A Universal Model for Hybrid HVAC Equipment in Building Energy Simulations

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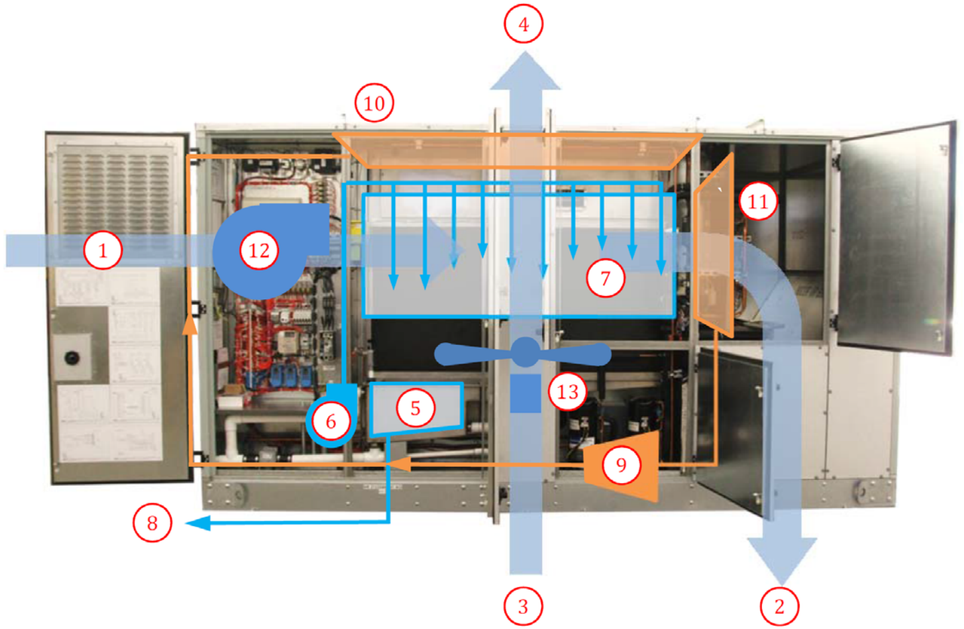
Overview of Hybrid HVAC

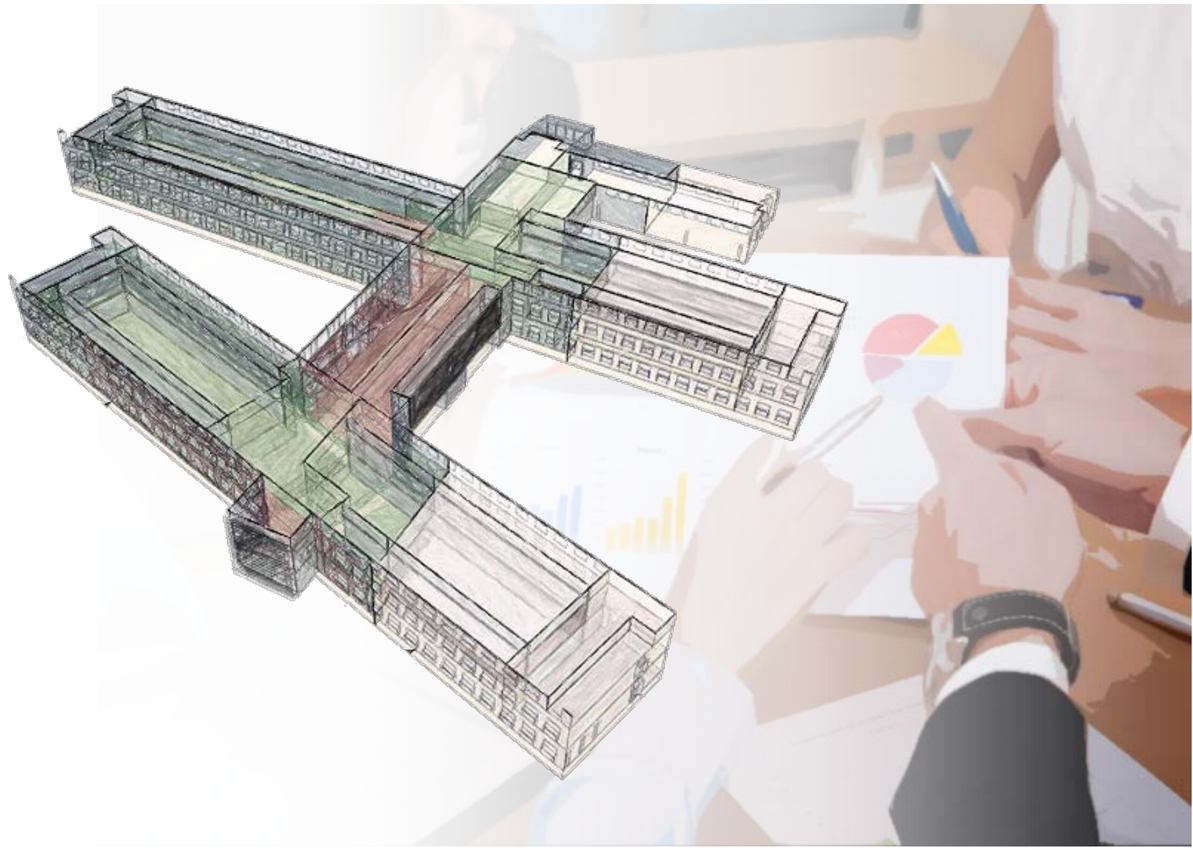
- Include multiple cooling strategies and switch between numerous operating modes to heat/cool/dehumidify more efficiently across a range of operating conditions
- Integrate component operations for mutualistic efficiency advantages
- Some advanced technologies include
  - Variable speed fans and compressors
  - Heat recovery
  - Desiccant dehumidification
  - Indirect evaporative cooling (various types)
  - Evaporative condenser cooling
- Best strategy differs by climate and application
- Can reduce peak demand by 40% or more
- Can achieve 65% savings for annual cooling energy consumption



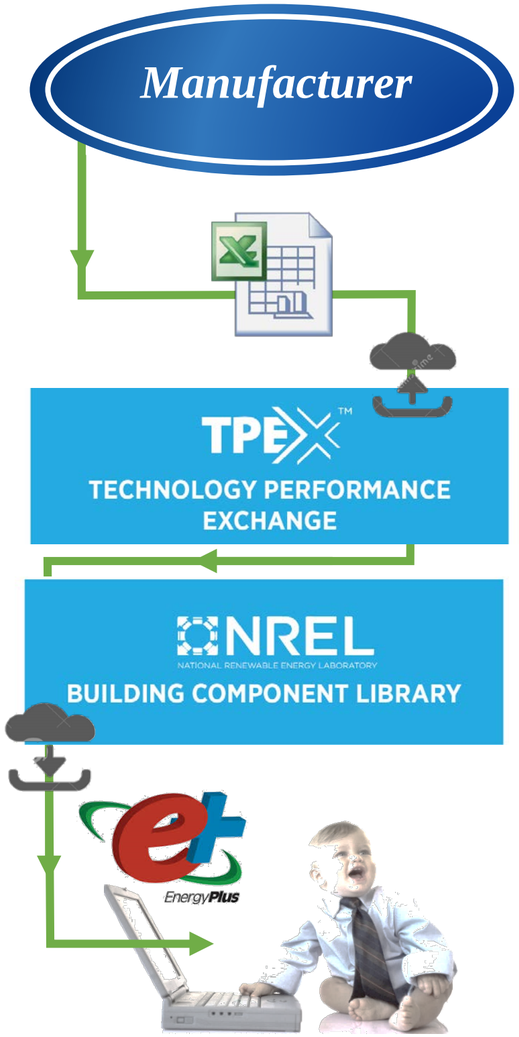
1	*Outside Air (Primary Inlet)*	5	*Sump*	10	*DX Condenser*
2	*Supply Air*	6	*Circulation Pump*	11	*DX Evaporator*
3	*Return Air (Secondary Inlet)*	7	*EPX (Indirect Evap. Heat Exch.)*	12	*Blower (Primary Air)*
4	*Exhaust Air*	8	*Drain*	13	*Fan (Secondary Air)*
		9	*Compressors*		

Why we need a standard model for hybrid unitary HVAC

- There are many unique hybrid system architectures
- Current building energy simulations tools are not capable of modeling most hybrid systems
- It is infeasible for practitioners to model systems from first principals
- Previous simulations are not comparable, and not transferable
- Need a compliance pathway for Building Energy Efficiency Standards
- Utilities, energy service companies, and efficiency programs need accurate projections of energy savings and demand reductions
- Engineers require parametric simulation of alternatives
- Customers require cost justification

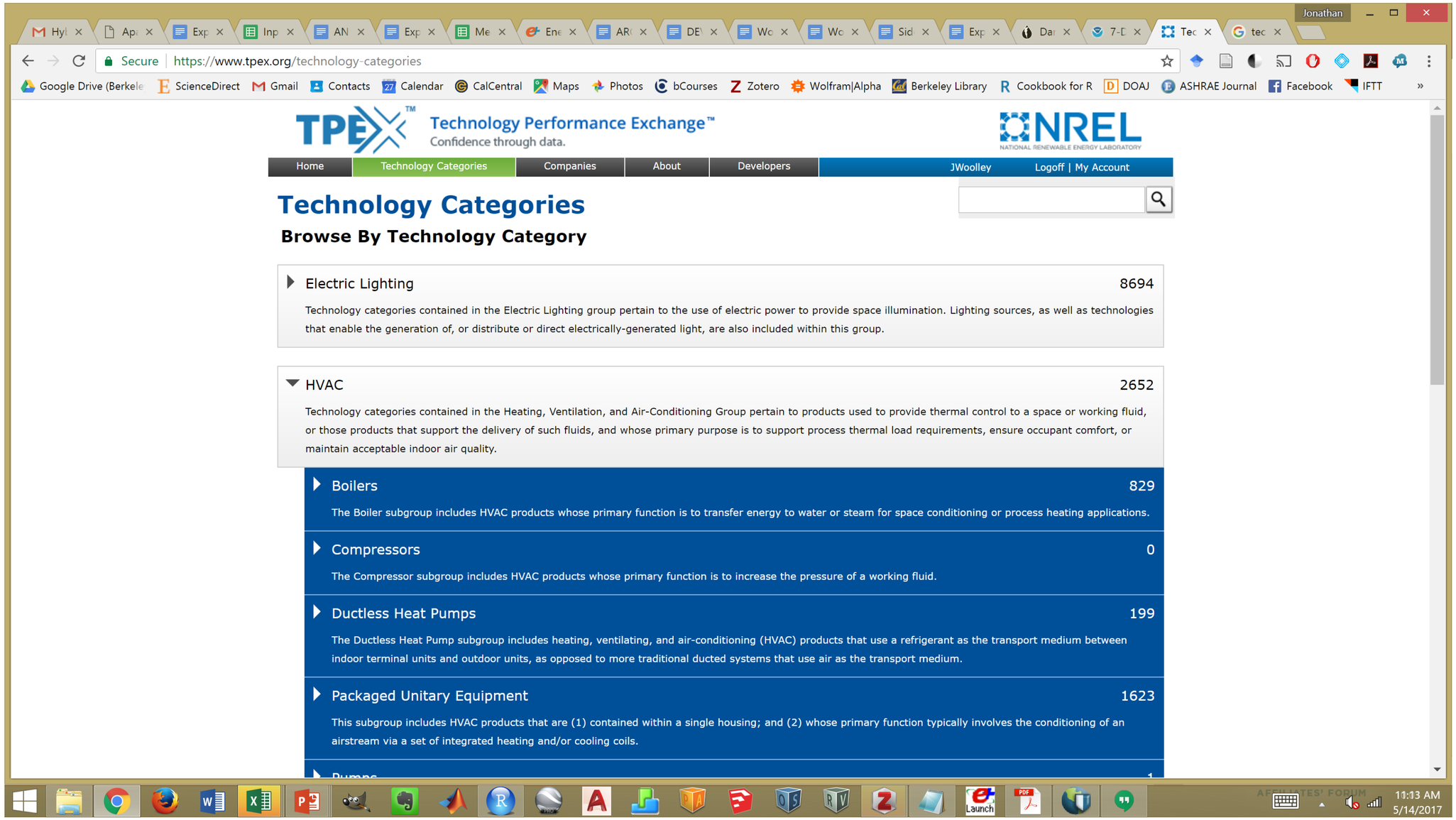


Overall information workflow for our model

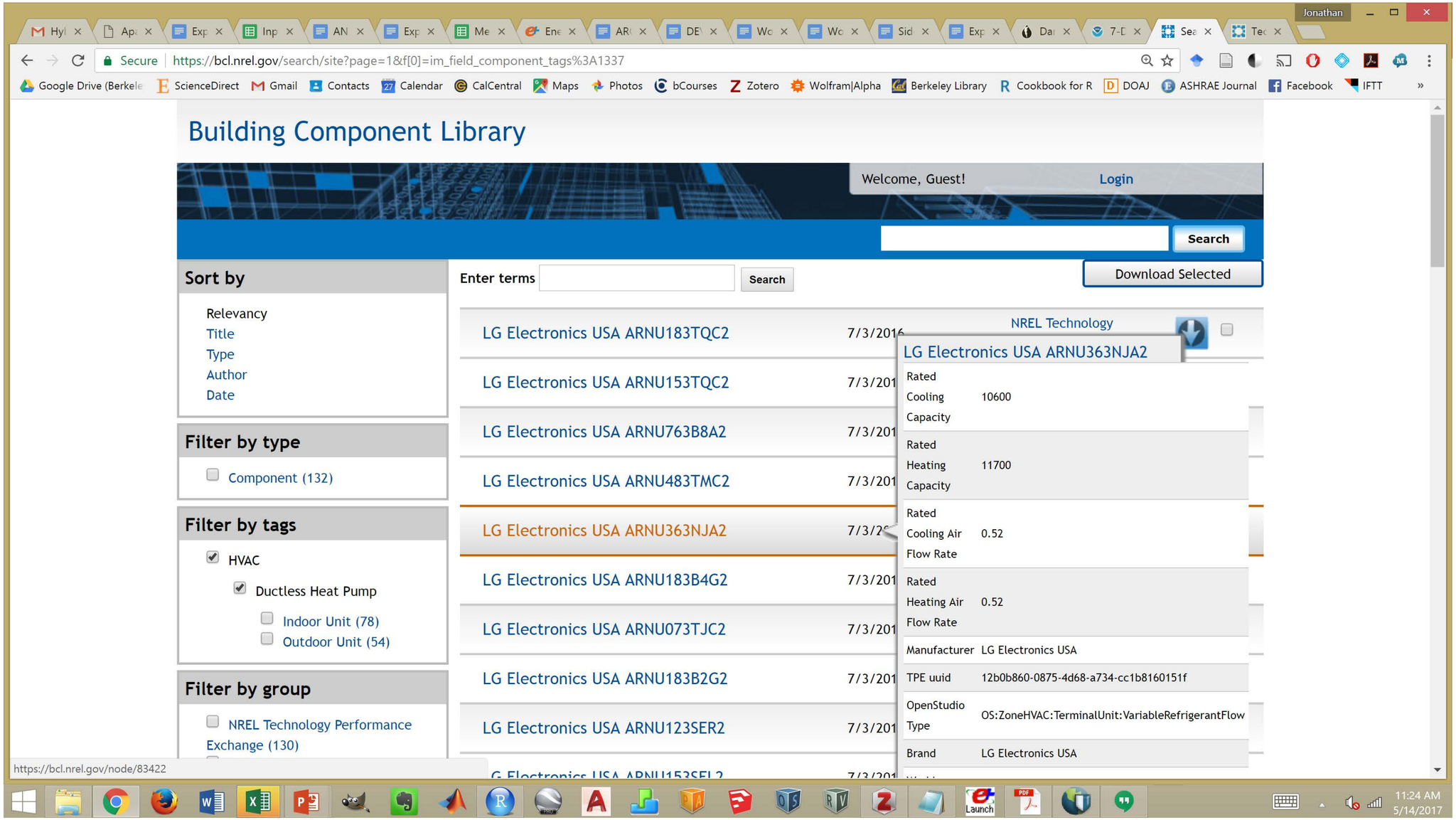


- Manufacturers that publish data benefit from public modeling capabilities
- Equipment performance data input to a standard format template
- Manufacturers upload data to Technology Performance Exchange
- Users download data from Building Component Library
- EnergyPlus “Hybrid Unitary HVAC” is simple to use

Technology Performance Exchange – https://www.tpex.org

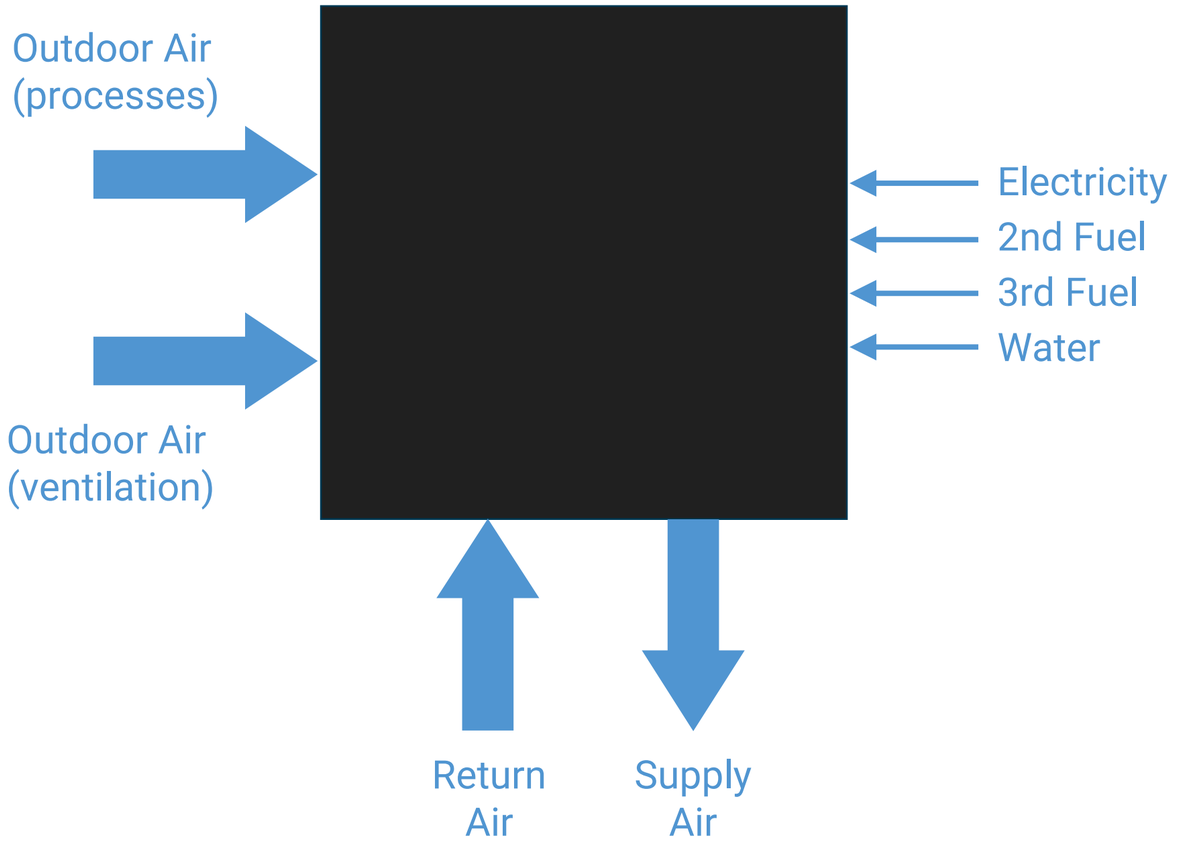


Building Component Library – https://bcl.nrel.gov/



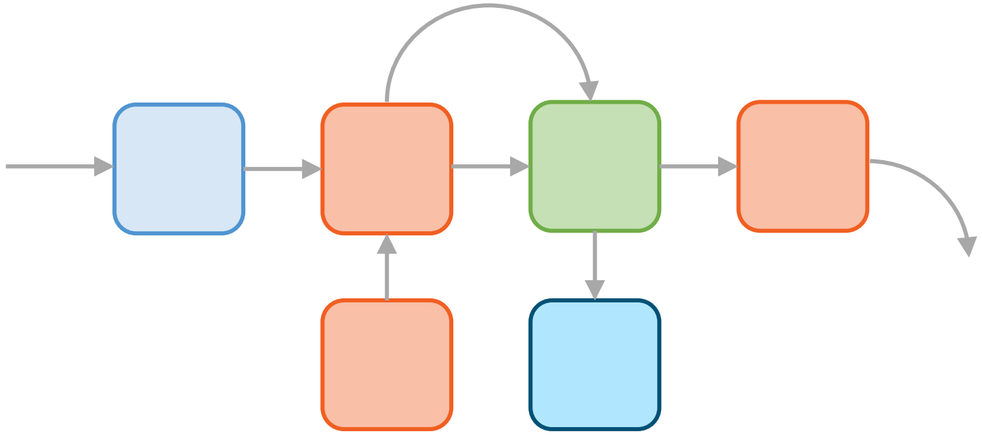
Basic formulation for our model

- A new ZoneHVAC object class in EnergyPlus
- Accommodates any unitary HVAC system
- May have return air, outdoor air, and supply air streams
- May consume electricity, water, and two other fuels
- An empirical model, does not require definition of internal elements
- Allows many operating modes
- Responds to need for heating, cooling, dehumidification, and ventilation

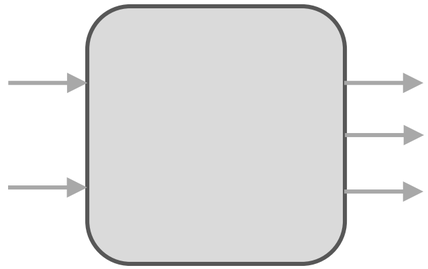


Why we chose an empirical (black box) model

- It is infeasible to expect practitioners to model hybrid systems from first principals
- A sub-component based model approach is useful, but limited, and slow to evolve
  - Must have a standard model for every sub component
  - Models must be flexible enough to accommodate many architectures
  - New component innovations cannot be immediately represented
- An empirical model minimizes confusion for practitioners
- 1 product = 1 empirical data set
- More reliable and flexible for compliance
- Protects trade secrets

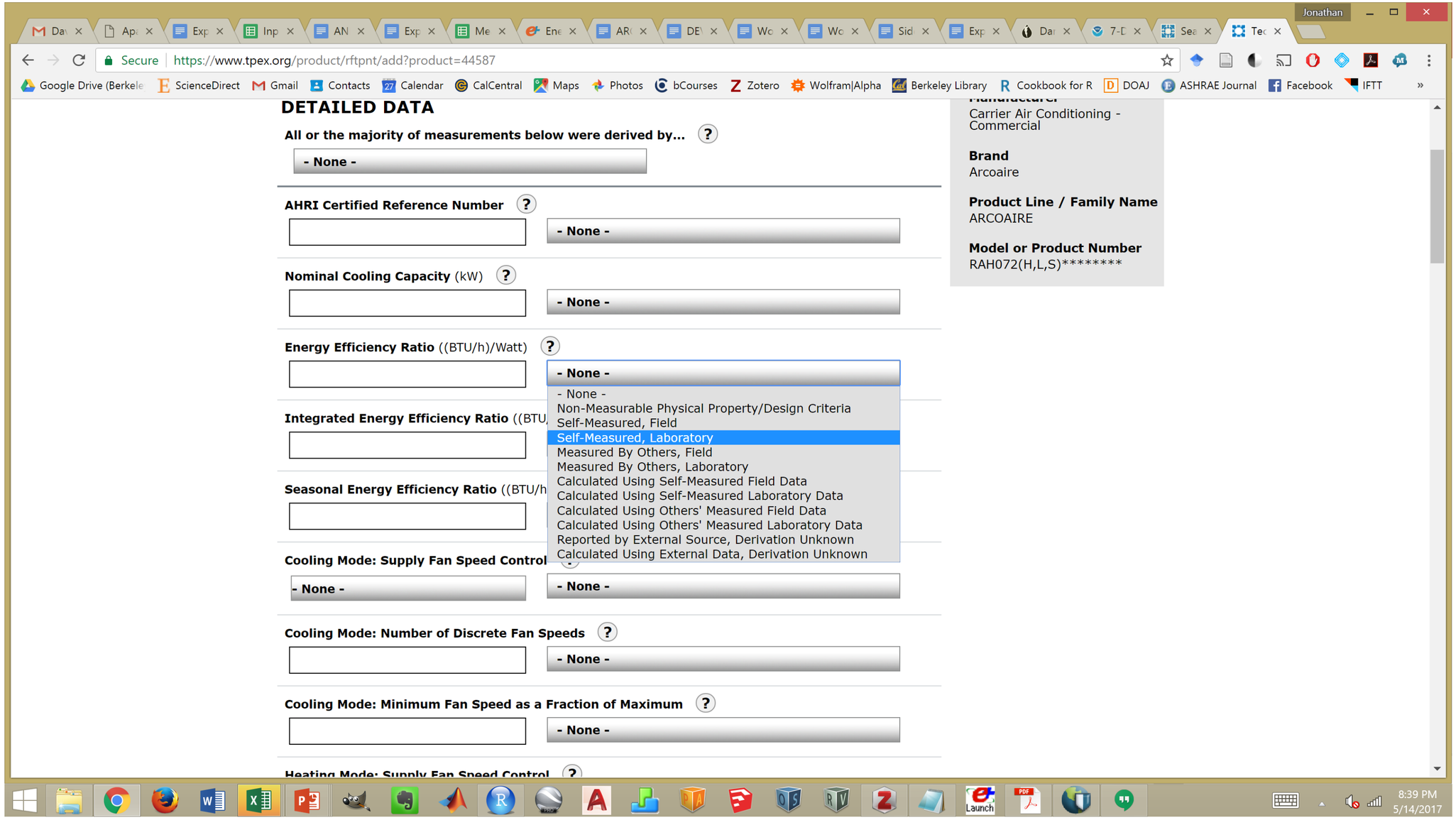


A sub-component based model approach

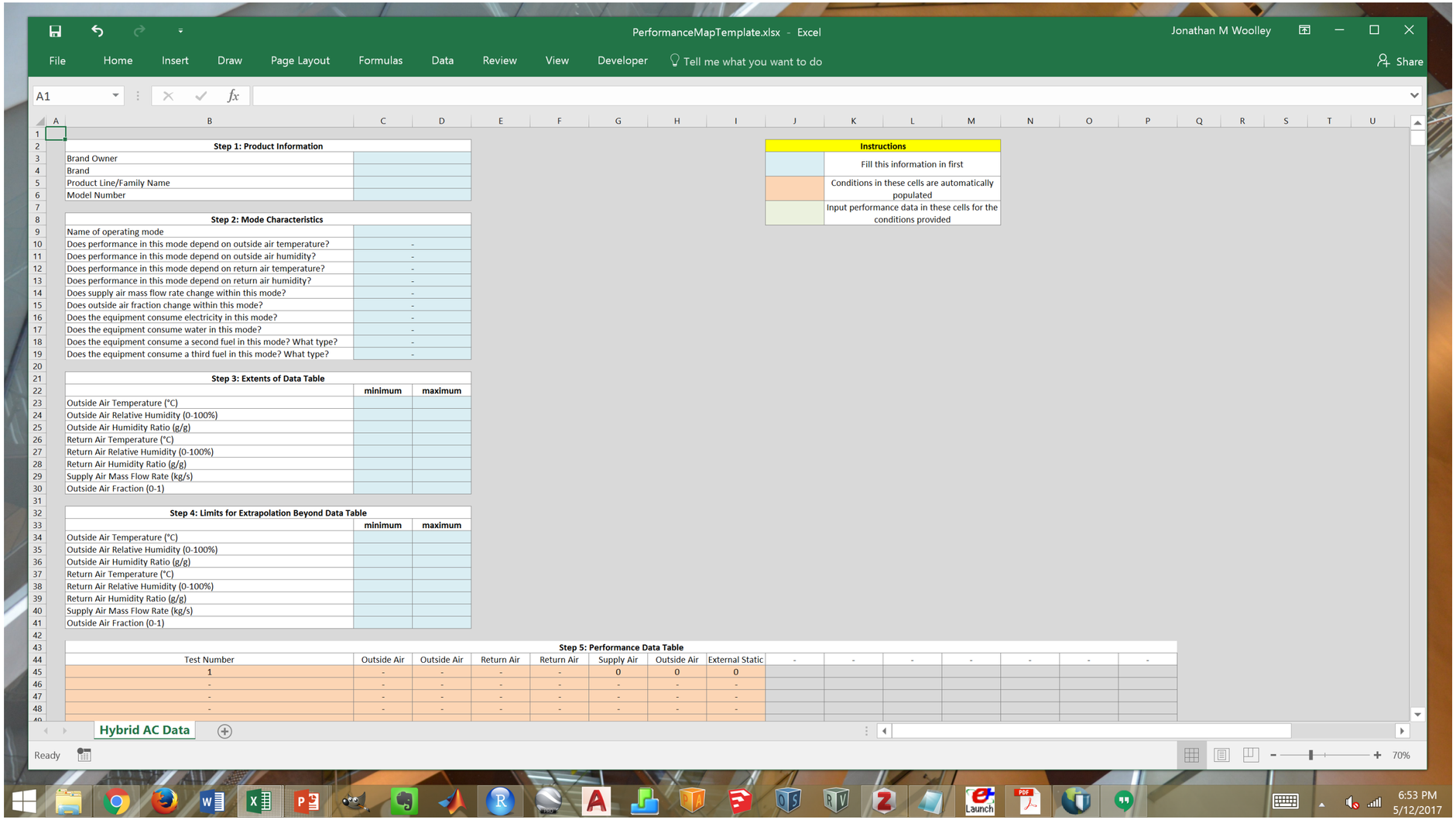


A black box model approach

Technology Performance Exchange – https://www.tpex.org



Performance Map Template (Screenshot)



PerformanceMapTemplate.xlsx - Excel

Jonathan M Woolley

File Home Insert Draw Page Layout Formulas Data Review View Developer Tell me what you want to do Share

A1

Step 1: Product Information	
Brand Owner	
Brand	
Product Line/Family Name	
Model Number	

Step 2: Mode Characteristics	
Name of operating mode	
Does performance in this mode depend on outside air temperature?	-
Does performance in this mode depend on outside air humidity?	-
Does performance in this mode depend on return air temperature?	-
Does performance in this mode depend on return air humidity?	-
Does supply air mass flow rate change within this mode?	-
Does outside air fraction change within this mode?	-
Does the equipment consume electricity in this mode?	-
Does the equipment consume water in this mode?	-
Does the equipment consume a second fuel in this mode? What type?	-
Does the equipment consume a third fuel in this mode? What type?	-

Step 3: Extents of Data Table	minimum	maximum
Outside Air Temperature (°C)		
Outside Air Relative Humidity (0-100%)		
Outside Air Humidity Ratio (g/g)		
Return Air Temperature (°C)		
Return Air Relative Humidity (0-100%)		
Return Air Humidity Ratio (g/g)		
Supply Air Mass Flow Rate (kg/s)		
Outside Air Fraction (0-1)		

Step 4: Limits for Extrapolation Beyond Data Table	minimum	maximum
Outside Air Temperature (°C)		
Outside Air Relative Humidity (0-100%)		
Outside Air Humidity Ratio (g/g)		
Return Air Temperature (°C)		
Return Air Relative Humidity (0-100%)		
Return Air Humidity Ratio (g/g)		
Supply Air Mass Flow Rate (kg/s)		
Outside Air Fraction (0-1)		

Instructions	
	Fill this information in first
	Conditions in these cells are automatically populated
	Input performance data in these cells for the conditions provided

Step 5: Performance Data Table

Test Number	Outside Air	Outside Air	Return Air	Return Air	Supply Air	Outside Air	External Static	-	-	-	-	-	-	-
1	-	-	-	-	0	0	0							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							

Hybrid AC Data

Ready

70%

6:53 PM
5/12/2017

Each operating mode is a distinct combination of system subcomponent functions

Mode	Primary Blower	Secondary Fan	Compressor 1	Compressor 2	Circulation Pump	Heat
Indirect Evaporative Cooling	ON	ON	OFF	OFF	ON	OFF
Indirect Evaporative & DX1	ON	ON	ON	OFF	ON	OFF
Indirect Evaporative & DX2	ON	ON	ON	ON	ON	OFF
Ventilation Only	ON	ON	OFF	OFF	OFF	OFF
Heating	ON	ON	OFF	OFF	OFF	ON

Performance map template

Step 1: Product Information	
Brand Owner	
Brand	
Product Line/Family Name	
Model Number	

Step 2: Mode Characteristics	
Name of operating mode	
Does performance in this mode depend on outside air temperature?	-
Does performance in this mode depend on outside air humidity?	-
Does performance in this mode depend on return air temperature?	-
Does performance in this mode depend on return air humidity?	-
Does supply air mass flow rate change within this mode?	-
Does outside air fraction change within this mode?	-
Does the equipment consume electricity in this mode?	-
Does the equipment consume water in this mode?	-
Does the equipment consume a second fuel in this mode? What type?	-
Does the equipment consume a third fuel in this mode? What type?	-

Instructions	
	Fill this information in first
	Conditions in these cells are automatically populated
	Input performance data in these cells for the conditions provided

Performance map template

Step 1: Product Information	
Brand Owner	Munters Corp
Brand	Munters
Product Line/Family Name	HCUc
Model Number	6030

Step 2: Mode Characteristics	
Name of operating mode	Cool DCBA
Does performance in this mode depend on outside air temperature?	Yes
Does performance in this mode depend on outside air humidity?	Yes
Does performance in this mode depend on return air temperature?	No
Does performance in this mode depend on return air humidity?	No
Does supply air mass flow rate change within this mode?	Yes
Does outside air fraction change within this mode?	No
Does the equipment consume electricity in this mode?	Yes
Does the equipment consume water in this mode?	No
Does the equipment consume a second fuel in this mode? What type?	No
Does the equipment consume a third fuel in this mode? What type?	No

Instructions	
	Fill this information in first
	Conditions in these cells are automatically populated
	Input performance data in these cells for the conditions provided

Performance map template

Step 3: Extents of Data Table		
	minimum	**maximum**
Outside Air Temperature (°C)		
Outside Air Relative Humidity (0-100%)		
Outside Air Humidity Ratio (g/g)		
Return Air Temperature (°C)		
Return Air Relative Humidity (0-100%)		
Return Air Humidity Ratio (g/g)		
Supply Air Mass Flow Rate (kg/s)		
Outside Air Fraction (0-1)		

Step 4: Limits for Extrapolation Beyond Data Table		
	minimum	**maximum**
Outside Air Temperature (°C)		
Outside Air Relative Humidity (0-100%)		
Outside Air Humidity Ratio (g/g)		
Return Air Temperature (°C)		
Return Air Relative Humidity (0-100%)		
Return Air Humidity Ratio (g/g)		
Supply Air Mass Flow Rate (kg/s)		
Outside Air Fraction (0-1)		

Instructions	
	Fill this information in first
	Conditions in these cells are automatically populated
	Input performance data in these cells for the conditions provided

Performance map template

Step 3: Extents of Data Table		
	minimum	**maximum**
Outside Air Temperature (°C)	35.0	49.0
Outside Air Relative Humidity (0-100%)	0	100
Outside Air Humidity Ratio (g/g)	0.006857143	0.016
Return Air Temperature (°C)		
Return Air Relative Humidity (0-100%)		
Return Air Humidity Ratio (g/g)		
Supply Air Mass Flow Rate (kg/s)	2.62	3.58
Outside Air Fraction (0-1)	1.00	1.00

Step 4: Limits for Extrapolation Beyond Data Table		
	minimum	**maximum**
Outside Air Temperature (°C)		
Outside Air Relative Humidity (0-100%)		
Outside Air Humidity Ratio (g/g)		
Return Air Temperature (°C)		
Return Air Relative Humidity (0-100%)		
Return Air Humidity Ratio (g/g)		
Supply Air Mass Flow Rate (kg/s)		
Outside Air Fraction (0-1)		

Instructions	
	Fill this information in first
	Conditions in these cells are automatically populated
	Input performance data in these cells for the conditions provided

Performance map template

Instructions	
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	Conditions in these cells are automatically populated
	Input performance data in these cells for the conditions provided

Step 5: Performance Data Table														
Test Number	Outside Air Temperature (°C)	Outside Air Humidity Ratio (g/g)	Return Air Temperature (°C)	Return Air Humidity Ratio (g/g)	Supply Air Mass Flow (kg/s)	Outside Air Fraction	External Static Pressure (Pa)	-	-	-	-	-	-	-
1	-	-	-	-	0	0	0							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
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-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							
-	-	-	-	-	-	-	-							

Performance map template

Instructions	
	Fill this information in first
	Conditions in these cells are automatically populated
	Input performance data in these cells for the conditions provided

Step 5: Performance Data Table														
Test Number	Outside Air Temperature (°C)	Outside Air Humidity Ratio (g/g)	Return Air Temperature (°C)	Return Air Humidity Ratio (g/g)	Supply Air Mass Flow (kg/s)	Outside Air Fraction	External Static Pressure (Pa)	Supply Air Temperature (°C)	Supply Air Humidity Ratio (g/g)	Total Electric Power (kW)	Supply Fan Electric Power (kW)	-	-	
1	26.67	0.0187	-	-	2.611	1	114	20	0.0051	29.24	2.4			
2	26.67	0.0187	-	-	2.925	1	143	20.56	0.0061	30.14	3			
3	26.67	0.0187	-	-	3.239	1	175	21.11	0.007	31.34	3.7			
4	26.67	0.0222	-	-	2.603	1	11	21.11	0.0069	30.04	2.4			
5	26.67	0.0222	-	-	2.917	1	142	21.67	0.0079	31.04	3			
6	26.67	0.0222	-	-	3.227	1	173	22.78	0.0087	32.04	3.8			
7	26.67	0.0222	-	-	2.603	1	113	21.11	0.0069	30.04	2.4			
8	26.67	0.0222	-	-	2.917	1	142	21.67	0.0079	31.04	3			
9	26.67	0.0222	-	-	3.227	1	174	22.78	0.0087	32.04	3.8			
10	36.39	0.0187	-	-	2.590	1	112	24.44	0.0066	36.04	2.4			
11	36.39	0.0187	-	-	2.901	1	141	25.56	0.0074	36.94	3			
12	36.39	0.0187	-	-	3.212	1	172	26.67	0.0081	37.94	3.8			
13	36.39	0.0244	-	-	2.578	1	111	27.22	0.0093	36.94	2.4			

Industry collaboration

- Partnered with three manufacturers to develop initial performance maps and to test new EnergyPlus features
- 2015-2016 focused on developing performance maps with each manufacturer
- Working with NREL to expand Technology Performance Exchange
- Working with LBNL to integrate model into EnergyPlus
- Currently pilot testing new features and continuing development
- Targeting public release in Fall 2017

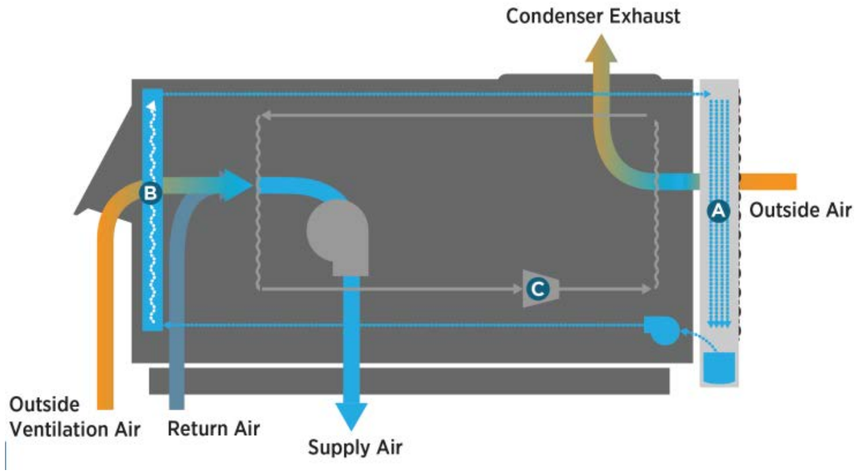
Munters

SEELEY INTERNATIONAL

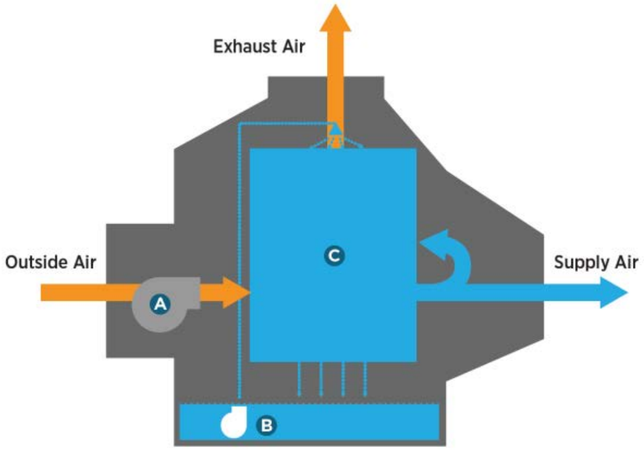
INTEGRATED COMFORT INC.

Manufacturer partners will submit initial performance maps

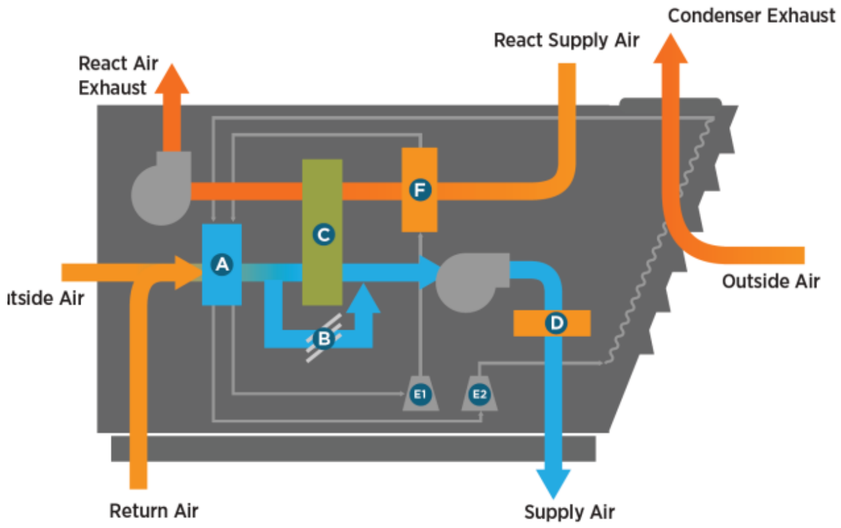
- IntegratedComfort – DualCool – 8 modes
- Seeley – ClimateWizard – 3 modes
- Mutners – Humidity Control Unit – 15 modes



DualCool

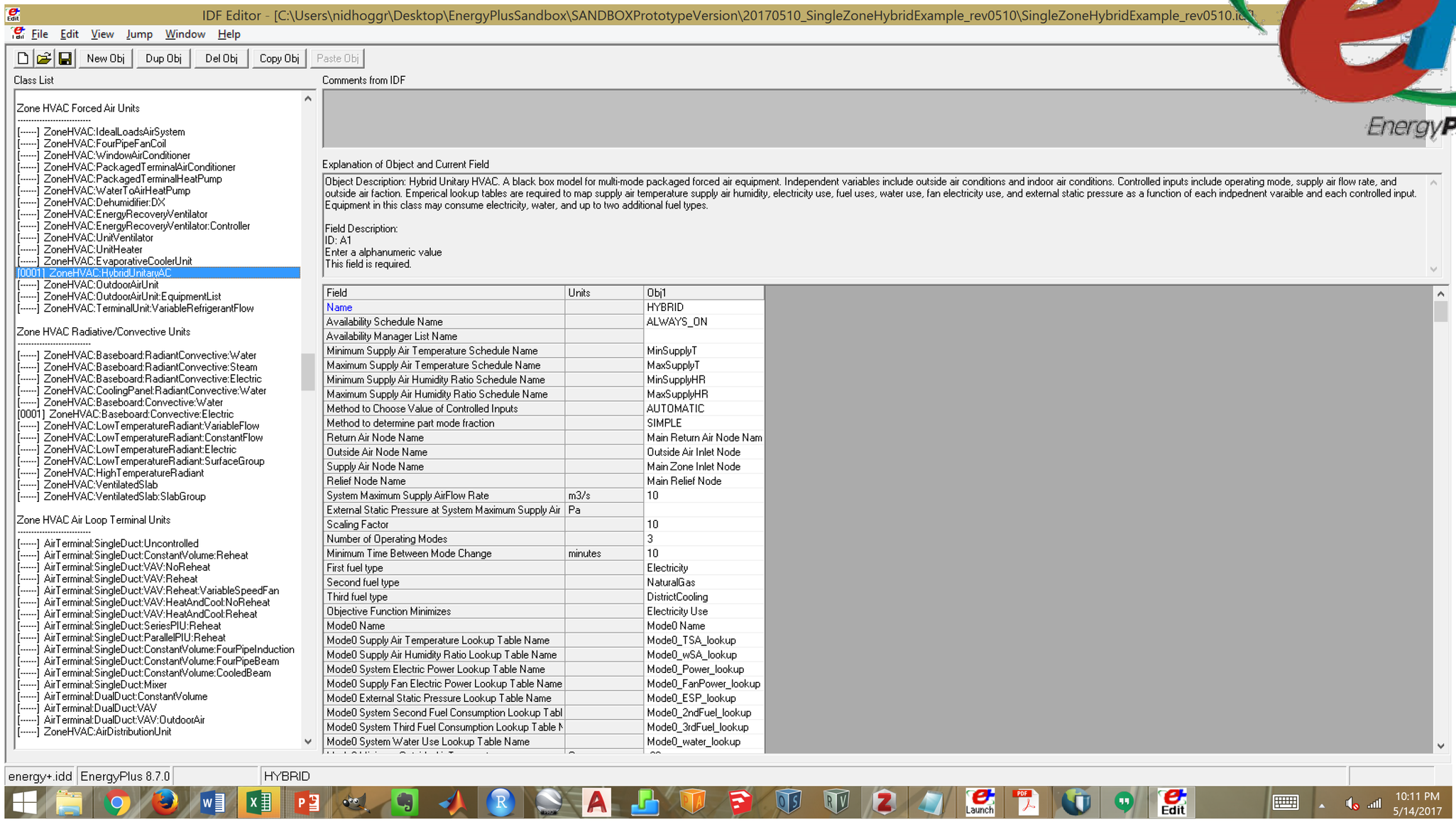


ClimateWizard

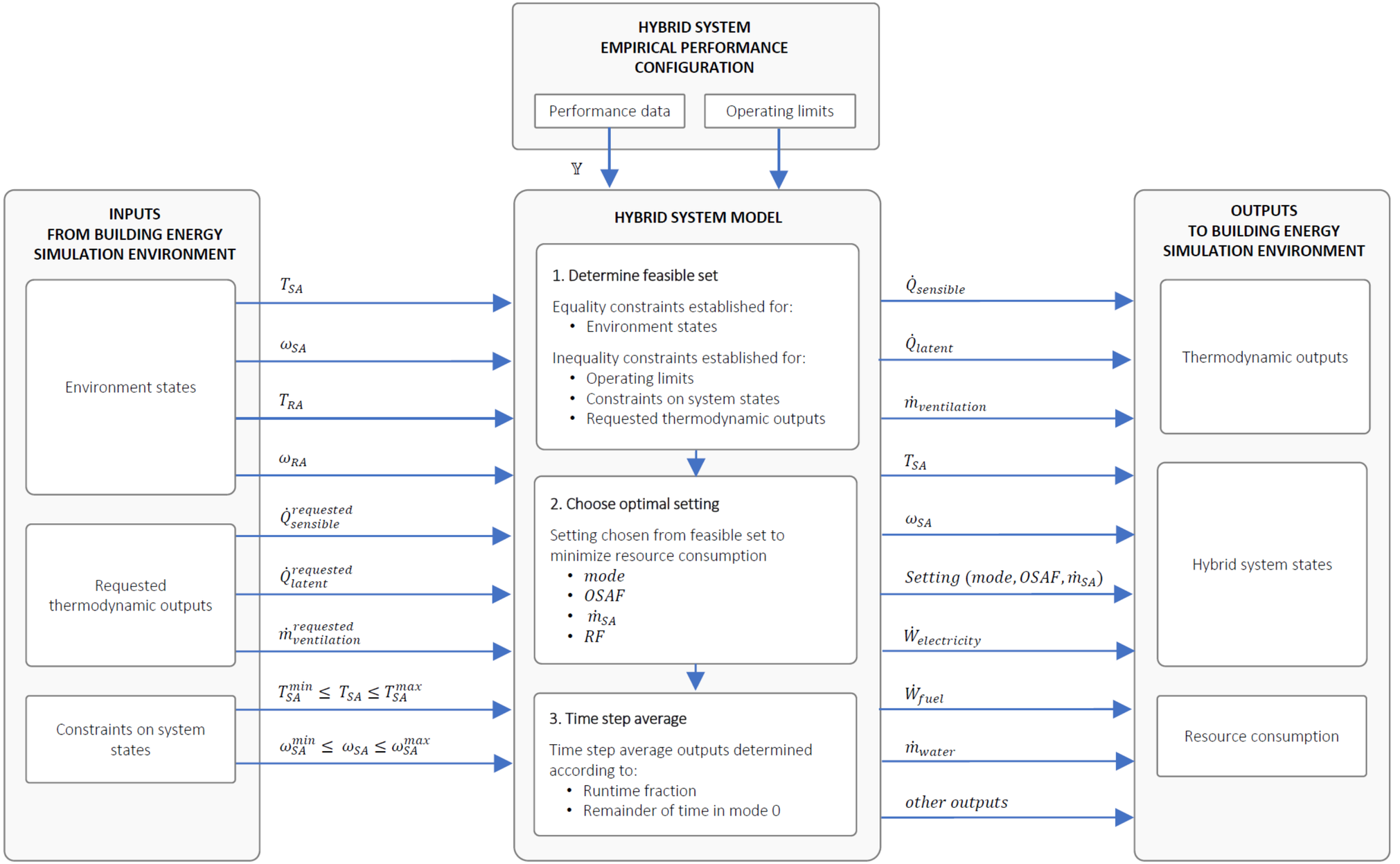


HCU

EnergyPlus Interface

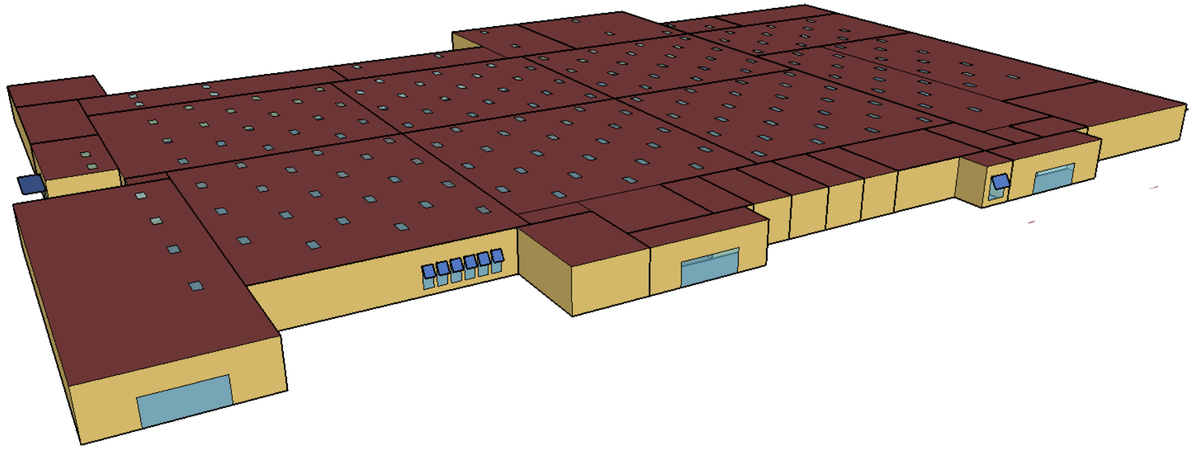


Schematic of model architecture



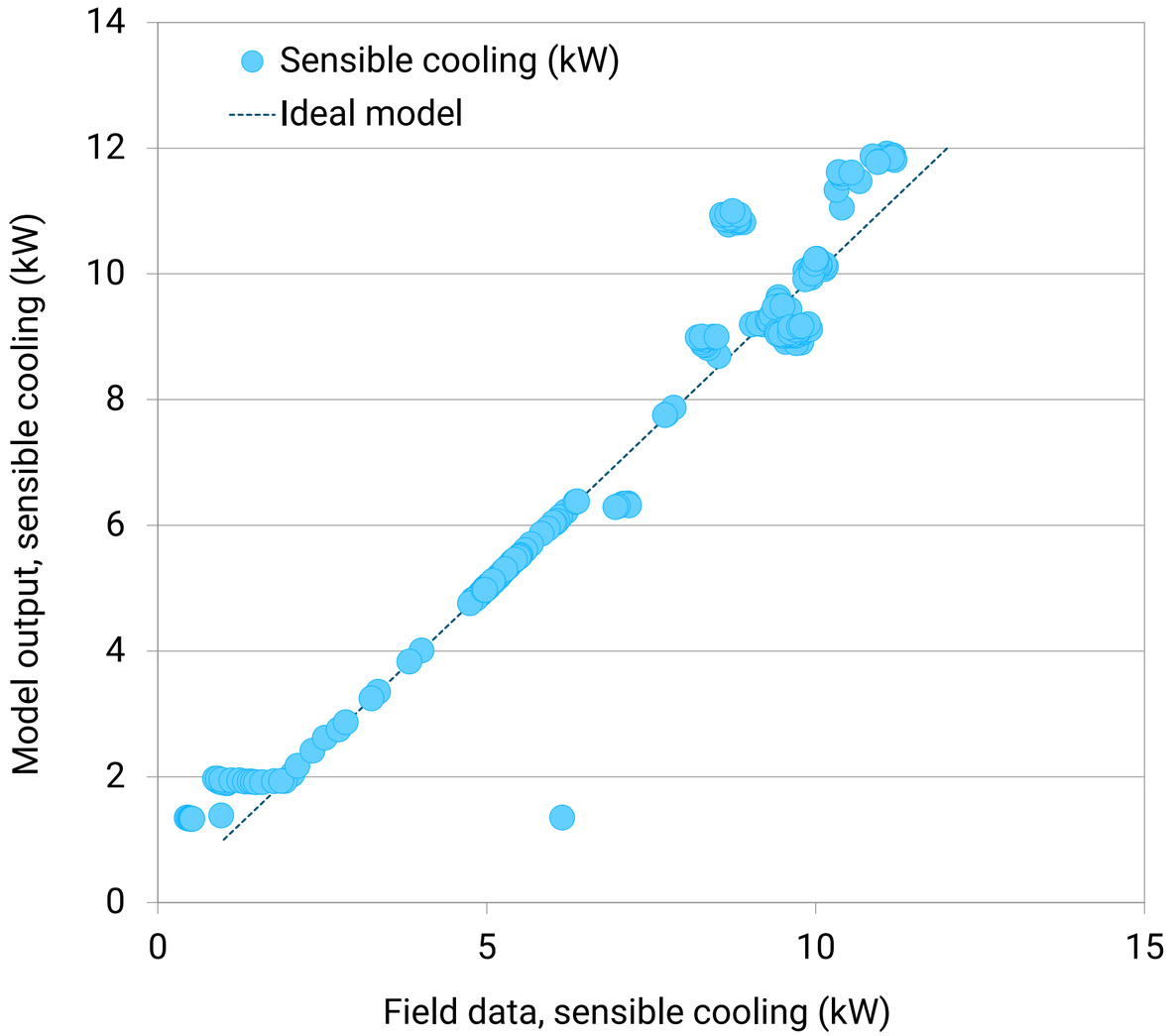
EnergyPlus Building Models for Pilot Testing

- DOE sponsored undergraduate research program
- Students collaborating with manufacturer partners
- Manufacturers hosted students for internships
- Each industry partner pilot testing model
  - Munters:
    Retail with transfer air between zones
  - Integrated Comfort:
    Large retail with multiple hybrid rooftop units
  - Seeley:
    Conditioned warehouse and office space



DEPARTMENT OF ENERGY
UNDERGRADUATE RESEARCH FELLOWSHIP
FOR ENERGY EFFICIENCY IN BUILDINGS

Model validation and next steps



- Proposing for EnergyPlus public release
- Developing code tests
- Developing example simulations
- Developing documentation
- Model validation in process
- Developing final modeling structure
  - Lookup tables with polynomial interpolation
  - Partial runtime fraction
  - Custom control option
- Pilot testing model to estimate energy savings for DualCool in multiple climate zones

Questions

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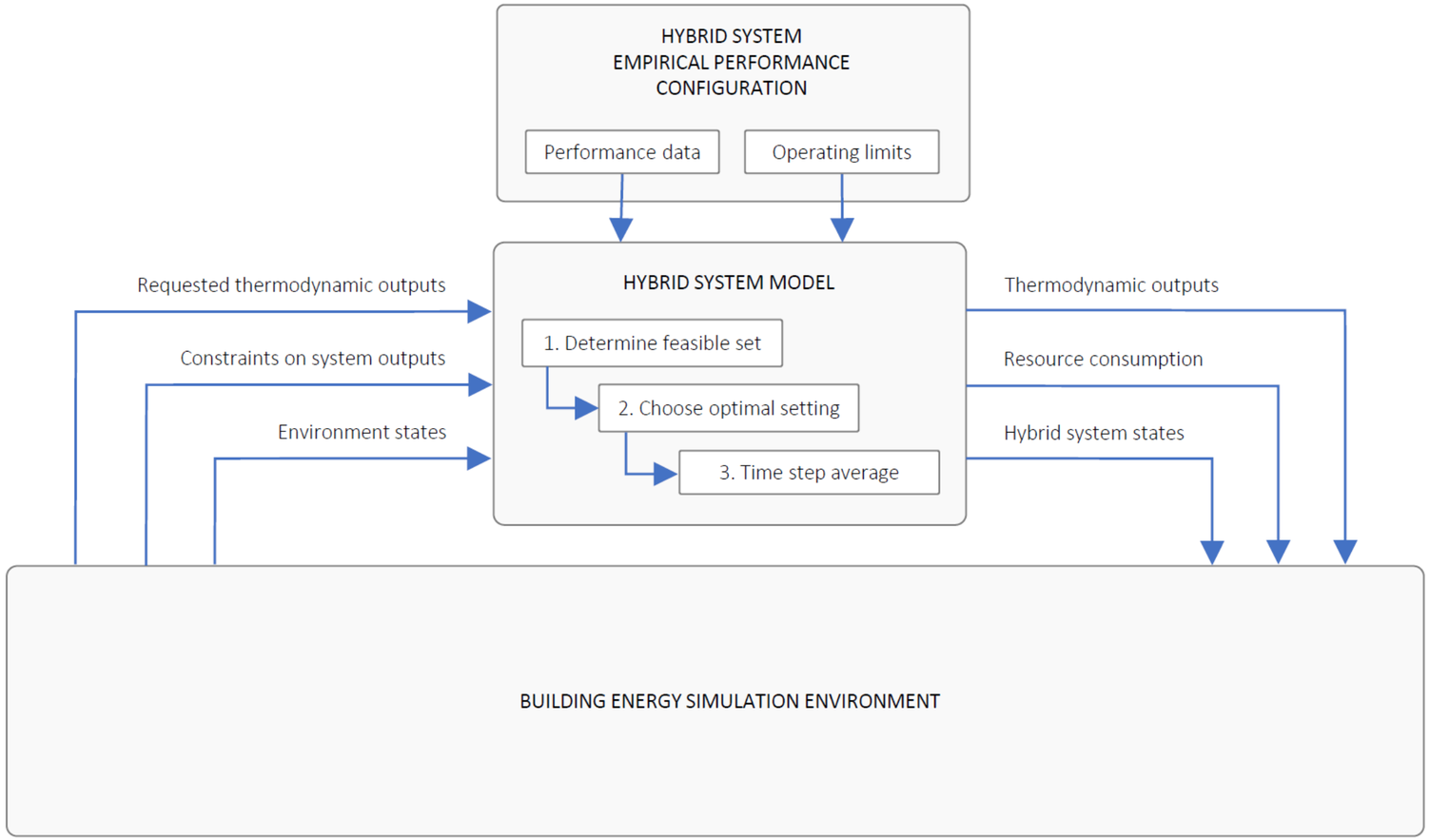

EnergyPlus inputs for “ZoneHVAC:HybridUnitaryHVAC”

Name		
Availability Schedule Name		
Availability Manager List Name		
Minimum Supply Air Humidity Ratio Schedule Name		
Maximum Supply Air Humidity Ratio Schedule Name		
Method to Choose Value of Controlled Inputs		
Method to determine part mode fraction		
Return Air Node Name		
Return air node for the hybrid unit		
Outside Air Node Name		
Supply Air Node Name		
Relief Node Name		
System Maximum Supply AirFlow Rate	m3/s	
External Static Pressure at System Max SA Flow	Pa	
Scaling Factor		
Number of Operating Modes		
Minimum Time Between Mode Change	Minutes	
First fuel type		
Second fuel type		
Third fuel type		
Objective Function Minimizes		

EnergyPlus inputs for each operating mode

Mode X Name		
Mode X Supply Air Temperature Lookup Table Name		
Mode X Supply Air Humidity Ratio Lookup Table Name		
Mode X System Electric Power Lookup Table Name		
Mode X Supply Fan Electric Power Lookup Table Name		
Mode X External Static Pressure Lookup Table Name		
Mode X System Second Fuel Consumption Lookup Table Name		
Mode X System Third Fuel Consumption Lookup Table Name		
Mode X System Water Use Lookup Table Name		
Mode X Minimum Outside Air Temperature	C	
Mode X Maximum Outside Air Temperature	C	
Mode X Minimum Outside Air Humidity Ratio	kgWater/kgDryAir	
Mode X Maximum Outside Air Humidity Ratio	kgWater/kgDryAir	
Mode X Minimum Outside Air Relative Humidity	%	
Mode X Maximum Outside Air Relative Humidity	%	
Mode X Minimum Return Air Temperature	C	
Mode X Maximum Return Air Temperature	C	
Mode X Minimum Return Air Humidity Ratio	kgWater/kgDryAir	
Mode X Maximum Return Air Humidity Ratio	kgWater/kgDryAir	
Mode X Minimum Return Air Relative Humidity	%	
Mode X Maximum Return Air Relative Humidity	%	