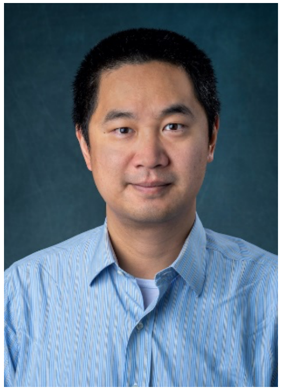
Open Source Modelica Models for Data Center Cooling



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2. Lawrence Berkeley National Laboratory
3. Schneider Electric

University of Colorado Boulder

SBS LAB Sustainable Buildings and Societies Laboratory

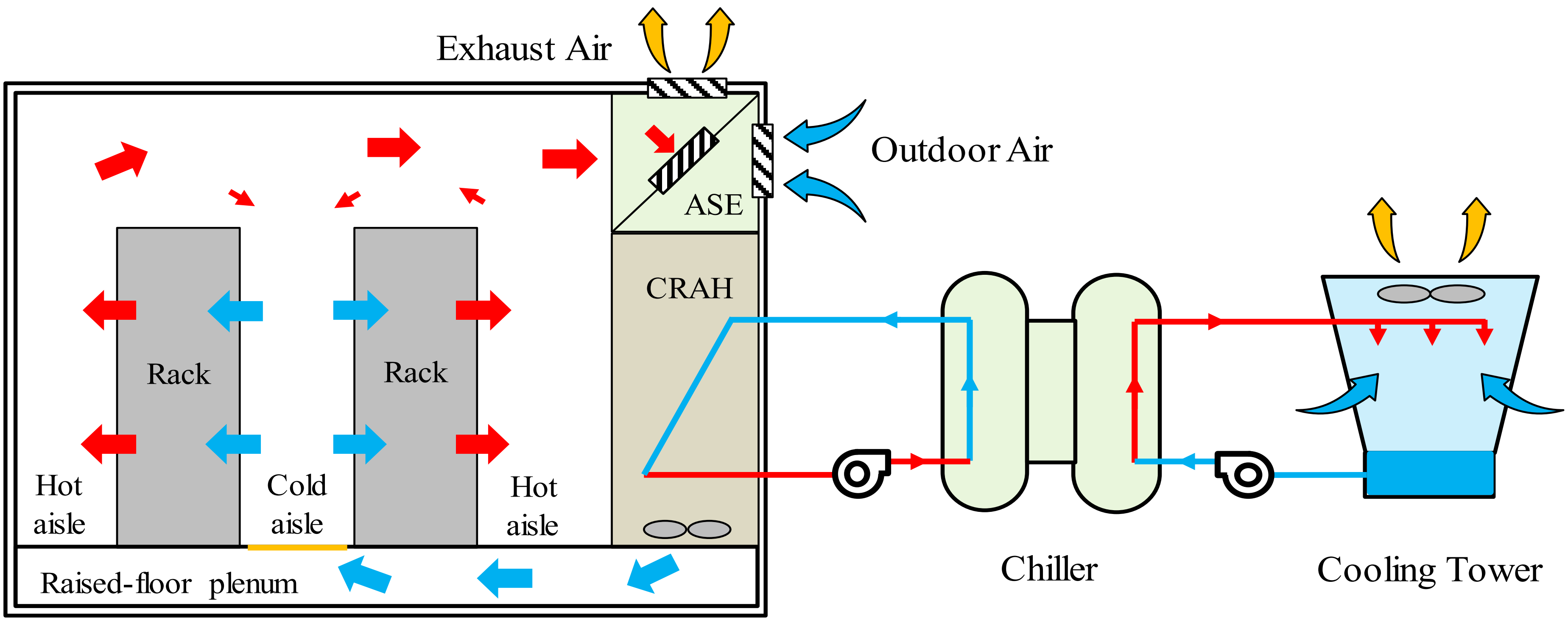
BERKELEY LAB Lawrence Berkeley National Laboratory

Schneider Electric

Outline

- Introduction
- Modelica Models for Data Center Cooling
- Case Study
- Conclusions

Typical Data Center Cooling

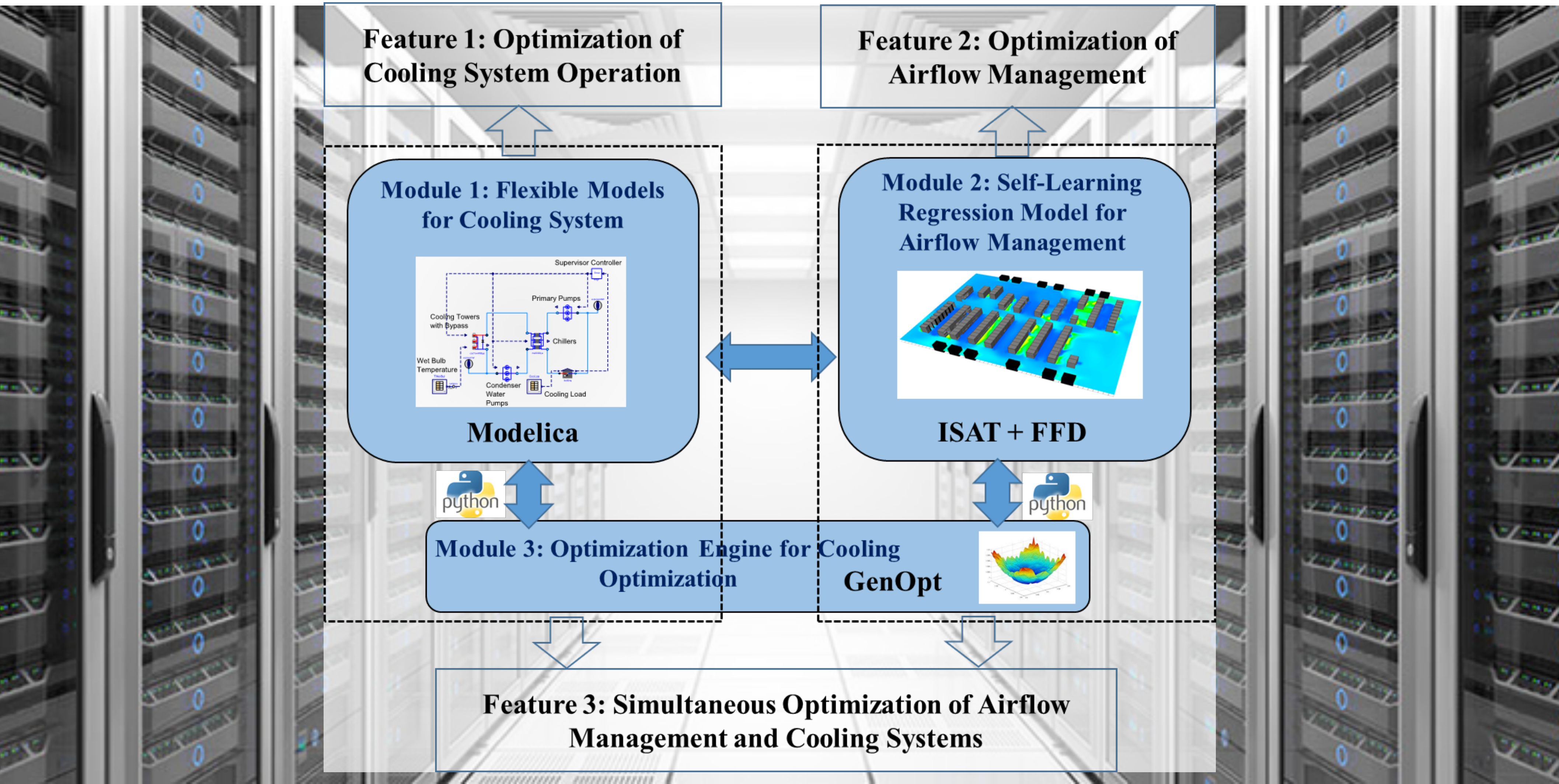


Airflow Management

Cooling System

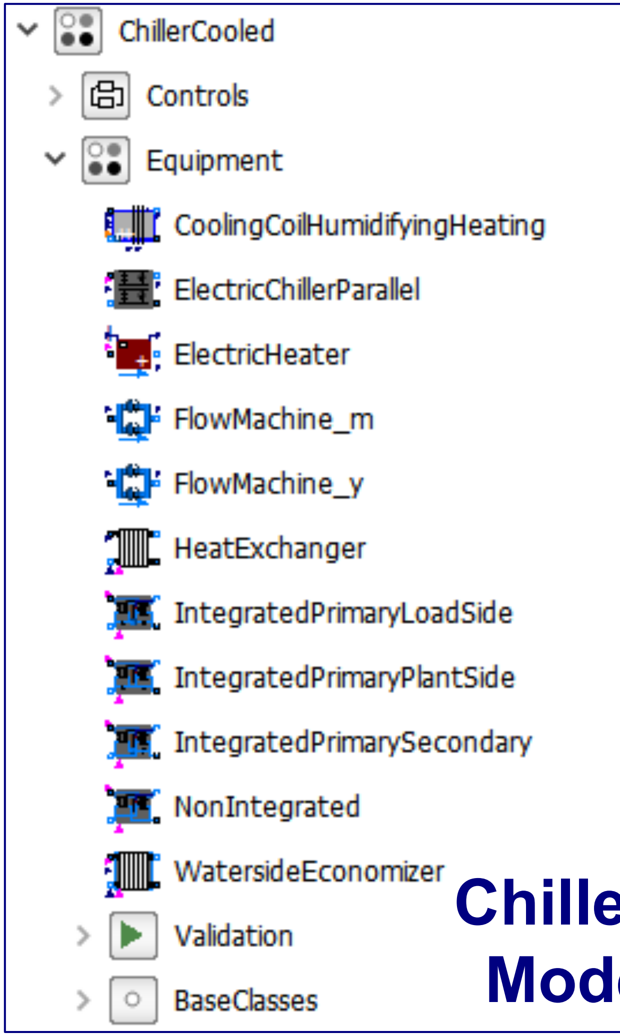
Energy Efficient Data Center Cooling

Improving Data Center Energy Efficiency through End-to-End Cooling Modeling and Optimization, sponsored by DOE, https://www.colorado.edu/lab/sbs/doe-datacenter

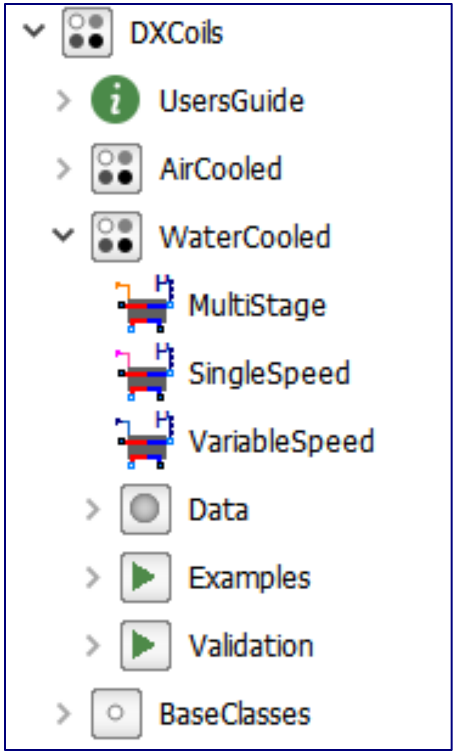


Cooling System Models in Buildings Library

Created 81 new models in Modelica Buildings library in 2017



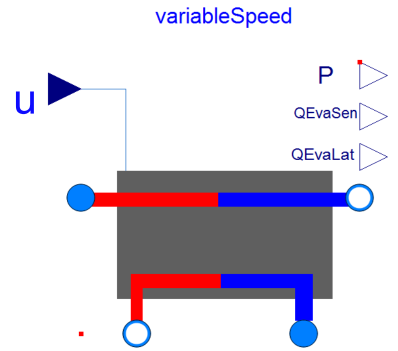
Chilled Water System Models (58 Models)



DX Cooled System Models (23 Models)

Component Models

Example: Water-cooled Variable Speed Computer Room Air Conditioner (CRAC)



Icon of CRAC Model

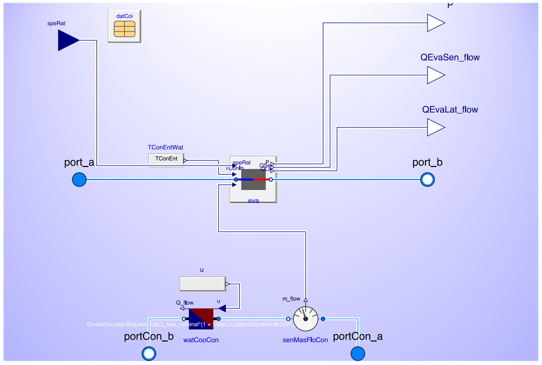


Diagram of CRAC Model

User's Guide

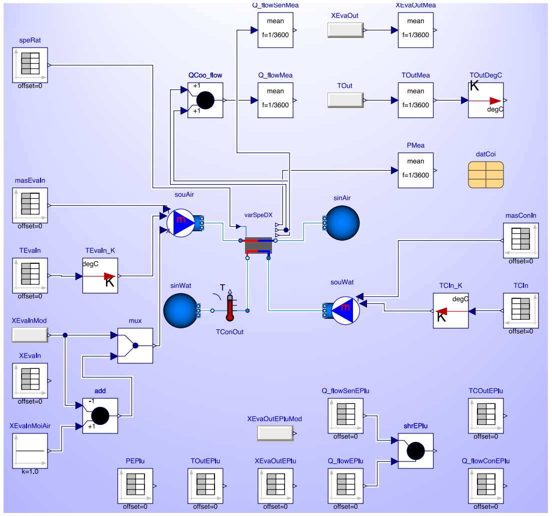
Information

This package contains models for direct evaporation cooling coils (DX coils).

The following six DX coil models are available:

DX coil condenser	DX coil model	Properties	Control signal
Air-cooled	Buildings.Fluid.HeatExchangers.DXCoils.AirCooled.MultiStage	Coil with multiple operating stages, each stage having a constant speed. Each stage has its own performance curve, which may represent the coil performance at different compressor speed, or the coil performance as it switches between cooling only, cooling with hot gas reheat, or heating only.	Integer; *0* for off, *1* for first stage, *2* for second stage, etc.
Air-cooled	Buildings.Fluid.HeatExchangers.DXCoils.AirCooled.SingleSpeed	Single stage coil with constant compressor speed	Boolean signal; `true` if coil is on.
Air-cooled	Buildings.Fluid.HeatExchangers.DXCoils.AirCooled.VariableSpeed	Coil with variable speed compressor with lower speed limit. If the control signal is below the lower limit, the coil switches off. It switches on if the control signal is above the lower limit plus a hysteresis. By default, the minimum speed ratio is `minSpeRat` and obtained from the coil data record `datCoi.minSpeRat`. The hysteresis is by default `speDeaBanRat=0.05`.	Real number; *0* for coil off, *1* for coil at full speed.
Water-cooled	Buildings.Fluid.HeatExchangers.DXCoils.WaterCooled.MultiStage	Coil with multiple operating stages, each stage having a constant speed. Each stage has its own performance curve, which may represent the coil performance at different compressor speed, or the coil performance as it switches between cooling only, cooling with hot gas reheat, or heating only.	Integer; *0* for off, *1* for first stage, *2* for second stage, etc.
Water-cooled	Buildings.Fluid.HeatExchangers.DXCoils.WaterCooled.SingleSpeed	Single stage coil with constant compressor speed	Boolean signal; `true` if coil is on.

Documentation for CRAC Model



Example for validating CRAC Model

System Template Models

Example: Primary-only Chilled Water System with Integrated Waterside Economizer

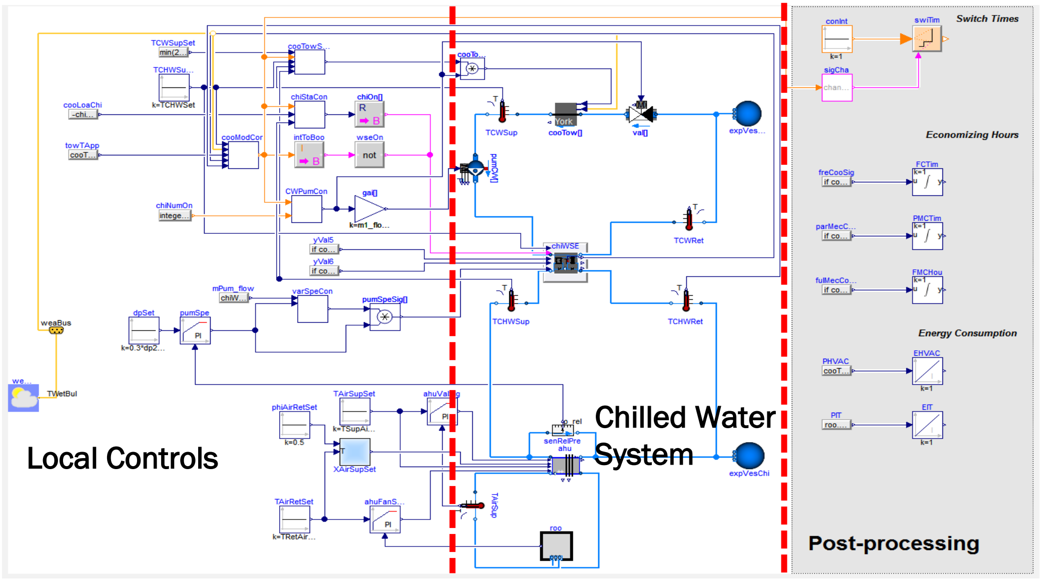
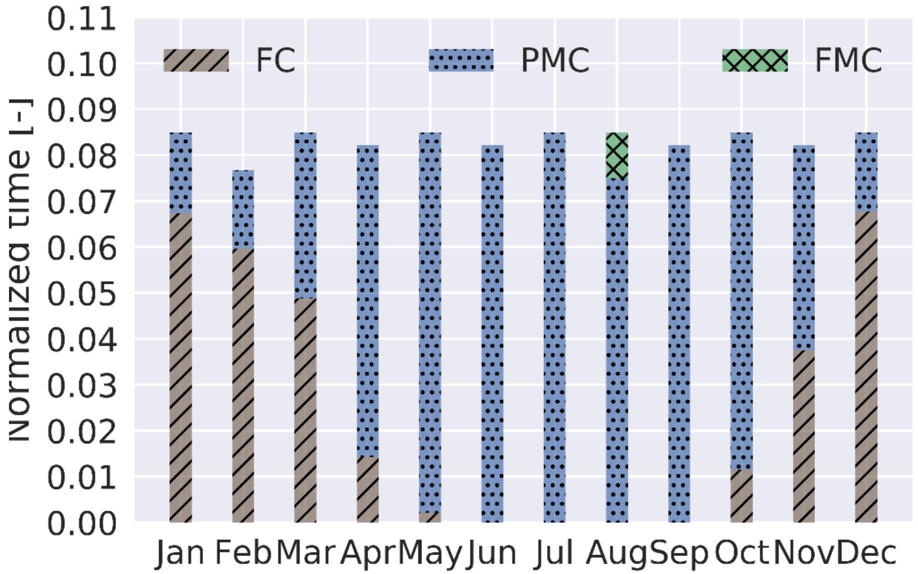
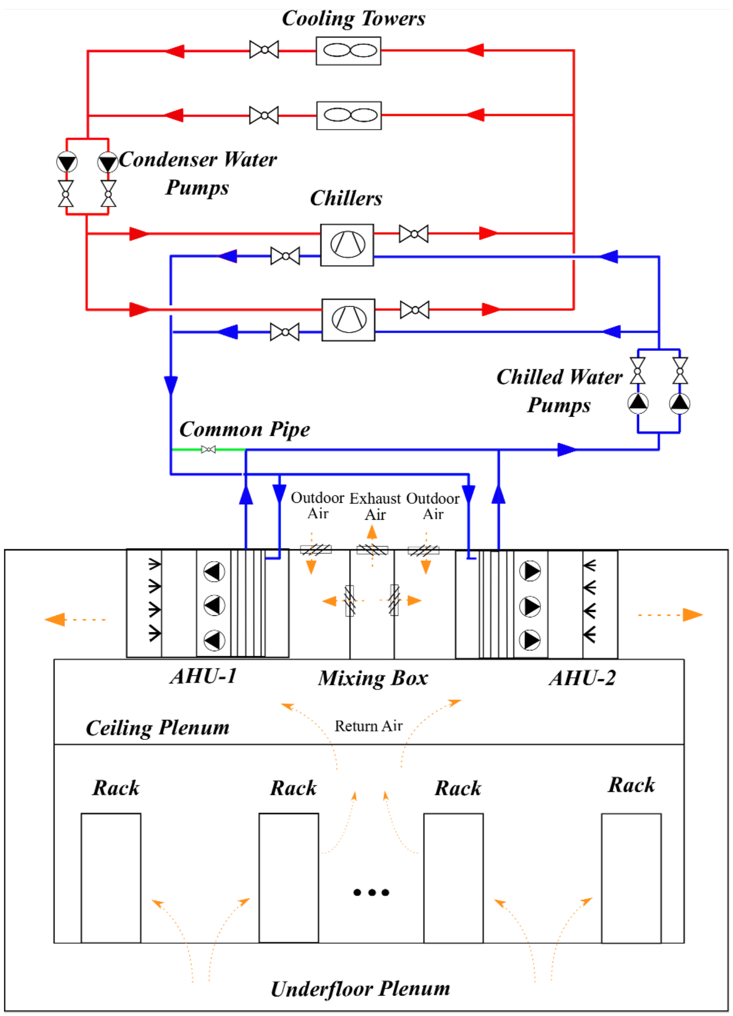


Diagram of Modelica Implementation



Simulated monthly normalized run time of Free Cooling (FC), Partial Mechanical Cooling (PMC), Fully Mechanical Cooling (FMC)

Case Study



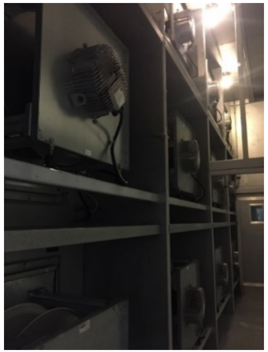
Location: Massachusetts

Climate Zone: 5A – cool and humid

IT Load: *316 kW*

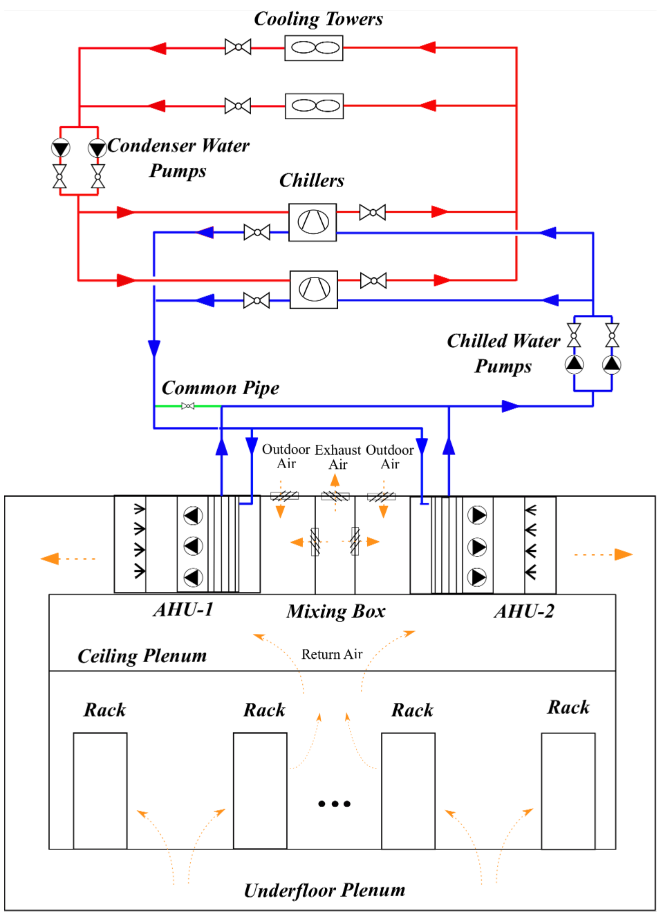
Cooling Load: *100 tons*

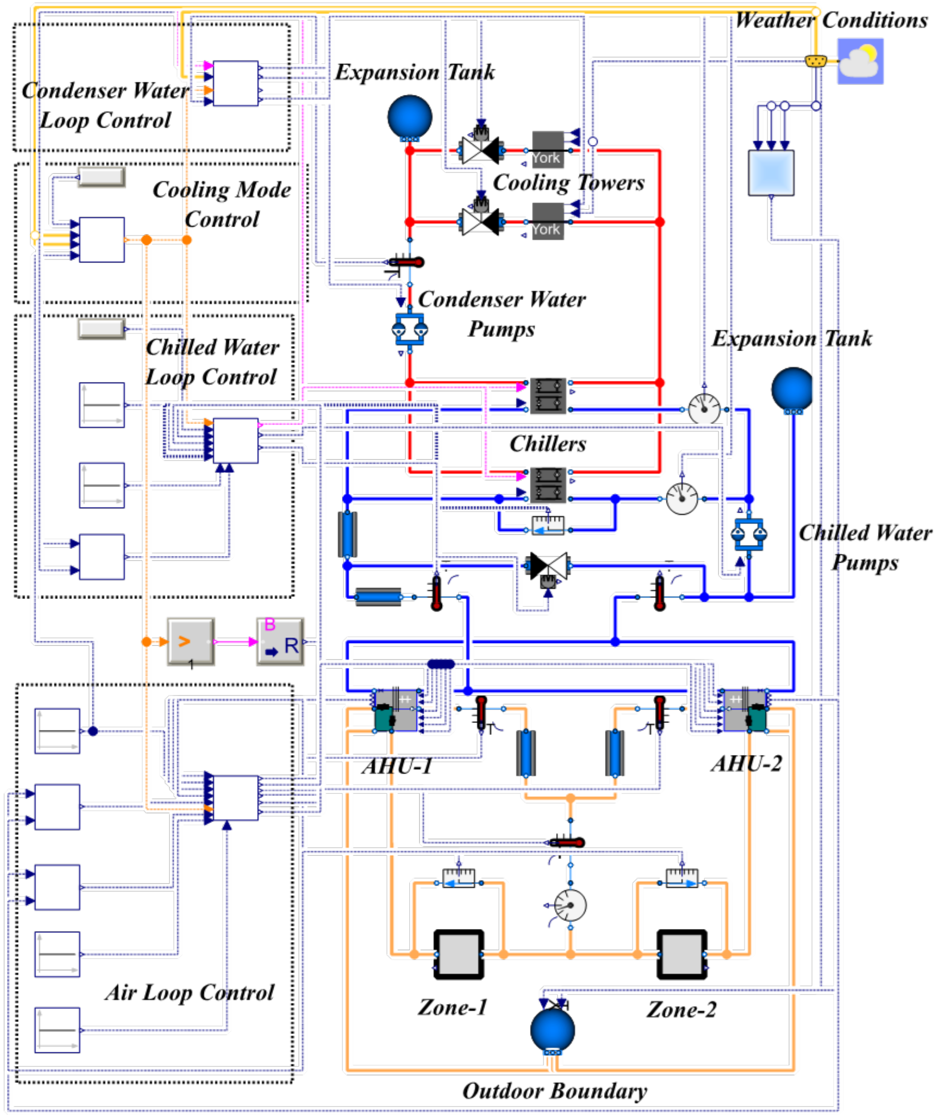
Cooling System: chilled water system + airside economizer



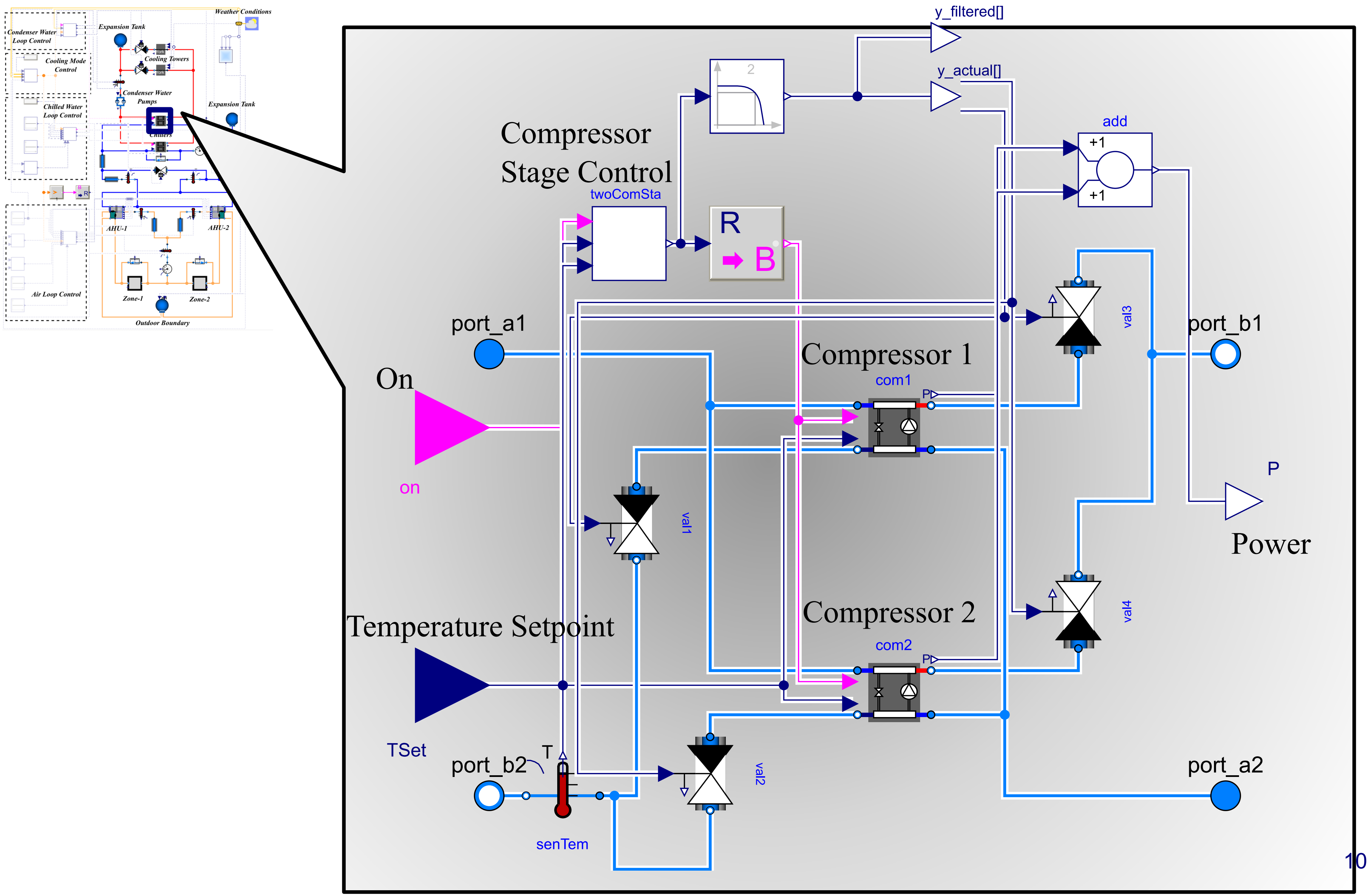
Modelica System Model

Modelica: An equation-based object-oriented modeling language for multi-domain dynamic systems.

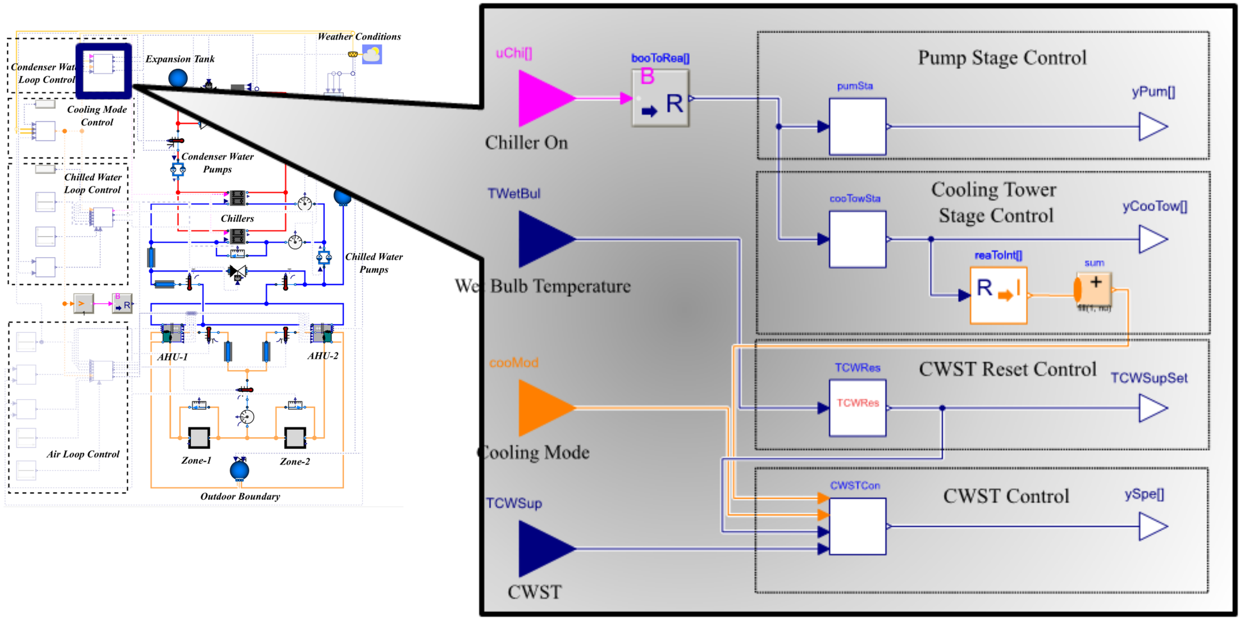




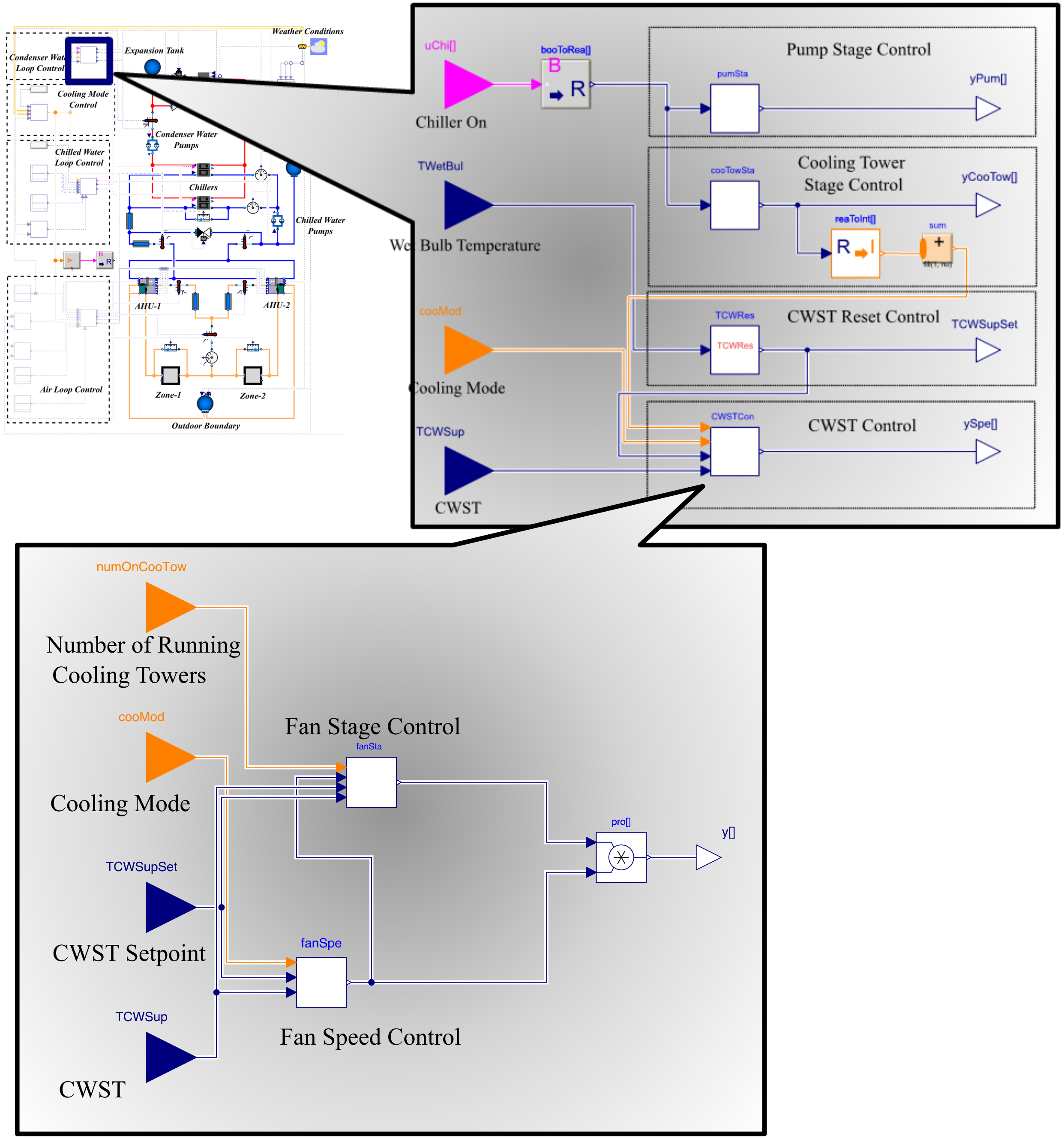
Chiller with Two Compressors



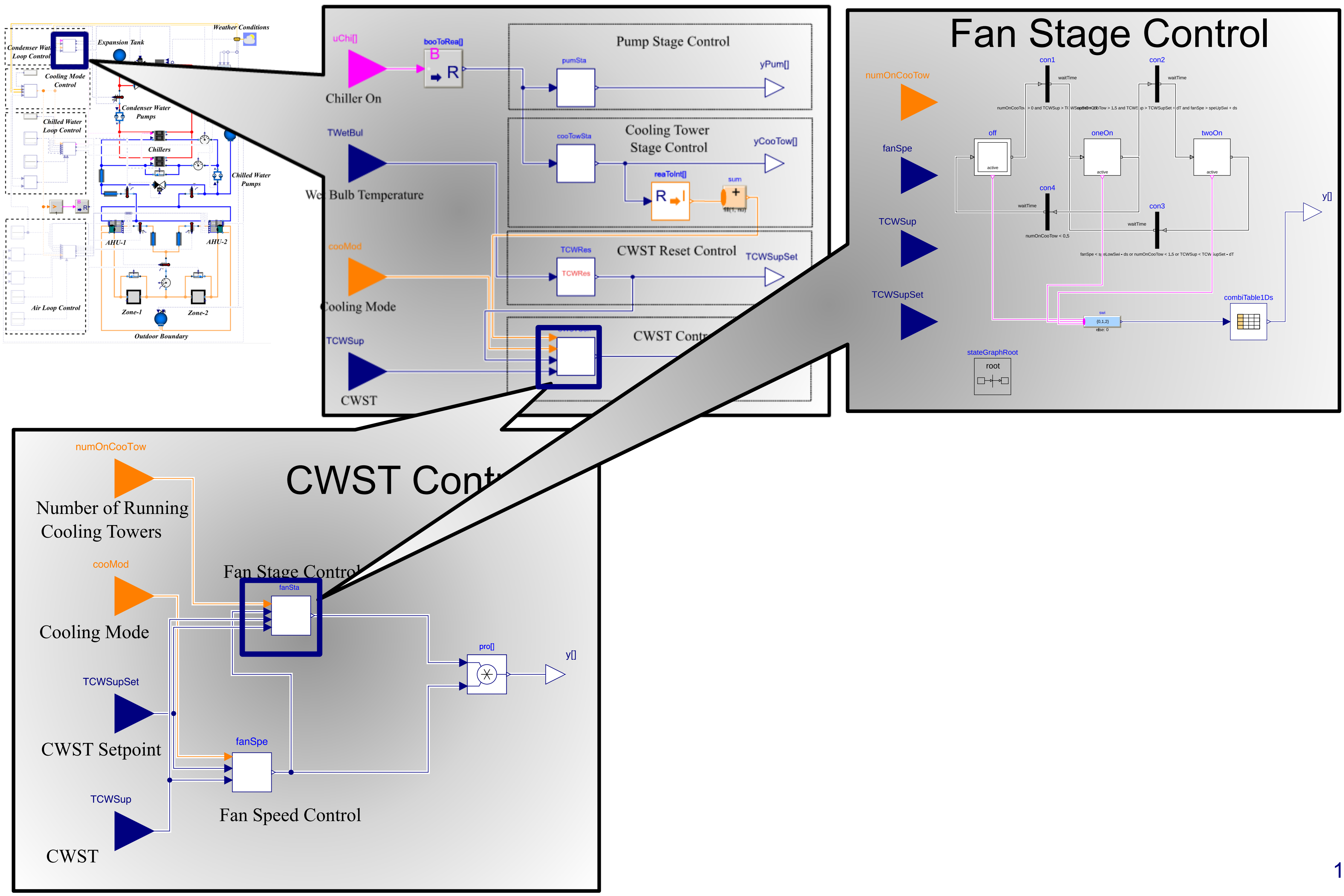
Condenser Water Loop Control



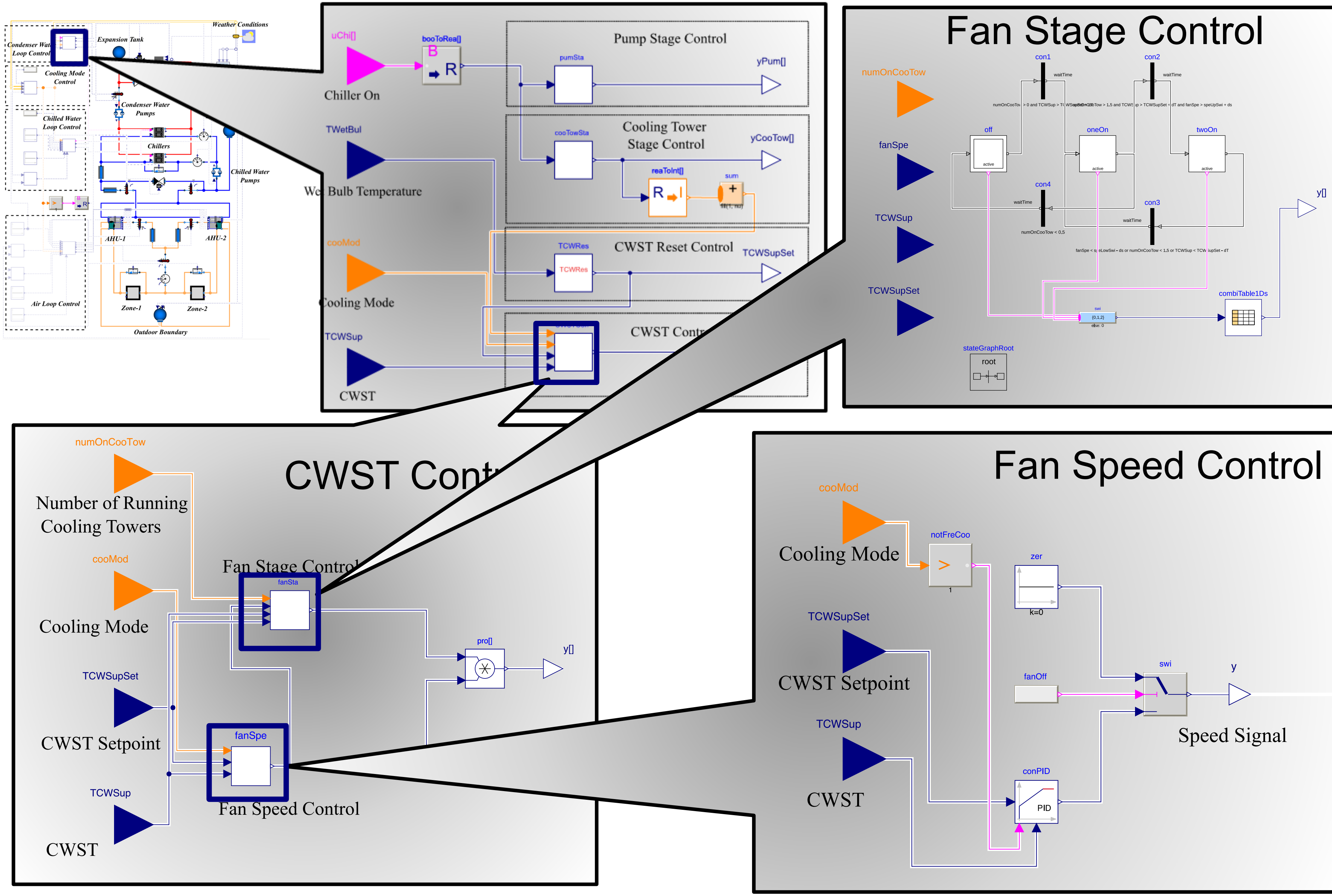
Condenser Water Loop Control



Condenser Water Loop Control

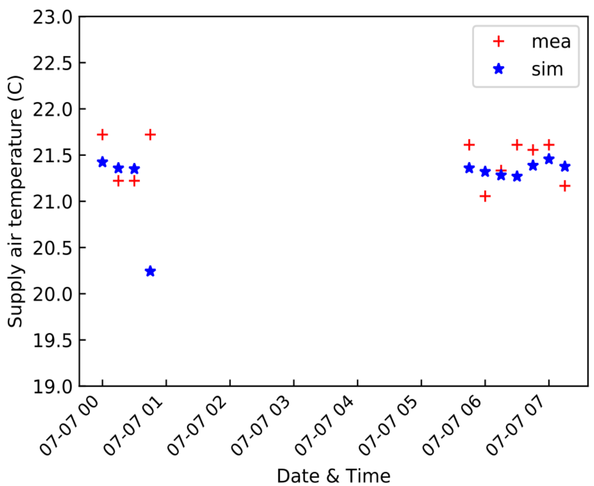


Condenser Water Loop Control

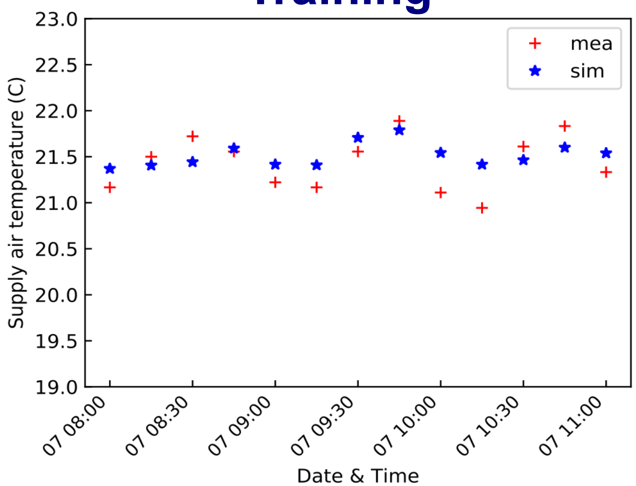


Calibration Results

Cooling Coil

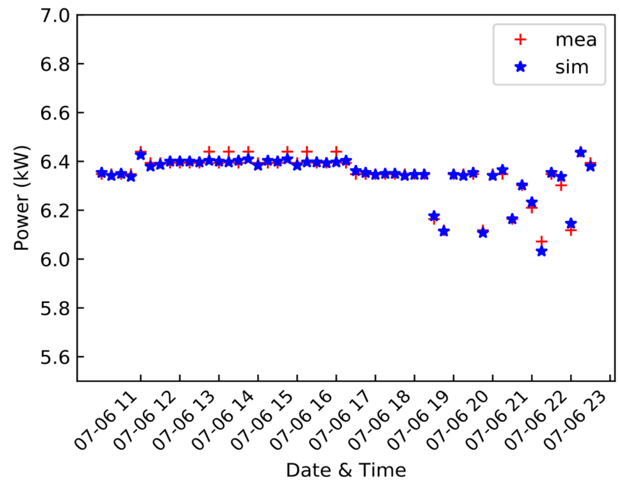


Training

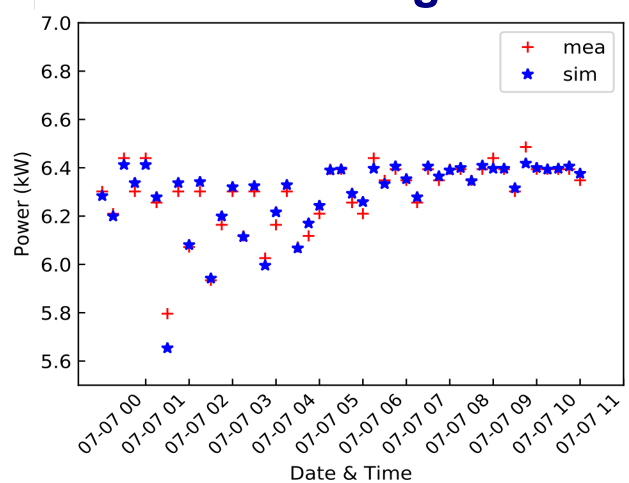


Validation

Primary Pump

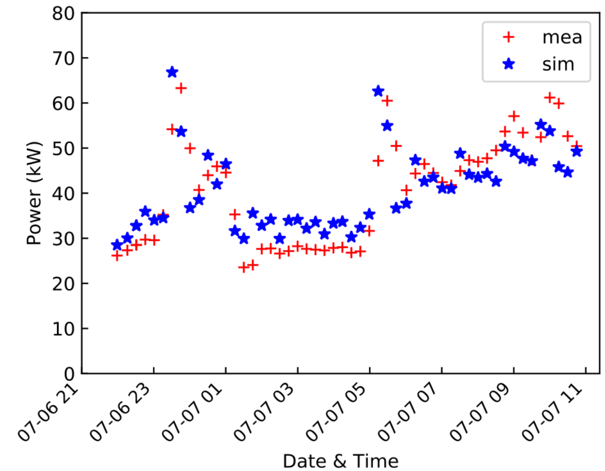


Training

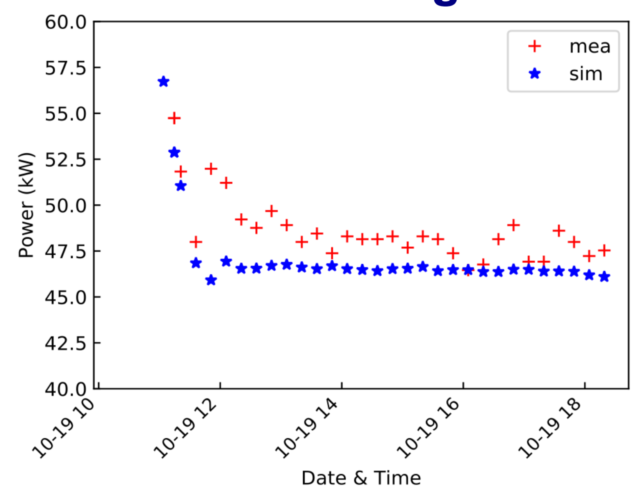


Validation

Chiller



Training



Validation

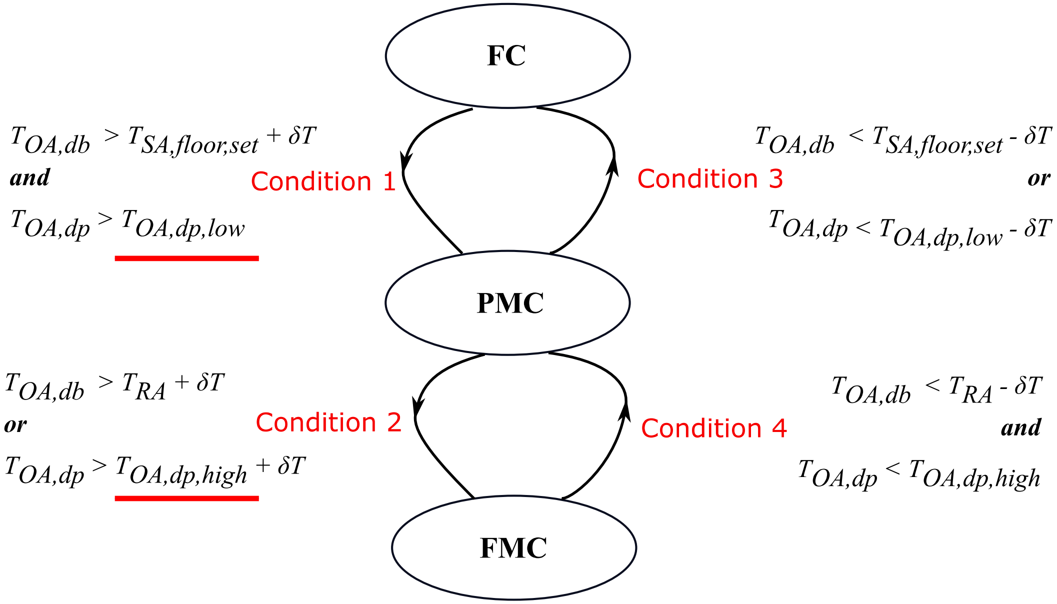
Calibration error is within **8%** for all component models, and within **6%** for the system model.

Energy Saving: Opportunity 1

Cooling Coils are **degraded**.

Model	Nominal UA (kW/K)	Degraded UA (kW/K)
AHU 1	**77.4**	**28.6**
AHU 2	**77.4**	**30.2**

Energy Saving: Opportunity 2



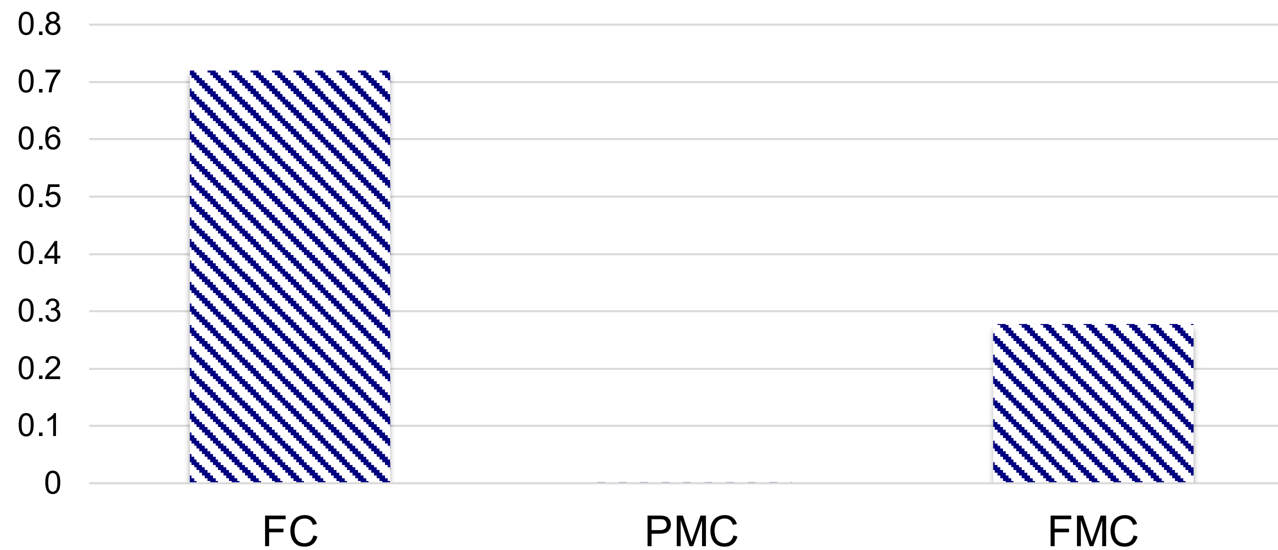
$$T_{OA,dp,low} = T_{OA,dp,high} = 12.2°\mathrm{C}$$

$$\delta T = 1.1°\mathrm{C}$$

$$T_{SA,floor,set} = 22.2°\mathrm{C}$$

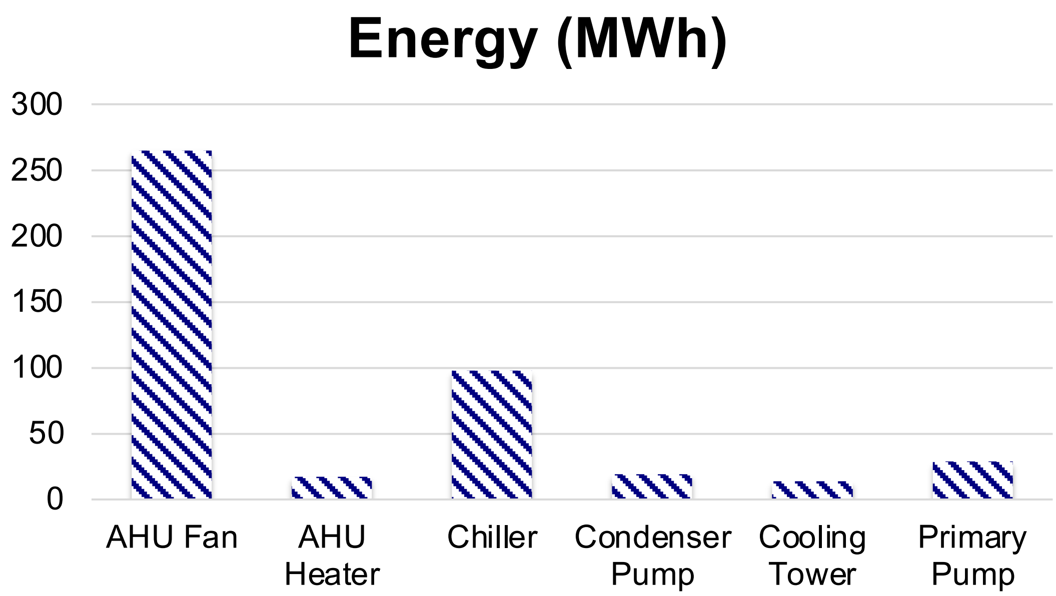
FC: free cooling mode. Only economizers are on
PMC: partial mechanical cooling. Both economizer and chillers are on.
FMC: fully mechanical cooling. Only chillers are on.

Normalized Hours



Energy Saving: Opportunity 3

- **Simultaneous** heating and cooling in AHUs



Optimization Strategies & Potential Savings

System	Clean Cooling Coils	Improved Cooling Mode Control	Added Two-way Valve	Optimal Floor Air Temperature Setpoint
Baseline System				
System 1	✓			
System 2		✓		
System 3			✓	
System 4		✓	✓	
System 5_1				✓
System 5_2		✓		✓
System 5_3		✓	✓	✓

System	Annual Energy (MWh)	$T_{floor,set}$	Savings
Baseline System	447	22.2 ℃	\
System 1	787	22.2 ℃	-76.1%
System 2	406	22.2 ℃	9.2%
System 3	404	22.2 ℃	9.6%
System 4	358	22.2 ℃	16.9%
System 5_1	426	25.1 ℃	4.7%
System 5_2	381	25.1 ℃	14.8%
System 5_3	338	27.0 ℃	24.4%

Conclusion

1. Open source Modelica model for data center cooling has been developed and released.

2. The case study on a real data center has shown up to 24% energy saving with the proposed energy retrofit solutions.

3. Owners have implemented the solutions at their data center.

Acknowledgement and References

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Y. Fu, W. Zuo, M. Wetter, J. W. VanGilder, P. Yang 2019. "Equation-Based Object-Oriented Modeling and Simulation of Data Center Cooling Systems." Energy and Buildings, 198, pp. 503-519.

Y. Fu, W. Zuo, M. Wetter, J. W. VanGilder, X. Han, D. Plamondon 2019. "Equation-Based Object-Oriented Modeling and Simulation for Data Center Cooling: A Case Study." Energy and Buildings,186, pp. 108-125.