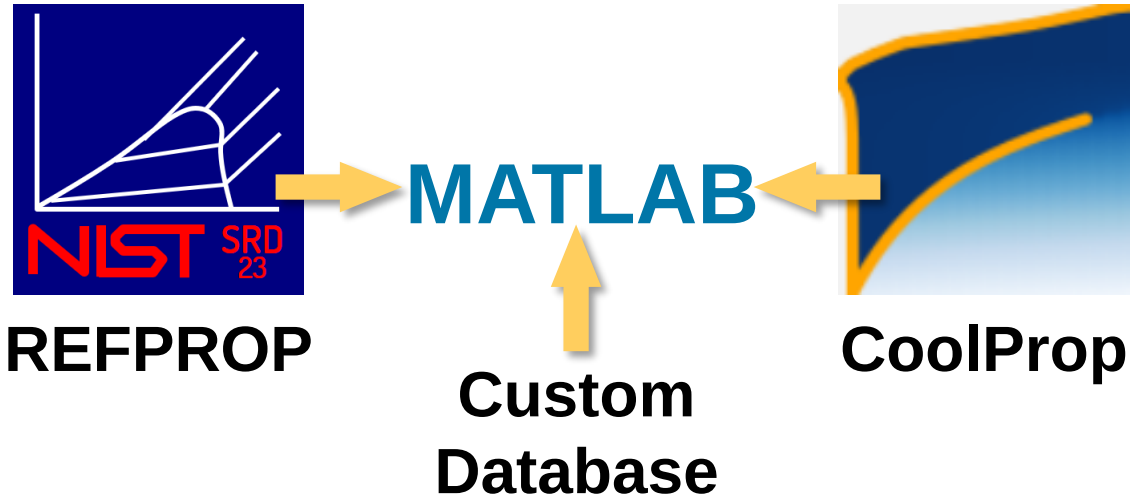


Simscape Fluids
Fluid Properties

- Select predefined fluid properties
  - Includes water, seawater, and solutions of glycerol, ethylene glycol, and many more



- Import from common databases
  - REFPROP, CoolProp
  - Any database with a connection to MATLAB



Simscape Resources

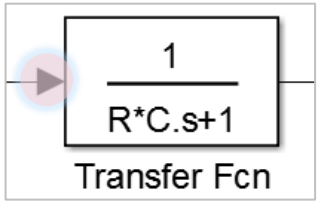
General from mathworks.com

- Web page: simscape
- Documentation: simscape/index.html
- All Videos: simscape/videos.html
  1. Simscape Overview
  2. Modeling an Engine Cooling System
  3. Modeling a Hydraulic Actuation System
  4. Modeling a Fuel Supply System
- Examples: simscape/examples.html
- File Exchange: matlabcentral/fileexchange
- MATLAB Answers: matlabcentral/answers

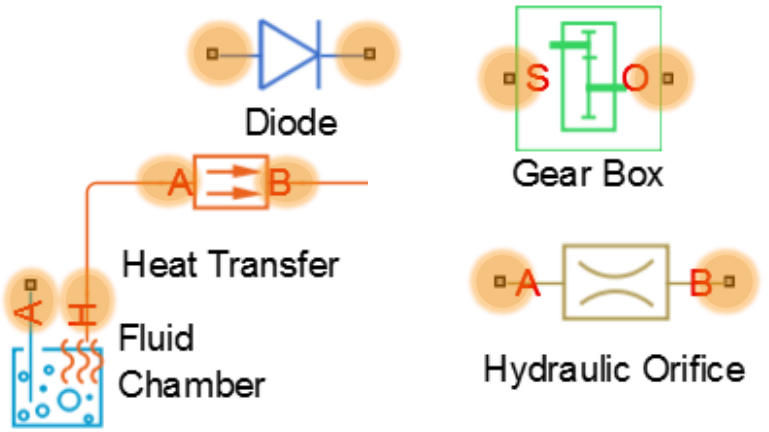
Key Messages

- Simscape offers a modeling method that is well-suited to thermal, fluid, and other types of physical systems
- Combining CARNOT Blockset content with Simscape capabilities could offer big benefits to CARNOT users
- CARNOT Blockset could tackle a wider range of problems if it leveraged Simscape

Signal-Based



Simscape (physical networks)



CARNOT Content **Simscape Network**