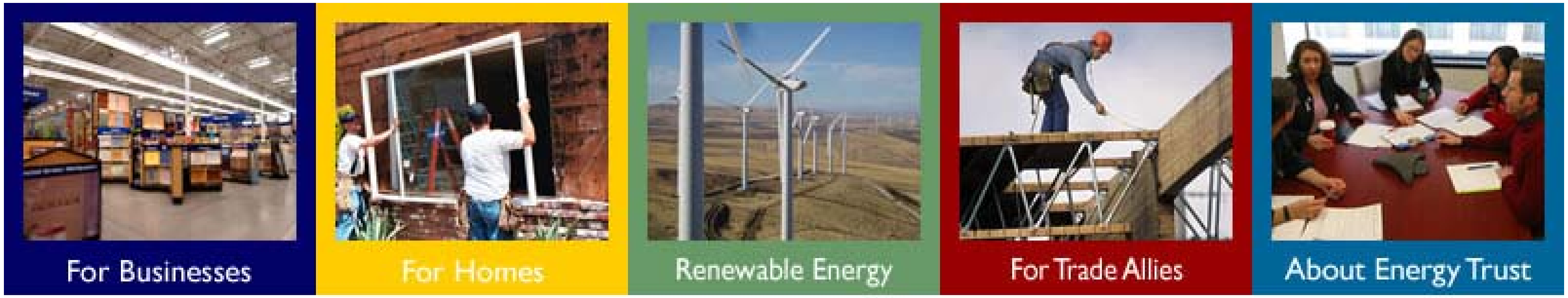

Energy Trust of Oregon, Inc.
BSUG – April 15, 2009

EnergyTrust
of Oregon, Inc.

Building Simulation Users' Group

Sponsors

- The Energy Trust - Funding
- NW Natural – Space & AV
- ODOE – Technical Input
- BPA – Outreach
- NEEA - Outreach
- ASHRAE - PDHs for P.E.s & CEMs
- Members – Substance

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Building Simulation Users' Group

Fourth Year

- 35 sessions – one weather cancellation
- April 2006: 38 members
- April 2009: 343 members
- April 2006: 32 Attendees
- April 2009: 114 attendees up as of Monday
- April 2009: 153 organizations

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Building Simulation Users' Group

BSUG MEMBERSHIP		
130	38%	Engineer
70	20%	Analyst
37	11%	Conservation Administrator
32	9%	Architect
29	8%	Unknown
6	2%	Contractor
9	3%	Designer
6	2%	N/A
9	3%	Student
5	1%	Management
3	1%	Programmer
3	1%	Recruiter
2	1%	Facilities Operation
2	1%	Marketing
343	100%	**Active Only**

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Volunteers

Growth in membership has not been paralleled by number of volunteers

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Building Simulation Users' Group

Today's Discussion

Variable-Refrigerant Volume/Flow (VRV/VRF) Systems

Mark Denyer, P.E., LEED™ AP, Associate, MFIA, Inc. Consulting Engineers

Dana Troy, LEED™ AP, Energy Analyst, Glumac

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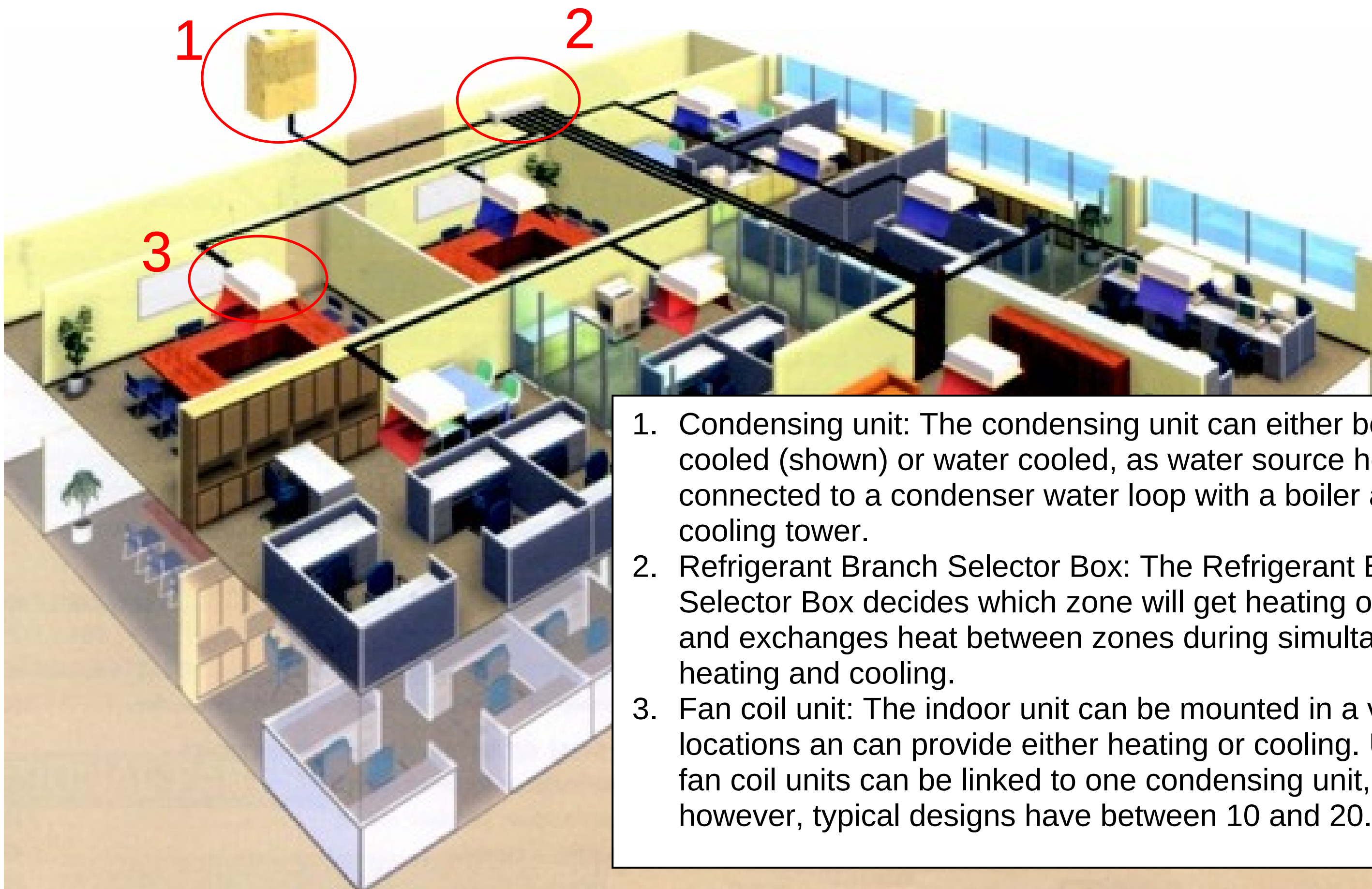
What is VRF/VRV and how does it work?

- Variable refrigerant flow/volume.
- Works as a split system heat pump with local air movement.
- Multiple indoor units linked to one condenser, either air cooled or water cooled.
- The system controls the amount of refrigerant flowing to each of the indoor units.
- The Refrigerant Branch Selector Box connects all of the indoor units and allows each unit to "exchange" heat with one another. Any heat that needs to be added or rejected is then provided by the condensing unit.

Variable Refrigerant Flow Systems



1. Condensing unit: The condensing unit can either be air-cooled (shown) or water cooled, as water source heat pump connected to a condenser water loop with a boiler and cooling tower.
2. Refrigerant Branch Selector Box: The Refrigerant Branch Selector Box decides which zone will get heating or cooling and exchanges heat between zones during simultaneous heating and cooling.
3. Fan coil unit: The indoor unit can be mounted in a variety of locations an can provide either heating or cooling. Up to 50 fan coil units can be linked to one condensing unit, however, typical designs have between 10 and 20.

Picture courtesv of Mitsubishi

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Effective Building Types for VRV

1. Existing Buildings
   a. Buildings with not enough room for cooling ductwork
   b. Option for adding cooling to a hydronic heat replacement project
2. Core and Shell Projects
   a. Very easy system to expand or modify
   b. Cost effective option to water source heat pumps or HW/CW Fan Coils
3. Energy Efficiency Projects
   a. Energy efficient option to standard VAV with reheat type projects
      - No energy penalty for reheat
      - Significant reduction of fan energy
      - Better zoning options than CV systems for buildings under 75,000 sq ft

Effective Building Types for VRV (Cont)

3. Energy Efficiency Projects (Cont)
   b. Energy efficient option to standard DX split systems
      - Significantly higher part load performance than typical split system condensing units and heat pumps
      - Higher SEER/EER ratings due to digital DC compressors and condensing fans
      - Allows for smaller condensing units due to load sharing with multiple indoor units.

4. Buildings with a high level of diversity
   - Mixed-use projects where certain zones require cooling year round while other zones require heating.
   - Restaurants - -dining areas vs. cooking areas

System capacities and efficiencies

- Each condenser can support up to 50 indoor units; however, in common design there is typically no more than 10 to 20 indoor units connected to one condensing unit.
- Each condensing unit has a maximum capacity of approximately 20 tons.
- ILPV values have been verified as high as 16.

How does ventilation work with VRF systems

- Very similar to two and four pipe fan coils, water source heat pumps, and other zonal systems.
- 100% OA make-up air unit can provide outside air either in series or parallel.
  - Series: The outside air is ducted directly to the fan coil. The fan is always on during scheduled hours in order to keep the ventilation air moving.
  - Parallel: The outside air is ducted directly into the room, apart from the fan coil. The fan coil can then be cycled on and off when the space temperatures can be maintained with the ventilation alone.

Oregon Installations

- Esquire Apartments/Restaurant (7 story historic building)
  35,000 sf mixed use (restaurant and apartments) historic building
- NuMiss office Building (3 story C&S office – under construction)
  18,250 square foot 3 story core and shell office
- Oregon Air Reps Office (Daikin demonstration project)
  ~5,000 sf general office
- Redmond High School (Under Preliminary Design)
  260,000 sq ft of all inclusive high school
- Mercy Corps (Under construction)
  80,000 sf office spaces, 4 stories, half existing, half addition
- The Allison Inn (Under construction)
  140,000 sf hotel, 4 stories, new construction
- UW Tacoma Joy Building (DD phase)
  50,000 sf college building, 3 stories, 100% remodel
- UW Tacoma Jefferson Avenue Building (DD phase)
  40,000 sf college offices and library stacks, 4 stories, new construction

Oregon VRV System Distributers

- Daikin - Oregon Air Reps 503-620-4300
- LG - Johnson Air Products 503-234-5071
- Sanyo - Airefco 503-691-4320
- Mitsubishi - FE Company - Applied Equipment Sales 503-351-1379

Comparative Costs

- VRV = $17.75/ sq ft
- VAV w/central chiller = $22.50/ sq ft
- VAV packaged DX units = $18.70/sq ft
- The above values were a cost estimate for preliminary design options for a New 260,000 square foot High School in Central Oregon.

Energy Savings – Modeled Results (Using Trace 700)

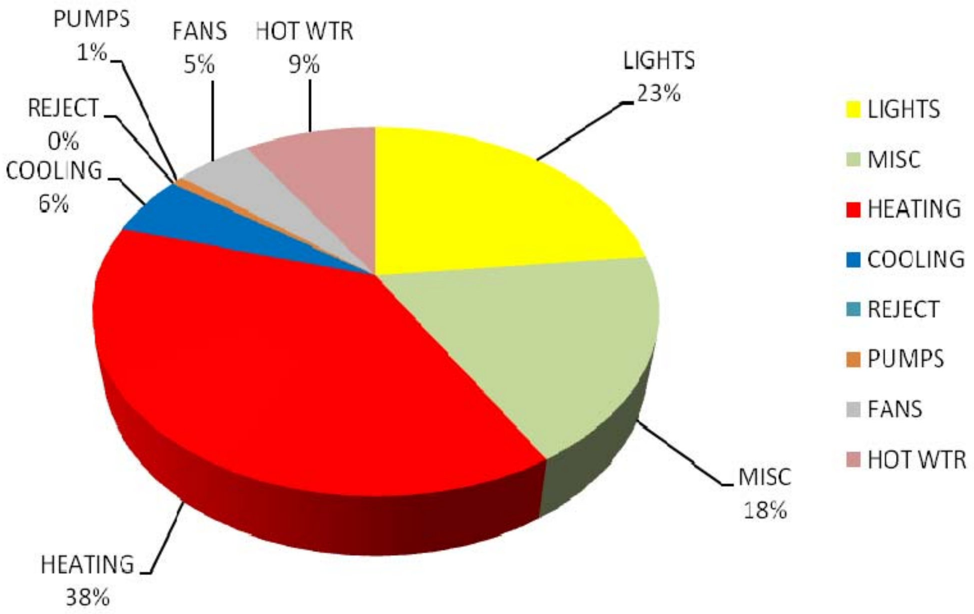
- Modeled results for a well designed building with a heat recovery ventilation unit show about a 33% savings when compared to a ASHRAE baseline building (CV DX systems) These results were based on the final LEED EA-1 model for the NuMiss Office building – a 18,250 square foot 3 story core and shell office.
- Modeled results show about a 12.5% savings when comparing a VRV to Packaged DX CV systems. These results were simulated by taking the above office energy model of the proposed building and running the simulation with packaged DX in place of the VRV system that was designed.
- Modeled results have shown up to 40% to 45% savings when using a VRV with ventilation heat recovery for a remodeled mixed-use type building. These results were based on the final LEED EA-1 model for the Esquire Apartments - - a 35,000 square foot mixed use (restaurant and apartments) historic building.

Energy Savings – Modeled Results (Using eQUEST)

Modeled results for a well designed building with a heat recovery ventilation unit show about a 10-20% total building energy savings when compared to a ASHRAE baseline HVAC system.

The total HVAC energy costs are about 50% of the total building energy use (fans, pumps, cooling, and heating). Therefore, if the *HVAC* savings is 100%, the total building energy savings is only 50%.

A 10-20% total building energy savings is actually a 20-40% savings in HVAC energy use.



Modeling VRV with TRACE

- Baseline Algorithms
  - TRACE can explicitly model VRV, both heat recovery and non-heat recovery options.
  - Algorithms based on Daikin empirical model
  - Baseline equipment based on first generation Daikin VRV
  - Equipment easily modified to match current generation equipment or any other manufacturer.
  - The following slide provides a description of the program's and modeler's approach to the system (from TRACE programmers).
- Modeling Inputs
  - Enter Heating and Cooling compressor COP or KW/ton
  - Enter Condensing Fan power consumption KW/ton
  - Select unloading curve, compressor power consumption curve, condensing fan curve and cycling point as appropriate.

TRACE programming information

Basis of the TRACE model: Daikin empirical model

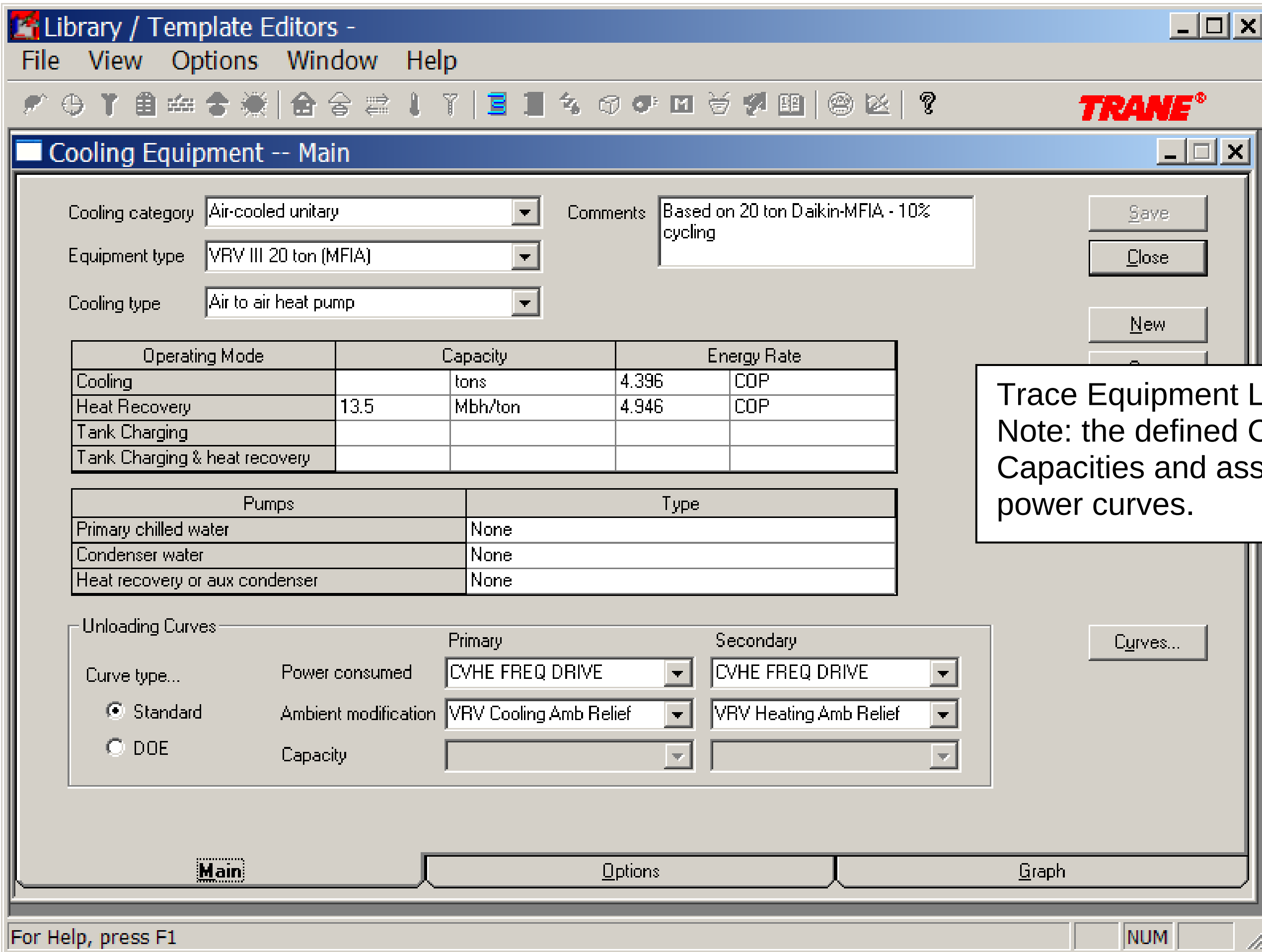
Airside simulation:

Similar to a water source heat pump, when the room drift temperature rises above the cooling thermostat, the cooling coil is engaged at a constant cooling supply air temperature for the a percentage of the hour that it takes to bring the room temperature down to the cooling thermostat temperature. This heat is rejected to the refrigerant condenser loop. For the portion of the hour that the cooling coil is de-energized, the supply air will remain at the return/outside air dry bulb temperature (plus fan heat).

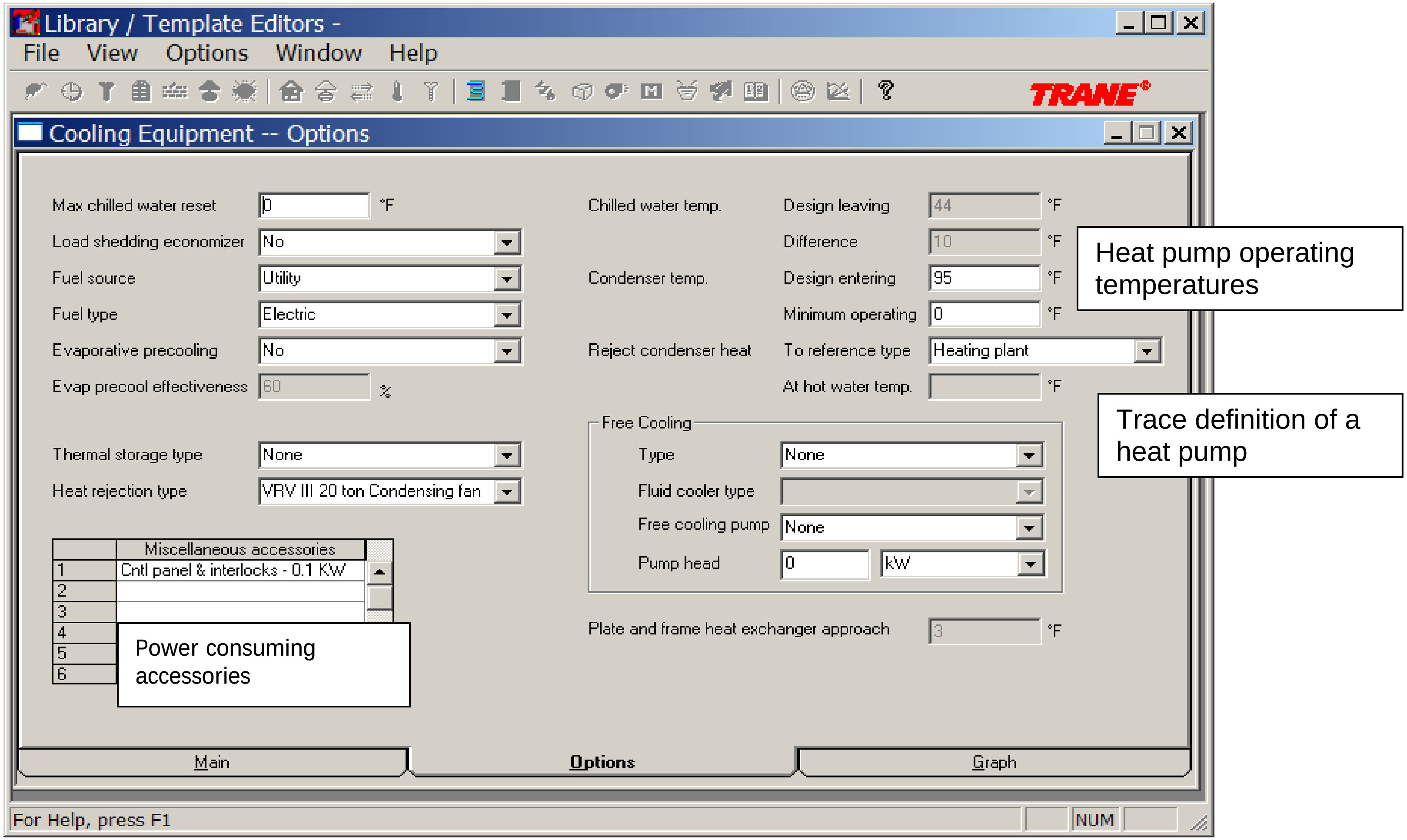
When the room drift temperature drops below the heating thermostat, the heating coil is engaged at a constant heating supply air temperature for the a percentage of the hour that it takes to bring the room temperature up to the heating thermostat temperature. The indoor unit will remove heat from the refrigerant condenser loop. For the portion of the hour that the cooling coil is de-energized, the supply air will remain at the return/outside air dry bulb temperature (plus fan heat).

Although the system default reheat minimum will be set to 10%, the user can change it on a room by room basis if they want. This minimum airflow is only used during the part of the hour in which neither heating nor cooling coils are active.

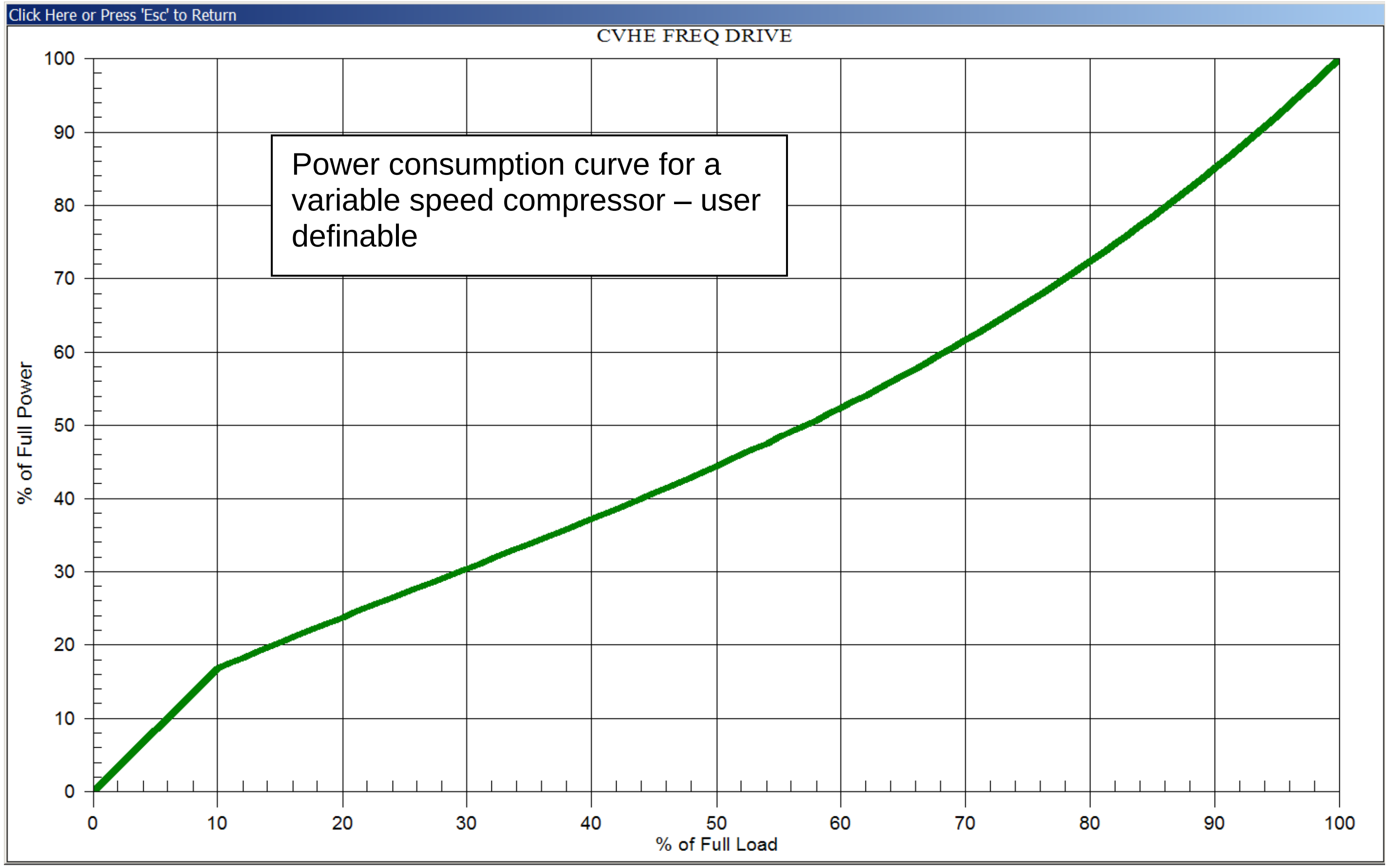
Variable Refrigerant Flow Systems



Trace Equipment Library definitions
Note: the defined COPs, Heating Capacities and associated equipment power curves.

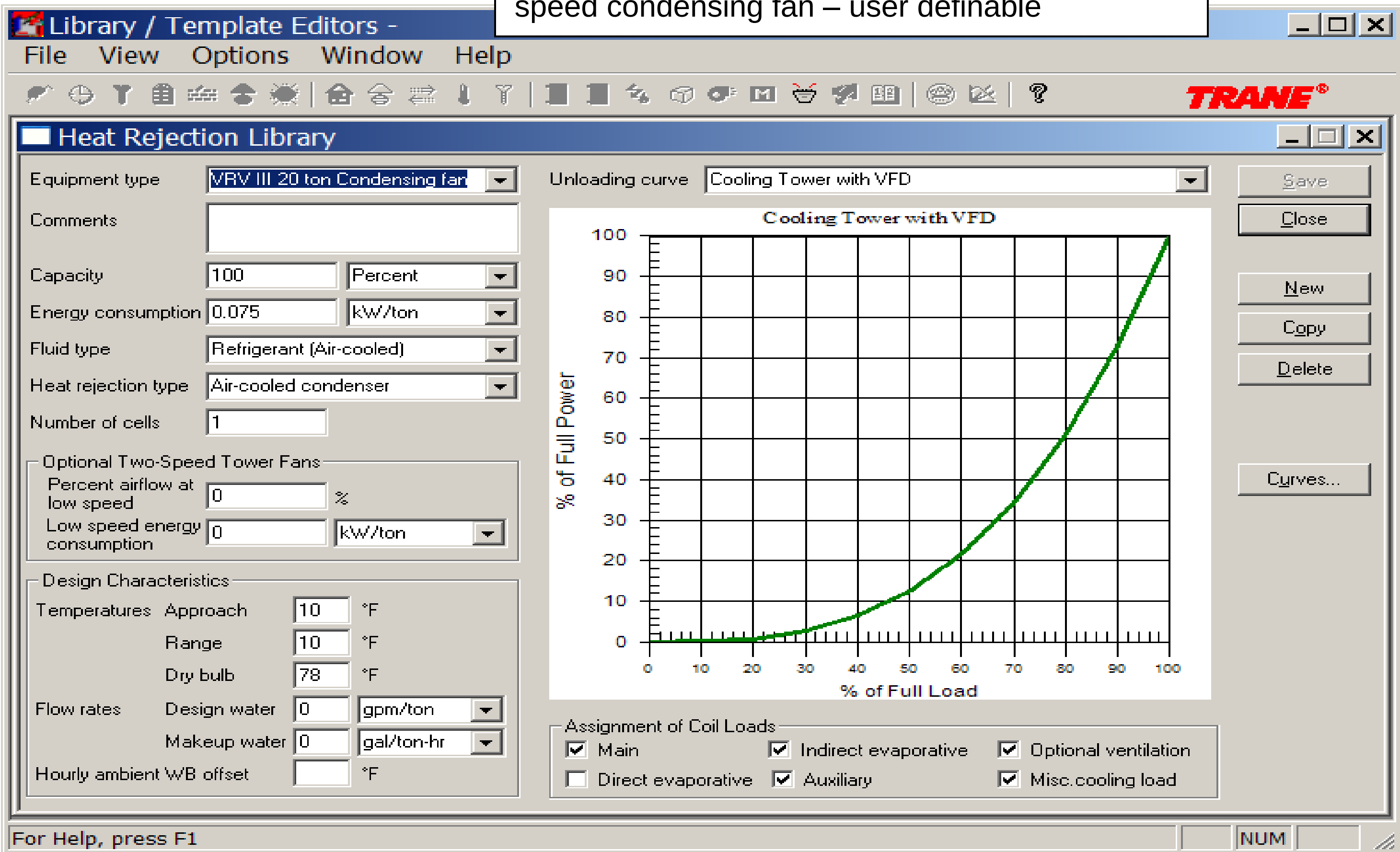

Library / Template Editors -
File View Options Window Help
TRANE
Cooling Equipment -- Options
Max chilled water reset 0 °F
Load shedding economizer No
Fuel source Utility
Fuel type Electric
Evaporative precooling No
Evap precool effectiveness 60 %
Thermal storage type None
Heat rejection type VRV III 20 ton Condensing fan
Miscellaneous accessories
1 Cntl panel & interlocks - 0.1 KW
2
3
4
5
6
Chilled water temp. Design leaving 44 °F
Difference 10 °F
Condenser temp. Design entering 95 °F
Minimum operating 0 °F
Reject condenser heat To reference type Heating plant
At hot water temp. °F
Free Cooling
Type None
Fluid cooler type
Free cooling pump None
Pump head 0 kW
Plate and frame heat exchanger approach 3 °F
Main Options Graph
For Help, press F1
NUM
Heat pump operating temperatures
Trace definition of a heat pump
Power consuming accessories

Variable Refrigerant Flow Systems



Variable Refrigerant Flow Systems

Power consumption rate and curve for a variable speed condensing fan – user definable



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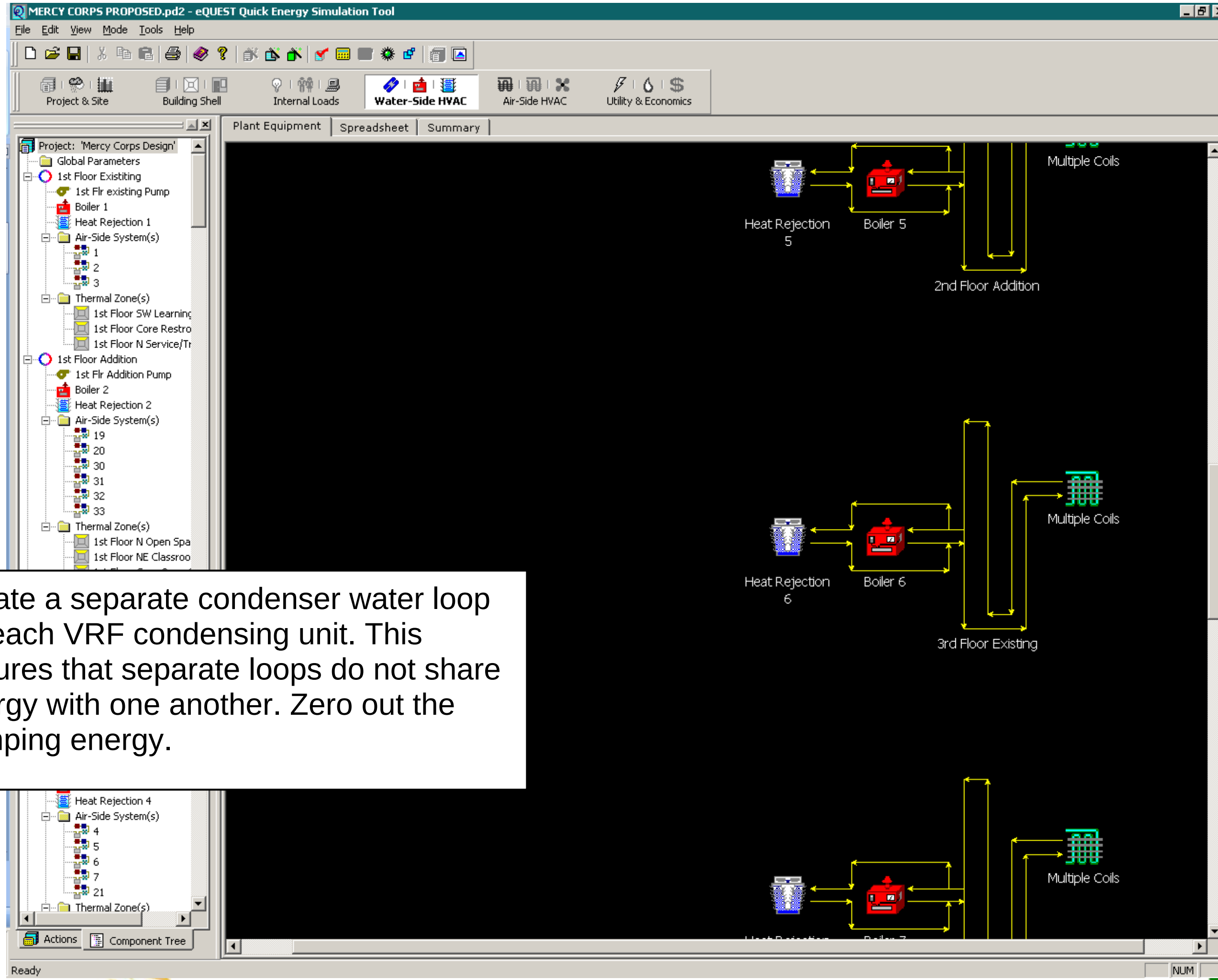
Modeling the VRF in eQUEST: PVVT Water Source Heat Pumps

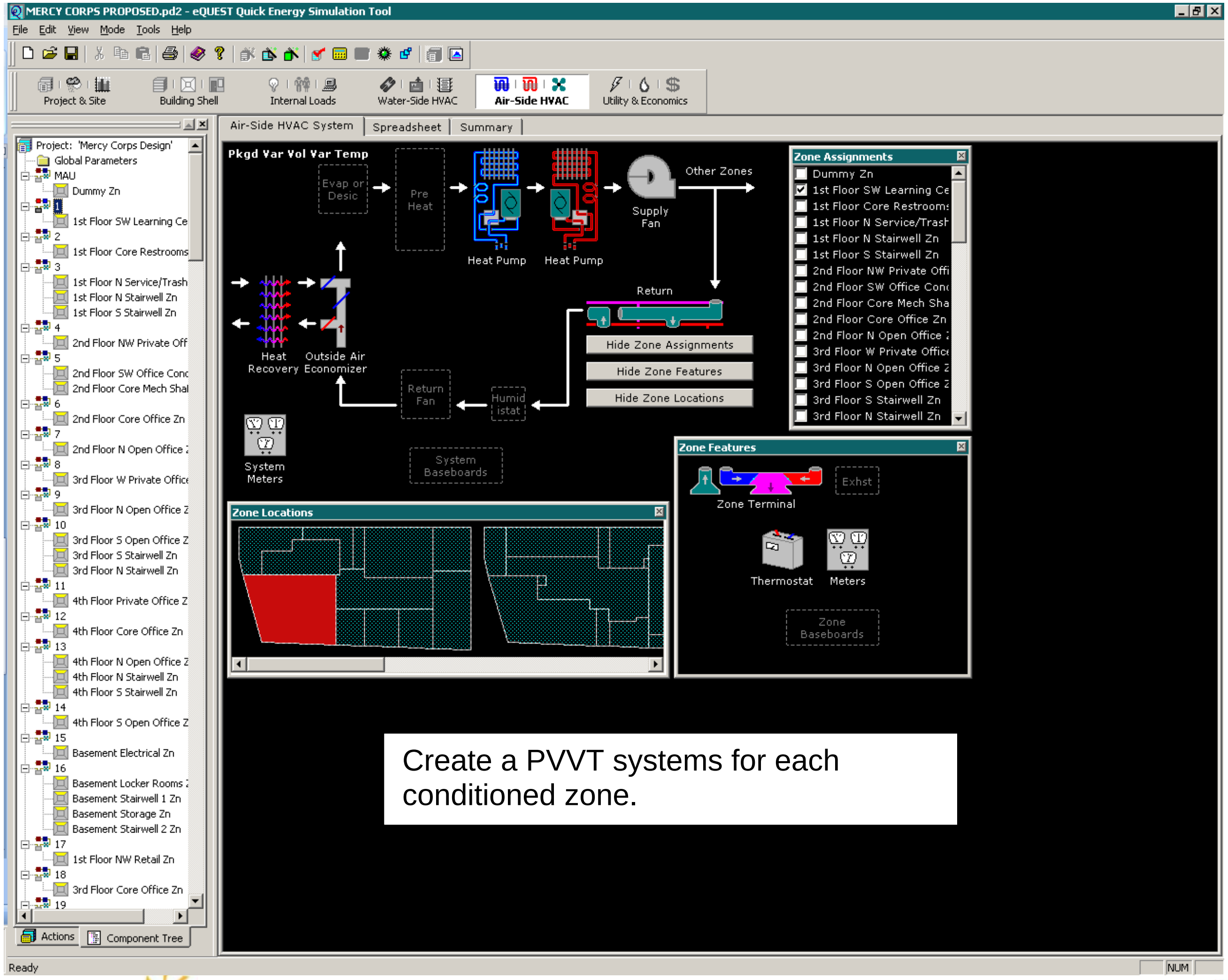
- Zone the building in the same manner as the design. This is very important for the energy sharing capabilities of the VRF system.
- We do not use this method for our energy models, but it is one way of approaching the system.
- eQUEST system: PVVT, with the condenser set to water cooled to activate a condenser water loop. Create one system per zone.
- Create separate condenser water loops for each VRF condenser and zero out the pump energy.
- Manipulate the fan efficiency ratio and the electric boiler EIR to reflect the efficiencies of the VRF units.

Variable Refrigerant Flow Systems



Create a separate condenser water loop for each VRF condensing unit. This ensures that separate loops do not share energy with one another. Zero out the pumping energy.

Variable Refrigerant Flow Systems



Create a PVVT systems for each conditioned zone.

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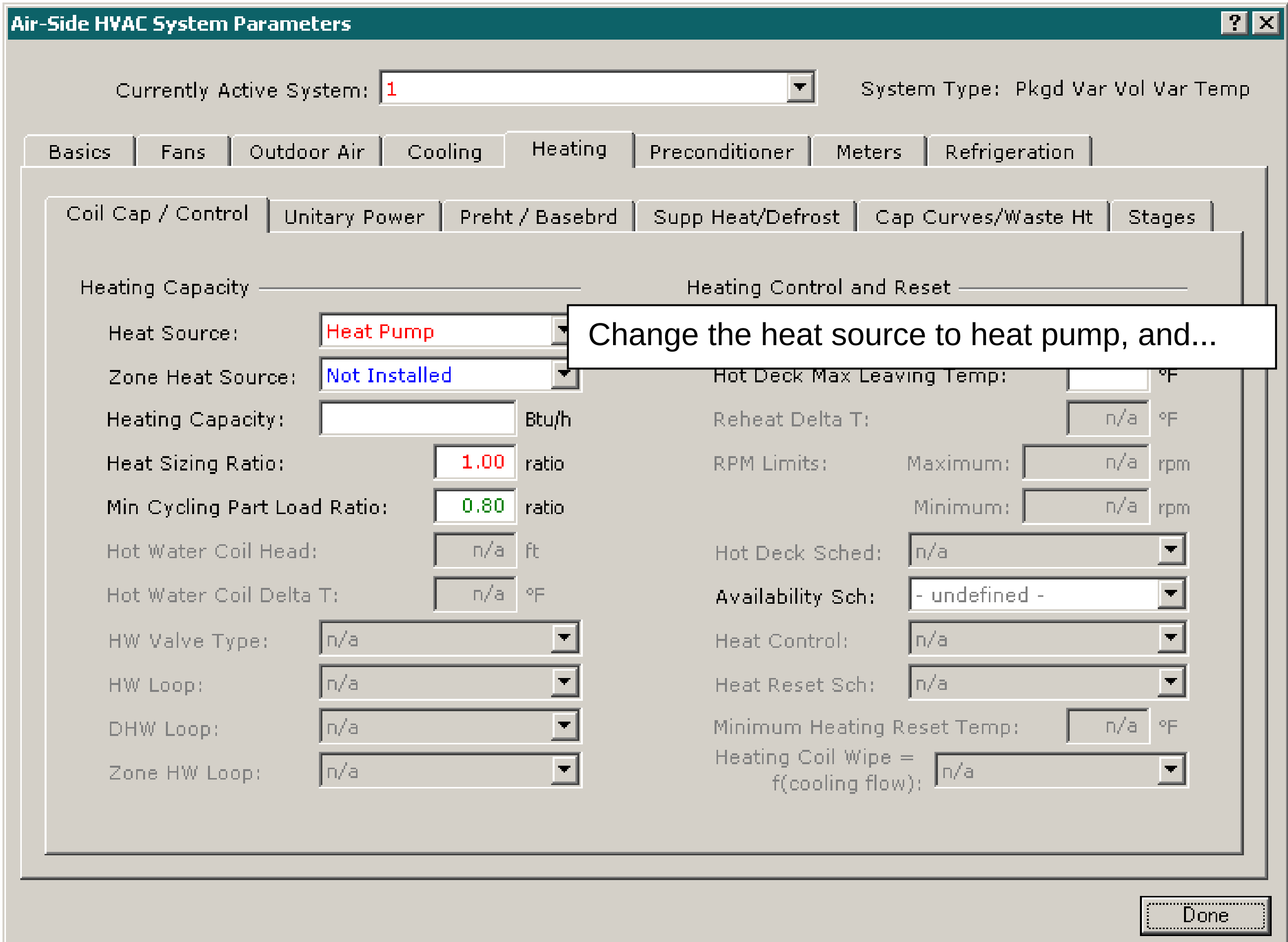
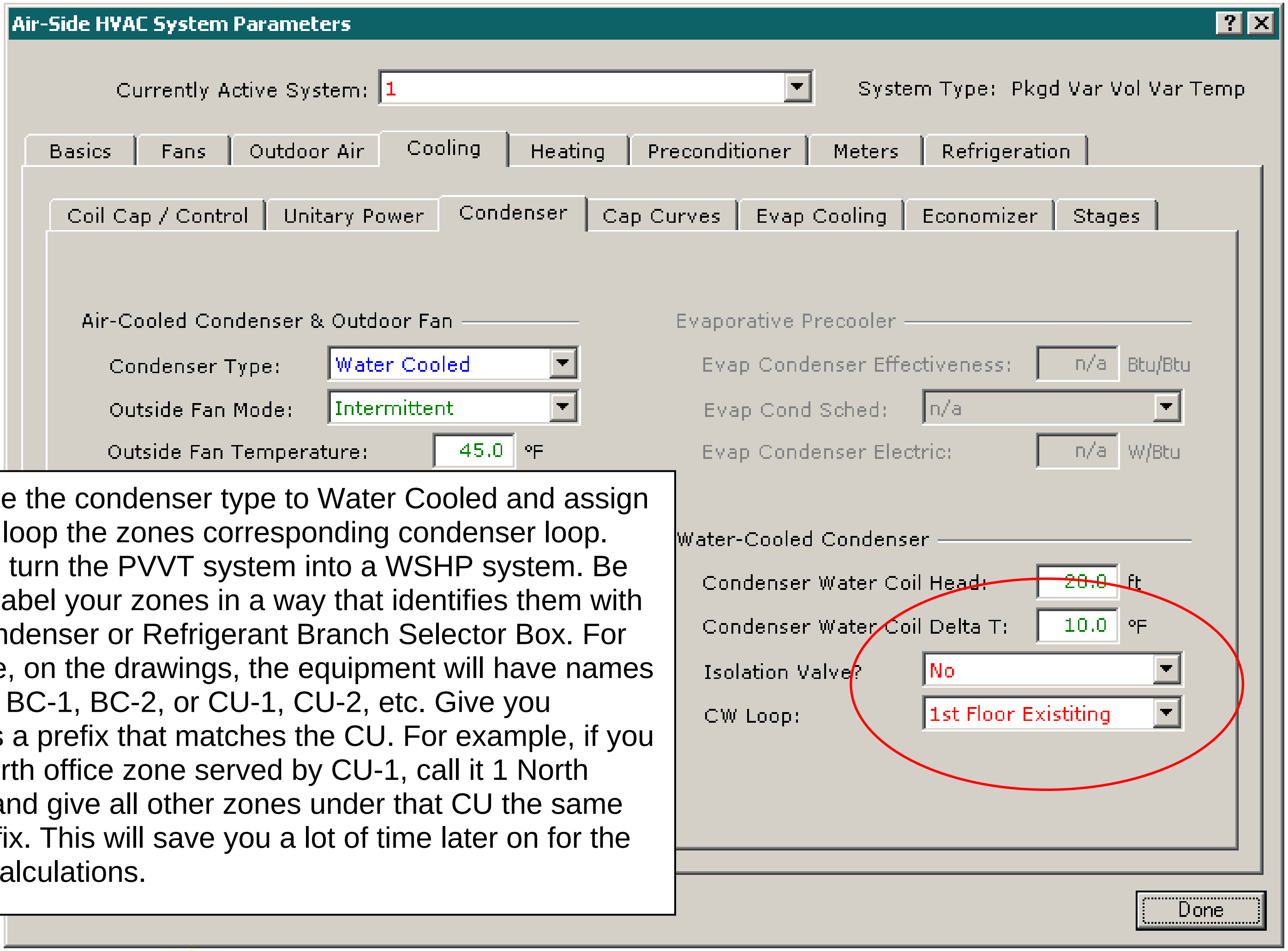
Variable Refrigerant Flow Systems

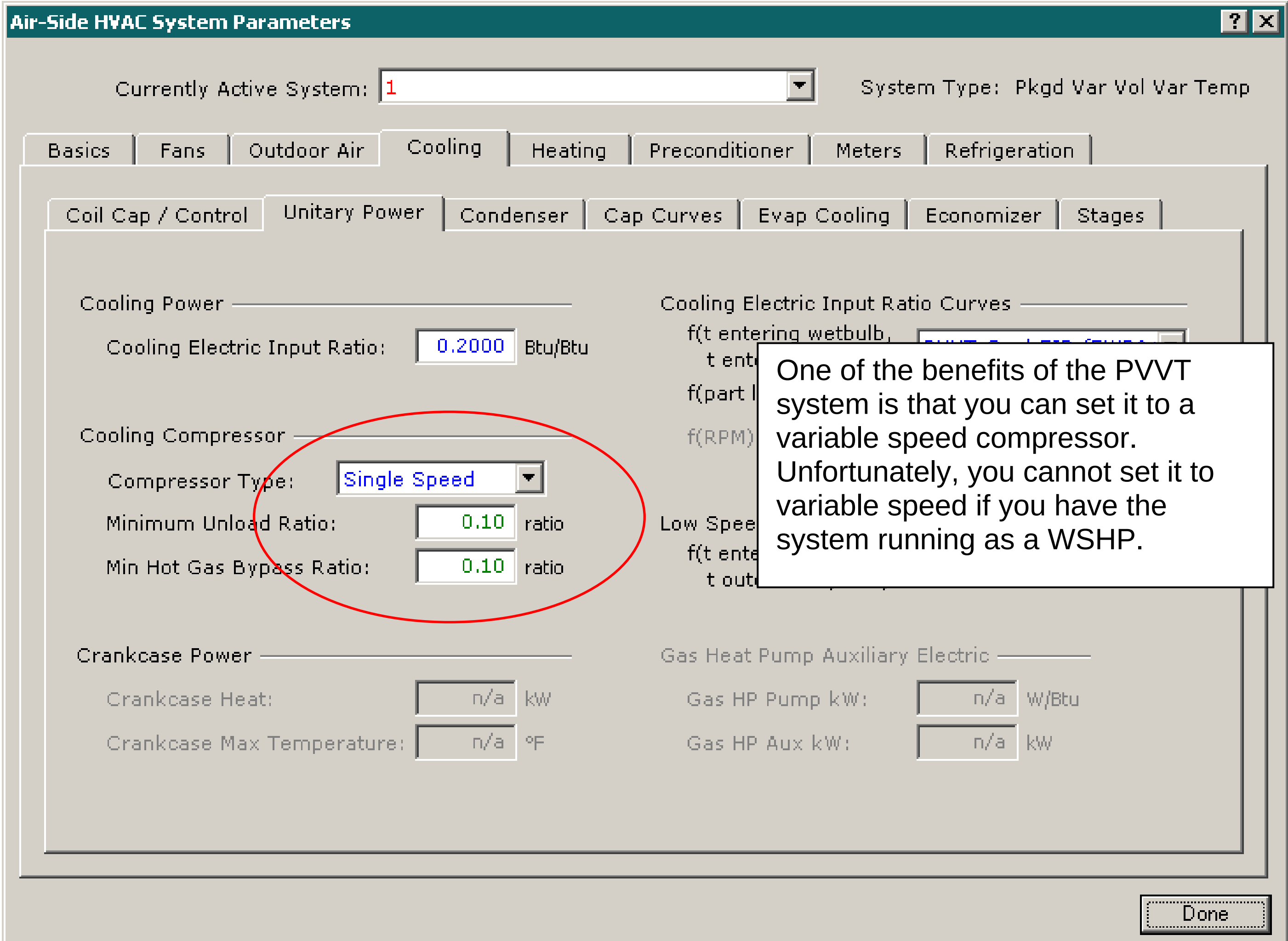


Variable Refrigerant Flow Systems



...change the condenser type to Water Cooled and assign the CW loop the zones corresponding condenser loop. This will turn the PVVT system into a WSHP system. Be sure to label your zones in a way that identifies them with their condenser or Refrigerant Branch Selector Box. For example, on the drawings, the equipment will have names such as BC-1, BC-2, or CU-1, CU-2, etc. Give you systems a prefix that matches the CU. For example, if you have north office zone served by CU-1, call it 1 North Office, and give all other zones under that CU the same "1-" prefix. This will save you a lot of time later on for the hourly calculations.

Variable Refrigerant Flow Systems

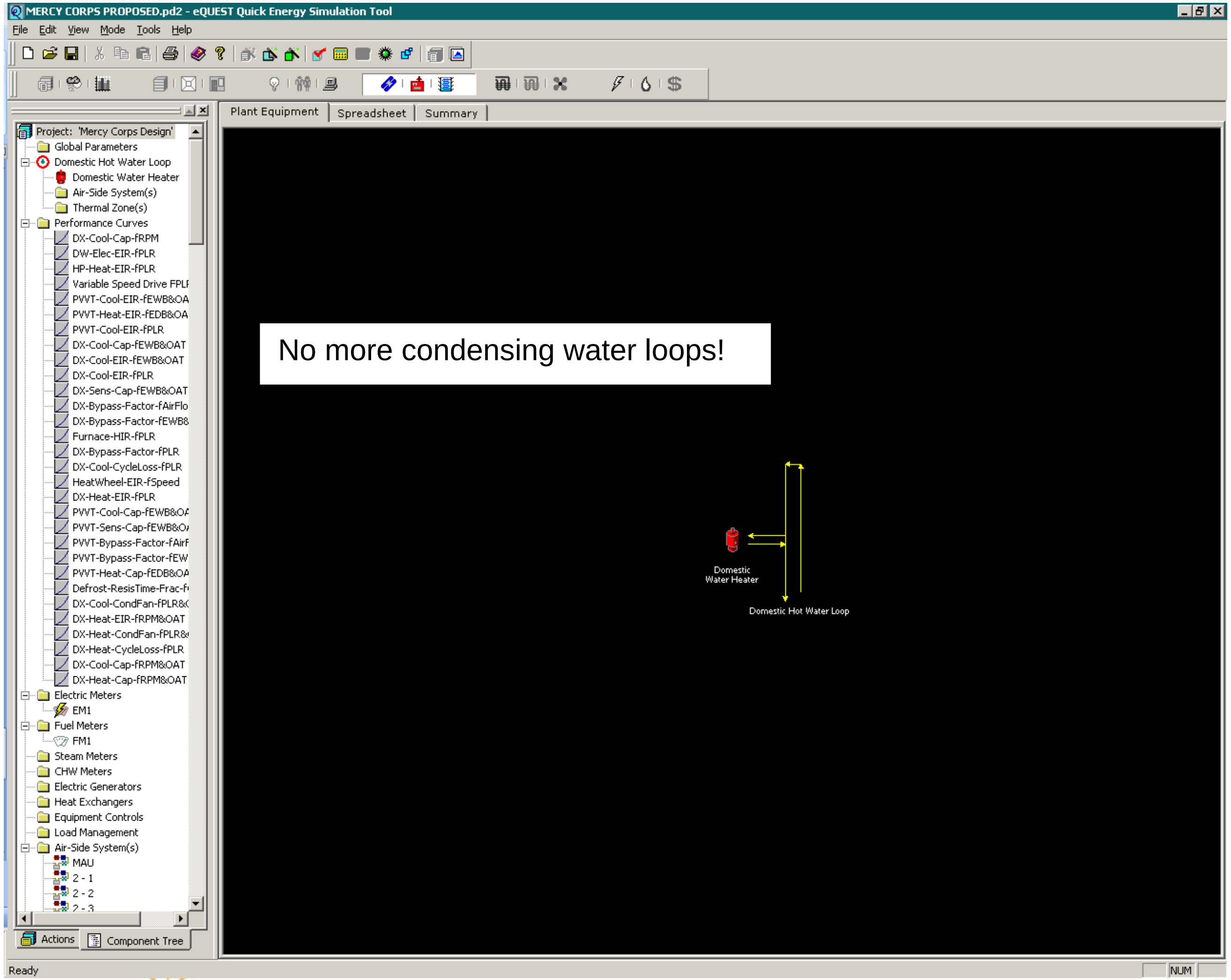


One of the benefits of the PVVT system is that you can set it to a variable speed compressor. Unfortunately, you cannot set it to variable speed if you have the system running as a WSHP.

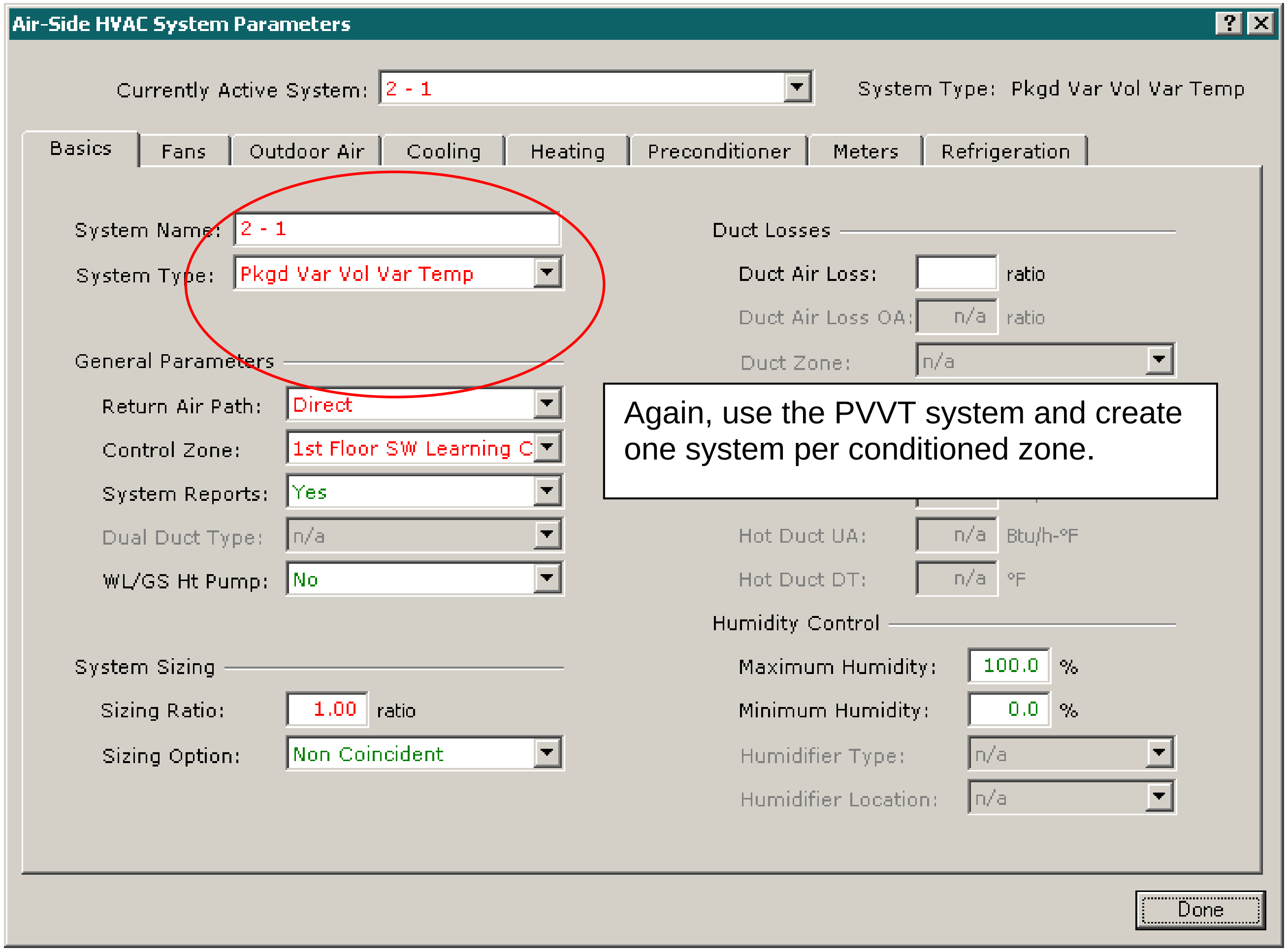
Modeling the VRF in eQUEST: PVVT air cooled heat pumps

- eQUEST system: PVVT, modeled as air cooled heat pumps. Create one system per zone.
- Change the compressor speed to variable.
- Be sure to label each system and zone so you can identify which condenser each zone is connected to.
- Create hourly reports for the total energy uses for heating and cooling for each system. Use the spreadsheet to find the simultaneous heating and cooling performed for each system and sum the savings.

Variable Refrigerant Flow Systems



Variable Refrigerant Flow Systems



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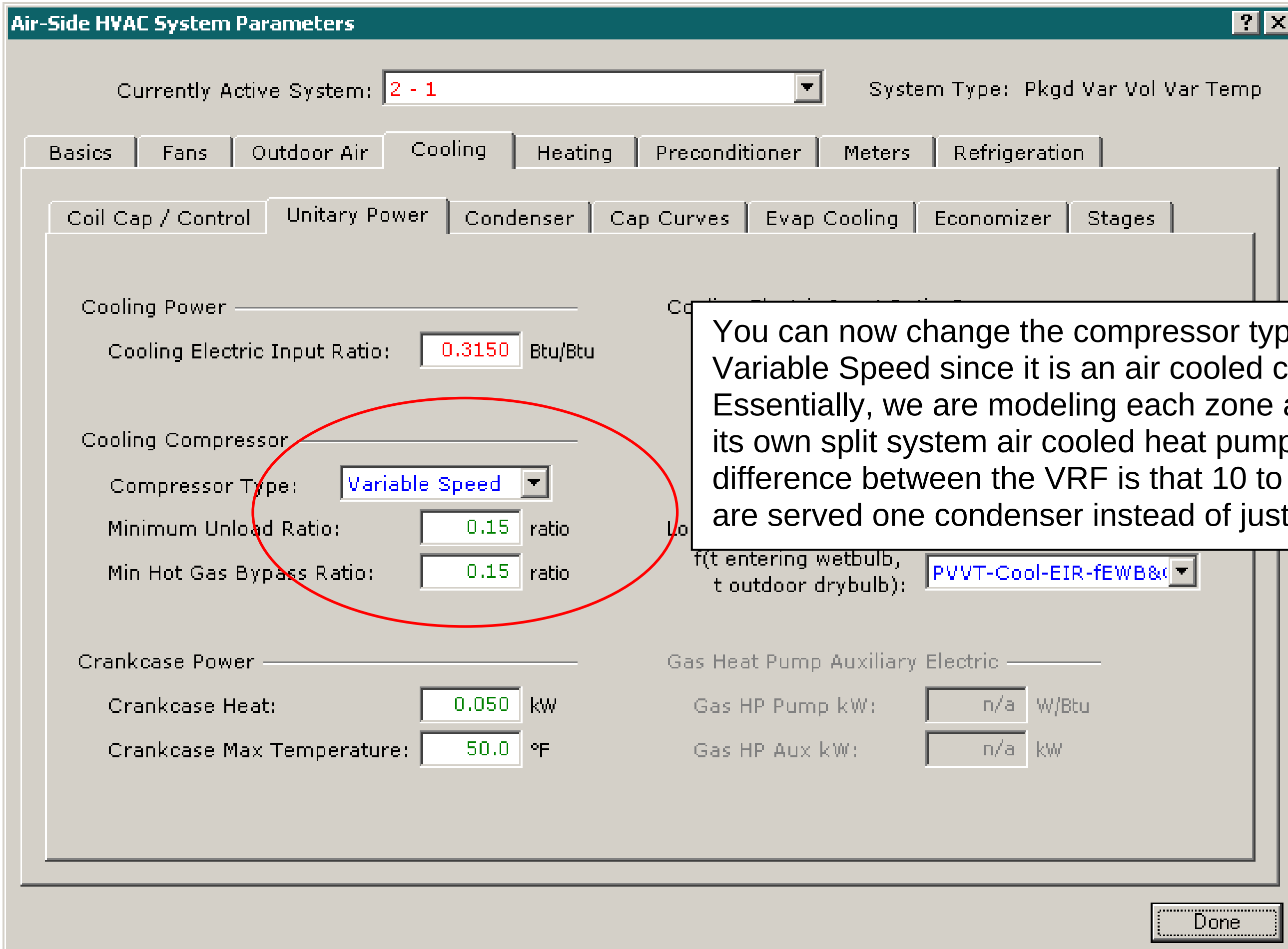
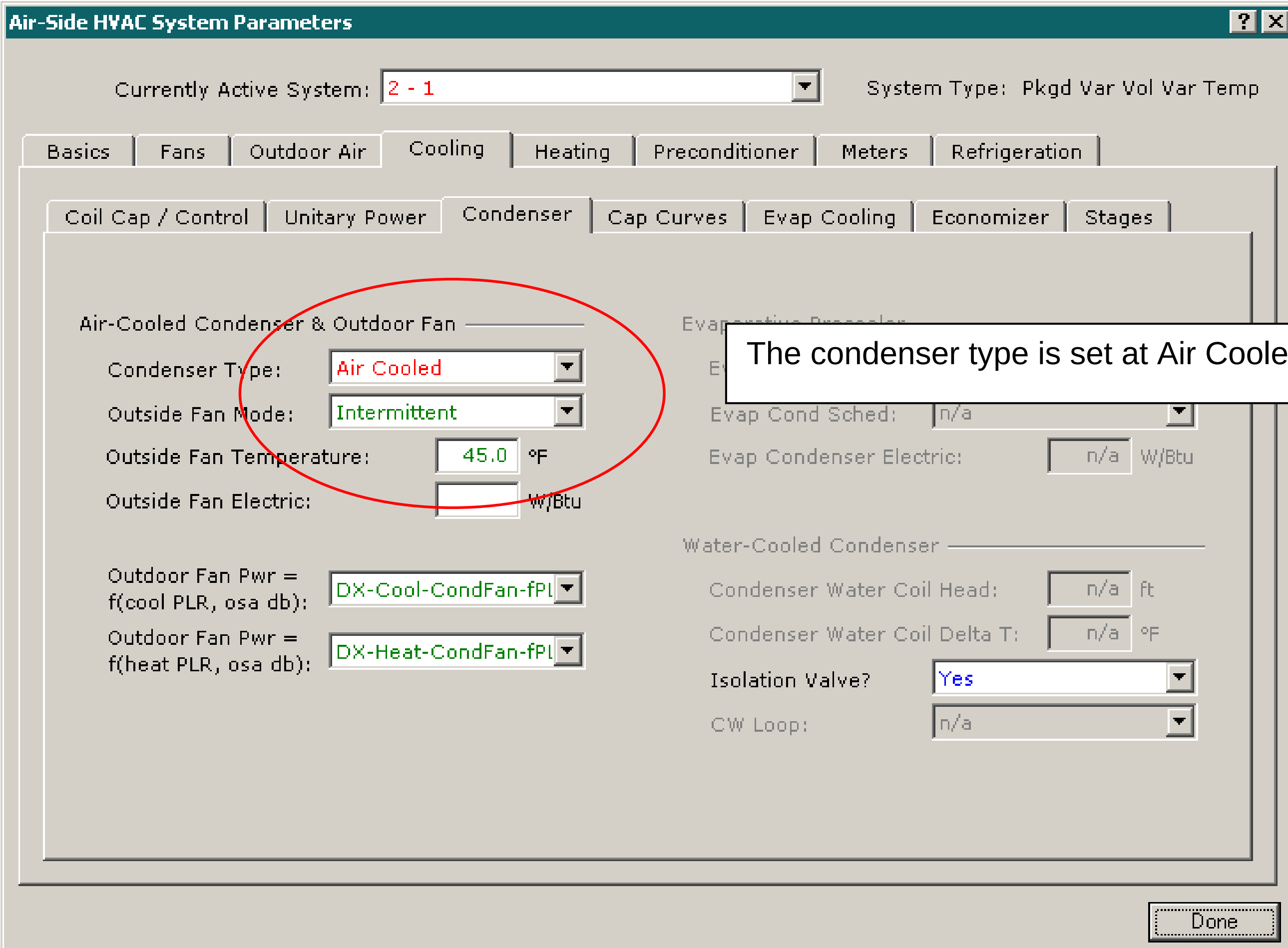
Variable Refrigerant Flow Systems



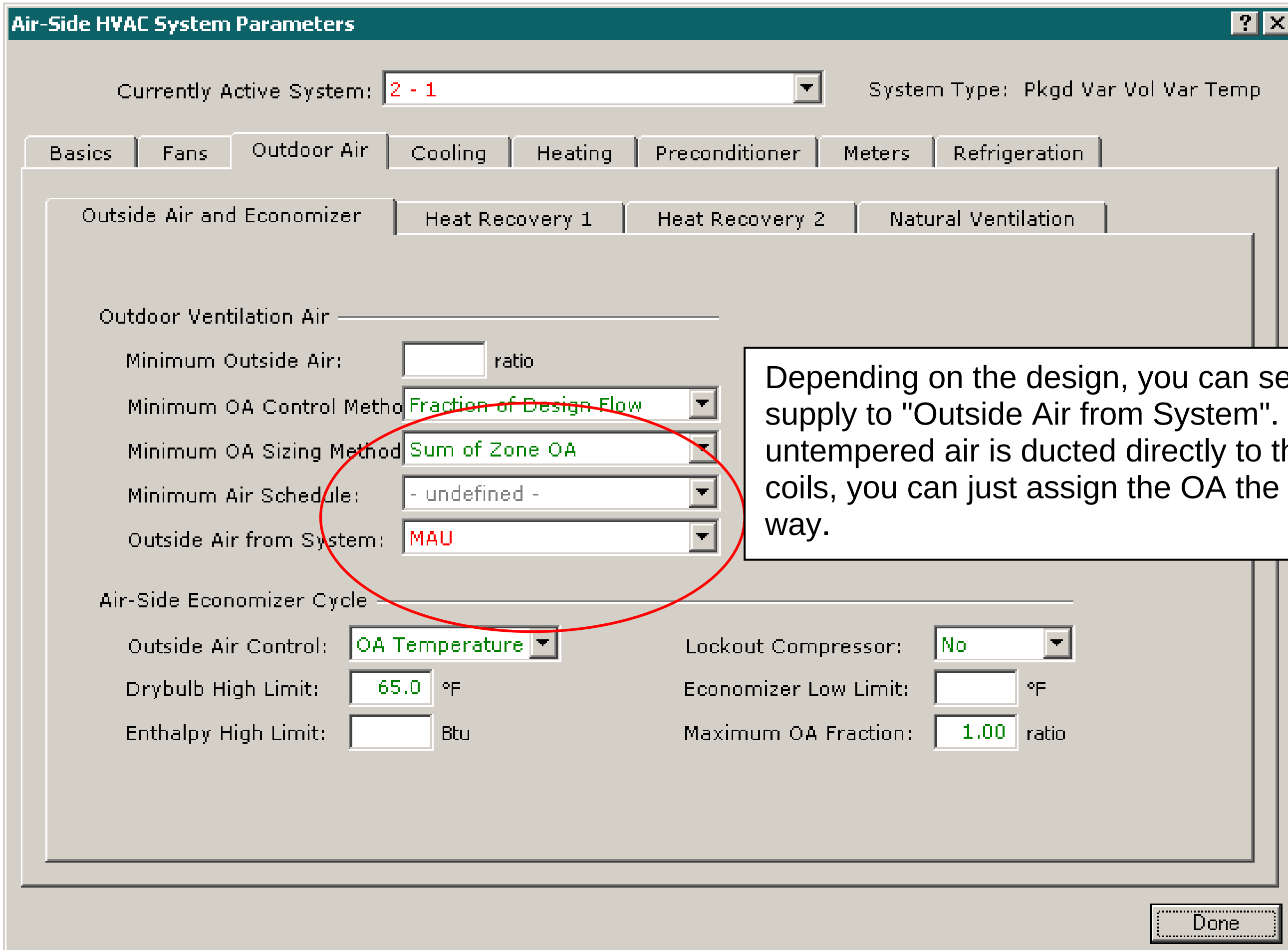
You can now change the compressor type to Variable Speed since it is an air cooled condenser. Essentially, we are modeling each zone as having its own split system air cooled heat pump. The main difference between the VRF is that 10 to 20 zones are served one condenser instead of just one.

Variable Refrigerant Flow Systems



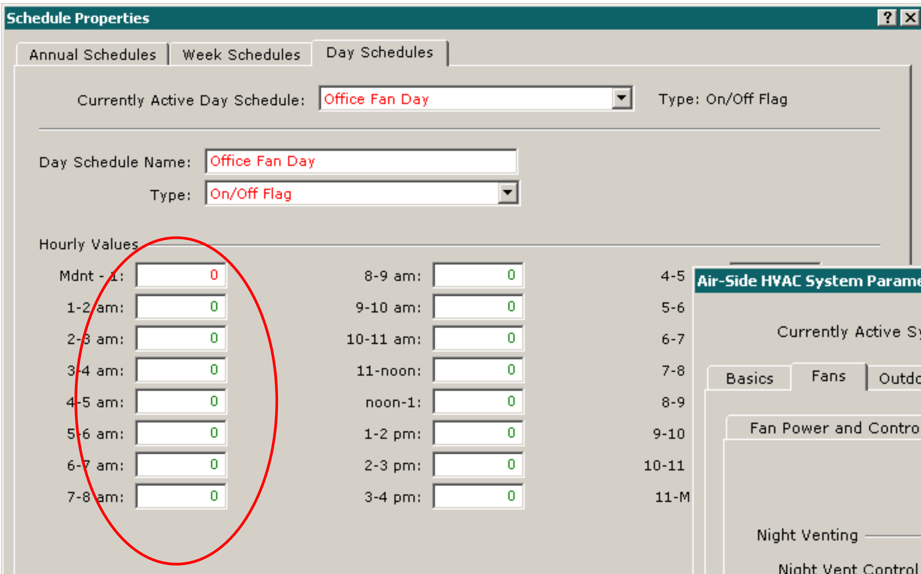
The condenser type is set at Air Cooled.

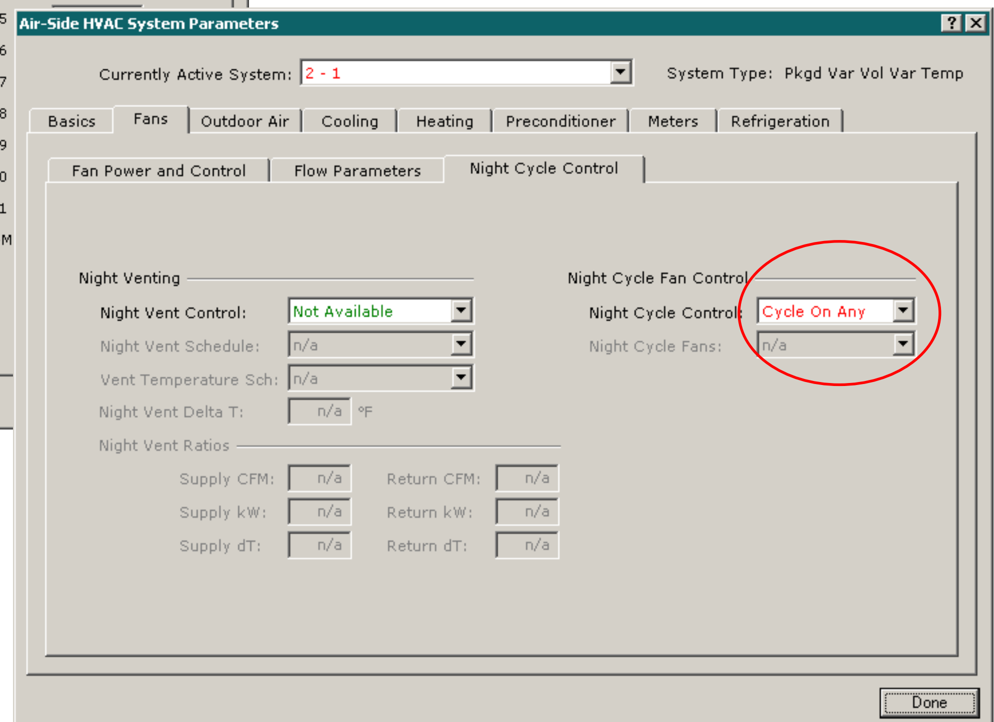
Variable Refrigerant Flow Systems



Depending on the design, you can set the OA supply to "Outside Air from System". If untempered air is ducted directly to the fan coils, you can just assign the OA the standard way.

Variable Refrigerant Flow Systems



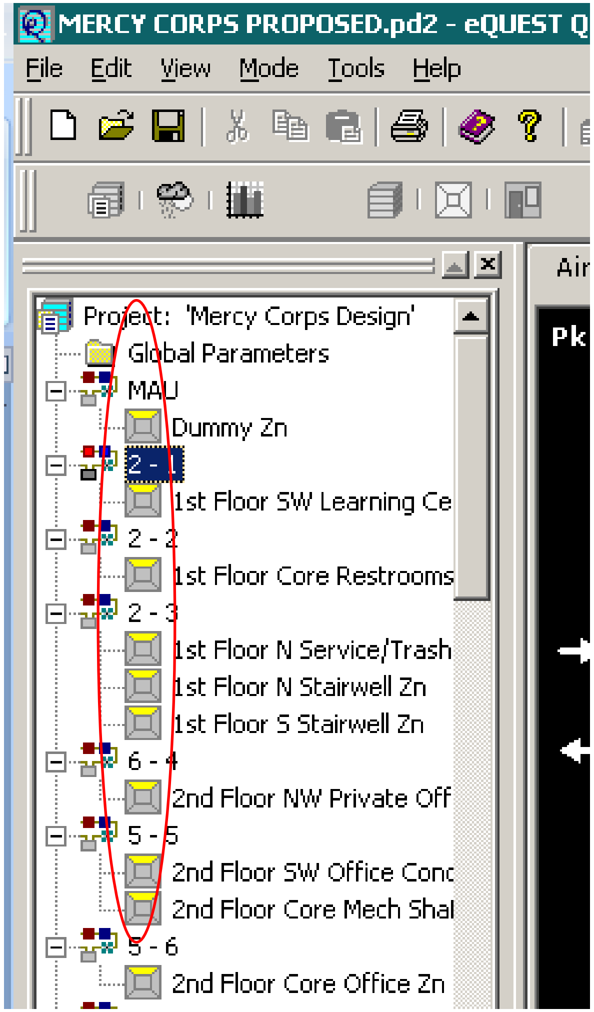


This model has OA running in Parallel, so we set the fan control to be "off" for all hours of the day, but changed the Night Cycle Control to "Cycle On Any", which turns the fans on and off to meet set points. The design must include these controls to incorporate these changes in the model.

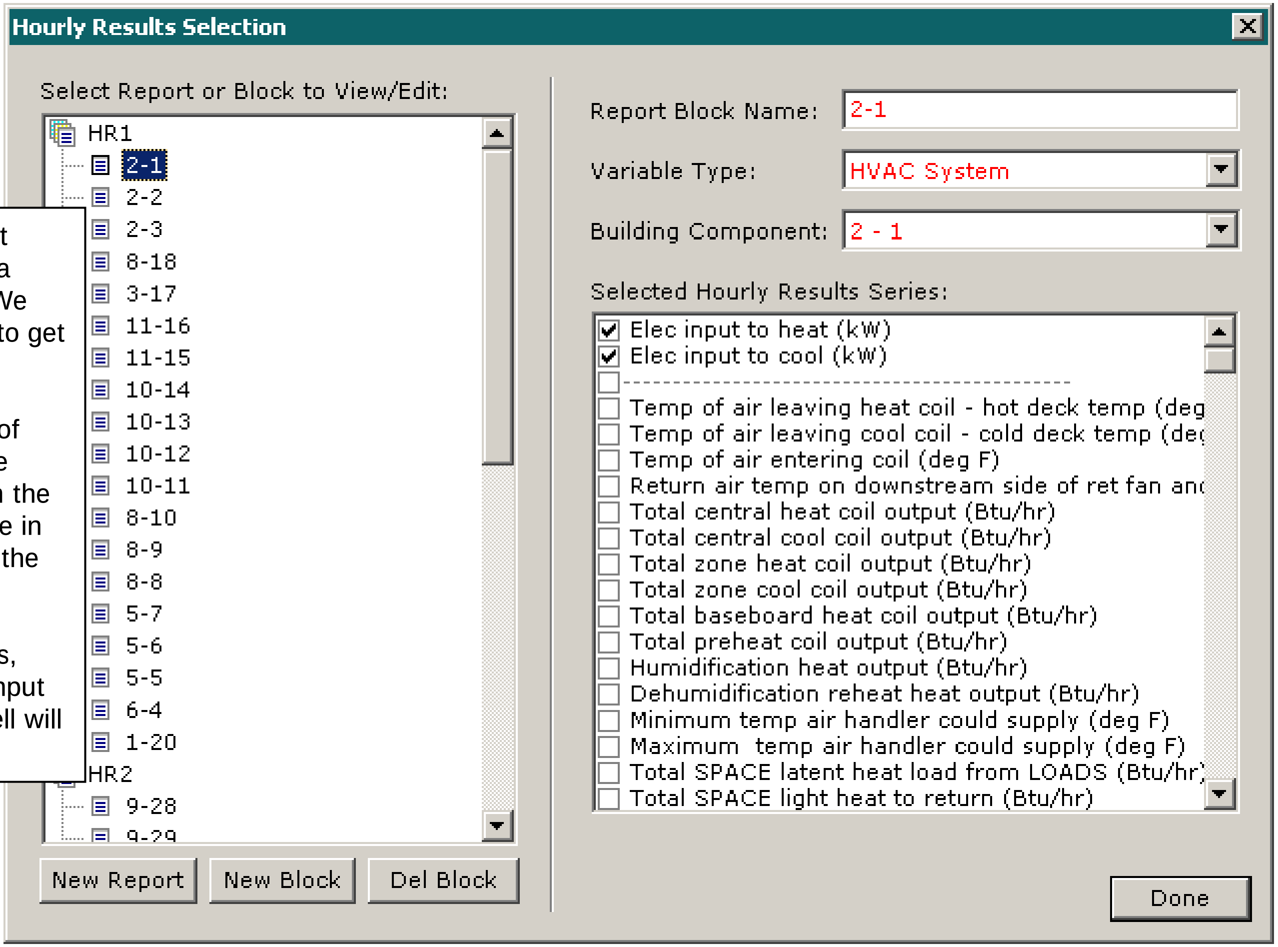
Variable Refrigerant Flow Systems

Here is a closer look at the naming of the systems. We named each system 1, 2, 3, etc and put the CU prefix before it. Most of these systems are linked to one another, so we created each system in the INP file, saving a couple of hours.

Note that the MAU has to be before any of the systems that reference it. DOE-2 is a top-down type code.



Variable Refrigerant Flow Systems

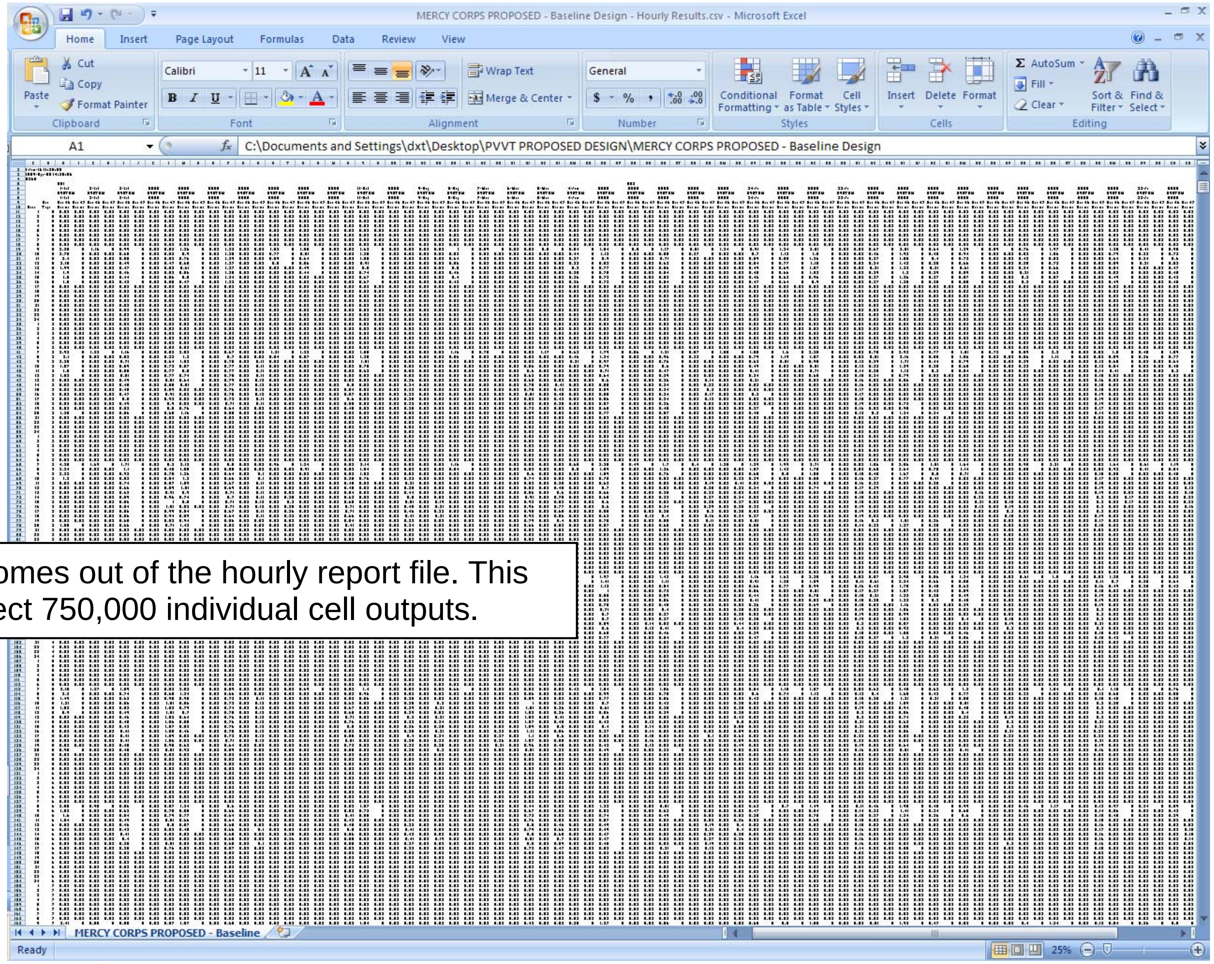


Create an hourly report. Note that each hourly report can only hold a finite amount of hourly outputs. We had to create two hourly reports to get all of the data we needed.

Create a separate block for each of the VRF (PVVT) systems you have defined in eQUEST and give them the same name, but slightly difference in case eQUEST gets confused with the naming.

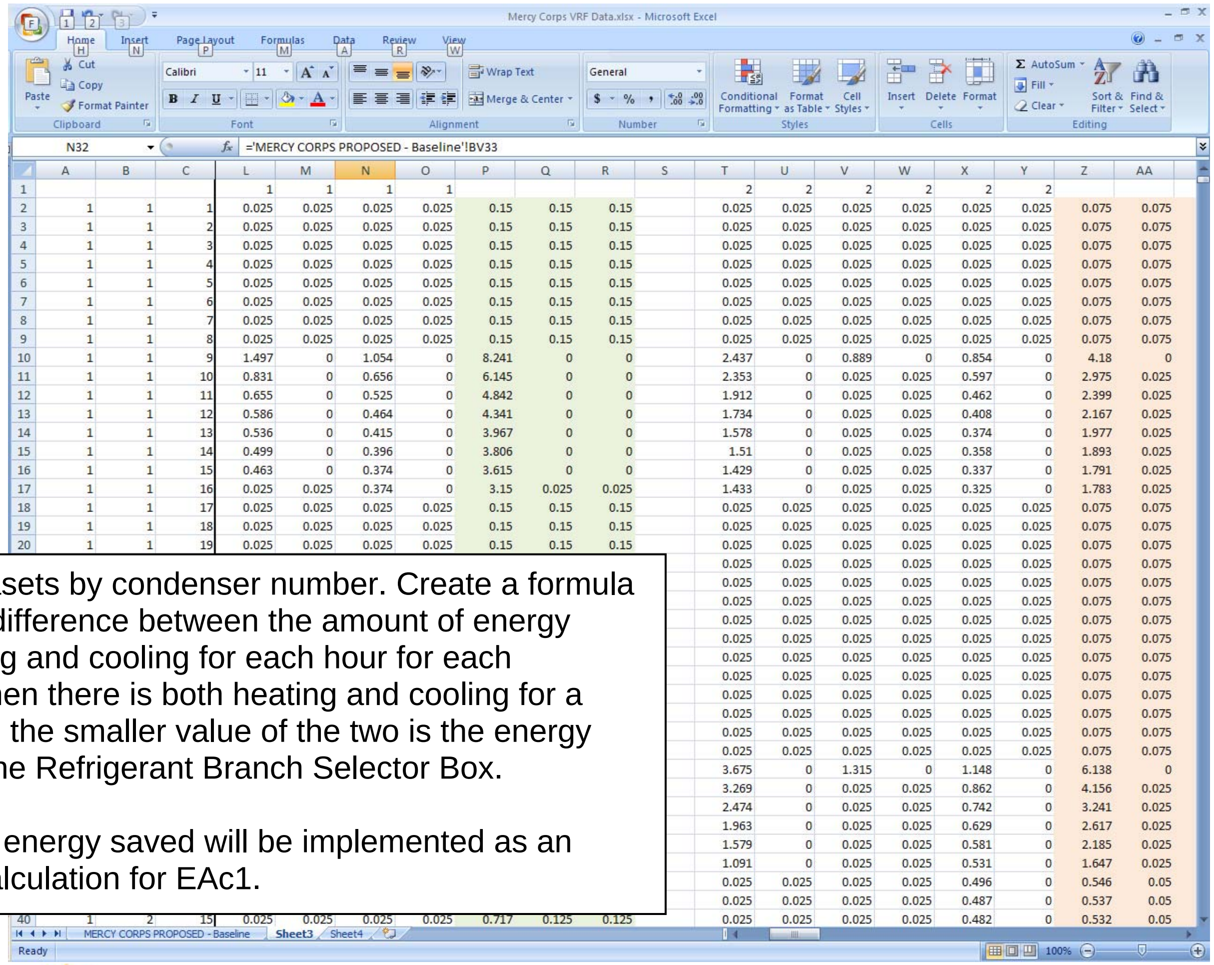
Each block should have two series, Elec input to heat (kW and Elec input to cool (kW). Each data output cell will be in kWh.

Variable Refrigerant Flow Systems



A lot of data comes out of the hourly report file. This particular project 750,000 individual cell outputs.

Variable Refrigerant Flow Systems



	A	B	C	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1				1	1	1	1					2	2	2	2	2	2		
2	1	1	1	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
3	1	1	2	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
4	1	1	3	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
5	1	1	4	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
6	1	1	5	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
7	1	1	6	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
8	1	1	7	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
9	1	1	8	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
10	1	1	9	1.497	0	1.054	0	8.241	0	0		2.437	0	0.889	0	0.854	0	4.18	0
11	1	1	10	0.831	0	0.656	0	6.145	0	0		2.353	0	0.025	0.025	0.597	0	2.975	0.025
12	1	1	11	0.655	0	0.525	0	4.842	0	0		1.912	0	0.025	0.025	0.462	0	2.399	0.025
13	1	1	12	0.586	0	0.464	0	4.341	0	0		1.734	0	0.025	0.025	0.408	0	2.167	0.025
14	1	1	13	0.536	0	0.415	0	3.967	0	0		1.578	0	0.025	0.025	0.374	0	1.977	0.025
15	1	1	14	0.499	0	0.396	0	3.806	0	0		1.51	0	0.025	0.025	0.358	0	1.893	0.025
16	1	1	15	0.463	0	0.374	0	3.615	0	0		1.429	0	0.025	0.025	0.337	0	1.791	0.025
17	1	1	16	0.025	0.025	0.374	0	3.15	0.025	0.025		1.433	0	0.025	0.025	0.325	0	1.783	0.025
18	1	1	17	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
19	1	1	18	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
20	1	1	19	0.025	0.025	0.025	0.025	0.15	0.15	0.15		0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												0.025	0.025	0.025	0.025	0.025	0.025	0.075	0.075
												3.675	0	1.315	0	1.148	0	6.138	0
												3.269	0	0.025	0.025	0.862	0	4.156	0.025
												2.474	0	0.025	0.025	0.742	0	3.241	0.025
												1.963	0	0.025	0.025	0.629	0	2.617	0.025
												1.579	0	0.025	0.025	0.581	0	2.185	0.025
												1.091	0	0.025	0.025	0.531	0	1.647	0.025
												0.025	0.025	0.025	0.025	0.496	0	0.546	0.05
												0.025	0.025	0.025	0.025	0.487	0	0.537	0.05
40	1	2	15	0.025	0.025	0.025	0.025	0.717	0.125	0.125		0.025	0.025	0.025	0.025	0.482	0	0.532	0.05

Group the datasets by condenser number. Create a formula that takes the difference between the amount of energy used for heating and cooling for each hour for each condenser. When there is both heating and cooling for a particular hour, the smaller value of the two is the energy recovered by the Refrigerant Branch Selector Box.

The amount of energy saved will be implemented as an Exceptional Calculation for EAc1.

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DOE-2 Accuracy

- The eQUEST methodology is not perfect, but it is felt to be a conservative approach to modeling the system.
- The methodology has been accepted by the USGBC (to date).
- DOE-2 VRF system curves: any volunteers to create these?

Questions