Design & Engineering Services

Performance of Residential Variable-Refrigerant Flow Systems

ET06SCE1020 Report

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Disclaimer

ABBREVIATIONS AND ACRONYMS

AC	Conventional residential split-system Air Conditioner with gas heat, SEER as designated
ARI	Air-Conditioning and Refrigeration Institute
Btu	British thermal units
Btu-e	British thermal units, of electrical energy
Btu-c	British thermal units, of cooling capacity
CFM	Cubic feet per minute
COP	Coefficient of Performance
CZ	California Climate Zone
DEER	Database for Energy Efficient Resources
DX	Direct Expansion
EDB	Entering indoor Dry Bulb temperature
EER	Energy Efficiency Ratio
EIR	Electric Input Ratio
EPRI	Electric Power Research Institute
EWB	Entering indoor Wet Bulb temperature
HP	Conventional residential split-system Heat Pump, SEER as designated
HVAC	Heating, Ventilating and Air-Conditioning
kW	kiloWatt
MBtuh	Millions of British thermal units, per hour
NTU	Number of Transfer Unit
ODB	Outdoor Dry Bulb temperature
OWB	Outdoor Wet Bulb temperature
Pa	Pascal
PLR	Part Load Ratio

ResVVT	Residential Variable-Volume Variable-Temperature
SCE	Southern California Edison
SDT	Saturated Discharge Temperature
SEER	Seasonal Energy Efficiency Ratio
SFM	DEER Single Family Model
SHR	Sensible Heat Ratio
SST	Saturated Suction Temperature
TDV	Time-Dependent Valuation, TDV-MBTU
TOU	SCE's time-of-use blocks, as defined by the TOU-8 electric rate structure
Var Rfg Flow	See VRF
VRF	Residential Variable-Refrigerant Flow heat pump system; comprised of an outdoor unit with variable-speed compressor, and multiple indoor units

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EXECUTIVE SUMMARY

"Ductless" air conditioning is a popular method of cooling in many countries, most notably in Asia. Though the product has been on the market for over twenty years, it is just beginning to penetrate the market in the United States. The simplest configuration for a ductless system consists of a single indoor fan coil coupled to an outdoor condensing unit; often referred to as a mini-split. A step up in complexity is the multi-split, which consists of multiple indoor evaporators connected to a single outdoor condensing unit. As the indoor fan coils may operate at different loads, the refrigerant flow is variable, and the outdoor unit must be capable of matching its output to the sum of the indoor loads. This is most commonly achieved via one or more variable-speed compressors. Both mini-split and multi-split systems are often referred to as variable-refrigerant flow (VRF) systems. These systems are applicable to both residential and small-to-medium sized commercial buildings.

Residential systems may indeed be ductless, and often are in other countries. However homes in the United States are usually constructed with HVAC systems that deliver air to every room in the conditioned envelope. As a result, residential VRF systems will not usually be ductless, but instead have a reduced amount of ducting compared to more conventional systems.

While claims have been made regarding the efficiency of VRF systems compared to more conventional systems, their actual performance is not well understood. SEERs in excess of 20 have been claimed by various third parties, but a review of catalog data suggests this cannot be the case.

In order to better understand the performance of VRF systems, a developmental version of the eQUEST building energy simulation program was enhanced to include algorithms to simulate a residential VRF system. The eQUEST residential VRF system is a heat pump capable of providing both winter heating and summer cooling to one or more indoor fan coils. In the future, these residential algorithms may be expanded to accommodate commercial applications.

This eQUEST was then used to study of the performance of typical VRF systems in single-family homes within SCE's service territory. The base case models used in the study were based on the California's Database for Energy Efficient Resources (DEER) single-family models (SFM). The SFM input consists of four houses total:

- A two story model oriented in both a north/south and east/west direction
- A single-story model, also oriented north/south and east/west

Base case configurations were developed for SEER-13 air conditioning systems with gas heat as well as for heat-pump systems. High efficiency conventional systems (SEER-16) were also developed for both gas and heat-pump systems. These DEER-based models were then expanded to include a VRF system of typical efficiency. The five prototypes were simulated for each of the 5 DEER residential thermostat schedules, and in each of the 8 climate zones comprising the SCE service territory: CZ06, 08, 09, 10, 13, 14, 15 and 16. The results were weighted by the DEER thermostat schedule factors and by the number of stories. Approximately 400 runs were conducted in total.

The general findings of this study are:

- The refrigeration cycle of a VRF system is not inherently efficient. The full load power consumption of the outdoor unit (compressor and condenser fan) is about 30%

higher than the power consumption of the condensing unit of a conventional SEER-13 split-AC/furnace system. As load decreases, performance improves due to the variable-speed compressor. But, as loads drop further, efficiency starts to decrease. At the minimum unloading point (about 30% part load), efficiency is about the same as it is at full load. In other words, the variable-speed compressor helps to make up for the poor full-load efficiency, but does not necessarily give the unit superior performance compared to a conventional system; particularly higher SEER conventional systems.

- Savings that accrue in residential VRF systems are due mainly to:
  - Reduced duct losses - The VRF system typically has less ductwork, and in some cases may have no ductwork. Accurate assessment of duct losses in both conventional and VRF systems is crucial in understanding the potential savings of a VRF system. Refer to section "Impact of Duct Losses" for more information.
  - Reduced cooling/heating loads - A conventional system having only one indoor unit and one thermostat may result in overcooling and/or overheating of the spaces not directly controlled by the thermostat. However these savings are highly dependent on how the occupants split the airflow between zones. This study assumed an equal split between living and bedroom areas; other splits may possibly reduce or reverse the savings. Refer to section "SS-D Cooling/Heating Loads" for more information.
  - Improved defrost cycle - For conventional heat pump systems, the supplemental electric coil activates whenever the system goes into defrost. A VRF system does not have a supplemental electric coil, and does not experience the electric penalty associated with electric coils. Of course, this advantage does not apply if the VRF system is compared to a system with a gas furnace.

Table 1 summarizes the results of the eQUEST VRF study for SCE's five time-of-use periods in the eight climate zones. All results are weighted by the climate-zone dependent thermostat schedules, the number of stories, and normalized by tonnage:

- Results for both heating and cooling modes are sensitive to climate. In general, VRF systems perform better in more extreme climates, and do not perform as well in mild climates. For example in mild CZ06, the VRF system uses more energy than conventional systems. This is because the outdoor unit is running fully unloaded and cycling most hours. As noted above, energy efficiency at the minimum unloading point is poor.
- Compared to conventional SEER-13 and SEER-16 AC/furnaces, VRF winter demand and energy is greater in all climate zones. This is to be expected, as the VRF system is a heat pump; while the conventional system is gas.
- Compared to conventional heat pumps, both SEER-13 and SEER-16, VRF winter demand and energy is less. This is due to the improved defrost mode which does not rely upon an electric coil to provide supplemental heat during defrost.
- Compared to conventional split-system AC/furnaces and heat pumps, VRF summer demand in mild climates is similar or higher. In hotter climates, performance is typically better than a SEER-13 conventional system, and may be comparable to a SEER-16 system. However, virtually all of these savings are due to reductions in duct conductive and leakage losses, as well as reduced cooling loads due to improved zoning.

TABLE 1. RESIDENTIAL VRF SUMMARY RESULTS (PER INSTALLED TON)

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ06	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.50	0.46	0.50	0.51	0.51	529.3	745.2	140.1	200.4	323.9	1939.0	0.36
(% of Annual)	137.7%	126.6%	137.5%	140.6%	141.8%	27.3%	38.4%	7.2%	10.3%	16.7%	100.0%	100.0%
AC SEER-16	0.45	0.42	0.45	0.46	0.46	521.8	734.6	131.9	197.2	317.9	1903.4	0.33
	135.6%	126.1%	135.9%	138.7%	138.4%	27.4%	38.6%	6.9%	10.4%	16.7%	100.0%	100.0%
HP SEER-13	0.53	0.68	0.51	0.54	0.53	532.3	935.6	139.8	200.3	330.3	2138.3	0.37
	143.4%	185.4%	139.9%	147.0%	143.4%	24.9%	43.8%	6.5%	9.4%	15.4%	100.0%	100.0%
HP SEER-16	0.47	0.61	0.46	0.47	0.46	527.0	934.8	132.9	197.7	326.0	2118.4	0.34
	139.6%	181.1%	135.8%	138.6%	137.4%	24.9%	44.1%	6.3%	9.3%	15.4%	100.0%	100.0%
Var Rfg Flow	0.51	0.54	0.51	0.50	0.50	545.3	929.7	144.8	201.7	337.1	2158.6	0.37
	136.5%	145.9%	135.4%	134.7%	133.2%	25.3%	43.1%	6.7%	9.3%	15.6%	100.0%	100.0%

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ08	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.80	0.70	0.80	0.71	0.78	617.4	807.3	227.4	253.5	384.9	2290.5	0.70
(% of Annual)	113.9%	99.8%	113.7%	101.3%	111.5%	27.0%	35.2%	9.9%	11.1%	16.8%	100.0%	100.0%
AC SEER-16	0.72	0.63	0.72	0.65	0.71	600.2	794.5	207.7	243.1	372.4	2218.1	0.65
	110.4%	97.3%	111.5%	100.8%	108.7%	27.1%	35.8%	9.4%	11.0%	16.8%	100.0%	100.0%
HP SEER-13	0.92	0.83	0.88	0.79	0.87	629.2	984.6	235.2	254.8	389.0	2492.9	0.75
	122.2%	110.9%	116.8%	105.7%	116.2%	25.2%	39.5%	9.4%	10.2%	15.6%	100.0%	100.0%
HP SEER-16	0.72	0.73	0.73	0.66	0.71	614.0	971.8	209.3	244.1	374.7	2414.0	0.65
	110.2%	111.9%	111.4%	101.2%	108.0%	25.4%	40.3%	8.7%	10.1%	15.5%	100.0%	100.0%
Var Rfg Flow	0.73	0.67	0.73	0.67	0.71	645.4	972.9	223.8	251.9	384.9	2479.0	0.67
	108.5%	100.6%	108.8%	100.0%	106.2%	26.0%	39.2%	9.0%	10.2%	15.5%	100.0%	100.0%

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ09	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.77	0.96	1.11	1.07	0.98	729.2	939.2	286.5	295.5	489.7	2740.0	0.86
(% of Annual)	89.6%	111.2%	128.7%	124.6%	114.1%	26.6%	34.3%	10.5%	10.8%	17.9%	100.0%	100.0%
AC SEER-16	0.71	0.84	1.01	0.97	0.88	705.5	919.5	259.7	282.1	467.5	2634.3	0.77
	92.4%	109.8%	131.7%	126.3%	114.9%	26.8%	34.9%	9.9%	10.7%	17.7%	100.0%	100.0%
HP SEER-13	0.86	1.07	1.24	1.17	1.10	737.8	1217.8	303.6	297.9	505.1	3062.2	0.96
	90.2%	111.2%	129.0%	122.0%	114.5%	24.1%	39.8%	9.9%	9.7%	16.5%	100.0%	100.0%
HP SEER-16	0.73	0.86	0.99	0.96	0.87	715.0	1195.3	260.7	283.1	471.8	2926.0	0.76
	96.2%	112.1%	130.1%	125.7%	114.5%	24.4%	40.9%	8.9%	9.7%	16.1%	100.0%	100.0%
Var Rfg Flow	0.75	0.86	0.98	0.95	0.88	758.1	1190.0	276.1	292.0	487.9	3004.2	0.77
	96.4%	111.4%	125.9%	122.5%	113.2%	25.2%	39.6%	9.2%	9.7%	16.2%	100.0%	100.0%

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ10	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.90	0.82	1.15	1.06	1.07	782.5	1047.6	344.4	374.3	537.5	3086.3	1.02
(% of Annual)	88.2%	80.1%	112.5%	104.5%	105.4%	25.4%	33.9%	11.2%	12.1%	17.4%	100.0%	100.0%
AC SEER-16	0.83	0.75	1.09	0.98	1.02	764.0	1023.5	318.3	354.2	517.1	2977.0	0.96
	86.5%	78.2%	113.6%	101.5%	105.8%	25.7%	34.4%	10.7%	11.9%	17.4%	100.0%	100.0%
HP SEER-13	1.00	1.36	1.29	1.16	1.18	797.7	1586.2	375.7	383.7	557.2	3700.6	1.13
	88.4%	120.0%	113.9%	102.2%	103.9%	21.6%	42.9%	10.2%	10.4%	15.1%	100.0%	100.0%
HP SEER-16	0.91	1.17	1.07	0.96	1.02	776.1	1521.9	318.0	355.0	521.9	3492.9	0.96
	94.7%	121.6%	111.8%	100.1%	106.2%	22.2%	43.6%	9.1%	10.2%	14.9%	100.0%	100.0%
Var Rfg Flow	0.85	0.89	1.00	0.94	0.94	809.3	1445.6	320.0	361.7	531.4	3468.0	0.90
	93.7%	98.2%	110.3%	103.7%	104.2%	23.3%	41.7%	9.2%	10.4%	15.3%	100.0%	100.0%

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ13	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.97	0.92	1.29	1.22	1.22	759.6	1013.5	372.7	422.2	595.8	3163.8	1.14
(% of Annual)	85.3%	81.3%	113.1%	107.2%	107.7%	24.0%	32.0%	11.8%	13.3%	18.8%	100.0%	100.0%
AC SEER-16	0.89	0.84	1.20	1.12	1.15	741.9	992.3	343.8	395.4	567.6	3041.0	1.05
	85.0%	79.9%	113.9%	106.2%	109.2%	24.4%	32.6%	11.3%	13.0%	18.7%	100.0%	100.0%
HP SEER-13	1.25	1.47	1.42	1.34	1.37	838.7	1594.9	414.7	438.4	622.7	3909.4	1.28
	97.5%	114.9%	110.6%	104.8%	106.4%	21.5%	40.8%	10.6%	11.2%	15.9%	100.0%	100.0%
HP SEER-16	1.06	1.28	1.18	1.11	1.14	813.9	1519.5	345.1	397.8	569.6	3645.8	1.04
	101.6%	122.8%	113.2%	106.3%	108.9%	22.3%	41.7%	9.5%	10.9%	15.6%	100.0%	100.0%
Var Rfg Flow	0.90	0.96	1.11	1.05	1.06	826.6	1382.9	342.0	405.5	573.7	3530.7	0.98
	91.9%	97.6%	113.1%	107.0%	107.3%	23.4%	39.2%	9.7%	11.5%	16.2%	100.0%	100.0%

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ14	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.72	0.77	1.06	1.07	1.02	633.5	881.8	318.3	372.4	512.3	2718.2	0.91
(% of Annual)	79.0%	83.9%	116.3%	116.9%	112.1%	23.3%	32.4%	11.7%	13.7%	18.8%	100.0%	100.0%
AC SEER-16	0.68	0.72	1.00	1.01	0.97	622.7	865.5	299.4	353.6	493.6	2634.7	0.86
	78.2%	82.9%	116.3%	116.7%	112.2%	23.6%	32.8%	11.4%	13.4%	18.7%	100.0%	100.0%
HP SEER-13	1.10	1.25	1.15	1.15	1.11	741.1	1388.7	343.0	387.7	529.5	3390.1	1.00
	110.3%	125.1%	115.1%	115.8%	111.7%	21.9%	41.0%	10.1%	11.4%	15.6%	100.0%	100.0%
HP SEER-16	0.94	1.10	0.99	0.99	0.95	725.2	1323.2	300.4	355.7	495.6	3200.1	0.86
	109.1%	127.8%	115.5%	115.6%	111.0%	22.7%	41.3%	9.4%	11.1%	15.5%	100.0%	100.0%
Var Rfg Flow	0.76	0.80	0.94	0.96	0.92	748.6	1237.1	306.6	371.3	510.8	3174.3	0.82
	93.3%	98.1%	115.0%	116.7%	112.3%	23.6%	39.0%	9.7%	11.7%	16.1%	100.0%	100.0%

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ15	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.78	0.89	1.07	1.16	1.23	691.1	895.2	373.0	453.3	665.8	3078.5	0.94
(% of Annual)	82.1%	94.6%	113.7%	122.8%	130.3%	22.4%	29.1%	12.1%	14.7%	21.6%	100.0%	100.0%
AC SEER-16	0.73	0.83	0.99	1.05	1.14	673.8	877.8	346.4	420.8	623.3	2942.1	0.86
	84.7%	96.1%	115.3%	121.6%	132.1%	22.9%	29.8%	11.8%	14.3%	21.2%	100.0%	100.0%
HP SEER-13	0.87	0.96	1.28	1.30	1.39	704.5	1020.9	427.1	490.6	710.3	3353.4	1.12
	77.9%	85.6%	113.9%	116.1%	123.8%	21.0%	30.4%	12.7%	14.6%	21.2%	100.0%	100.0%
HP SEER-16	0.74	0.84	1.00	1.05	1.14	680.7	994.5	351.4	426.8	631.9	3085.2	0.87
	85.4%	96.5%	114.9%	120.7%	131.0%	22.1%	32.2%	11.4%	13.8%	20.5%	100.0%	100.0%
Var Rfg Flow	0.71	0.82	0.94	1.03	1.07	693.9	1013.0	342.6	433.4	647.6	3130.5	0.84
	85.0%	98.1%	111.6%	122.5%	128.2%	22.2%	32.4%	10.9%	13.8%	20.7%	100.0%	100.0%

	Winter Demand, kW/ton		Summer Demand, kW/ton			Winter Energy, kWh/ton		Summer Energy, kWh/ton			Annual	
CZ16	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Mid-Peak	Off-Peak	On-Peak	Mid-Peak	Off-Peak	Total	Peak
AC SEER-13	0.49	0.48	0.66	0.77	0.67	537.9	795.6	164.0	224.0	346.8	2068.3	0.55
(% of Annual)	89.4%	87.0%	120.1%	140.2%	122.0%	26.0%	38.5%	7.9%	10.8%	16.8%	100.0%	100.0%
AC SEER-16	0.47	0.45	0.64	0.73	0.63	531.6	777.2	158.4	220.4	342.9	2030.5	0.53
	88.7%	83.8%	120.4%	135.9%	117.8%	26.2%	38.3%	7.8%	10.9%	16.9%	100.0%	100.0%
HP SEER-13	1.01	1.22	0.73	0.83	0.75	770.6	1607.9	172.7	226.7	355.2	3133.1	0.61
	166.1%	201.4%	120.0%	137.5%	123.5%	24.6%	51.3%	5.5%	7.2%	11.3%	100.0%	100.0%
HP SEER-16	0.92	1.19	0.62	0.70	0.63	739.7	1512.4	156.3	220.7	346.9	2976.0	0.52
	178.3%	229.3%	119.3%	136.2%	122.5%	24.9%	50.8%	5.3%	7.4%	11.7%	100.0%	100.0%
Var Rfg Flow	0.70	0.69	0.64	0.72	0.65	690.6	1254.1	171.0	227.7	363.2	2706.6	0.54
	129.3%	126.8%	118.8%	133.6%	120.0%	25.5%	46.3%	6.3%	8.4%	13.4%	100.0%	100.0%

- If VRF systems were improved so that their full load efficiency were comparable to conventional SEER-13 units, then their annual cooling performance would almost certainly be better than conventional systems in all climate zones. Heating performance would also be enhanced.
- This study assumed that the thermostat schedules for the VRF systems were identical for the living and bedroom spaces. If occupants adjusted the thermostats according to when the respective areas were normally occupied, then significant savings might accrue. However, typical occupant behavior in VRF homes is unknown. Without further study, any predictions of behavior could be strongly influenced by the author's bias.
- The impact of occupant behavior in VRF homes will be included as a supplementary phase of this study. The results will be added as a revision of the final report.

In conclusion, residential VRF systems may be more or less efficient on an annual basis than conventional AC/furnace or heat pump systems. The savings are strongly dependent on assumptions made for duct losses, zoning and thermostat control, and climate.

RECOMMENDATIONS FOR FURTHER STUDY

The following areas of study would be valuable for VRF systems:

- Duct losses - This subject is controversial, with some sources claiming that duct leakage loss may comprise more than 30% of the total HVAC energy of a residential system. Other studies suggest that leakage is much less. Duct thermal conduction losses can also be significant. A study to determine the differences in typical ductwork configurations for VRF vs. conventional systems would be valuable.
- Occupant thermostat control - As it is unknown how the typical occupant will control the various thermostats of a VRF system, the savings for better zone temperature control cannot be assessed. A study to better quantify occupant thermostat control would be valuable. Of course, since VRF systems are new in this country and are expensive, such a study may be biased by the relatively "green" behavior of people currently willing to pay for these systems.
- Commercial systems - Algorithms implemented to date in eQUEST are targeted toward residential systems, and possibly small commercial buildings with

operable windows. Larger commercial systems are more complex, and require additional features:

- VRF systems with simultaneous heating and cooling - The residential model is a heat pump, and in a given hour can deliver only heating or cooling. Commercial systems are typically "heat recovery" systems capable of simultaneously delivering heating and cooling.
- Dedicated outside air systems - The small indoor fan coils in VRF systems do not typically have a source of outside air. Instead, a dedicated outdoor air system is used to provide ventilation air directly to each space. This system may preheat or precool the outdoor air, and may also incorporate an energy recovery ventilator.

INTRODUCTION

Variable refrigerant flow (VRF) air conditioning is a popular method of heating and cooling in many countries. Though the product has been on the market for over twenty years, it has only recently been introduced into the market in the United States. Because of its perceived energy efficiency, there is growing interest in this system by building owners, HVAC engineers, electric utilities, and code organizations. Current manufacturers of VRF systems include Mitsubishi, Daikin, Fujitsu, LG, Samsung, Sanyo, and others.

This project developed and implemented VRF algorithms into the eQUEST building energy simulation program. While VRF systems are applicable to both residential and small- to medium-sized commercial facilities, this project was limited to residential heat pumps. It is also possible to use the new algorithms to model small commercial facilities that utilize a heat pump, and that do not have a dedicated outside air system. The algorithms do not support the modeling of larger commercial systems which utilize simultaneous heating and cooling (heat recovery), and dedicated outside air systems. However, the residential algorithms were implemented in a manner that supports their extension to larger commercial systems in the future.

A study of single family residences in SCE's service territory was then conducted to compare the performance of VRF systems to conventional split-systems; both with gas heating and heat pump systems.

BACKGROUND

Conventional split systems for residential buildings have an outdoor condensing unit which contains the compressor, and an indoor unit which contains the fan and evaporator coil. Refrigerant is circuited from the outdoor unit to an indoor evaporator unit which can be located either in the garage, attic or interior closet. The outdoor unit may be either cooling-only, or may be a heat pump. If not a heat pump, then the indoor section will contain a heating component; most commonly a gas furnace.

The indoor unit distributes conditioned air to each room via ductwork. The ductwork is subject to losses, particularly if located in an attic. The losses may be comprised of radiant and ambient air heat gain, as well as air leakage. These distribution losses are directly related to energy use.

Typical leakage rates are controversial at this time, with estimates varying from a few percent of the supply airflow, to over 20% of the airflow. Title 24 specifies that air leakage shall not be greater than 6% of the supply flow, as measured using the duct-blaster procedure.

Like a conventional system, a residential multi-split system also has a single outdoor condensing unit; however the outdoor unit can serve multiple indoor fan coils. Each fan coil has its own thermostat and controls, so each can operate independently of the others. Rather than simply cycling on/off, the outdoor unit modulates its compressor capacity to match the total load of the system; once the compressor is fully unloaded it may cycle. Because flow varies with indoor load and compressor modulation, this system is also referred to as a "variable refrigerant flow" (VRF) system.

While multi-split commonly references residential systems, the term "VRF" applies both to residential and commercial systems. Residential systems typically have an outdoor heat-pump unit with a single inverter-driven 3-ton or 4-ton compressor. The outdoor unit for a commercial system may have multiple compressors, of which one is variable speed. Still larger commercial systems may have multiple outdoor units ganged in parallel.

The residential indoor fan coils are available in a variety of configurations:

- Each major room may have its own surface-mounted fan coil, mounted on either a wall or ceiling (Figure 1). As each fan coil is located within an individual room in the house, the ductwork required by a central system is eliminated, along with the associated losses. A disadvantage of this configuration is that not all spaces are directly conditioned (the cost of each indoor unit is significant). For example, a bathroom may not have its own unit, but instead may be conditioned indirectly via an adjacent bedroom or hallway.

FIGURE 1. WALL-MOUNTED INDOOR FAN COIL[1]

- Rather than surface-mounted units, the units may be recessed (**Error! Reference source not found.**).
- The units may be located in an attic or interstitial space, and ducted to one or more spaces (Figure 3). This configuration allows all rooms to be directly conditioned, while using less ductwork than a conventional central system.

FIGURE 2. CEILING MOUNTED INDOOR FAN COIL

FIGURE 3. DUCTED INDOOR FAN COIL

The fans in the indoor units can be controlled in a variety of fashions:

- Constant-speed/cycling
- Variable-speed - may be off when floating, or may be running at minimum speed (often, in order to measure space temperature; the thermostat is integral to the unit, rather than wall-mounted). This configuration is not common in the U.S.
- Multi-speed, with two to four speeds. The speeds may be manually selectable, or may be automatically selected by the thermostat. This configuration, with or without the auto-select feature, is most common in residential systems.

The VRF outdoor condensing unit is also available in a variety of configurations:

- Cooling only (commercial)
- Cooling/Heating (residential, small commercial) - The outdoor unit is a heat pump. The mode of operation is manually selected at the "master" indoor thermostat.
- Sequential Heating/Cooling (usually commercial) - The outdoor unit is a heat pump. When simultaneous heating and cooling loads exist, the unit first operates in the cooling mode, and then switches over to the heating mode. Indoor units

demanding cooling shut down when the outdoor unit is in the heating mode, and vice versa.

- Simultaneous Heating/Cooling (commercial) - The outdoor unit is a heat pump. When simultaneous loads exist, and the building is cooling-dominated, the heating loads are satisfied using hot gas from the compressor discharge; eliminating any additional expenditure of energy. Therefore, heat recovery is considered "free". The heat is actually not totally free, as the compressor is run at a higher discharge temperature than it would otherwise. In a similar fashion, cooling loads are satisfied for "free" when the building is heating dominated.

The perceived advantages of a residential VRF system include:

- Duct losses - May be partially or completely eliminated. Some ducting may still exist if a unit serves a smaller space, such as bedrooms or bathrooms, in addition to its primary space.
- Zoning - The ability to condition only one room is desirable. Many times only a few rooms in the home are occupied and it is difficult to condition only one or two rooms with a conventional system without zoning.
- Compressor efficiency - the compressor is usually variable-speed, which may result in high part-load efficiency.

Potential disadvantages of residential VRF systems include:

- Duct losses - Indoor units are relatively expensive, and for this reason each room will probably not have its own indoor unit; rooms without units are indirectly conditioned via hallways, transfer grills, etc. While this configuration may be acceptable in other regions of the world, new homes in the United States are typically expected to have conditioned air delivered directly to each room, bathroom, and sub-rooms such as toilet rooms, walk-in closets, etc. For this reason, ducting will normally still exist, but ducting may be smaller in diameter and/or have shorter runs compared to a conventional system.
- Outdoor unit efficiency - While the compressor is variable speed and can unload, the condenser fan typically runs at constant volume and power. Therefore, there is an unloading point where maximum efficiency is achieved, and below that point efficiency decreases. Depending on the shape of the overall unloading curve (compressor plus fan), and the minimum unloading point, the unit may be less efficient at minimum load than it is at full load. This is discussed in more detail below.
- Indoor unit sensible heat ratio - While airflow in conventional systems is typically on the order of 400 cfm/ton (less in actual practice), airflow in VRF units is typically around 330 cfm/ton, but may be as low as 260 cfm/ton. The corresponding sensible heat ratio may be as low as 65%. While low airflows and sensible heat ratios may be desirable in humid climates, they may be a disadvantage in dry California climates which do not need dehumidification.

EXISTING CAPABILITIES IN EQUEST

In some ways, A VRF system is like the eQUEST "residential variable-volume variable-temperature" system (ResVVT) in that part of the hour may be dedicated to heating, and the other part to cooling. However, the ResVVT is a central system, while this system consists of zonal air handlers served by a central condensing unit.

A VRF system also has some similarity to the eQUEST "fan coil" system (FC), however eQUEST's FC system uses chilled-water only (no direct expansion), and cannot be coordinated for sequential heating/cooling in the same hour.

Neither the existing ResVVT nor FC algorithms in eEQUEST can be suitably modified to model a VRF system. Instead, new algorithms are required, where a single DX condensing unit serves multiple indoor fan coils. This system may have considerable diversity among fan coils (east vs. west exposures, etc.). As a result, the fan coils may be oversized relative to the condensing unit.

TECHNICAL APPROACH

This project consisted of the following tasks:

1. Background Research - Two major manufacturers of VRF systems were contacted in order to obtain information on equipment configuration and simulation methodologies. Face-to-face meetings were held with Daikin, and telephone conversations with Mitsubishi. Performance data were also obtained and examined for suitability for use in eQUEST.
2. Development of new VRF algorithms - Based on the information obtained in Task 1, new algorithms were designed for eQUEST/DOE-2. For this project, the algorithms were limited to residential, but were designed so that they can be readily extended to commercial systems.
3. Implementation and debugging of VRF algorithms in DOE-2 - Algorithms developed in Task 2 were implemented in DOE-2. The algorithms were debugged using a residential input model based on the DEER residential prototype.
4. Analysis of VRF systems in residential buildings - The existing DEER single family models were the starting point used to compare the performance of conventional split-system air conditioning systems with gas heating, conventional heat pump systems, and a residential VRF system.
5. Implementation in eQUEST - This task was not completed in this project.

These tasks are detailed in the following sections.

BACKGROUND RESEARCH

There are several manufacturers of VRF systems, including Daikin, Mitsubishi, Sanyo and LG.

Daikin AC was the principal contact for this project. Telephone conversations and a meeting were held with Kenji Obata of the New York office and two of his engineers from Japan. Daikin also provided us with the same algorithms which have been incorporated into the EnergyPro program. We used some of this information in the development of the DOE-2 algorithms, but found we needed to develop much of the information independently.

We also worked with Nicholas Conklin of Mitsubishi. These conversations were centered on equipment configurations and control schemes.

Daikin and Mitsubishi provided complete catalogs of their VRF equipment lines. We compared data for both indoor and outdoor units and found them to be similar, but of course not exactly the same. We used these data in determining "typical" outdoor unit performance data and indoor unit fan power.

We also visited the websites of Sanyo and LG. We concluded that additional information would not be useful.

DEVELOPMENT OF VRF ALGORITHMS

EXISTING PACKAGED DX ALGORITHMS

For packaged DX equipment, eQUEST/DOE-2 utilizes bi-quadratic polynomials to modify both capacity and power consumption as a function of the entering indoor wetbulb temperature (EWB) and the outdoor drybulb temperature (ODB). Simplified for discussion, the cooling mode calculations are:

$$Cap = Cap_{Nominal} * Cap\text{-}f(EWB,ODB)$$
$$PLR = Load / Cap$$
$$Pwr = Cap * EIR_{Nominal} * EIR\text{-}f(EWB,ODB) * EIR\text{-}f(PLR) / 3413 Btu/kW$$

Where

Cap	Hourly capacity, Btuh
$Cap_{Nominal}$	Capacity at AHRI rated conditions, Btuh
Cap-f(EWB,ODB)	Bi-quadratic curve to adjust nominal capacity
PLR	Part load ratio
Load	Sum of hourly indoor unit loads, Btuh
Pwr	Hourly power, kWh
$EIR_{Nominal}$	Nominal kWh*3413 / $Cap_{Nominal}$, inverse of COP
EIR-f(EWB,ODB)	Bi-quadratic curve to adjust nominal power
EIR-f(PLR)	Quadratic curve to adjust power for unloading

There are also other adjustments made, such as for cycling, but these equations are the fundamental ones used. The VRF manufacturers publish catalog data in this format, and this is the form of the VRF equations used in EnergyPro.

APPLICABILITY OF EXISTING PACKAGED DX ALGORITHMS TO VRF SYSTEMS

We concluded that the packaged DX algorithms as described above are inadequate for VRF systems, for several reasons:

- Because a VRF system serves multiple indoor units, the outdoor unit is controlled to maintain a fixed suction temperature setpoint; approximately 41°F. Therefore, the indoor coil does not "see" the outdoor drybulb temperature, but instead responds to the suction temperature. A lower outdoor temperature can result in a slightly higher indoor unit capacity because the liquid refrigerant temperature is lower; however this is a second order effect and is not believed to have a significant effect on indoor unit capacity.
- In a similar fashion, the VRF outdoor unit does not "see" the entering wetbulb temperature of the indoor unit. Instead, it also responds to the suction temperature setpoint.

  It is only when the outdoor unit is overloaded that the outdoor unit can respond to indoor wetbulb temperature, and the indoor unit can respond to outdoor drybulb temperature. However, the unit is rarely overloaded, and correction factors can be applied to compensate in this situation.
- The suction temperature setpoint may need to be changed to compensate for long refrigerant lines and/or large changes in elevation. This affects both capacity and efficiency. This cannot be readily captured in the conventional equations.

- While no VRF system is currently known to dynamically reset the suction temperature setpoint as a function of the indoor loads, this strategy may be a significant source of energy savings; similar to chilled-water reset in a chiller system. Therefore, it is desirable to configure the algorithms in a fashion that can allow suction reset to be implemented in the future.
- If the outdoor unit is overloaded, the suction temperature will increase, the indoor coil capacity will decrease, and the system will find the balance point between the two. In this case, the capacity of coils running at colder air inlet temperatures will be reduced more strongly than coils running at higher inlet temperatures. This effect is negligible in the residential case, but may be more important in commercial systems; particularly if one coil has a larger outdoor air fraction than the others.
- As published in the catalogs, some of the coil performance data for the indoor units is suspect, particularly at low entering wetbulb temperatures. For example, some indoor coils are reported to have a sensible heat ratio of 0.78 or lower at an entering wetbulb temperature of 61°F. When plotted on a psychometric chart, the apparatus dew point temperature may be 35°F or lower, or may not exist (no intersection with the saturation line). This effect was observed in both Daikin and Mitsubishi tables. But, since the suction temperature setpoint of the outdoor unit is 41°F, the lower limit of the apparatus dew point has to be higher than 41°F. Therefore, we do not believe the published performance data for low entering wetbulb temperatures is correct.

Similar issues exist when the VRF system is operating in the heating mode. The saturated discharge temperature does not float, but is instead controlled to a fixed setpoint. Both the indoor and outdoor units are decoupled from each other via this setpoint temperature. As in the cooling mode, a future improvement in energy efficiency may be to reset the discharge setpoint during non-peak periods.

NEW VRF ALGORITHMS

The VRF algorithms as implemented in DOE-2 are split into several separate components:

- An outdoor unit - This unit uses cooling curves similar to the conventional system, but with a dependence on saturated suction temperature (SST) rather than entering indoor wetbulb temperature. As manufacturers do not publish performance data for varying suction temperature, the default curves currently are a function of outdoor drybulb temperature only, with place-holders for use of suction temperature in the future:

  $$\text{Cap} = \text{Cap}_{\text{Nominal}} * \text{Cap-f(SST,ODB)}$$
  $$\text{PLR} = \text{Load / Cap}$$
  $$\text{Pwr} = \text{Cap} * \text{EIR}_{\text{Nominal}} * \text{EIR-f(SST,ODB)} * \text{EIR-f(PLR)} / 3413\text{Btu/kW}$$

- An indoor cooling coil(s) - The coil uses an enthalpy-based NTU/effectiveness heat exchanger algorithm that takes into account both heat and mass transfer across a wet coil. This coil is modular in the sense that it can be extended to any of the system types in the future, such as a dual-duct VAV system (an extreme example). It can also be utilized in a future dedicated outdoor air system, which is often included in commercial VRF systems.

Heating is modeled in a similar fashion to cooling. For the outdoor unit, the operative variables are the saturated discharge temperature (SDT) and the outdoor *wetbulb* temperature (OWB).

$$
\begin{aligned}
HtCap &= HtCap_{Nominal} * HtCap\text{-}f(SDT,OWB) \\
PLR &= HtLoad / HtCap \\
HtPwr &= HtCap * HtEIR_{Nominal} * HtEIR\text{-}f(SST,ODB) * HtEIR\text{-}f(PLR) \\
&\qquad / 3413 \text{ Btu/kW}
\end{aligned}
$$

When the outdoor wetbulb is in the defrost range, a correction factor is applied to capacity and power to account for defrost.

The indoor heating coil is modeled having the same U-value*Area characteristics as the cooling coil. This algorithm is also based on an NTU/effectiveness heat exchanger model.

The new algorithms solve for the balance between suction pressure, fan coil capacity, mass flow, condensing unit capacity, and energy consumption. The solution for the hourly balance point requires iteration between the condensing unit, fan coils, and zone loads. For this reason, these algorithms were implemented in a version of the program, currently in development, that does this type of iteration. (The standard version, DOE-2.2, does not currently iterate through the airside HVAC systems.)

INDOOR UNIT CYCLING DIVERSITY

Indoor units may vary their airflow based on load. But, because hourly loads are usually significantly less than the installed capacity of the indoor unit, the indoor units typically operate on the lowest speed and cycle on/off according to the thermostat. When multiple indoor units exist, they do not necessarily cycle on/off concurrently; the cycling pattern of each unit is governed by the integration of its thermostat and the space, and is therefore random.

The outdoor unit must respond to this cycling. In a typical hour the compressor is running partially unloaded to match the cooling demands of the indoor units that are cycled on, but is also cycling to match the cycling of the indoor units. If three indoor units have respectively cycled on for 40%, 30%, and 20% of the hour, the net fraction of the hour the outdoor unit must run is:

$$
\begin{aligned}
CycleOn1 &= 0.40 \\
CycleOn2 &= CycleOn1 + (1\text{-}CycleOn1) * 0.30 = 0.58 \\
CycleOn3 &= CycleOn2 + (1\text{-}CycleOn2) * 0.20 = 0.66
\end{aligned}
$$

So, even though the maximum indoor unit runtime is 40% of the hour, the outdoor unit runs 66% of the time. During this runtime, the outdoor unit delivers an average cooling output equal to the sum of the hourly indoor coil loads. In summary, the diversity of the indoor unit cycling acts to increase the runtime of the outdoor unit, and reduces the average hourly part-load ratio of outdoor unit.

The diversity of indoor unit cycling is important, but zoning in eQUEST is often simplified by consolidating similar zones. This conflict is resolved via a keyword that allows the user to specify the number of identical indoor coils that exist within a single zone.

The Fortran listings for both the outdoor unit and the coil algorithms are included in Appendix 2.

PERFORMANCE CHARACTERISTICS FOR VRF SYSTEMS

eQUEST/DOE-2 algorithms typically have default values for most performance characteristics. The following sections describe the range of values found for the various performance characteristics, the chosen default value, and the potential error if the default is used.

OUTDOOR UNITS - SUCTION TEMPERATURE IN PERFORMANCE CURVES

As described above, performance curves are used to modify both the capacity and power consumption of the outdoor unit as a function of the saturated suction temperature and outdoor drybulb temperature. However, VRF manufacturers do not publish capacity or power data as a function of suction temperature. For this reason, the default bi-quadratic curves for the outdoor unit do not contain coefficients for suction temperature; these coefficients default to zero (the second, third and sixth coefficients). In the event that suction temperature reset is ever implemented in VRF systems and suction data becomes available, these curves can be modified.

A similar situation exists for discharge temperature when in the heating mode. Data is not published, and therefore the performance curve coefficients for discharge temperature are set to zero. But as long as suction/discharge temperatures are not reset, the impact on performance is negligible.

The limitations on suction/discharge temperature do not apply to the algorithms for the indoor units. The NTU/effectiveness heat exchanger algorithms used for the coils modify performance based on first principles, and automatically accommodate variations in suction/discharge temperature. For the cooling mode, the eQUEST algorithm closely matches catalog performance in the 67°F-72°F indoor wetbulb range, and gives more believable results at wetbulbs lower than this.

OUTDOOR UNITS - FULL LOAD EFFICIENCY

The full load efficiency can vary substantially within the same manufacturer's series of heat pumps. For example, the Daikin 3-ton residential unit consumes about 1.00 kW/ton (excluding fan energy of any indoor units). The 4-ton unit in the same residential series consumes almost 20% more power at full load. Based on catalog data, the two units appear to be the same; both the unit dimensions and the electrical data are the same (max circuit amps, etc.). The 3-ton unit appears to be simply a derated 4-ton unit.

Overall, full-load efficiency appears to be in the range of 0.95 kW/ton to about 1.25 kW/ton. Typical is on the order of 1.05 kW/ton.

Note that this report does not use the term "EER", as a variety of indoor units can be coupled to a given outdoor unit. The indoor units can have widely varying airflows/ton, and widely varying fan energy/airflow (see below).

OUTDOOR UNITS - PART-LOAD PERFORMANCE

Residential VRF systems typically unload down to part load ratios of about 0.30, and commercial systems may unload down to 0.15. However, manufacturers publish performance data for part load ratios only down to 0.7 - 0.5 range; performance at lower part load ratios is not published (the catalogs use the term "Combination %). Therefore, performance at the minimum unloading point cannot be determined from published data.

One of the VRF manufacturers provided us with a part load curve that is the basis of the default curve in the program (we believe this curve is also used in EnergyPro). This curve is shown in Figure 4. This curve represents the fraction of full-load power as a function of part load ratio. For comparison, the "constant efficiency" linear curve is plotted; representing the fraction of full-load power assuming a constant efficiency over the entire load range.

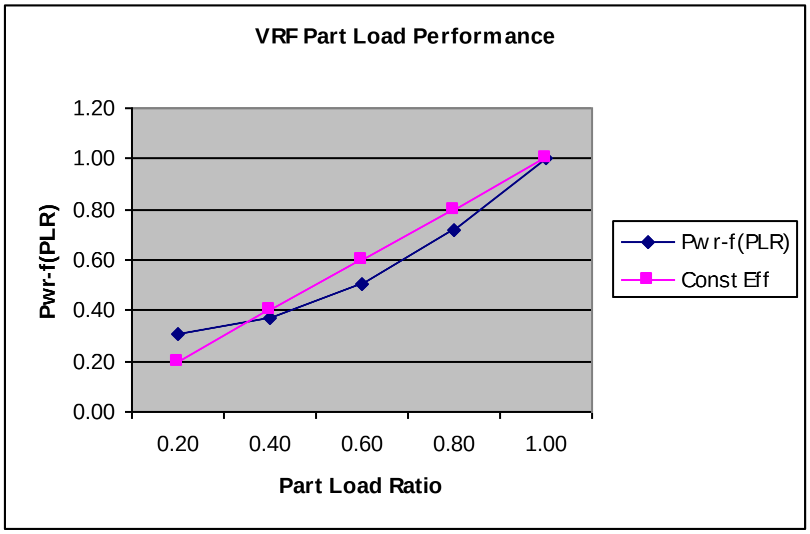

FIGURE 4. VRF DEFAULT PART LOAD PERFORMANCE

As the outdoor unit begins to unload, the inverter slows down the compressor and the efficiency of the unit increases (power consumption is less than the "constant efficiency" line). However, once the part load ratio drops below some point, efficiency starts to decrease. At about 35% part load, the efficiency is the same as it is at full load. Below this point, efficiency is less than it is at full load.

Part of this effect appears to be due to the condenser fan power. While the compressor is variable speed (and/or staged if commercial), the condenser fan usually operates at constant speed and power. As the condenser fan energy may be on the order of 15% of the total outdoor unit energy, the condenser fan energy becomes increasingly important as the load decreases. Additional part-load efficiency might be gained if the condenser fan were modulated.

This curve closely matches the published data down to 50% load. Since data is not published below 50% load, performance below 50% cannot be verified. (It is interesting that data is published at 50% load, which is of no engineering value other than to demonstrate improved efficiency. Perhaps data is not published at lower loads, as it would reveal decreasing efficiency.)

The residential unit used in this analysis can unload to 30% load, below which it cycles. If the majority of hours of operation at 30% load or less, then the annual efficiency may be similar to the efficiency of a unit that cycles, and the inverter may not provide significant efficiency gains. Part-load operation is discussed further in the results section of this document.

The default values assume the same performance curve is applicable to both the cooling and heating mode. This assumption appears reasonable, as the published part load data (down to 50% load) shows similar unloading characteristics in both modes.

Note that this discussion pertains to the default curve provided. It is not known whether this curve is applicable to both a single-compressor 3-ton residential units as well as larger multi-compressor commercial units. In addition, a unit with higher full-load efficiency would be expected to have a curve with poorer unloading characteristics than a unit having a lower full-load efficiency.

For example, in the section "Outdoor Units - Full Load Efficiency", a 3-ton unit is described as appearing to be a derated 4-ton unit. Per the catalog, at full load the 3-ton unit has the same efficiency at the 4-ton unit running at 75% load, which is right in the "sweet spot" of unit efficiency. Clearly, the 3-ton unit would not have the same part-load curve as the 4-ton unit.

Ideally, any standards developed for VRF systems should address these issues.

INDOOR UNIT - AIRFLOW, SENSIBLE HEAT RATIO AND FAN POWER

VRF indoor units come in a variety of configurations:

- Floor standing
- Wall mounted
- Ceiling suspended
- Ceiling mounted (recessed into ceiling)
- Above ceiling ducted
- Air handler ducted

Airflows and fan power can vary considerably among the various types of fan coils, and also within a fan coil category. For the various types of fan coils, Table 2 lists the range of characteristics found in a survey of equipment (Daikin and Mitsubishi).

TABLE 2 VRF FAN COIL CHARACTERISTICS

FAN COIL TYPE	AIRFLOW RANGE CFM/TON	SENS HEAT RATIO	FAN POWER WATT/CFM
Floor Standing	250 - 450	0.63 - 0.69	0.19 - 0.28
Wall Mounted	300 - 416	0.70 - 0.85	0.05 - 0.17
Ceiling Suspended	275 - 400	0.65 - 0.78	0.14 - 0.22
Ceiling Cassette (recessed)	330 - 600	0.66 - 0.78	0.13 - 0.22
Ceiling Concealed (ducted)	280 - 450	0.62 - 0.73	0.33 - 0.58
Air Handler (ducted)	350 - 400	Note 1	0.25 - 0.45
Note 1. SHR is not listed for this configuration, but coil bypass factor ~0.35; implying a low SHR			

In comparison, conventional systems typically have a design airflow on the order of 400 cfm/ton (although in practice most are lower than this), and a sensible heat ratio (SHR) on the order of 0.8. ARI assumes fan power is 0.365 watt/cfm.

Because of the large variation in fan power between various models, this paper does not attempt to compute EERs including the effect of fan power on both power and cooling load. Instead, kW/ton is cited for outdoor units, and excludes indoor fan power.

ANALYSIS OF VRF SYSTEMS - MODEL INPUT

BUILDING CHARACTERISTICS

The existing Database for Energy Efficient Resources (DEER) single-family residential (SFM) models were used as the basis for the DOE-2 analysis of VRF systems. The residential model is described in detail in existing DEER documentation, including:

- 2001 DEER Update Study.pdf
- 2004-05 DEER Update Final Report-Wo.pdf
- 2005 DEERResidentialPrototypeCharacteristics-051207.xls

The following summarizes the characteristics:

- Both single- and two-story prototypes, each oriented in both a north/south and east/west direction; for four homes total (Figure 5). The single-story prototype has two zones, a living zone oriented either south or west, and a bedroom zone oriented either north or east. The two-story prototype also has two zones, a living zone downstairs and a bedroom zone upstairs.

  Figure 5The graphic in Figure 5 is not completely correct, as there are vertical shading surfaces located outside the perimeter of each house. These surfaces approximate the shading due to landscaping, fences, etc. These shades have been removed so that the homes can be viewed more easily.
- The two-story prototype has twice the conditioned area, and twice the HVAC capacity, of the single-story prototype. The square footage of each prototype is dependent on the climate zone (Table 4), as determined by the RASS data. The simulated energy consumption of the two-story and single story prototypes are summed into separate meters, and the meters are weighted by the relative proportion of two-story vs. single-story homes in a given climate zone.
- Each prototype is simulated with 5 different thermostat schedules to take into account varying occupancy patterns and HVAC usage. (For example, one home may shelter a stay-at-home family, while an identical home is a vacation home.) The thermostat schedules, and their relative weighting, vary by climate zone.

  The thermostat schedules and their weighting are the principal method by which the models are calibrated to statistical data on residential energy consumption by climate zone.

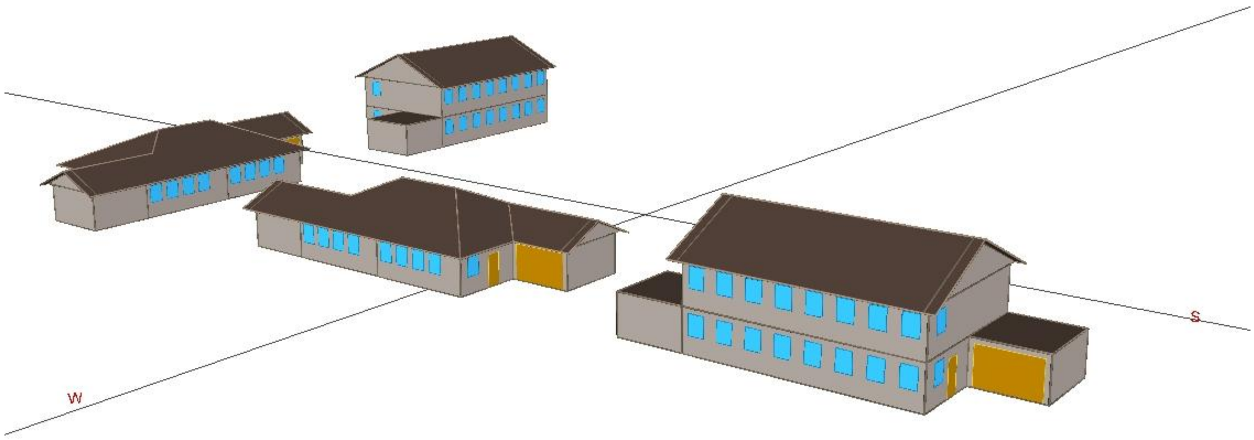

FIGURE 5. DEER RESIDENTIAL PROTOTYPES

- The analysis assumes that residential VRF systems will be primarily installed in new homes, rather than existing. For this reason, the base case homes and HVAC systems are assumed to comply with the latest Title 24 standards, denoted using Vintage 11 (2011) in the MASControl run generator.

Some minor changes were made to the model in order to better simulate conventional vs. VRF systems. They are:

- Airwall - The two zones in each house were originally separated with an interior wall of stick frame construction and gypsum board on either side. While typical of residential construction, this wall did not provide for any convective coupling between zones, and therefore acted to isolate the two zones more than they would actually be isolated. To account for convective coupling, an airwall was added having an effective area of 20% of the demising interior wall.
- Split attic - As the single-story VRF system has two systems with duct losses to the attic (see below), the attic was split in half so that each VRF system could have its own attic. The two attics were convectively coupled to keep temperatures approximately the same.

HVAC CHARACTERISTICS

CONVENTIONAL SYSTEMS

A total of four conventional systems were modeled in addition to the VRF system (Table 3):

- Split AC with gas furnace - This is the predominate residential system in SCE's territory. Title 24 requires a SEER of 13. The DEER base case of SA-13-ML is assumed.

- Split AC with gas furnace, high efficiency - This uses the DEER SEER-16 system. The compressor and fan are 2-speed.
- Split heat pump - Uses the DEER SH-13-MM prototype.
- Split heat pump, high efficiency - Uses the DEER SH-16-LM prototype. The compressor and fan are 2-speed.

The capacity of the installed system is the same for all types of systems. It varies by climate zone, as defined by DEER (Table 4).

TABLE 3. RESIDENTIAL HVAC SYSTEM PERFORMANCE CHARACTERISTICS

SYSTEM TYPE	SEER BTU/WATT	DOE-2 COOLING-EIR BTU-E/BTU-C	PERFORMANCE CURVES (DEER)	AIRFLOW CFM/TON	SENS HEAT RATIO	FAN POWER WATT/CFM
AC/Gas	13	0.2567	SA-13-ML	376	0.75	0.364
	16	0.2527	SA-16-LL	408	0.81	0.275
Heat Pump	13	0.2718	SH-13-MM	337	0.73	0.292
	16	0.2361	SH-16-LM	400	0.78	0.321
VRF	1.18 kW/ton	0.3356	VRF-* in Library	290	0.70	0.300

TABLE 4. HOUSING AREA AND TONNAGE BY CLIMATE ZONE

		Housing Area, sq.ft.			Cooling Tonnage		
Climate	Stories	2-story	1-story	Weighted	2-story	1-story	Weighted
CZ06	1.8	2660	1330	2394	4.45	2.23	4.01
CZ08	1.8	2660	1330	2394	4.19	2.09	3.77
CZ09	1.8	2692	1346	2423	3.74	1.87	3.37
CZ10	1.4	2784	1392	1949	3.61	1.81	2.53
CZ13	1.4	2784	1392	1949	3.65	1.82	2.55
CZ14	1.2	3602	1801	2161	5.27	2.64	3.16
CZ15	1.2	3602	1801	2161	5.66	2.83	3.40
CZ16	1.7	2702	1351	2297	4.25	2.12	3.61

The airflow is assumed to be split evenly between the living and bedroom zones. It is possible that the occupants might adjust the airflow split on a seasonal basis for maximum comfort; however this effect is not modeled.

Ductwork is in the attic. Title 24 requires ductwork to be sealed so that it has a leakage rate of no more than 6% (supply and return), as measured using a duct-blaster at 25 Pa. This analysis assumes that 3% of the leakage occurs on the supply side, with the remainder on the return side. Ten percent of the leakage is assumed to be made up by outside air, with the remainder made up by the attic.

To bound the issue of duct losses, simulations of all conventional and VRF systems were also made with 14% duct leakage (the DEER default), and 0% leakage. The 0% case would be for a home having all ductwork within the conditioned space.

SIMULATION LIMITATIONS FOR CONVENTIONAL HEAT PUMP SYSTEMS

When making test runs of VRF systems vs. conventional systems, the existing heat pump algorithms were inspected to verify their applicability for modeling the base-case conventional heat pumps. These algorithms are over 25 years old and were originally based on a study conducted by the Electric Power Research Institute (EPRI). Problems discovered include:

- Outdoor temperature - The algorithm calculates corrections to heating capacity and power consumption based on the outdoor *drybulb* temperature. Since the outdoor coil is running wet in the heating mode, the relevant parameter is actually the outdoor *wetbulb* temperature. (This argument is analogous to why packaged DX air conditioners use the indoor entering wetbulb temperature to calculate the cooling parameters.) We did not make any changes here, as it would require the generation of new, non-DEER performance curves.
- Defrost calculations - The original EPRI documentation is not available, but the defrost calculation appeared to have a couple bugs, which we fixed. However, a problem still remains. The defrost algorithms are hard-coded (not modifiable via keywords) and are based on data for equipment sold over 25 years ago. To meet modern efficiency standards, manufacturers have enlarged the outdoor heat exchanger and increased the outdoor airflow. Both of these enhancements act to reduce the outdoor wetbulb temperature at which defrost is required, and also reduce the defrost duration, however the existing algorithm does not capture these effects.

As an indoor electric coil is typically activated during defrost, the uncertainty in defrost time potentially introduces errors into the VRF study. These issues should be addressed in a future project.

Note that these limitations do not apply to the new VRF defrost algorithm. VRF outdoor units shut down the indoor unit during defrost, and do not utilize a supplemental electric coil. The manufacturer's catalogs include correction tables for capacity during defrost, which are incorporated into the eQUEST VRF algorithms.

VRF SYSTEM

The VRF system uses the same two-zone model for each home as the conventional systems. However, a home typically has more than two VRF indoor units, and as described in the section "Indoor Unit Cycling Diversity", the cycling diversity of the indoor units is very important. This is resolved by using the new capability to specify the number of identical indoor units per zone. The VRF model assumes two zones and two identical units per zone, for four indoor units total.

OUTDOOR UNIT

The capacity of the outdoor unit is assumed to be the same as for the conventional systems. The capacity of each of four indoor coils is assumed to be 30% of the outdoor unit capacity, so the total indoor unit capacity is 120% of the outdoor unit.

The outdoor unit efficiency is assumed to be 1.18 kW/ton. This represents the average of several surveyed residential units (but excludes the Daikin 3-ton, which appears to be a derated 4-ton unit). As discussed in the section "Outdoor Units - Part-Load Performance", it is not known how well the default part-load performance curve applies over the range of outdoor unit efficiencies.

Note that a VRF system is NOT very energy efficient at full load. In Table 3, The DOE-2 Cooling-EIR is the ratio of electric energy consumed by the compressor and condenser fan (no evaporator fan), to cooling capacity at AHRI conditions (EIR = electric input ratio). As can be seen, the VRF outdoor unit consumes approximately 30% more power at full load than the conventional systems. At 50% load, the inverter-driven VRF outdoor unit at its point of maximum efficiency; at this point its efficiency (kW/ton) is virtually identical to a SEER-13 unit cycling on/off. For this reason, statements by third-parties claiming SEERs in excess of 20 do not appear to have any basis in fact.

INDOOR FAN COILS

The indoor units are assumed to be ducted so that each room receives conditioned air directly. This is in conformance with typical construction standards and expectations in California.

The airflow of the indoor units is low, only 290 CFM/ton (Table 3). As a result, the sensible heat ratio is also low. This is consistent with the typical catalog data for ducted indoor units.

As ducted indoor units are assumed, duct losses are modeled, but are less than assumed for the conventional units:

- Single-story - Duct conductive losses are assumed to be one-half the loss of conventional systems. Duct leakage is also assumed to be one-half the leakage of conventional systems. As described in the section "Building Characteristics", the attic is divided into two equal halves to accommodate the ductwork of each zone.
- Two-story - All ductwork in the downstairs living zone is assumed to be within the conditioned space, so no duct conductive loss or leakage is assumed. Ductwork in the upstairs bedroom zone is assumed to be in the attic. For this zone, duct conductive and leakage losses are assumed to be one-half of the losses of the conventional system. But, because the VRF system divides the house into two systems, the losses in the bedroom system are one-half of one-half of the conventional system, or one-fourth of the conventional system's losses.

THERMOSTAT CONTROL

All indoor units are assumed to be controlled to the same thermostat schedule(s). As a significant portion of the potential energy savings may accrue due to varying schedules in living vs. bedroom areas, this is a major assumption. But, until data is collected on how people actually use these systems, any assumption other than uniform thermostat settings is speculation, and can bias the study.

A residential VRF system typically has a manual heat/cool selector switch on a designated "master" thermostat. But if we assume that the occupants will select the mode to maximize comfort throughout the home, this is similar to allowing each zone to "vote" on an hourly basis. Accordingly, voting is the control method used in the analysis.

RESULTS

As described above, the four base-case conventional residential systems and the VRF system were simulated in all eight climate zones within SCE's service territory. Each case was simulated using both the single-story and two-story configurations, and with 5 different thermostat schedules. The results were weighted by the average number of stories in each climate zone, as well as by the DEER thermostat schedule factors.

Additional simulations were conducted in select climate zones to investigate the sensitivity of the results to duct leakage and conductive losses.

GENERAL RESULTS AT TITLE 24 DUCT LEAKAGE

The majority of runs assumed 3% duct leakage on the supply side which is consistent with Title 24's requirement for not more than 6% leakage overall. Table 5 is summary of these runs. For a given climate zone, all of these results are weighted by the number of stories and the thermostat schedules for that climate zone (except report SS-D values; see section "SS-D Cooling/Heating Loads"). Systems within a climate zone can be compared directly, but systems across climate zones may not be compared directly, because the tonnage in each climate zone is different (Table 4). (The discussion for Table 1, the SCE TOU summary, follows.)

SS-D COOLING/HEATING LOADS

This section summarizes the total cooling and heating loads on the HVAC systems, as reported in the eQUEST SS-D output report. Loads in this report include not only the zone extraction loads, but also latent cooling, fan heat, and the benefits due to night ventilation. Unlike other results, these loads were weighted only by thermostat factors, not by the number of stories, and not normalized by tonnage.

The total cooling and heating loads for the four base-case conventional systems tend to be similar, but vary due to several causes:

- Fan heat - Total airflow and fan Wattage/cfm vary from one system to the next. Fan heat directly increases cooling loads, and reduces heating loads.
- Sensible heat ratio - Latent loads vary based on airflow and sensible heat ratio. Coil bypass factor also affect results.
- Capacity vs. temperature - The capacity of the various systems varies differently with both indoor wetbulb and outdoor drybulb temperatures.

The VRF system tends to have the largest deviation in loads compared to the base case systems (but not true for all climate zones). The conventional base-case systems respond only to the thermostats in the living zones; the bedroom zones are subzones with no direct temperature control. Depending on the airflow split between the living and bedroom zones, the bedroom zones may be either over-conditioned or under-conditioned (this analysis assumes equal airflows between the two zones).

In contrast, the VRF system has thermostats in both the living and bedroom zones, so neither zone is passive to the other, and loads can be met exactly. See also the BEPU data "Loads %UnMet", which is the percentage of all hours that a zone's temperature is more than 1F out of range (further discussion below).

TABLE 5. GENERAL SUMMARY RESULTS (NORMALIZED BY TONNAGE)

		SS-D		BEPU						TDV		
Climate Zone	HVAC Type	Cooling MMBtuh	Heating MMBtuh	Heat Therm	Heat kWh	Cool kWh	Fan kWh	Total kWh	Loads %UnMet	Elec TDV-MBTU	Gas TDV-MBTU	Total TDV-MBTU
CZ06	AC SEER-13	9.26	-6.71	24.09	0.0	123.3	36.0	1939.0	0.18	28.93	14.67	43.60
	AC SEER-16	9.13	-6.78	24.33	0.0	103.4	20.3	1903.4	0.17	28.23	14.71	42.94
	HP SEER-13	9.30	-6.94	0.00	197.6	127.6	33.4	2138.3	0.17	30.99	10.93	41.92
	HP SEER-16	9.19	-7.17	0.00	198.6	104.5	35.6	2118.4	0.16	30.49	10.93	41.42
	Var Rfg Flow	8.81	-7.63	0.00	189.1	148.6	34.6	2158.6	0.00	31.40	10.93	42.33
CZ08	AC SEER-13	18.60	-5.51	20.04	0.0	329.0	67.6	2290.5	0.40	36.88	14.63	51.52
	AC SEER-16	18.49	-5.57	20.25	0.0	282.7	41.5	2218.1	0.40	35.26	14.67	49.93
	HP SEER-13	19.09	-5.80	0.00	185.7	356.1	57.2	2492.9	0.38	39.51	11.47	50.98
	HP SEER-16	18.56	-6.05	0.00	177.9	282.4	59.9	2414.0	0.36	37.41	11.47	48.88
	Var Rfg Flow	16.47	-6.39	0.00	163.5	352.7	58.0	2479.0	0.00	38.66	11.47	50.13
CZ09	AC SEER-13	25.55	-8.51	31.17	0.0	493.5	100.2	2740.0	0.14	44.70	17.61	62.31
	AC SEER-16	25.40	-8.61	31.53	0.0	425.8	62.1	2634.3	0.14	42.40	17.66	60.06
	HP SEER-13	26.73	-8.89	0.00	281.2	548.4	86.3	3062.2	0.13	49.01	12.74	61.75
	HP SEER-16	25.44	-9.22	0.00	268.2	422.3	89.3	2926.0	0.11	45.48	12.74	58.22
	Var Rfg Flow	22.58	-9.60	0.00	247.1	511.8	87.4	3004.2	0.00	46.86	12.74	59.59
CZ10	AC SEER-13	37.56	-17.28	50.69	0.0	569.1	121.4	3086.3	0.56	50.58	24.87	75.45
	AC SEER-16	37.78	-17.48	51.27	0.0	505.2	75.9	2977.0	0.55	48.32	24.96	73.29
	HP SEER-13	40.27	-18.55	0.00	538.7	653.3	112.7	3700.6	0.51	58.24	16.94	75.18
	HP SEER-16	37.68	-19.49	0.00	480.3	499.1	117.7	3492.9	0.48	53.70	16.94	70.64
	Var Rfg Flow	33.33	-18.59	0.00	396.2	550.8	103.2	3468.0	0.00	53.57	16.94	70.51
CZ13	AC SEER-13	42.81	-18.57	54.68	0.0	659.1	134.5	3163.8	0.90	51.97	25.46	77.42
	AC SEER-16	42.91	-18.78	55.28	0.0	586.9	83.8	3041.0	0.86	49.48	25.55	75.03
	HP SEER-13	46.33	-20.24	0.00	638.0	774.5	126.6	3909.4	0.73	61.79	16.76	78.55
	HP SEER-16	43.02	-21.36	0.00	561.4	582.6	131.6	3645.8	0.61	56.32	16.76	73.08
	Var Rfg Flow	37.44	-19.08	0.00	405.0	618.1	107.4	3530.7	0.01	54.98	16.76	71.74
CZ14	AC SEER-13	38.30	-19.20	51.54	0.0	527.9	111.9	2718.2	1.89	45.55	22.07	67.62
	AC SEER-16	39.11	-19.45	52.17	0.0	485.4	70.9	2634.7	1.81	43.78	22.17	65.95
	HP SEER-13	40.98	-20.43	0.00	596.2	606.7	108.7	3390.1	1.43	53.97	13.90	67.87
	HP SEER-16	38.84	-21.27	0.00	521.9	484.9	114.9	3200.1	1.20	50.09	13.90	63.99
	Var Rfg Flow	35.45	-20.07	0.00	429.3	533.6	99.2	3174.3	0.00	50.08	13.89	63.98
CZ15	AC SEER-13	60.91	-4.75	11.72	0.0	975.5	149.1	3078.5	0.07	51.11	13.24	64.35
	AC SEER-16	61.00	-4.81	11.93	0.0	891.8	96.4	2942.1	0.07	48.43	13.26	61.69
	HP SEER-13	65.68	-4.95	0.00	118.2	1158.1	123.2	3353.4	0.07	56.13	11.35	67.49
	HP SEER-16	61.25	-5.12	0.00	106.9	901.9	122.4	3085.2	0.07	50.13	11.35	61.48
	Var Rfg Flow	54.78	-5.63	0.00	109.9	947.4	108.5	3130.5	0.00	50.40	11.35	61.75
CZ16	AC SEER-13	9.62	-22.68	75.11	0.0	106.6	61.9	2068.3	2.61	32.04	25.28	57.32
	AC SEER-16	9.79	-22.97	76.06	0.0	97.3	33.4	2030.5	2.50	31.34	25.43	56.77
	HP SEER-13	10.08	-24.88	0.00	1027.6	123.4	82.3	3133.1	2.13	44.45	13.48	57.93
	HP SEER-16	9.50	-26.14	0.00	893.6	92.0	90.5	2976.0	1.92	41.87	13.48	55.35
	Var Rfg Flow	9.80	-22.86	0.00	562.9	131.6	56.8	2706.6	0.00	39.52	13.48	53.01

BEPU BREAKDOWN OF HVAC ENERGY

This section of Table 5 gives a breakdown of the HVAC energy consumption. While the packaged AC/furnace system is the most common system in new construction today, total energy consumption cannot be directly compared with a VRF system, as the AC/furnace system consumes both electricity and natural gas, while the VRF system is an all-electric heat pump. Breaking the consumption down into heating, cooling, and fan categories allows for a better understanding of the system dynamics.

- Heat, therms - This column applies only to the conventional AC/furnace combination.
- Heat, kWh - This column applies to the conventional heat pump systems as well as the VRF system. In most climates, the VRF system uses significantly less heating energy than the conventional heat pump in either the SEER-13 or SEER-16 configuration. While a small fraction of the savings is due to the reduced heating load of the VRF system (due to better zone control), the difference is primarily due to the defrost mechanism of the two systems, and is most pronounced in the more Northern, humid climates that require defrost:

  - Conventional heat pump defrost - When this system goes into defrost, the compressor goes into the cooling mode in order to melt the frost on the outdoor coil, the indoor fan continues to run to provide a cooling load to the compressor, and the supplemental electric coil energizes to maintain the supply temperature and occupant comfort. Therefore, depending on the climate, a significant portion of the heating load may be met by the supplemental electric coil.

    Note that, as discussed in section "Simulation Limitations for Conventional Heat Pump Systems", we are uncertain as to whether the heat pump defrost is being handled correctly in eQUEST. However, the VRF mode of defrost is almost certainly more efficient.
  - VRF defrost - A VRF system defrosts by shutting down the indoor units, reversing the compressor, and transferring heat from the indoor unit coils to the outdoor coil. No supplemental electric heat is used, or even exists, in the system.
- Cool, kWh - The VRF units tend to use more cooling energy in mild climates than the conventional systems, but use less in hotter climates. This is directly related to the assumed part-load curve:
  - In mild climates, the outdoor unit is almost always running at the unit's minimum unloading ratio, and is cycling with the compressor fully unloaded. As discussed in section "Outdoor Units - Part-Load Performance", the unit cycling at minimum capacity may be no more efficient at part load than it is at full load. The mild climates also tend to be more humid than the hotter climates. Since the VRF has a lower sensible heat ratio than the conventional systems, latent loads may be greater.
  - In hotter climates, the outdoor unit runs more often at part load ratios in the region of maximum efficiency.
- Fan, kWh - These data reflect the variation in unit airflow/ton as well as fan Watts/cfm.
- Total kWh - This column is the sum of all sources of electric consumption by the HVAC systems. In this category, the VRF systems can only be compared directly to the conventional heat pumps, not AC/furnace systems which use gas for heating. In general VRF systems are more efficient than SEER-13 heat pumps, and may be more efficient than SEER-16 heat pumps in climates that do not require a lot of defrost. But, as noted elsewhere, the defrost calculations for conventional heat pumps may not be accurate.
- Loads % UnMet - This is the percentage of hours that a zone was either underheated or undercooled by more than 1°F (more than 1°F outside of the throttling range). However, this figure is calculated differently for conventional vs. VRF systems:
  - Conventional systems - For tight control, the control zone (the living area) was specified to have a throttling range of 0.25°F. The subzone (the bedroom area) is not conditioned directly, and can be expected to have a wider deviation from setpoint. The throttling range for the subzone was set to 4°F, so that the bedroom area was considered to be within the comfort band unless the temperature was more than 3°F above the cooling setpoint, or below the heating setpoint.
  - VRF systems - As both zones have their own thermostat, the throttling range was 0.25°F for all zones.

TIME-DEPENDENT VALUATION (TDV) ENERGY

The Time-Dependent Valuation energy is of interest for Title 24 energy budget calculations. These columns summarize the total TDV energy (HVAC, lighting, domestic water, etc.) for electricity, gas, and the sum of the two. Note, however, that Title 24 schedules are not used.

Results again vary by climate zone, with the VRF performing better in the more extreme climates.

IMPACT OF DUCT LOSSES

Some studies, using the duct-blaster testing technique, suggest that duct air leakage may comprise more than 30% of the total energy of an HVAC system. Other studies, such as some based on tracer gas analysis, disagree with this result; suggesting that losses are much less than 30%.

As VRF systems typically have less ductwork than conventional residential systems, (and in some cases may have no ductwork), duct losses may comprise a significant portion of the energy savings that these systems achieve. To bind the potential savings achievable by VRF systems, a series of runs was done for a selected subset of climate zones. Table 6 presents duct losses for the following cases:

- No Ducts - No ducts exist at all, or all ductwork is within the conditioned space. In addition to no leakage losses, there are also no conductive losses (no conduction through the duct walls to the unconditioned attic).
- 3% Supply Leakage - This is the base case assumed leakage, per Title 24. Conductive losses are in accordance with the DEER residential prototype.
- 14% Supply Leakage - This is the worst case, and is the value assumed in DEER (simplified to be the same leakage in both single-story and two-story homes). As with the 3% case, conductive losses are in accordance with the DEER residential prototype.

For the VRF system, the total duct leakage and conductivity for the four fan coils in each house is the same reduced ratio as described in the "HVAC Characteristics, VRF System" section; one-half the conductivity and leakage for the single-story house, and one-fourth the values of the two-story house.

As expected, higher duct leakage rates translate to more favorable results for the VRF system compared to the four conventional systems.

However, if ducts are eliminated entirely or are located within the conditioned space, then VRF systems do not appear to have a significant advantage over conventional systems; in most climates they use more energy on-peak. This is because the VRF system is inherently energy-*inefficient* at both full load and at minimum load; as described in previous sections.

TABLE 6. IMPACT OF DUCT LOSSES

Climate Zone	Duct Configuration	HVAC Type	Loads Cooling MMBtuh	Loads Heating MMBtuh	HVAC Energy Therm	HVAC Energy kWh	Total TDV-MBTU	TOU Summer Pk kWh	TOU Summer Pk kW	Peak 9 hours
CZ06	No Ducts	AC SEER-13	8.59	-5.84	21.1	1921.8	42.75	135.2	0.46	0.34
		AC SEER-16	8.34	-5.92	21.4	1888.0	42.13	127.3	0.42	0.31
		HP SEER-13	8.60	-5.82	0.0	2091.9	41.22	134.7	0.47	0.34
		HP SEER-16	8.41	-5.82	0.0	2067.2	40.70	128.4	0.43	0.32
		Var Rfg Flow	8.50	-7.02	0.0	2138.1	42.02	142.4	0.49	0.36
	3% Supply Leakage	AC SEER-13	9.26	-6.71	24.1	1939.0	43.60	140.1	0.50	0.36
		AC SEER-16	9.13	-6.78	24.3	1903.4	42.94	131.9	0.45	0.33
		HP SEER-13	9.30	-6.94	0.0	2138.3	41.92	139.8	0.51	0.37
		HP SEER-16	9.19	-7.17	0.0	2118.4	41.42	132.9	0.46	0.34
		Var Rfg Flow	8.81	-7.63	0.0	2158.6	42.33	144.8	0.51	0.37
	14% Supply Leakage	AC SEER-13	10.26	-7.80	27.5	1922.8	44.04	143.4	0.53	0.38
		AC SEER-16	10.09	-7.92	28.4	1922.1	44.00	137.5	0.49	0.36
		HP SEER-13	10.28	-8.28	0.0	2197.7	42.82	146.6	0.57	0.40
		HP SEER-16	10.17	-8.67	0.0	2177.6	42.27	138.4	0.49	0.36
		Var Rfg Flow	9.14	-8.18	0.0	2177.9	42.63	147.1	0.52	0.38
CZ09	No Ducts	AC SEER-13	22.48	-7.45	27.5	2666.0	59.82	262.5	0.96	0.76
		AC SEER-16	21.69	-7.55	27.8	2563.2	57.61	236.2	0.83	0.67
		HP SEER-13	23.25	-7.47	0.0	2936.5	59.01	275.0	1.04	0.83
		HP SEER-16	21.81	-7.48	0.0	2810.6	55.96	238.9	0.84	0.67
		Var Rfg Flow	21.21	-8.85	0.0	2960.4	58.73	267.6	0.92	0.74
	3% Supply Leakage	AC SEER-13	25.55	-8.51	31.2	2740.0	62.31	286.5	1.11	0.86
		AC SEER-16	25.40	-8.61	31.5	2634.3	60.06	259.7	1.01	0.77
		HP SEER-13	26.73	-8.89	0.0	3062.2	61.75	303.6	1.24	0.96
		HP SEER-16	25.44	-9.22	0.0	2926.0	58.22	260.7	0.99	0.76
		Var Rfg Flow	22.58	-9.60	0.0	3004.2	59.59	276.1	0.98	0.77
	14% Supply Leakage	AC SEER-13	30.12	-9.97	36.5	2846.7	65.85	320.4	1.27	1.01
		AC SEER-16	29.76	-10.14	37.1	2717.2	63.10	286.3	1.19	0.90
		HP SEER-13	31.77	-10.75	0.0	3235.5	65.51	343.2	1.34	1.15
		HP SEER-16	29.94	-11.33	0.0	3065.1	60.93	286.3	1.17	0.89
		Var Rfg Flow	24.00	-10.33	0.0	3047.5	60.47	284.6	1.04	0.82
CZ14	No Ducts	AC SEER-13	33.86	-17.00	45.3	2628.7	64.22	284.6	0.91	0.78
		AC SEER-16	33.47	-17.24	45.9	2540.6	62.37	262.2	0.83	0.71
		HP SEER-13	35.92	-17.10	0.0	3186.2	64.01	304.3	0.98	0.84
		HP SEER-16	33.45	-17.14	0.0	3005.6	60.43	266.6	0.84	0.72
		Var Rfg Flow	33.38	-18.70	0.0	3099.8	62.53	291.7	0.87	0.76
	3% Supply Leakage	AC SEER-13	38.30	-19.20	51.5	2718.2	67.62	318.3	1.06	0.91
		AC SEER-16	39.11	-19.45	52.2	2634.7	65.95	299.4	1.00	0.86
		HP SEER-13	40.98	-20.43	0.0	3390.1	67.87	343.0	1.15	1.00
		HP SEER-16	38.84	-21.27	0.0	3200.1	63.99	300.4	0.99	0.86
		Var Rfg Flow	35.45	-20.07	0.0	3174.3	63.98	306.6	0.94	0.82
	14% Supply Leakage	AC SEER-13	45.86	-22.87	61.4	2863.1	73.09	373.4	1.29	1.14
		AC SEER-16	47.08	-23.31	62.6	2766.2	71.33	352.8	1.27	1.13
		HP SEER-13	49.46	-25.75	0.0	3700.5	73.91	406.0	1.37	1.25
		HP SEER-16	46.80	-27.49	0.0	3481.4	69.24	350.6	1.24	1.10
		Var Rfg Flow	37.80	-21.70	0.0	3250.7	65.45	320.8	1.02	0.88
CZ16	No Ducts	AC SEER-13	9.17	-20.20	67.2	2051.9	55.57	157.7	0.60	0.50
		AC SEER-16	9.20	-20.48	68.1	2015.7	54.99	151.5	0.57	0.48
		HP SEER-13	9.53	-20.97	0.0	2959.7	55.59	164.7	0.66	0.55
		HP SEER-16	8.98	-21.24	0.0	2800.4	53.08	150.3	0.56	0.47
		Var Rfg Flow	9.56	-21.47	0.0	2672.0	52.47	168.1	0.62	0.52
	3% Supply Leakage	AC SEER-13	9.62	-22.68	75.1	2068.3	57.32	164.0	0.66	0.55
		AC SEER-16	9.79	-22.97	76.1	2030.5	56.77	158.4	0.64	0.53
		HP SEER-13	10.08	-24.88	0.0	3133.1	57.93	172.7	0.73	0.61
		HP SEER-16	9.50	-26.14	0.0	2976.0	55.35	156.3	0.62	0.52
		Var Rfg Flow	9.80	-22.86	0.0	2706.6	53.01	171.0	0.64	0.54
	14% Supply Leakage	AC SEER-13	10.46	-26.99	89.4	2098.0	60.46	175.2	0.75	0.62
		AC SEER-16	10.68	-27.50	91.1	2053.3	59.88	168.3	0.76	0.61
		HP SEER-13	11.12	-31.42	0.0	3424.5	61.94	187.4	0.86	0.70
		HP SEER-16	10.31	-33.84	0.0	3270.3	59.09	165.1	0.70	0.58
		Var Rfg Flow	10.13	-24.56	0.0	2750.2	53.68	174.6	0.67	0.56

VRF PART-LOAD OPERATING BINS

For the two-story house oriented north/south, Table 7 lists the number of hours the outdoor unit ran at various part-load ratios (the other 3 prototypes have similar patterns). In all climates, the majority of operational hours is in the 30% bin or lower, at which point the outdoor unit is running fully unloaded and is cycling. As discussed in earlier sections, the efficiency at the minimum unloading point is about the same as the efficiency at full load. However, the power consumption of the outdoor unit at full load is about 30% higher than the power consumption of the conventional system outdoor units at full load (in both cases, evaporator fan energy is excluded). The VRF efficiency is comparable to the conventional SEER-13 only around 50% load, the point of maximum VRF efficiency.

The observations above suggest that the VRF outdoor unit annual efficiency could be substantially improved by:

- Full load efficiency - Improve the full-load efficiency to be equivalent to conventional SEER-13 systems. This would most likely entail a larger outdoor heat exchanger.
- Part-load performance -Improve the part-load performance at minimum unloading so that the part-load efficiency is always higher than at full load. This would probably require modulation of the outdoor fan at low loads. (We are speculating here; VRF control systems are quite sophisticated, and we do not fully understand them.)
- Minimum unloading - With improved part-load performance, allow the VRF unit to unload to less than 30%

TABLE 7. VRF OUTDOOR UNIT - PART LOAD OPERATION BINS FOR 2-STORY N/S ORIENTATION

		Number of hours within each PART LOAD range											
		0	10	20	30	40	50	60	70	80	90		Total
Climate	Mode	10	20	30	40	50	60	70	80	90	100	100+	Annual
CZ06	Cooling	1041	858	288	18	0	0	0	0	0	0	0	2205
	Heating	1766	446	24	0	0	0	0	0	0	0	0	2236
CZ08	Cooling	991	850	639	346	89	1	0	0	0	0	0	2916
	Heating	1262	552	115	0	0	0	0	0	0	0	0	1929
CZ09	Cooling	803	724	635	494	255	95	18	0	0	0	0	3024
	Heating	1413	644	114	2	0	0	0	0	0	0	0	2173
CZ10	Cooling	796	759	644	502	349	196	34	0	0	0	0	3280
	Heating	1166	733	309	60	0	0	0	0	0	0	0	2268
CZ13	Cooling	728	717	657	556	430	279	120	9	0	0	0	3496
	Heating	945	747	459	102	2	0	0	0	0	0	0	2255
CZ14	Cooling	880	732	689	507	312	103	3	0	0	0	0	3226
	Heating	1305	924	410	56	1	0	0	0	0	0	0	2696
CZ15	Cooling	1106	677	573	541	583	408	80	1	0	0	0	3969
	Heating	806	366	45	0	0	0	0	0	0	0	0	1217
CZ16	Cooling	287	377	317	227	121	32	0	0	0	0	0	1361
	Heating	1051	1029	489	114	15	0	0	0	0	0	0	2698

As Table 7 reveals, the VRF outdoor units are oversized relative to what is actually required. (This is also true for the conventional systems, as all systems have the same capacity.) It is possible that the annual energy efficiency of residential VRF systems could be enhanced further if the installed tonnage were reduced. However, since these units also provide heating with no supplementary electric heat, reducing the capacity would impair the ability of these systems to raise space temperatures on winter mornings. In addition, downsizing the systems could increase the summer peak energy consumption, as the VRF outdoor unit less efficient when fully loaded.

BREAKDOWN INTO TIME-OF-USE BINS

Table 1 summarizes the results of the eQUEST VRF study for SCE's five time-of-use periods in the eight climate zones. All results are weighted by climate-zone dependent thermostat schedules, the average number of stories, and normalized by tonnage. Major conclusions are:

- Results for both heating and cooling modes are sensitive to climate. In general, VRF systems perform better in more extreme climates, and do not perform as well in mild climates. For example, in mild CZ06, the VRF system uses more energy than any of the conventional systems. This is because the outdoor unit is running fully unloaded and cycling most hours. As already discussed, energy efficiency at the minimum unloading point is approximately the same as when fully loaded; but fully loaded power consumption is about 30% higher than the conventional SEER-13 equipment.
- Compared to conventional SEER-13 and SEER-16 AC/furnaces, VRF winter demand and energy is greater in all climate zones. This is to be expected, as the VRF system is a heat pump; while the conventional system is gas.
- Compared to conventional heat pumps, both SEER-13 and SEER-16, VRF winter demand and energy is less. This is due to the improved defrost mode which does not rely upon an electric coil to provide supplemental heat during defrost.
- Compared to conventional split-system AC/furnaces and heat pumps, VRF summer demand in mild climates is similar or higher. In hotter climates, performance is typically better than a SEER-13 conventional system, and may be comparable to a SEER-16 system. However, virtually all of these savings are due to reductions in duct conductive and leakage losses, as well as reduced cooling loads due to improved zoning.

CONCLUSIONS

The refrigeration cycle of a VRF system is not inherently efficient. The full load power consumption of the outdoor unit (compressor and condenser fan) is about 30% higher than the power consumption of the condensing unit of a conventional SEER-13 split-AC/furnace system. As load decreases, performance improves due to the variable-speed compressor. However, as loads drop further, efficiency starts to decrease. At the minimum unloading point (about 30% part load), efficiency is about the same as it is at full load. In other words, the variable-speed compressor helps to make up for the poor full-load efficiency, but does not necessarily give the unit superior performance compared to a conventional system; particularly higher SEER conventional systems.

The majority of savings in a residential VRF system are due to:

- Reduced duct losses - a well-designed VRF system, even if fully ducted, should usually have less ductwork than a conventional system.
- Reduced heating/cooling loads due to better zoning. This may not always apply, however. With conventional systems, occupants may adjust room airflows to favor comfort in the main living spaces rather than the bedrooms, negating the effect shown in this study.
- Occupancy-based thermostat schedules for living vs. bedroom areas. While potentially a significant source of savings, insufficient information exists for evaluation in this study.
- The impact of occupant behavior in VRF homes will be included as a supplementary phase of this study. The results will be added as a revision of the final report.

If VRF outdoor units were improved so that their full load efficiency were comparable to conventional SEER-13 units, then their annual cooling performance would almost certainly be better than conventional systems in all climate zones. Heating performance would also be enhanced.

RECOMMENDATIONS

To better understand the performance of residential VRF systems, the following areas require further investigation:

- Duct losses in conventional systems - This is an area of ongoing study by the CPUC and others. Losses predicted based on the duct-blaster method may be a factor of 3 higher than losses predicted using tracer gas methods. As duct losses may comprise the majority of the potential savings, this issue is significant.
- Thermostat settings in VRF homes - Energy savings may accrue if occupants adjust the thermostat settings in living and bedroom areas to reflect the usage pattern of those rooms. But it is not known if occupants will routinely do this. A study of the few VRF homes in the United States may not yield valid data for the housing sector as a whole, because this technology is novel and homes with VRF systems tend to be occupied by "greener" residents who are willing to pay the premium in price for the perceived energy efficiency.

  Many homes with conventional systems may have two separate systems, particularly in two-story homes. Alternatively, the system may have multiple zones with thermostat-actuated dampers in duct runs. A study of these homes may reveal information that may be extrapolated to VRF systems.

Small- to medium-sized commercial systems are also candidates for VRF systems. eQUEST would require additional enhancements to simulate commercial systems. The major tasks include:

- Simultaneous heating and cooling - The residential VRF outdoor unit implemented in eQUEST is a heat pump that delivers either heating or cooling in a given hour, but never both simultaneously. Commercial buildings often simultaneously require heating in some zones, and cooling in other zones. Commercial VRF outdoor units are available in a heat recovery configuration that delivers both heating and cooling simultaneously. The performance of the outdoor unit then depends on the mode of operation:
  - Heating only - Similar to VRF heat pump
  - Cooling only - Similar to VRF heat pump
  - Simultaneous, heating dominated
  - Simultaneous, cooling dominated
- Cooling only outdoor units - Heating may be provided by other sources, such as baseboards.
- Multi-compressor outdoor units - A larger outdoor unit may have two or more compressors, with one compressor inverter-controlled, and the other compressors staged. As a result, the part-load performance of this unit is different than a unit with only one compressor.
- Ganged outdoor units - Similar to the above, multiple outdoor units may be ganged in parallel to satisfy larger loads.
- Water-cooled outdoor units - Air-cooled outdoor units are the most common, but outdoor units may also be water cooled. This technology would require that the

outdoor units be capable of attaching to the eQUEST water circulation loops and associated equipment; such as cooling towers, boilers, wells, etc.

- Dedicated outdoor air system - Unless a building has operable windows, commercial VRF systems often have a separate, dedicated outdoor-air system that delivers ventilation air directly to each space. This outdoor air may be either preheated, precooled, humidified or dehumidified. In addition, an energy recovery ventilator may be used that recovers heating/cooling energy from the exhaust air of multiple systems to precondition the outdoor air.

  The standard release of eQUEST does not support the capability for multiple systems to deliver air to the same zone. However, the residential VRF system is implemented in a developmental version that does not have this restriction. This version would allow the addition of a dedicated outdoor air system, with preconditioning energy provided either by the same outdoor unit(s) that the zonal fan coils use, or via a separate outdoor unit.

REFERENCES

[1]Photographs from www.Daikin.com website

BIBLIOGRAPHY

Daikin VRV Equipment Catalog, 2008

This manufacturer's catalog contains design and performance data for Daikin's variable-refrigerant flow systems for both residential and commercial systems. Various booklets within the catalog were referenced for residential systems, especially the RXYMQ-M outdoor heat pump and the FXDQ-M ducted indoor unit.

Mitsubishi City Multi VRFZ Equipment Catalog, 2009

This manufacturer's catalog contains design and performance data for Mitsubishi's variable-refrigerant flow systems for both residential and commercial systems. Various tabs within the catalog were referenced for residential systems, especially the Y-series outdoor units, S-series outdoor units, and PEFY series indoor units.

Goetzler, W. "Variable Refrigerant Flow Systems," ASHRAE Journal, April 2007, pp. 24-31

This article provides an overview of variable refrigerant flow systems.

APPENDIX 1. EQUEST VRF DOCUMENTATION

This section contains the eQUEST documentation written for the VRF algorithms, as found in the DOE-22 Volume 2: Dictionary, and DOE-22 Volume 6: New Features.

Residential Variable-Refrigerant Flow System

Introduction

This feature allows a residential variable-refrigerant flow (VRF) system to be modeled. The system consists of an outdoor unit featuring a variable-speed compressor that provides cooling or heat-pump heating, and one or more indoor units. Each indoor unit has its own thermostat. The outdoor unit operates whenever any of the indoor units runs, and cycles on/off according to the fraction of the hour the indoor units run. When indoor units are cycling, a statistical calculation is performed to calculate the diversity of indoor unit cycling and the result on the outdoor unit.

A residential VRF system can provide heating or cooling in a given hour, but not both. It does not provide simultaneous heating and cooling. The heating/cooling operating mode can be determined based on a single zone thermostat, or all of the indoor units can be allowed to "vote", with the maximum of the aggregate heating or cooling load determining which mode the indoor units run.

This capability is incorporated only into the PVVT system type.

Building Description Language Changes

SYSTEM

COOL-SOURCE

For certain system types, takes a code-word that specifies the cooling source for the SYSTEM's main cooling coil. Not all system types that accept this keyword allow all cooling sources. Allowed values of COOL-SOURCE are:

ELEC-DX	(The default for PVVT) The system uses an electric direct-expansion compressor. Both air-cooled and water-cooled CONDENSER-TYPEs are supported. When using this option, you specify the DX performance in a manner identical to packaged-VAV or packaged single-zone systems; using the COOLING-EIR, etc. Note: Not all systems allow this choice.
CONDENSING-UNIT	The system uses an outdoor condensing unit serving one or more direct-expansion cooling coils. The coil attaches to the condensing unit via the CONDENSING-UNIT keyword. Applicable only to the PVVT system type.

Condensing-Unit Coils

The following keywords specify the characteristics of a cooling coil attached to a condensing unit (COOL-SOURCE = CONDENSING-UNIT). Like other types of cooling coils, the COOLING-CAPACITY is defined at the RATED-EDB and RATED-EWB. The rated suction temperature is assumed to be the CONDENSING-UNIT:DESIGN-COIL-SST. The rated airflow is the corresponding airflow entered by the user; if not specified then the rated flow is based on the AIRFLOW/CAPACITY for central AHU and zonal coils.

CONDENSING-UNIT

Takes the U-name of a CONDENSING-UNIT to which the cooling coil(s) in this system are connected. This keyword also acts as the default for the keyword of the same name in the ZONE command.

HEAT/COOL-CONFIG

for a system having both heating and cooling coils attached to a condensing-unit, specifies whether separate heating and cooling coils exist, or if a single coil is used in both modes.

COMMON	the default, specifies that a single coil be used for both heating and cooling. If the capacity is not specified, the coil will be sized to the larger of the heating or cooling requirement; typically cooling.
SEPARATE	specifies that the heating and cooling coils are separate. Each coil will be sized independently.

RFG-COIL-CTRL

specifies how the coil is controlled in response to the zone thermostat or discharge air controller:

CYCLE-ON/OFF	the default, specifies that the coil cycles on/off to maintain the average supply temperature. This method will extract more latent energy than a modulating controller.
MODULATE	specifies that the coil modulates the suction temperature to maintain the average supply temperature.

ZONE

TERMINALS/ZONE

For a zone served by a CONDENSING-UNIT, specifies the number of indoor-units that are in the zone. This entry is important only when indoor-units cycle on/off rather than modulate. This value is used to calculate the impact on the outdoor unit of the diversity of operation of the indoor-units,

For example if an outdoor unit serves a single zone, the zone has 3 indoor-units, and the hourly load is 40% of maximum (each indoor unit runs 40% of the hour, but not necessarily simultaneously), the condensing unit will calculate the diversity of indoor-unit operation to be 78%. The outdoor-unit will then run 0.78 of the hour, at a part load ratio of 0.40/0.78 = 0.51.

This keyword only applies to the diversity calculation for a zone served by a CONDENSING-UNIT. Terminal airflow, capacity, etc. should be specified assuming there is only one terminal per zone.

CONDENSING-UNIT

This is a new command that defines all of the operating parameters of an outdoor condensing unit, to which one or more indoor units attach. A U-name must be specified for each condensing unit. This U-name will be referenced by indoor units that are served by this outdoor unit, and will also be used in the heading of the condensing unit report to identify the chiller.

Currently, the condensing-unit is configured in a variable-refrigerant flow (VRF) configuration. For these units, manufacturers typically rate the performance of the equipment as a composite of the indoor and outdoor units. For example, for cooling, the performance is specified as a function of the weighted entering-wetbulb of the indoor units, and the outdoor drybulb. For heating, performance is specified as a function of the weighted entering-drybulb temperature of the indoor units, and the outdoor wetbulb. This program does not follow this convention exactly, as it simulates indoor and outdoor units separately, and recognizes that various indoor units may be operating at significantly different entering air temperatures. For this reason, indoor units are defined relative to the air entering coil temperature, and either the refrigerant suction (for cooling) or condensing (for heating) temperature. The outdoor unit is specified relative to the refrigerant suction or condensing temperature, and the outdoor drybulb or wetbulb.

This approach allows both indoor and outdoor units to be simulated more precisely, and also allows for more energy-efficient control sequences to be implemented in the future. For example, suction/condensing pressure reset can potentially yield significant energy savings during periods of reduced demand. While manufacturers do not incorporate this strategy into the units available at the time of this writing, the algorithms implemented allow for this type of reset to be implemented in the future.

TYPE

Takes a code-word that specifies the configuration of the condensing unit:

COOLING	*future*
HEAT-PUMP	*future*
VRF-COOLING	*future*
VRF-HEAT-PUMP	A variable-refrigerant flow heat pump. In a given hour, this unit may operate in either the heating or cooling mode, but not both. To simulate a unit that simultaneously delivers heating and cooling, use VRF-HEAT-RECOVERY (future). For a condensing-unit serving a single indoor unit, heating/cooling operation is determined by the demand of that coil. For an outdoor unit serving more than one indoor unit, heating/cooling operation most commonly is determined by a single indoor unit designated as the master zone (the CONDENSING-UNIT:CONTROL-ZONE). Alternatively, all indoor units may be polled, and the heating/cooling load determined on the basis of whether heating or cooling

dominates. The unit will operate in that mode for the hour, ignoring the less-dominant need. The unit.

VRF-HEAT-RECOVERY *future*

RATED-SST

The saturated-suction temperature at which the cooling-mode capacity and power are specified.

Note that, while the cooling-mode capacity and power curves reference the saturated-suction temperature, the default curves ignore this parameter. This is because manufacturers do not publish performance data based on this value.

COOL-RATED-ODB

The outdoor-drybulb temperature at which the cooling-mode capacity and power are specified, either ARI or other.

COOL-MIN-ODB

The minimum outdoor drybulb below which the cooling-mode capacity and power are assumed to be constant. The program assumes that the outdoor fan will modulate below this temperature to maintain the condensing temperature at a setpoint.

COOLING-CAPACITY

The cooling capacity of the condensing-unit (English: millions of Btu, Metric: kW). The specified capacity corresponds to the rated conditions, i.e. the RATED-SST and the COOL-RATED-ODB.

If you do not specify COOLING-CAPACITY, the capacity defaults to the design-day indoor unit load.

COOLING-TONS

For English units only, specifies the cooling capacity in tons. This is an alternative to COOLING-CAPACITY, and gives identical results. For a 10-ton condensing-unit, you may specify either COOLING-TONS = 10 or CAPACITY = 0.120 (millions of Btuh)

COOL-CAP-RATIO

When the capacity is not user-defined, specifies the cooling-mode sizing ratio for the condensing unit. To oversize the unit by a factor of 20%, specify 1.2. Note that this factor is in addition to any oversizing specified for the indoor units.

COOL-CAP-FSST&OD

Takes the U-name of a curve that adjusts the cooling capacity of the condensing-unit as a function of the saturated-suction temperature and the outdoor-drybulb temperature. This curve is usually normalized to 1.0 at the rated conditions (RATED-SST, COOL-RATED-ODB), although this is not mandatory, (the program will normalize this curve internally).

Note that, because manufacturers did not publish capacity as a function of suction temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-drybulb temperature.

MIN-UNLOAD-RATIO

The point, expressed as a part load ratio (PLR), at which compressor unloading stops and hot gas bypass or cycling begins. The heating/cooling *-EIR-FPLR applies in the range of PLR between MIN-UNLOAD-RATIO and 1.0. See MIN-HGB-RATIO.

MIN-HGB-RATIO

The part load ratio where hot gas bypass ends and the compressor starts a cycling mode. MIN-HGB-RATIO is always equal to or less than MIN-UNLOAD-RATIO.

For example, if MIN-UNLOAD-RATIO = 0.25, and MIN-HGB-RATIO = 0.10, then the compressor unloads using the *-EIR-FPLR curve between part load ratios of 1.0 and 0.25, uses hot gas bypass between 0.25 and 0.10 (constant compressor power calculated using PLR = 0.25), and cycles below 0.10 (when running, power is at PLR - 0.25; but adjusted for cycling losses).

COOLING-POWER

An alternative to COOLING-EIR, is the cooling-mode power consumption of the condensing unit (compressor plus outdoor fan) at the rated conditions. When using COOLING-POWER, you must also specify the COOLING-CAPACITY (or COOLING-TONS). The program will calculate the COOLING-EIR as a function of these two values.

COOLING-EER

An alternative to COOLING-EIR, is the ratio of the rated capacity of the condensing unit (Btu) divided by the rated power consumption in Watts (English units only; not valid for metric input). The program will translate this value into the COOLING-EIR.

COOLING-EIR

The electric input ratio (EIR) is the ratio of electric input power to cooling capacity (i.e., the inverse of the cooling coefficient of performance (COP)). The EIR is dimensionless, so the same units for input and capacity should be used. The EIR must correspond to the rated conditions, i.e. the RATED-SST and COOL-RATED-ODB. If you change any of the rated conditions, then you should also specify the EIR at the new conditions.

This keyword is the value that the program uses in all hourly calculations. As an alternative, you may enter either the COOLING-POWER (together with capacity) or COOLING-EER. The program will translate any of these alternative inputs into the COOLING-EIR.

COOL-EIR-FSST&ODB

Takes the U-name of a curve that adjusts the cooling capacity of the condensing-unit as a function of the saturated-suction temperature and the outdoor-drybulb temperature This curve is usually normalized to 1.0 at the rated conditions (RATED-SST, COOL-RATED-ODB), although this is not mandatory (the program will normalize this curve internally).

Note that, because manufacturers did not publish power as a function of suction temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-drybulb temperature.

COOL-EIR-FPLR

Takes the U-name of a curve that adjusts the electric input ratio as a function of

- The part load ratio (PLR) – The PLR is defined as the ratio of the hourly load to the hourly capacity; Load / Cap_{hour}

- The temperature differential between the outdoor drybulb and the saturated-suction temperature.

  The dT term is included for consistency with chillers. For most condensing units, the dT has a negligible effect on part-load performance and can be ignored.

COOL-CLOSS-FPLR

Takes the U-name of a quadratic curve that gives the ratio of the effective compressor output when cycling at minimum speed to the non-cycling output at minimum speed, as a function of the cycling part load ratio. The cycling part load ratio is defined as the cooling load divided by the cooling capacity at minimum output. The curve is used only when the unit is cycling; that is, whenever the cooling load is less than the cooling capacity at minimum output. It expresses the extra run time needed to make up for cycling losses. The curve is normalized to 1.0 at minimum output (cycling part load ratio = 1.0).

COOL-CLOSS-MIN

Is the minimum cycling part load ratio used as input to COOL-CLOSS-FPLR

DESIGN-COIL-SST

The saturated-suction temperature at the fan coil units; used for design sizing of the coils. By default, this temperature is the RATED-SST, but increased by a few degrees to take into account the rise in suction temperature due to piping friction and elevation.

SST-CTRL

Accepts a code-word specifying the control sequence used to control the cooling-mode suction temperature.

Currently, only FIXED is a valid input, as manufacturers do not reset suction temperature to save energy, and performance data as a function of suction temperature is not published.

FLOAT	*future*

FIXED	The suction temperature setpoint is fixed all hours
SCHEDULED	*future*
OA-RESET	*future*
LOAD-RESET	future

SST-SETPT

When SST-CTRL = FIXED, specifies the suction temperature setpoint. The default is the RATED-SST.

SST-SETPT-SCH

future

SST-RESET-SCH

future

MIN-SST-SETPT

future

MAX-SST-SETPT

future

REFG-FLOW-DT

The rise in suction temperature between the condensing-unit and the indoor units due to friction, at full load. The program will adjust this value hourly for actual load.

REFG-HEIGHT-DT

The rise in suction temperature between the condensing-unit and the indoor units due to a change in elevation. This value is assumed constant all hours.

RATED-SCT

The saturated-condensing temperature at which the heating-mode capacity and power are specified.

Note that, while the heating-mode capacity and power curves reference the saturated-condensing temperature, the default curves ignore this parameter. This is because manufacturers do not publish performance data based on this value.

HEAT-RATED-OWB

The outdoor-wetbulb temperature at which the heating-mode capacity and power are specified, either ARI or other.

HEAT-MAX-OWB

The maximum outdoor wetbulb above which the heating-mode capacity and power are assumed to be constant. The program assumes that the outdoor fan will modulate above this temperature to maintain the suction temperature at a setpoint.

HEATING-CAPACITY

The heating capacity of the condensing-unit (English: millions of Btu, Metric: kW). The specified capacity corresponds to the rated conditions, i.e. the RATED-SCT and the HEAT-RATED-OWB.

HEAT-CAP-RATIO

When the capacity is not user-defined, specifies the heating-mode sizing ratio for the condensing unit. To oversize the unit by a factor of 20%, specify 1.2. Note that this factor is in addition to any oversizing specified for the indoor units.

HEAT/COOL-CAP

Is the ratio of the heating capacity to the cooling capacity at the rated conditions.

The condensing-unit's COOLING-CAPACITY is the cooling capacity at the rated temperature conditions. At the ARI standard rated conditions, the heating capacity is usually close to the cooling capacity. If however, the heating capacity was only 80% of the cooling capacity, then this keyword would have a value of 0.8

HEAT-CAP-FCT&OWB

Takes the U-name of a curve that adjusts the heating capacity of the condensing-unit as a function of the saturated-condensing temperature and the outdoor-wetbulb temperature. This curve is usually normalized to 1.0 at the rated conditions (RATED-SCT, HEAT-RATED-OWB), although this is not mandatory, (the program will normalize this curve internally).

Note that, because manufacturers did not publish capacity as a function of discharge temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-wetbulb temperature.

DEFROST-CAP-FOWB

Takes the U-name of a curve that adjusts the heating capacity of the condensing-unit for defrost as a function of the outdoor-wetbulb temperature. This curve must be normalized to 1.0 at maximum outdoor wetbulb at which defrost starts.

HEATING-POWER

An alternative to HEATING-EIR, is the heating-mode power consumption of the condensing unit (compressor plus outdoor fan) at the rated conditions. When using HEATING-POWER, you must also specify the HEATING-CAPACITY. The program will calculate the HEATING-EIR as a function of these two values.

HEATING-EER

An alternative to HEATING-EIR, is the ratio of the rated capacity of the condensing unit (Btu) divided by the rated power consumption in Watts (English units only; not valid for metric input). The program will translate this value into the HEATING-EIR.

HEATING-EIR

The electric input ratio (EIR) is the ratio of electric input power to heating capacity (i.e., the inverse of the heating coefficient of performance (COP)). The EIR is dimensionless, so the same units for input and capacity should be used. The EIR must correspond to the rated conditions, i.e. the RATED-SCT and HEAT-RATED-OWB. If you change any of the rated conditions, then you should also specify the EIR at the new conditions.

This keyword is the value that the program uses in all hourly calculations. As an alternative, you may enter either the HEATING-POWER (together with capacity) or HEATING-EER. The program will translate any of these alternative inputs into the HEATING-EIR.

HEAT-EIR-FCT&OWB

Takes the U-name of a curve that adjusts the heating capacity of the condensing-unit as a function of the saturated-condensing temperature and the outdoor-wetbulb temperature This curve is usually normalized to 1.0 at the rated conditions (RATED-SCT, HEAT-RATED-OWB), although this is not mandatory (the program will normalize this curve internally).

Note that, because manufacturers did not publish power as a function of condensing temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-wetbulb temperature

HEAT-EIR-FPLR

Takes the U-name of a curve that adjusts the electric input ratio as a function of

- The part load ratio (PLR) – The PLR is defined as the ratio of the hourly load to the hourly capacity; Load / Cap_{hour}

- The temperature differential between the saturated-condensing and outdoor-wetbulb temperatures

  The dT term is included for consistency with chillers. For most condensing units, the dT has a negligible effect on part-load performance and can be ignored.

HEAT-CLOSS-FPLR

Takes the U-name of a quadratic curve that gives the ratio of the effective compressor output when cycling at minimum speed to the non-cycling output at minimum speed, as a function of the cycling part load ratio. The cycling part load ratio is defined as the heating load divided by the heating capacity at minimum output. The curve is used only when the unit is cycling; that is, whenever the heating load is less than the heating capacity at minimum output. It expresses the extra run time needed to make up for cycling losses. The curve is normalized to 1.0 at minimum output (cycling part load ratio = 1.0).

HEAT-CLOSS-MIN

Is the minimum cycling part load ratio used as input to HEAT-CLOSS-FPLR

MAX-COOLING-CAP

The maximum cooling output of the unit, expressed as a multiplier on the COOLING-CAPACITY (for example, 1.06).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the COOLING-MAX-PWR. If the cooling demand of the indoor units rises above this value, then the suction temperature will float upwards, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor-unit capacity.

MAX-COOLING-PWR

The maximum cooling-mode power consumption of the unit, expressed as a multiplier on the full load power (for example, 1.02).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the COOLING-MAX-LOAD. If the cooling demand of the indoor units rises above nominal, then the suction temperature will float upwards, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor-unit capacity

MAX-HEATING-CAP

The maximum heating output of the unit, expressed as a multiplier on the HEATING-CAPACITY (for example, 1.03).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the HEATING-MAX-PWR. If the heating demand of the indoor units rises above this value, then the condensing temperature will float downward, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor-unit capacity.

MAX-HEATING-PWR

The maximum heating-mode power consumption of the unit, expressed as a multiplier on the full load power (for example, 1.02).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the HEATING-MAX-LOAD. If the heating demand of the indoor units rises above nominal, then the discharge temperature will float downward, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor unit capacity

DESIGN-COIL-SCT

The saturated-condensing temperature at the fan coil units; used for design sizing of the coils. By default, this temperature is the RATED-SCT, but decreased by a few degrees to take into account the drop in condensing temperature due to piping friction and elevation.

SCT-CTRL

Accepts a code-word specifying the control sequence used to control the heating-mode condensing temperature.

Currently, only FIXED is a valid input, as manufacturers do not reset condensing temperature to save energy, and performance data as a function of condensing temperature is not published.

FLOAT	*future*
FIXED	The suction temperature setpoint is fixed all hours
SCHEDULED	*future*
OA-RESET	*future*
LOAD-RESET	future

SCT-SETPT

When SCT-CTRL = FIXED, specifies the condensing temperature setpoint. The default is the RATED-SCT.

SCT-SETPT-SCH

future

SCT-RESET-SCH

future

MAX-SCT-SETPT

future

MIN-SCT-SETPT

future

CRANKCASE-HEAT

An alternative to CRANKCASE-EIR, is the electric power (Watts) used to heat the crankcase of the compressor(s). The crankcase heater is assumed to modulate as determined by the CRANK-EIR-FPLR curve. Crankcase electric power is allocated to the AUX-ELEC-METER.

CRANKCASE-EIR

Specifies crankcase heater power as the ratio of crankcase power to cooling capacity. This ratio is dimensionless, so the same units for input and capacity should be used. The EIR must correspond to the rated conditions, i.e. the RATED-SST and COOL-RATED-ODB. If you change any of the rated conditions, then you should also specify the EIR at the new conditions.

CRANK-EIR-FPLR

Takes the U-name of a curve that adjusts the electric input ratio as a function of the part-load ratio.

CRANKCASE-MAX-T

The outside temperature above which the crankcase heater is always off.

CONTROL-ZONE

For the HEAT PUMP condensing-unit, specifies the U-name of the zone that determines whether the outdoor-unit is enabled to operate in the heating mode or cooling mode. All fan coils must then run in this mode. If the control zone does not have a heating or cooling demand in a given hour, then the outdoor unit will be enabled to operate in the last mode used by the control zone.

If not specified, then all indoor-units are polled, and the outdoor-unit will run according to the larger of the heating or cooling demand.

AUX-POWER

Accepts a numeric value specifying an auxiliary electrical consumption, such as for controls.

AUX-MODE

Accepts a code-word specifying when the AUX-KW is consumed.

ALWAYS	(default) indicates that the auxiliary power is consumed all hours.
WHEN-ON	indicates that auxiliary power is consumed only during the hours, or fraction of an hour, the unit is operating.
WHEN-OFF	indicates that auxiliary power is consumed only during the hours, or fraction of an hour, the component is off.
SCHEDULED	indicates that the power consumption is scheduled.

AUX-SCHEDULE

When AUX-MODE = SCHEDULED, accepts a U-name of a schedule (TYPE = FRACTION or MULTIPLIER) that varies the AUX-POWER on an hourly basis.

AUX-METER

Accepts the U-name of a meter that supplies the auxiliary energy. This keyword defaults to the MASTER-METER:AUX-ELEC-METER.

ELEC-METER

ELEC-METER

Takes the U-name of the ELEC-METER to which the electricity consumption of the chiller is assigned. The default is the MASTER-METER: COOL-ELEC-METER.

COST-DATA

Takes the U-name of a MATERIALS-COST command, which allows you to define first costs, maintenance costs, etc. for this component.

EQUIPMENT-REPORTS

Takes the code-words YES or NO. When report PS-H of the PLANT-REPORTS is enabled, a report will print for the component unless this keyword is set to NO.

PS-H Loads and Energy Usage for <condensing-unit name>

This report summarizes the performance of an outdoor condensing unit, most commonly associated with a variable-refrigerant flow system. For the component, this report summarizes relevant design information as well as monthly and yearly performance. This report is an expansion of the information provided in PV-A and PS-C; most of the information will be identical with the exception of the monthly performance. For this report to print, PS-H must be specified in PLANT-REPORTS, and the component's EQUIPMENT-REPORTS = YES.

This example illustrates a user-defined cooling and heating capacity that is undersized for the design loads.

The first set of data is design information:

EQUIPMENT TYPE

Specifies the type of equipment that is identical to the TYPE code-word originally specified by the user.

FUNCTION

Entries may be for cooling only, or for cooling/heating (heat pump). Cooling/heating data is listed on separate lines.

RATED CONDITIONS

Entries are for (cooling on first line, heating on second)

- the cooling/heating capacity at rated conditions (in this example user-defined),
- power at rated conditions,
- the rated suction or discharge temperature,
- the rated outdoor temperature (outdoor wetbulb for heat pump in heating mode),
- the electric input ratio,
- the crankcase heater power.

DESIGN CONDITIONS

Entries are for

- The peak design-day cooling load or heating load. This value is independent of the actual capacity specified.
- The cooling/heating capacity at the peak design conditions. If the capacity is defaulted, the capacity will be the peak design-day load, adjusted by the sizing ratio. For a heat pump, the defaulted capacity will be based on either the peak heating or cooling load, whichever requires the largest unit. If capacity is user-specified, the capacity is translated from the rated conditions to the peak design conditions.
- The power at the design conditions. This is compressor power only; auxiliary and crankcase heat is not included.
- The suction or discharge temperature at the peak conditions
- The outdoor ambient temperature at the peak conditions. For an air-cooled heat-pump, the temperature is the outdoor wetbulb.

Following the design data is the monthly and yearly performance summary:

COOL LOAD

is the cooling load on the unit.

HEAT LOAD

is the heating load on the unit.

ELEC USE

is the total electrical use of the unit, including compressor, auxiliary, and crankcase; excluding indoor units.

AUX ENERGY

is the auxiliary and crankcase power.

For each month and for the year, information is presented on the category total, peak monthly or yearly value, and the time when the peak occurred. Bin information is presented in terms of the number of hours the cooling load, heating load, and power fell into the appropriate part load bin. The part load bin is calculated in terms of the hourly value divided by the design value.

The number of hours the unit was overloaded is reported at the bottom of the report.

REPORT- PS-H Loads and Energy Usage for VRF-Cond WEATHER FILE- CZ12RV2 WYEC2

EQUIPMENT TYPE	FUNCTION	RATED CONDITIONS CAPACITY (MBTU/HR)	POWER (KW)	REFG T (F)	AMB T (F)	EIR (FRAC)	HEATER (KW)	DESIGN CONDITIONS PEAK LOAD (MBTU/HR)	CAPACITY (MBTU/HR)	POWER (KW)	REFG T (F)	AMB T (F)
VRF-HEAT-PUMP	Cooling	0.090	9.0	43.0	95.0	0.340	0.050	0.235	0.087	9.7	43.0	103.3
	Heating	-0.100	8.2	115.0	43.0	0.280		-0.076	-0.074	7.1	115.0	20.1

MON	SUM PEAK	COOL LOAD (MBTU) (KBTU/HR)	HEAT LOAD (MBTU) (KBTU/HR)	ELEC USE (KWH) (KW)	AUX ENERGY (KWH) (KW)		00-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	TOTAL RUN HOURS
JAN	SUM	0.208	-7.191	10.997	25.460	COOL	0	0	0	0	1	3	0	0	0	0	0	4
	PEAK	54.229	-89.810	2.910	0.050	HEAT	174	134	65	40	20	7	3	1	1	2	1	448
	DAY/HR	23/15	7/ 8	23/15	2/10	ELEC	0	0	1	3	0	0	0	0	0	0	0	4
FEB	SUM	2.506	-3.553	146.165	15.733	COOL	0	1	2	1	12	15	3	1	3	5	0	43
	PEAK	98.669	-66.739	6.664	0.050	HEAT	160	75	41	18	4	2	0	2	0	0	0	302
	DAY/HR	27/15	9/ 8	27/16	2/ 9	ELEC	0	3	11	20	0	1	4	4	0	0	0	43
MAR	SUM	4.011	-1.293	262.967	13.292	COOL	3	8	7	9	11	5	1	3	8	10	7	72
	PEAK	101.218	-25.281	7.402	0.050	HEAT	132	42	11	0	0	0	0	0	0	0	0	185
	DAY/HR	20/13	6/ 8	20/16	1/ 1	ELEC	3	12	19	10	0	4	14	5	5	0	0	72
APR	SUM	11.510	-0.313	827.397	9.980	COOL	12	12	11	7	9	6	2	6	19	31	50	165
	PEAK	101.346	-22.219	8.250	0.050	HEAT	43	8	2	0	0	0	0	0	0	0	0	53
	DAY/HR	16/13	6/ 8	29/16	1/22	ELEC	14	17	13	12	2	7	22	33	40	5	0	165
MAY	SUM	19.059	0.000	1467.425	3.200	COOL	14	35	18	17	13	12	12	12	27	31	96	287
	PEAK	105.469	0.000	9.131	0.050	HEAT	0	0	0	0	0	0	0	0	0	0	0	0
	DAY/HR	5/12	0/ 0	31/16	1/ 3	ELEC	24	37	18	15	11	16	28	39	71	27	1	287
JUN	SUM	24.209	0.000	1979.295	0.700	COOL	19	35	27	26	23	19	13	12	13	34	148	369
	PEAK	105.746	0.000	9.727	0.050	HEAT	0	0	0	0	0	0	0	0	0	0	0	0
	DAY/HR	22/11	0/ 0	16/17	1/ 3	ELEC	33	42	24	23	24	14	22	36	62	65	24	369
JUL	SUM	27.935	0.000	2408.057	0.050	COOL	25	31	33	24	24	17	15	11	15	25	197	417
	PEAK	102.170	0.000	9.926	0.050	HEAT	0	0	0	0	0	0	0	0	0	0	0	0
	DAY/HR	14/11	0/ 0	24/17	5/ 6	ELEC	39	45	29	16	14	20	16	31	57	91	59	417
AUG	SUM	25.330	0.000	2193.060	0.050	COOL	37	30	27	18	21	18	19	11	20	19	173	393
	PEAK	104.572	0.000	9.925	0.050	HEAT	0	0	0	0	0	0	0	0	0	0	0	0
	DAY/HR	12/11	0/ 0	7/17	27/ 7	ELEC	47	40	21	22	15	18	19	27	56	74	54	393
SEP	SUM	22.300	0.000	1815.164	0.750	COOL	37	28	15	18	15	14	10	14	6	19	160	336
	PEAK	102.168	0.000	9.537	0.050	HEAT	0	0	0	0	0	0	0	0	0	0	0	0
	DAY/HR	9/11	0/ 0	4/17	12/ 4	ELEC	42	35	18	16	14	10	18	27	70	66	20	336
OCT	SUM	16.722	-0.071	1240.514	5.310	COOL	12	12	7	11	15	16	10	11	9	17	107	227
	PEAK	105.727	-8.119	8.891	0.050	HEAT	21	0	0	0	0	0	0	0	0	0	0	21
	DAY/HR	27/16	13/ 8	5/14	1/ 6	ELEC	16	12	19	16	14	11	12	46	58	23	0	227
NOV	SUM	5.474	-1.948	359.169	13.800	COOL	1	1	1	1	6	7	12	6	4	9	23	71
	PEAK	102.338	-39.087	7.501	0.050	HEAT	127	57	21	6	1	0	0	0	0	0	0	212
	DAY/HR	4/11	30/ 8	25/14	1/ 1	ELEC	1	2	4	15	9	5	4	19	12	0	0	71

WLHP DOE-2.2-D22v 12/07/2009 14:02:53 BDL RUN 1

REPORT- PS-H Loads and Energy Usage for VRF-Cond WEATHER FILE- CZ12RV2 WYEC2 (CONTINUED)

MON	SUM PEAK	COOL LOAD (MBTU) (KBTU/HR)	HEAT LOAD (MBTU) (KBTU/HR)	ELEC USE (KWH) (KW)	AUX ENERGY (KWH) (KW)		00-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	TOTAL RUN HOURS
DEC	SUM	0.274	-6.170	14.500	24.828	COOL	0	0	0	0	1	4	0	0	0	0	0	5
	PEAK	61.282	-82.269	3.206	0.050	HEAT	176	140	70	24	11	8	1	0	1	2	0	433
	DAY/HR	7/13	23/ 8	7/13	1/ 9	ELEC	0	0	1	4	0	0	0	0	0	0	0	5
Yr	SUM	159.538	-20.539	12724.711	113.153	COOL	160	193	148	132	151	136	97	87	124	200	961	2389
	PEAK	105.746	-89.810	9.926	0.050	HEAT	833	456	210	88	36	17	4	3	2	4	1	1654
	MON/DAY	6/22	1/ 7	7/24	1/ 2	ELEC	219	245	178	172	103	106	159	267	431	351	158	2389

Number of Hours Overloaded Cool: 3147 Heat: 0

CONDENSING-UNIT Hourly Report Variables

Variable-List Number	Variable in FORTRAN Code	Description
1	cu.CoilOnHt	Fraction of hour indoor heating coils are active
2	cu.CoilOnCl	Fraction of hour indoor cooling coils are active
3	cu.fCycle	Adjustment to run time to offset cycling loss
4	cu.FracOn	Fraction of hour unit runs
5	cu.SST	Saturated suction temperature, at unit
6	cu.SSTcoil	Saturated suction temperature, at indoor units
7	cu.ECTcl	Entering condensing temperature, cooling mode
8	cu.QcoilCl	Indoor coil cooling load, total over hour
9	cu.QcoilCl'	Cooling load, when outdoor unit is actually running
10	cu.CapfTcl	Cooling capacity adjustment factor, f(SST, ECTcl)
11	cu.QcapCl	Cooling capacity
12	cu.PLRcl	Cooling part-load ratio
13	cu.EIRfPLRcl	Cooling EIR adjustment, f(PLRcl)
14	cu.EIRfTcl	Cooling EIR adjustment, f(SST, ECTcl)
15	cu.EIRcl	Cooling adjusted EIR, excluding cycling
16	cu.kWcl	Cooling compressor power
17	cu.SCT	Saturated discharge temperature, at unit
18	cu.SCTcoil	Saturated discharge temperature, at coils
19	cu.ECTht	Entering outdoor temperature, heating mode (outdoor wetbulb if air-cooled)
20	cu.QcoilHt	Indoor coil heating load, total over hour
21	cu.QcoilHt'	Heating load, when outdoor unit is actually running
22	cu.CapfTht	Heating capacity adjustment factor, f(SCT, ECTht)
23	cu.DefCap	Defrost degradation factor; PLR = QcoilHt'/(QcapHt*DefCap)
24	cu.QcapHt	Heating capacity, unadjusted for defrost
25	cu.PLRht	Heating part-load ratio
26	cu.EIRfPLRht	Heating EIR adjustment, f(PLRht)
27	cu.EIRfTht	Heating EIR adjustment, f(SCT, ECTht)
28	cu.EIRht	Heating adjusted EIR, excluding cycling
29	cu.kWht	Heating compressor power
30	cu.kWaux	Auxiliary power
31	cu.kWcrank	Crankcase heater power
32	pe.kWtotal	Total power of compressor, auxiliary, crankcase; excludes indoor units
33	cu.Qcond	Condenser heat rejected (negative is heat pump absorbed)

APPENDIX 2. VRF SIMULATION ALGORITHMS

The following are the principle new algorithms implemented to simulate residential VRF systems. These algorithms are implemented within the general structure of DOE-2, and as a result cannot stand alone.

CONDENSING UNIT

```
      Subroutine CondUnit_VRF_HP(Mode, Jcu)
c
c              Simulates a Variable-Refrigerant Flow heat pump
c
c              This device provides both heating and cooling

*CA /JJHSDG/
*CA /BLANK/
*CA /FILES/
*CA /FNSYS/
*CA /HRPSYS/
*CA /MISCD/
*CA /PtrPlt/
*CA /PtrSys/
*CA /SYSTD/
*CA /TIME/
*CA /WEATH/
*CA /WCTRL/

*CA /EQKY/
*CA /LOOPKY/

      Kpe = <cu:Kpe>         ! statistics block

c?????? light blue was a second check prior to SCE study

      SELECT CASE (Mode)
c
c
c ============= HOURLY INITIALIZATION ==========================================
      CASE (10)

c              Initialize operation in both modes

c              Suction/discharge temperature setpoints
      IF (ModeDD .gt. 8) THEN
c              Cooling setpoint and zone temperature
        <cu.SSTsetpt> = <cu:DESIGN-COIL-SST>                 ! setpoint
     &                - <cu:REFG-FLOW-DT> - <cu:REFG-HEIGHT-DT>
        <cu.SST>      = <cu.SSTsetpt>
        <cu.SSTcoil>  = <cu:DESIGN-COIL-SST>                 ! at coil
c              heating setpoint and zone temperature
        <cu.SCTsetpt> = <cu:DESIGN-COIL-SCT>
     &                 + <cu:REFG-FLOW-DT> + <cu:REFG-HEIGHT-DT>
        <cu.SCT>      = <cu.SCTsetpt>
        <cu.SCTcoil>  = <cu:DESIGN-COIL-SCT>
      ELSE
c              Cooling setpoint
        SELECT CASE (<cu:SST-CTRL>)
        CASE (0,1)  ! float(unused), fixed
          <cu.SSTsetpt> = <cu:SST-SETPT>
        CASE (2)    ! scheduled
          <cu.SSTsetpt> = SchVal(<cu:SST-SETPT-SCH>, <cu:RATED-SST>)
        CASE (3)    ! oa-reset
          <cu.SSTsetpt> = DRSVal(<cu:SST-RESET-SCH>)
```

```
        CASE (4)    ! load-reset
          <cu.SSTsetpt> = <cu:MIN-SST-SETPT>
        END SELECT
c              initial suction temperature; at unit and coils
c              (assumes no load so 0.1F pipe dT)
        <cu.SST>     = <cu.SSTsetpt>         ! at compressor
        <cu.SSTcoil> = <cu.SSTsetpt> + 0.1   ! at coils

c              Heating setpoint
        SELECT CASE (<cu:SCT-CTRL>)
        CASE (0,1)  ! float(unused), fixed
          <cu.SCTsetpt> = <cu:SCT-SETPT>
        CASE (2)    ! scheduled
          <cu.SCTsetpt> = SchVal(<cu:SCT-SETPT-SCH>, <cu:RATED-SCT>)
        CASE (3)    ! oa-reset
          <cu.SCTsetpt> = DRSVal(<cu:SCT-RESET-SCH>)
        CASE (4)    ! load-reset
          <cu.SCTsetpt> = <cu:MAX-SCT-SETPT>
        END SELECT
c              initial condensing temperature; at unit and coils
c              (assumes no load so 0.1F pipe dT)
        <cu.SCT>     = <cu.SCTsetpt>        ! at compressor
        <cu.SCTcoil> = <cu.SCTsetpt> - 0.1  ! at coils
      ENDIF

c              To start, enable coil operation in either mode. As soon
c              as one mode needs heat/cool, the other mode will be
c              locked out for the hour.
      <cu.EnableHt> = 1
      <cu.EnableCl> = 1
      <cu.OperMode> = OffMode
      <cu.OvrldHt>  = 0         ! Not overloaded
      <cu.OvrldCl>  = 0
c
c
c============= HOURLY LOAD ====================================================
      CASE (30)

c              Zero hourly data
      Call ZeroAA(<#cu~HrZeroStart>, <#cu~HrZeroEnd>)

c              Look at coils to determine whether heating or cooling
      IF (<cu.OperMode> .ne. OffMode) THEN  :OperMode
c              A previous iteration this hour has called for heating
c              or cooling; the mode is locked in for the hour

      ELSEIF (<cu:CONTROL-ZONE>) THEN
        IF (<cu:KccCtrl>) THEN
          Kcc = <cu:KccCtrl>
          IF (<cc.Qcoil> .gt. 0.) THEN
            <cu.OperMode> = CoolMode
            Quit :OperMode
          ENDIF
        ENDIF
        IF (<cu:KhcCtrl>) THEN
          Khc = <cu:KhcCtrl>
          IF (<hc.Qcoil> .lt. 0.) THEN
            <cu.OperMode> = HeatMode
            Quit :OperMode
          ENDIF
        ENDIF
c              If here, no control zone demand.  Use last mode
        <cu.OperMode> = <cu.LastOperMode>
      ELSE
c              cycle thru all coils and let all coils vote
        QcoilHt = 0.
        QcoilCl = 0.
        IF (<cu:ListKcc>) THEN
          Kli    = <cu:ListKcc>   ! list of cooling coils
          NumKcc = <li;NumItems>  ! number of coils
          DO  LI=1,NumKcc
            Kcc     = <li;List>
            QcoilCl = QcoilCl + <cc.Qloop>*<cc:Multiplier>
```

```
          ENDDO
        ENDIF
        IF (<cu:ListKhc>) THEN
          Kli    = <cu:ListKhc>   ! list of heating coils
          NumKhc = <li;NumItems>  ! number of coils
          DO  LI=1,NumKhc
            Khc     = <li;List>
            QcoilHt = QcoilHt + <hc.Qloop>*<hc:Multiplier>
          ENDDO
        ENDIF
        QcoilHt = Abs(QcoilHt)
        IF (QcoilCl .gt. QcoilHt) THEN
          <cu.OperMode> = CoolMode
        ELSEIF (QcoilHt .gt. QcoilCl) THEN
          <cu.OperMode> = HeatMode
        ENDIF
      ENDIF  ! cu:CONTROL-ZONE

c              Now jump to correct mode. Do not disable heating or
c              cooling coils before they have been sized. Once either
c              heating is selected for the hour, the choice is locked
c              until the next hour.
      SELECT CASE (<cu.OperMode>)
      CASE (-1)  ! Off
        <cu.EnableHt> = 1           ! heating coils enabled
        <cu.EnableCl> = 1           ! cooling coils enabled
        Call CnvgCheck(2, <cu:HstyQcoils>)
        GoTo 3300
      CASE (1)   ! Heating
        IF (ModeDD .lt. 12)  <cu.EnableCl> = 0
        GoTo 3100
      CASE (2)   ! Cooling
        IF (ModeDD .lt. 12)  <cu.EnableHt> = 0
        GoTo 3200
      END SELECT
c
c
c------------ HEATING MODE --------------------------------------------------
 3100 Continue

c              Outdoor wetbulb temperature
      <cu.ECTht> = Min(WBT, <cu:HEAT-MAX-OWB>)

c              Degradation in capacity due to defrost; below 18F defrost
c              is constant
      TwbDef = Min(50., Max(<cu.ECTht>, 18.))
      <cu.DefCap> = Min(1., Cval(<cu:DEFROST-CAP-FOWB>,TwbDef,xx))

c              Get total coil load. If coils are cycling, meld
c              individual run time fractions into a diversity factor
      Kli    = <cu:ListKhc>   ! list of cooling coils
      NumKhc = <li;NumItems>  ! number of coils
      DO  LI=1,NumKhc
        Khc = <li;List>
        <cu.QcoilHt>  = <cu.QcoilHt> + <hc.Qloop>*<hc:Multiplier>
c              assume diversity among coils
        Mult = Int(<hc:Multiplier>*<hc:Diversity> + 0.5)
        DO iMult=1,Mult
          <cu.CoilOnHt> = <cu.CoilOnHt>
     &             + (1.-<cu.CoilOnHt>)*Min(1.,<hc.CoilOn>)
        ENDDO
      ENDDO
c              heating might have existed in a previous iteration, but
c              may be off now; will not changeover to cooling
      IF (<cu.QcoilHt> .eq. 0.)  GoTo 3300
c              dampen any persistent oscillations
      Call CnvgCheck(2, <cu:HstyQcoils>)

c              Coil load when running, circuit friction
      IF (<cu;SizingFlag>)  THEN          ! design sizing
        <cu.CoilOnHt> = 1.                ! no diversity during sizing
        <cu.QcoilHt'> = <cu.QcoilHt> / <cu.DefCap>
        dTrefg        = <cu:REFG-FLOW-DT> ! pressure drop to coils
```

```
     &                + <cu:REFG-HEIGHT-DT>
      ELSE
        <cu.QcoilHt'> = <cu.QcoilHt> / (<cu.CoilOnHt>*<cu.DefCap>)
        dTrefg        = <cu:REFG-FLOW-DT>
     &                * Min(1.1, <cu.QcoilHt'>/<cu;QcoilHt>)**1.8
     &                + <cu:REFG-HEIGHT-DT>
        dTrefg        = Max(0.1, dTrefg)
      ENDIF

c              Skip SCT calcs if persistent convergence issue
      IF (IterAHU .gt. 30) GoTo 3105

c              Load-reset temperature control
      IF (<cu:SCT-CTRL> .eq. 4  .and.  ModeDD .lt. 10
     &                          .and.  IterAHU .gt. 1) THEN
        SCTreqd = -888.
        DO  LI=1,NumKhc
          Khc = <li;List>
          Call Coils(37, Khc)
          SCTreqd = Max(SCTreqd, <hc.Treqd>)
        ENDDO
c              Hold 1F above required setpoint for stability
        SCTreqd = SCTreqd + dTrefg + 1.0
        <cu.SCTsetpt> = Min(<cu:MAX-SCT-SETPT>,
     &                      Max(SCTreqd, <cu:MIN-SCT-SETPT>))
      ENDIF

c              Heating capacity
      <cu.CapfTht> = Cval(<cu:HEAT-CAP-FSCT&OWB>,
     &                    <cu.SCTsetpt>, <cu.ECTht>)
      IF (<cu;SizingFlag>)   ! design sizing
     &  <cu;QnormalHt> = <cu.QcoilHt'> / <cu.CapfTht>
     &                                * <cu:HEAT-SIZING-RATI>
      <cu.QcapHt>   = <cu;QnormalHt> * <cu.CapfTht>
      <pe;RecoverQ> = <cu.QcapHt>  ! for statistics
c              maximum capacity
      CapMax        = <cu.QcapHt> * <cu:MAX-HEATING-CAP>

c              Condensing temperature
      IF (IterAHU .eq. 1  .or.
     &   (<cu.OvrldHt> .eq. 0  .and.              ! not overloaded
     &          CapMax .le. <cu.QcoilHt'>)) THEN  ! at setpoint
        <cu.SCT> = <cu.SCTsetpt>

      ELSE  !  Overloaded; see where discharge temperature floats.
        <cu.OvrldHt> = 1
c              Minimum possible discharge temperature is the Tinlet of the
c              coldest coil
        TinletMin = 888.
        DO  LI=1,NumKhc
          Khc       = <li;List>
          IF (<hc.CoilOn> .eq. 0.)  Cycle
          TinletMin = Min(TinletMin, <hc.Tinlet>)
        ENDDO
c              temporarily shift fixed dTrefg to coil inlet
        TinletMin = TinletMin + <cu:REFG-HEIGHT-DT>
        dTrefg    = dTrefg    - <cu:REFG-HEIGHT-DT>  ! flow only now
c              discharge must be at least 0.1F warmer, with 0.1 dTflow
        SCTmin = TinletMin + 0.2

c              Guess this iteration's value of SCT
        <cu.SCT> = SCTmin + (<cu.SCT>-SCTmin) * CapMax/<cu.QcoilHt'>
        <cu.SCT> = Min(<cu.SCT>, <cu.SCTsetpt>)

c              Constrain dTrefg if discharge close to coil TinletMin;
c              gives a minimum value of 0.1
        dTrefg = Min(dTrefg, <cu.SCT> - (TinletMin+0.1))
        dTrefg = dTrefg + <cu:REFG-HEIGHT-DT>

  !  Original code based on SCT floating down based on cap curve
  !     CapMin = <cu;QnormalHt>
  !   &         * Cval(<cu:HEAT-CAP-FSCT&OWB>, SCTmin, <cu.ECTht>)
  !     IF (CapMin .gt. <cu.QcoilHt'>) THEN  ! at minimum
```

```
  !        SCTreqd = SCTmin
  !      ELSE  ! floating between setpoint and minimum
  !        <cu.CapfTht> = <cu.QcoilHt'> / <cu;QnormalHt>
  !        Limits(2)    = SCTmin           ! min limit
  !        Limits(1)    = <cu.SCTsetpt>    ! max limit
  !        Jcv          = <cu:HEAT-CAP-FSCT&OWB>
  !        Call CURINV(<cv:COEF-1>,<cv:TYPE>,
  !    &       1,SCTreqd,<cu.ECTht>, <cu.CapfTht>, Limits(1),IERR)
  !      ENDIF
 c!             do not let drop more than 3F per iteration
  !      <cu.SCT> = Max(SCTreqd, <cu.SCT>-3.)
 c!             constrain dTrefg if discharge close to coil TinletMin;
 c!             gives a minimum value of 0.1
  !      dTrefg = Min(dTrefg, <cu.SCT> - (TinletMin+0.1))
  !      dTrefg = dTrefg + <cu:REFG-HEIGHT-DT>
 c!             floating coil capacity
  !      <cu.CapfTht> = Cval(<cu:HEAT-CAP-FSCT&OWB>, <cu.SCT>,<cu.ECTht>)
  !      <cu.QcapHt>  = <cu;QnormalHt> * <cu.CapfTht>

       ENDIF  !cu.QcapHt

 c              Condensing temperature at coils
       <cu.SCTcoil> = <cu.SCT> - dTrefg

  3105 Continue

 c              Part load ratio and cycling losses
       <cu.PLRht> = <cu.QcoilHt'> / <cu.QcapHt>
       IF (<cu.PLRht> .ge. <cu:MIN-HGB-RATIO>) THEN  ! runs full hour
         <cu.FracOn> = 1.
       ELSE  ! fraction of hour operating
         <cu.FracOn> = <cu.PLRht> / <cu:MIN-HGB-RATIO>
         <cu.PLRht>  = <cu:MIN-HGB-RATIO>
       ENDIF
 c              adjust for time coils enabled
       <cu.FracOn> = <cu.FracOn> * <cu.CoilOnHt>
 c              adjust for cycling losses
       IF (<cu:HEAT-CLOSS-FPLR>) THEN
         <cu.fCycle> = Cval(<cu:HEAT-CLOSS-FPLR>,
      &                     Max(<cu.FracOn>, <cu:HEAT-CLOSS-MIN>), xx)
         <cu.FracOn> = Min(1., <cu.FracOn> / Max(0.001, <cu.fCycle>))
       ENDIF

 c              Compressor power, adjusted for temperature and load.
 c              When running, the machine must operate at or above the
 c              min-unload-ratio
       <cu.EIRfTht>   = Cval(<cu:HEAT-EIR-FSCT&OWB>, <cu.SCT>,<cu.ECTht>)
       dTplr          = <cu.SCT> - <cu.ECTht>
       PLRhgb         = Min(1., Max(<cu.PLRht>, <cu:MIN-UNLOAD-RATIO>))
       <cu.EIRfPLRht> = Cval(<cu:HEAT-EIR-FPLR>, PLRhgb, dTplr)
 c              adjust EIR if overloaded (linear adjustment)
       IF (<cu.PLRht> .gt. 1.) THEN
         IF (<cu:MAX-HEATING-CAP> .gt. 1.) THEN
           Ratio = (<cu.PLRht>-1.) / (<cu:MAX-HEATING-CAP>-1.)
           <cu.EIRfPLRht> = <cu.EIRfPLRht>
      &                  + <cu.EIRfPLRht>*(<cu:MAX-HEATING-PWR>-1.)*Ratio
         ELSE  ! assume linear for small overloads
           <cu.EIRfPLRht> = <cu.EIRfPLRht> * <cu.PLRht>
         ENDIF
       ENDIF
       <cu.EIRht>     = <cu;NormalEIRht> * <cu.EIRfTht> * <cu.EIRfPLRht>
       <cu.kWht>      = -<cu.QcapHt> * <cu.EIRht> * <cu.FracOn> * kWBtu

 c              Absorbed heat
       <cu.Qcond> = <cu.QcoilHt> + <cu.kWht>*BtuKW

       GoTo 3300
 c
 c
 c------------- COOLING MODE ---------------------------------------------------
  3200 Continue

 c              Outdoor drybulb temperature
```

```
      <cu.ECTcl> = Max(DBT, <cu:COOL-MIN-ODB>)

c              Get total coil load. If coils are cycling, meld
c              individual run time fractions into a diversity factor
      Kli    = <cu:ListKcc>   ! list of cooling coils
      NumKcc = <li;NumItems>  ! number of coils
      DO  LI=1,NumKcc
        Kcc = <li;List>
        <cu.QcoilCl>  = <cu.QcoilCl> + <cc.Qloop>*<cc:Multiplier>
c              assume diversity among coils
        Mult = Int(<cc:Multiplier>*<cc:Diversity> + 0.5)
        DO iMult=1,Mult
          <cu.CoilOnCl> = <cu.CoilOnCl> + (1.-<cu.CoilOnCl>)*<cc.CoilOn>
        ENDDO
      ENDDO
c              cooling might have existed in a previous iteration, but
c              may be off now; will not changeover to heating
      IF (<cu.QcoilCl> .eq. 0.)  GoTo 3300
c              dampen any persistent oscillations
      Call CnvgCheck(2, <cu:HstyQcoils>)


      IF (<cu;SizingFlag>)  THEN          ! design sizing
        <cu.CoilOnCl> = 1.                ! no diversity during sizing
c              coil load when running
        <cu.QcoilCl'> = <cu.QcoilCl>
        dTrefg        = <cu:REFG-FLOW-DT> ! pressure drop to coils
     &                + <cu:REFG-HEIGHT-DT>
      ELSE
c              coil load when running
        <cu.QcoilCl'> = <cu.QcoilCl> / <cu.CoilOnCl>
        dTrefg        = <cu:REFG-FLOW-DT>
     &                * Min(1.1, <cu.QcoilCl'>/<cu;QcoilCl>)**1.8
     &                + <cu:REFG-HEIGHT-DT>
        dTrefg        = Max(0.1, dTrefg)
      ENDIF

c              Skip SST calcs if persistent convergence issue
      IF (IterAHU .gt. 30) GoTo 3205

c              Load-reset temperature control
      IF (<cu:SST-CTRL> .eq. 4  .and.  ModeDD .lt. 10
     &                          .and.  IterAHU .gt. 1) THEN
        SSTreqd = 888.
        DO  LI=1,NumKhc
          Kcc = <li;List>
          Call Coils(37, Kcc)
          SSTreqd = Min(SSTreqd, <cc.Treqd>)
        ENDDO
c              Hold 1F below required setpoint for stability
        SSTreqd = SSTreqd - dTrefg - 1.0
        <cu.SSTsetpt> = Min(<cu:MAX-SST-SETPT>,
     &                      Max(SSTreqd, <cu:MIN-SST-SETPT>))
      ENDIF

c              Cooling capacity
      <cu.CapfTcl> = Cval(<cu:COOL-CAP-FSST&ODB>,
     &                    <cu.SSTsetpt>, <cu.ECTcl>)
      IF (<cu;SizingFlag>)   ! design sizing
     &  <cu;QnormalCl> = <cu.QcoilCl'> / <cu.CapfTcl>
     &                                 * <cu:COOL-SIZING-RATI>
      <cu.QcapCl>  = <cu;QnormalCl> * <cu.CapfTcl>
      <pe.MaxLoad> = <cu.QcapCl>  ! for statistics
c              maximum capacity
      CapMax       = <cu.QcapCl> * <cu:MAX-COOLING-CAP>

c              Suction temperature
      SSTsave = <cu.SST>
      IF (IterAHU .eq. 1  .or.
     &   (<cu.OvrldCl> .eq. 0  .and.              ! not overloaded
     &          CapMax .ge. <cu.QcoilCl'>)) THEN  ! at setpoint
        <cu.SST> = <cu.SSTsetpt>
```

```
      ELSE  !  Overloaded; see where discharge temperature floats.
        <cu.OvrldCl> = 1
c              Maximum possible suction temperature is the Tinlet
c              of the warmest coil
        TinletMax = -888.
        DO  LI=1,NumKcc
          Kcc       = <li;List>
          IF (<cc.CoilOn> .eq. 0.)  Cycle
          TinletMax = Max(TinletMax, <cc.Tinlet>)
        ENDDO
c              temporarily shift fixed dTrefg to coil inlet
        TinletMax = TinletMax - <cu:REFG-HEIGHT-DT>
        dTrefg    = dTrefg    - <cu:REFG-HEIGHT-DT>  ! flow only now
c              suction must be at least 0.1F cooler, with 0.1 dTflow
        SSTmax = TinletMax - 0.2

        <cu.SST> = SSTmax + (<cu.SST>-SSTmax) * CapMax/<cu.QcoilCl'>
        <cu.SST> = Max(<cu.SST>, <cu.SSTsetpt>)

c              Constrain dTrefg if suction close to coil TinletMax;
c              gives a minimum value of 0.1
        dTrefg = Min(dTrefg, (TinletMax-0.1) - <cu.SST>)
        dTrefg = dTrefg + <cu:REFG-HEIGHT-DT>


 !  Original code based on SST floating up based on cap curve
c!             suction must be at least 0.1F cooler, with 0.1 dTflow
 !      CapMax = <cu;QnormalCl>
 !   &          * Cval(<cu:COOL-CAP-FSST&ODB>, SSTmax, <cu.ECTcl>)
 !   &          * <cu:MAX-COOLING-CAP>
 !      IF (CapMax .lt. <cu.QcoilCl'>) THEN  ! at maximum
 !        SSTreqd = SSTmax
 !      ELSE  ! floating between setpoint and maximum
 !        <cu.CapfTcl> = <cu.QcoilCl'> / <cu;QnormalCl>
 !        Limits(2)    = <cu.SSTsetpt>   ! min limit
 !        Limits(1)    = SSTmax          ! max limit
 !        Jcv          = <cu:COOL-CAP-FSST&ODB>
 !        Call CURINV(<cv:COEF-1>,<cv:TYPE>,
 !   &          1,SSTreqd,<cu.ECTcl>, <cu.CapfTcl>, Limits(1),IERR)
c!                   ^calcs this value
 !      ENDIF
c!             do not let rise more than 3F per iteration
 !      <cu.SST> = Min(SSTreqd, <cu.SST>+3.)
c!             constrain dTrefg if suction close to coil TinletMax;
c!             gives a minimum value of 0.1
 !      dTrefg = Min(dTrefg, (TinletMax-0.1) - <cu.SST>)
 !      dTrefg = dTrefg + <cu:REFG-HEIGHT-DT>
 !
c!             floating coil capacity
 !      <cu.CapfTcl> = Cval(<cu:COOL-CAP-FSST&ODB>, <cu.SST>,<cu.ECTcl>)
 !      <cu.QcapCl>  = <cu;QnormalCl> * <cu.CapfTcl>

      ENDIF  !cu.QcapCl

c              Suction temperature at coils
      <cu.SSTcoil>   = <cu.SST> + dTrefg

 3205 Continue

c              Part load ratio and cycling losses
      <cu.PLRcl> = <cu.QcoilCl'> / <cu.QcapCl>
      IF (<cu.PLRcl> .ge. <cu:MIN-HGB-RATIO>) THEN  ! runs full hour
        <cu.FracOn> = 1.
      ELSE  ! fraction of hour operating
        <cu.FracOn> = <cu.PLRcl> / <cu:MIN-HGB-RATIO>
        <cu.PLRcl>  = <cu:MIN-HGB-RATIO>
      ENDIF
c              adjust for time coils enabled
      <cu.FracOn> = <cu.FracOn> * <cu.CoilOnCl>
c              adjust for cycling losses
      IF (<cu:COOL-CLOSS-FPLR>) THEN
        <cu.fCycle> = Cval(<cu:COOL-CLOSS-FPLR>,
     &                       Max(<cu.FracOn>, <cu:COOL-CLOSS-MIN>), xx)
```

```
          <cu.FracOn> = Min(1., <cu.FracOn> / Max(0.001, <cu.fCycle>))
        ENDIF

c               Compressor power, adjusted for temperature and load.
c               When running, the machine must operate at or above the
c               min-unload-ratio
        <cu.EIRfTcl>   = Cval(<cu:COOL-EIR-FSST&ODB>, <cu.SST>,<cu.ECTcl>)
        dTplr          = <cu.ECTcl> - <cu.SST>
        PLRhgb         = Min(1., Max(<cu.PLRcl>, <cu:MIN-UNLOAD-RATIO>))
        <cu.EIRfPLRcl> = Cval(<cu:COOL-EIR-FPLR>, PLRhgb, dTplr)
c               adjust EIR if overloaded (linear adjustment)
        IF (<cu.PLRcl> .gt. 1.) THEN
          IF (<cu:MAX-COOLING-CAP> .gt. 1.) THEN
            Ratio = (<cu.PLRcl>-1.) / (<cu:MAX-COOLING-CAP>-1.)
            <cu.EIRfPLRcl> = <cu.EIRfPLRcl>
     &                 + <cu.EIRfPLRcl>*(<cu:MAX-COOLING-PWR>-1.)*Ratio
          ELSE  ! assume linear for small overloads
            <cu.EIRfPLRcl> = <cu.EIRfPLRcl> * <cu.PLRcl>
          ENDIF
        ENDIF
        <cu.EIRcl> = <cu;NormalEIRcl> * <cu.EIRfTcl> * <cu.EIRfPLRcl>
        <cu.kWcl>  = <cu.QcapCl> * <cu.EIRcl> * <cu.FracOn> * kWBtu

c               Rejected heat
        <cu.Qcond> = <cu.QcoilCl> + <cu.kWcl>*BtuKW
c
c
c------------- Auxiliary Power & Misc------------------------------------------

c               Re-entry point for heating mode or no load
 3300 Continue
        Call CnvgCheck(2, <cu:HstySST&SCT>)

c               Crankcase power
        IF (<cu;kWcrank> .gt. 0.) THEN
          IF (DBT .gt. <cu:CRANKCASE-MAX-T>) THEN
            <cu.kWcrank> = 0.
          ELSE
            PLR          = Max(<cu.PLRht>, <cu.PLRcl>)
            fPLR         = Cval(<cu:CRANK-EIR-FPLR>, PLR, xx)
            fPLR         = Max(0., Min(1., fPLR))
c               assume fully on during time cycled off
            Ratio        = <cu.FracOn>*fPLR + (1.-<cu.FracOn>)
            <cu.kWcrank> = <cu;kWnorCrnk> * Ratio
          ENDIF
        ENDIF

c               Auxiliary power
        IF (<cu:AUX-POWER> .gt. 0.) THEN
c               if always on
          IF (<cu:AUX-MODE> .eq. Always) THEN
            <cu.kWaux> = <cu:AUX-POWER>
          ELSEIF (<cu:AUX-MODE> .eq. WhenOn) THEN
            <cu.kWaux> = <cu:AUX-POWER> * <cu.FracOn>
          ELSEIF (<cu:AUX-MODE> .eq. WhenOff) THEN
            <cu.kWaux> = <cu:AUX-POWER> * (1.0 - <cu.FracOn>)
          ELSE
            <cu.kWaux> = <cu:AUX-POWER> * SchVal(<cu:AUX-SCHEDULE>, 1.)
          ENDIF
        ENDIF
c
c
c============= HOURLY RECONCILIATION ==========================================
        CASE (39)

c               Save operating mode for next hour (if control zone)
        <cu.LastOperMode> = <cu.OperMode>

c               Transfer variables to Kpe statistics block
        <pe.Load>     = <cu.QcoilCl>
        <pe.Qrecover> = <cu.QcoilHt>
        <pe.kWtotal>  = <cu.kWht> + <cu.kWcl> + <cu.kWaux> + <cu.kWcrank>
        <pe.kWaux>    = <cu.kWcrank> + <cu.kWaux>
```

```
c              hours overloaded
      IF (<cu.CoilOnCl> .gt. 0.99  .and.
     &                       <cu.SST> .gt. <cu.SSTsetpt>+0.1)
     &   <cu.OvrldClYr> = <cu.OvrldClYr> + 1
      IF (<cu.CoilOnHt> .gt. 0.99  .and.
     &                       <cu.SCT> .lt. <cu.SSTsetpt>-0.1)
     &   <cu.OvrldHtYr> = <cu.OvrldHtYr> + 1

c              Store design-day sizing
      IF (iSaveDD .eq. 10  .and.  <cu.FracOn> .gt. 0.) THEN
        SELECT CASE (<cu.OperMode>)
        CASE (1)  ! heating
          IF (<cu;QnormalHt> .lt. <cu;QnormalHtDD>) THEN
            <cu;QnormalHtDD> = <cu;QnormalHt>
            <cu;QcoilHtDD>   = <cu.QcoilHt>
            <cu;SCTDD>       = <cu.SCT>
            <cu;ECThtDD>     = <cu.ECTht>
          ENDIF
        CASE (2)  ! cooling
          IF (<cu;QnormalCl> .gt. <cu;QnormalClDD>) THEN
            <cu;QnormalClDD> = <cu;QnormalCl>
            <cu;QcoilClDD>   = <cu.QcoilCl>
            <cu;SSTDD>       = <cu.SST>
            <cu;ECTclDD>     = <cu.ECTcl>
          ENDIF
        END SELECT
      ENDIF

c              hourly-report variables
      IF (<cu:HREP> .ne. 0  .and.  iRSch .ne. 0) THEN
        IAptr        = <cu:HREP> - 1
        AA(IAptr+ 1) = <cu.CoilOnHt>
        AA(IAptr+ 2) = <cu.CoilOnCl>
        AA(IAptr+ 3) = <cu.fCycle>
        AA(IAptr+ 4) = <cu.FracOn>
        AA(IAptr+ 5) = <cu.SST>
        AA(IAptr+ 6) = <cu.SSTcoil>
        AA(IAptr+ 7) = <cu.ECTcl>
        AA(IAptr+ 8) = <cu.QcoilCl>
        AA(IAptr+ 9) = <cu.QcoilCl'>
        AA(IAptr+10) = <cu.CapfTcl>
        AA(IAptr+11) = <cu.QcapCl>
        AA(IAptr+12) = <cu.PLRcl>
        AA(IAptr+13) = <cu.EIRfPLRcl>
        AA(IAptr+14) = <cu.EIRfTcl>
        AA(IAptr+15) = <cu.EIRcl>
        AA(IAptr+16) = <cu.kWcl>
        AA(IAptr+17) = <cu.SCT>
        AA(IAptr+18) = <cu.SCTcoil>
        AA(IAptr+19) = <cu.ECTht>
        AA(IAptr+20) = <cu.QcoilHt>
        AA(IAptr+21) = <cu.QcoilHt'>
        AA(IAptr+22) = <cu.CapfTht>
        AA(IAptr+23) = <cu.DefCap>
        AA(IAptr+24) = <cu.QcapHt>
        AA(IAptr+25) = <cu.PLRht>
        AA(IAptr+26) = <cu.EIRfPLRht>
        AA(IAptr+27) = <cu.EIRfTht>
        AA(IAptr+28) = <cu.EIRht>
        AA(IAptr+29) = <cu.kWht>
        AA(IAptr+30) = <cu.kWaux>
        AA(IAptr+31) = <cu.kWcrank>
        AA(IAptr+32) = <pe.kWtotal>
        AA(IAptr+33) = <cu.Qcond>
      ENDIF
c
c
c============= DESIGN INITIALIZATION ==========================================
      CASE (100)

c              Sizing flag
      <cu;SizingFlag> = 1
```

```
c              Electric input ratio at curve normalization point
      dTplr            = <cu:COOL-RATED-ODB> - <cu:RATED-SST>
      EIRfRatedCl      = Cval(<cu:COOL-EIR-FSST&ODB>,
     &                         <cu:RATED-SST>, <cu:COOL-RATED-ODB>)
     &                 * Cval(<cu:COOL-EIR-FPLR>, 1.0, dTplr)
      <cu;NormalEIRcl> = <cu:COOLING-EIR> / EIRfRatedCl

c              heating mode
      dTplr            = <cu:RATED-SCT> - <cu:HEAT-RATED-OWB>
      EIRfRatedHt      = Cval(<cu:HEAT-EIR-FSCT&OWB>,
     &                         <cu:RATED-SCT>, <cu:HEAT-RATED-OWB>)
     &                 * Cval(<cu:HEAT-EIR-FPLR>, 1.0, dTplr)
      <cu;NormalEIRht> = <cu:HEATING-EIR> / EIRfRatedHt

      IF (<cu:COOLING-CAPACITY> .ne. 0.) <cu:COOL-SIZING-RATI> = 1.
      IF (<cu:HEATING-CAPACITY> .ne. 0.) <cu:HEAT-SIZING-RATI> = 1.
      <cu:HEAT/COOL-CAP> = -Abs(<cu:HEAT/COOL-CAP>)

      <cu:MIN-UNLOAD-RATIO> = Max(<cu:MIN-UNLOAD-RATIO>,
     &                             <cu:MIN-HGB-RATIO>)

c              Max capacity and power when overloaded
      <cu:MAX-HEATING-CAP> = Max(1., <cu:MAX-HEATING-CAP>)
      IF (<cu:MAX-HEATING-PWR> .le. 1.)  <cu:MAX-HEATING-CAP> = 1.
      <cu:MAX-COOLING-CAP> = Max(1., <cu:MAX-COOLING-CAP>)
      IF (<cu:MAX-COOLING-PWR> .le. 1.)  <cu:MAX-COOLING-CAP> = 1.

c              Initialize control zone operating mode
      <cu.LastOperMode> = HeatMode
c
c
c============= DESIGN RECONCILIATION =========================================
      CASE (110)

c              Rated capacity factors, cooling and heating
      CapfRatedCl = Cval(<cu:COOL-CAP-FSST&ODB>,
     &                    <cu:RATED-SST>, <cu:COOL-RATED-ODB>)
      CapfRatedHt = Cval(<cu:HEAT-CAP-FSCT&OWB>,
     &                    <cu:RATED-SCT>, <cu:HEAT-RATED-OWB>)
      TwbDef      = Min(50., Max(<cu:HEAT-RATED-OWB>, 18.))
      <cu.DefCap> = Min(1., Cval(<cu:DEFROST-CAP-FOWB>,TwbDef,xx))
      CapfRatedHt = CapfRatedHt * <cu.DefCap>

c              User-specified capacity
      IF (<cu:HEATING-CAPACITY> .lt. 0.  .or.
     &    <cu:COOLING-CAPACITY> .gt. 0.) THEN
        IF (<cu:HEATING-CAPACITY> .eq. 0.) THEN
          <cu:HEATING-CAPACITY> = <cu:COOLING-CAPACITY>
     &                          * <cu:HEAT/COOL-CAP>
        ELSEIF (<cu:COOLING-CAPACITY> .eq. 0.) THEN
          <cu:COOLING-CAPACITY> = <cu:HEATING-CAPACITY>
     &                          / <cu:HEAT/COOL-CAP>
        ENDIF
        <cu;QnormalCl> = <cu:COOLING-CAPACITY> / CapfRatedCl
        <cu;QnormalHt> = <cu:HEATING-CAPACITY> / CapfRatedHt

c              Capacity at rated conditions
        <cu;QratedHt>   = <cu;QnormalHt> * CapfRatedHt
        <cu;QratedCl>   = <cu;QnormalCl> * CapfRatedCl
        <cu;SizingFlag> = 0

      ELSEIF (<cu;QnormalHtDD> .lt. 0.  .or.
     &        <cu;QnormalClDD> .gt. 0.) THEN
c              Size based on design day
        IF (<cu;QnormalHtDD> .eq. 0.) THEN
c              only cooling during design days
          <cu;QratedCl>  = <cu;QnormalClDD> * CapfRatedCl
          <cu;QratedHt>  = <cu;QratedCl> * <cu:HEAT/COOL-CAP>
          <cu;QnormalHt> = <cu;QratedHt> / CapfRatedHt

          Call MsgSim(-3,ii,ii,ii,ii)
          Write (Ioutpt, 11001) (<cu:NAME>,II=1,8)
          Call MessageBox( NULL,'Cond Unit has no design-day heating -'
```

```
     &      //' Caution'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )

        ELSEIF (<cu;QnormalClDD> .eq. 0.) THEN
c              only heating during design days
          <cu;QratedHt>  = <cu;QnormalHtDD> * CapfRatedHt
          <cu;QratedCl>  = <cu;QratedHt> / <cu:HEAT/COOL-CAP>
          <cu;QnormalCl> = <cu;QratedCl> / CapfRatedCl

          Call MsgSim(-3,ii,ii,ii,ii)
          Write (Ioutpt, 11002) (<cu:NAME>,II=1,8)
          Call MessageBox( NULL,'Cond Unit has no design-day cooling -'
     &      //' Caution'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )

        ELSE
c              both heating and cooling on design-days; size to larger
          <cu;QratedHt>  = <cu;QnormalHtDD> * CapfRatedHt
          <cu;QratedCl>  = <cu;QnormalClDD> * CapfRatedCl
          <cu;QratedHt>  = Min(<cu;QratedHt>,
     &                        <cu;QratedCl>*<cu:HEAT/COOL-CAP>)
          <cu;QratedCl>  = <cu;QratedHt> / <cu:HEAT/COOL-CAP>
          <cu;QnormalHt> = <cu;QratedHt> / CapfRatedHt
          <cu;QnormalCl> = <cu;QratedCl> / CapfRatedCl
        ENDIF
        <cu;SizingFlag> = 0

      ELSE
c              no design sizing
        Call MsgSim(-3,ii,ii,ii,ii)
        Write (Ioutpt, 11003) (<cu:NAME>,II=1,8)
        Call MessageBox( NULL,'Cond Unit has no design-day loads -'
     &    //' Caution'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &    + MB_ICONSTOP + MB_TASKMODAL )
      ENDIF  ! cu:HEATING-CAPACITY

c              Power at rated conditions
      <cu;kWratedHt> = -<cu;QratedHt> * <cu:HEATING-EIR> * kWBtu
      <cu;kWratedCl> =  <cu;QratedCl> * <cu:COOLING-EIR> * kWBtu

c              Crankcase power
      IF (<cu:CRANKCASE-HEAT> .gt. 0.) THEN
        <cu;kWcrank> = <cu:CRANKCASE-HEAT>
      ELSE
        <cu;kWcrank> = <cu;QratedCl> * <cu:CRANKCASE-EIR> * kWBtu
      ENDIF
      <cu;kWnorCrnk> = <cu;kWcrank> / Cval(<cu:CRANK-EIR-FPLR>,0.,xx)

c              Capacity and power at design conditions, excluding aux kW
      IF (<cu;QcoilHtDD> .lt. 0.) THEN
        <cu;QcoilHt>    = <cu;QnormalHt>
     &                  * Cval(<cu:HEAT-CAP-FSCT&OWB>,
     &                         <cu;SCTDD>, <cu;ECThtDD>)
        <cu.EIRfTht>    = Cval(<cu:HEAT-EIR-FSCT&OWB>,
     &                         <cu;SCTDD>, <cu;ECThtDD>)
        dTplr           = <cu;SCTDD> - <cu;ECThtDD>
        <cu.EIRfPLRht>  = Cval(<cu:HEAT-EIR-FPLR>, 1., dTplr)
        <cu.EIRht>      = <cu;NormalEIRht>*<cu.EIRfTht>*<cu.EIRfPLRht>
        <cu;kWdesignHt> = -<cu;QcoilHt> * <cu.EIRht> * kWBtu
c              now include defrost in design load
        TwbDef          = Min(50., Max(<cu;ECThtDD>, 18.))
        <cu;QcoilHt>    = <cu;QcoilHt>
     &                  * Min(1., Cval(<cu:DEFROST-CAP-FOWB>,TwbDef,xx))

        IF (<cu;QcoilHt> .gt. <cu;QcoilHtDD>*0.95) THEN
          Call MsgSim(-3,ii,ii,ii,ii)
          Write (Ioutpt, 11004) (<cu:NAME>,II=1,8),
     &                          <cu;SCTDD>, <cu;ECThtDD>,
     &                          <cu;QcoilHt>, <cu;QcoilHtDD>
          Call MessageBox( NULL,'Cond Unit heating undersized -'
     &      //' Caution'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )
        ENDIF
```

```
      ENDIF
      IF (<cu;QcoilClDD> .gt. 0.) THEN
        <cu;QcoilCl>    = <cu;QnormalCl>
     &                  * Cval(<cu:COOL-CAP-FSST&ODB>,
     &                         <cu;SSTDD>, <cu;ECTclDD>)
        <cu.EIRfTcl>    = Cval(<cu:COOL-EIR-FSST&ODB>,
     &                         <cu;SSTDD>, <cu;ECTclDD>)
        dTplr           = <cu;ECTclDD> - <cu;SSTDD>
        <cu.EIRfPLRcl>  = Cval(<cu:COOL-EIR-FPLR>, 1., dTplr)
        <cu.EIRcl>      = <cu;NormalEIRcl>*<cu.EIRfTcl>*<cu.EIRfPLRcl>
        <cu;kWdesignCl> = <cu;QcoilCl> * <cu.EIRcl> * kWBtu

        IF (<cu;QcoilCl> .lt. <cu;QcoilClDD>*0.95) THEN
          Call MsgSim(-3,ii,ii,ii,ii)
          Write (Ioutpt, 11005) (<cu:NAME>,II=1,8),
     &                          <cu;SSTDD>, <cu;ECTclDD>,
     &                          <cu;QcoilCl>, <cu;QcoilClDD>
          Call MessageBox( NULL,'Cond Unit cooling undersized -'
     &      //' Caution'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )
        ENDIF
      ENDIF

c              Values for Kpe statistics block
      <pe.OperCapacity> = <cu;QratedCl>
      <pe;kW>           = <cu;QratedCl> * <cu:COOLING-EIR> * kWBtu
      <pe;AuxKW>        = <cu:AUX-POWER>
      <pe;RecoverQ>     = <cu;QratedHt>
c
c
c ============ ATTACHMENTS ====================================================
c
c              Initial attachments
      CASE (201)

c              pointers
        <cu:COOL-CAP-FSST&ODB> = Jcurve(<cu:COOL-CAP-FSST&ODB>)
        <cu:COOL-EIR-FSST&ODB> = Jcurve(<cu:COOL-EIR-FSST&ODB>)
        <cu:COOL-EIR-FPLR>     = Jcurve(<cu:COOL-EIR-FPLR>)
        <cu:COOL-CLOSS-FPLR>   = Jcurve(<cu:COOL-CLOSS-FPLR>)
        <cu:HEAT-CAP-FSCT&OWB> = Jcurve(<cu:HEAT-CAP-FSCT&OWB>)
        <cu:DEFROST-CAP-FOWB>  = Jcurve(<cu:DEFROST-CAP-FOWB>)
        <cu:HEAT-EIR-FSCT&OWB> = Jcurve(<cu:HEAT-EIR-FSCT&OWB>)
        <cu:HEAT-EIR-FPLR>     = Jcurve(<cu:HEAT-EIR-FPLR>)
        <cu:HEAT-CLOSS-FPLR>   = Jcurve(<cu:HEAT-CLOSS-FPLR>)
        <cu:CRANK-EIR-FPLR>    = Jcurve(<cu:CRANK-EIR-FPLR>)
        <cu:SST-SETPT-SCH>     = Jsched(<cu:SST-SETPT-SCH>)
        <cu:SST-RESET-SCH>     = Jsched(<cu:SST-RESET-SCH>)
        <cu:SCT-SETPT-SCH>     = Jsched(<cu:SCT-SETPT-SCH>)
        <cu:SCT-RESET-SCH>     = Jsched(<cu:SCT-RESET-SCH>)
        <cu:AUX-SCHEDULE>      = Jsched(<cu:AUX-SCHEDULE>)
        IF (<cu:ELEC-METER>)
     &      <cu:ELEC-METER> = Iem + (<cu:ELEC-METER>-1)*Lem
        IF (<cu:AUX-METER>)
     &      <cu:AUX-METER>  = Iem + (<cu:AUX-METER>-1)*Lem
        IF (<cu:CONTROL-ZONE>)
     &      <cu:CONTROL-ZONE> = Izn + (<cu:CONTROL-ZONE>-1)*Lzn
        IF (<cu:COST-DATA>)
     &      <cu:COST-DATA> = Imc + (<cu:COST-DATA>-1)*Lmc

c              Set up Kpe block (for statistics only)
        <cu:Kpe> = NewKpe(Jcu, <cu:ALGORITHM>)

c              Second level of attachments
      CASE (202)

c              initialize refrigerant for CoilBF calcs, as coil(100)
c              is called before CondUnit(100)
      <cu.SSTcoil> = <cu:DESIGN-COIL-SST>
      <cu.SCTcoil> = <cu:DESIGN-COIL-SCT>

c              Links, lists
      CASE (205)
```

```
c              List of heating coils attached to this unit
        Kcl = Icl
        DO WHILE (Kcl)
          IF (<cl:Type> .eq. -8  .and.  <cl:Jcu> .eq. Jcu)
     &      Call ListAdd(<cu:ListKhc>, Kcl)
          Kcl = <cl:Next>
        ENDDO
c              list of cooling coils attached to this unit
        Kcl = Icl
        DO WHILE (Kcl)
          IF (<cl:Type> .eq. 8  .and.  <cl:Jcu> .eq. Jcu)
     &      Call ListAdd(<cu:ListKcc>, Kcl)
          Kcl = <cl:Next>
        ENDDO

        IF (<cu:ListKhc> .eq. 0  .and.  <cu:ListKcc> .eq. 0) THEN
          Call MsgSim(-2,ii,ii,ii,ii)
          Write (Ioutpt, 20501) (<cu:NAME>,II=1,8)
          Call MessageBox( NULL,'Cond Unit serves no coils -'
     &      //' Warning'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )
        ELSEIF (<cu:ListKhc> .eq. 0) THEN
          Call MsgSim(-2,ii,ii,ii,ii)
          Write (Ioutpt, 20502) (<cu:NAME>,II=1,8)
          Call MessageBox( NULL,'Cond Unit serves no heating coils -'
     &      //' Warning'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )
        ELSEIF (<cu:ListKcc> .eq. 0) THEN
          Call MsgSim(-2,ii,ii,ii,ii)
          Write (Ioutpt, 20503) (<cu:NAME>,II=1,8)
          Call MessageBox( NULL,'Cond Unit serves no cooling coils -'
     &      //' Warning'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )
        ENDIF

c              If control zone specified, find the coil
        IF (<cu:CONTROL-ZONE>) THEN
c              loop thru the air handlers and find the zone
          Kah = Iah
          DO WHILE (Kah)  :KahLoop
            Kli    = <ah:ListZones>   ! list of zones in AHU
            NumJzn = <li;NumItems>    ! number of zones
            DO  LI=1,NumJzn
              Jzn = <li;List>         ! pointer to zone
              IF (Jzn .eq. <cu:CONTROL-ZONE>) THEN
                Kcc = <ah:CoilCool>
                IF (<cc:Type> .eq. 8  .and.  <cc:Jcu> .eq. Jcu)
     &            <cu:KccCtrl> = Kcc
                Khc = <ah:CoilHeat>
                IF (<hc:Type> .eq. -8  .and.  <hc:Jcu> .eq. Jcu)
     &            <cu:KhcCtrl> = Khc
                Exit :KahLoop
              ENDIF
            ENDDO
            Kah = <ah:Next>
          ENDDO

c              Check if coil attached to this unit
          IF (<cu:KccCtrl> .eq. 0  .and.  <cu:KhcCtrl> .eq. 0) THEN
            Jzn = <cu:CONTROL-ZONE>
            Call MsgSim(-2,ii,ii,ii,ii)
            Write (Ioutpt, 20504) (<cu:NAME>,II=1,8), (<zn:NAME>,II=1,8)
            Call MessageBox( NULL,'Cond Unit has illegal ctrl zone -'
     &      //' Warning'//char(0),'Cond Unit Errors'//char(0), MB_OK
     &      + MB_ICONSTOP + MB_TASKMODAL )

            <cu:CONTROL-ZONE> = 0
          ENDIF
        ENDIF  ! cu:CONTROL-ZONE

c              Histories
      CASE (208)
```

```
c              SST & SDT
        <cu:HstySST&SCT> = NewHistory(Jcu, Jcu, Jcu, 0, 0,
     &                           0, 3, 1.2,
     &                           <#cu.SCTcoil>, 0.20,  1,
     &                           <#cu.SSTcoil>, 0.20,  1,
     &                    0,0.,0, 0,0.,0, 0,0.,0, 0,0.,0)
c              Coil loads; delete this if coils ever have a history
        <cu:HstyQcoils>  = NewHistory(Jcu, Jcu, Jcu, 0, 0,
     &                           0, 10, 1.2,
     &                           <#cu.CoilOnHt>, 0.02,  2,
     &                            <#cu.QcoilHt>, 0.02,  2,
     &                           <#cu.CoilOnCl>, 0.02,  2,
     &                            <#cu.QcoilCl>, 0.02,  2,
     &                            0,0.,0, 0,0.,0)


      END SELECT  ! Mode
c
      Return

c              Message formats
11001 Format(14x,'Condensing Unit: ',8A4,'has no design-day'         /
     &14x,'heating load; unit will be sized based on cooling load.'    )
11002 Format(14x,'Condensing Unit: ',8A4,' has no design-day'        /
     &14x,'cooling load; unit will be sized based on heating load.'    )
11003 Format(14x,'Condensing Unit: ',8A4,' has no design-day'        /
     &14x,'heating or cooling loads. Unit will be modeled with no'     /
     &14x,'correction for part-load efficiency. Results will be'       /
     &14x,'erroneous.'                                                 )
11004 Format(14x,'Condensing Unit: ',8A4,' has a user'               /
     &14x,'specified heating capacity that is less than the required'  /
     &14x,'capacity. Design-day SCT and ambient wetbulb T:',2F6.1,'F'  /
     &14x,'Specified/required at design-day conditions:',2F10.0,' MBtu')
11005 Format(14x,'Condensing Unit: ',8A4,' has a user'               /
     &14x,'specified cooling capacity that is less than the required'  /
     &14x,'capacity. Design-day SST and ambient drybulb T:',2F6.1,'F'  /
     &14x,'Specified/required at design-day conditions:',2F10.0,' MBtu')

20501 Format(14x,'Condensing Unit: ',8A4,' has no attached'          /
     &14x,'heating or cooling coils. Unit will not operate.'           )
20502 Format(14x,'Condensing Unit: ',8A4,' has no attached'          /
     &14x,'heating coils. Only cooling will be provided.'              )
20503 Format(14x,'Condensing Unit: ',8A4,' has no attached'          /
     &14x,'cooling coils. Only heating will be provided.'              )
20504 Format(14x,'Condensing Unit: ',8A4,' has a'                    /
     &14x,'control zone: ',8A4,' that is not served'                   /
     &14x,'by the unit. The control zone will be ignored and the unit' /
     &14x,'will sample all attached coils, with preference given to'   /
     &14x,'cooling.'                                                   )

      End
```

VRF EVAPORATOR COIL

```
      Subroutine Coil_RfgCool(Mode, Kcc)

c              Simulates a refrigerant cooling coil in an airhandler.
c              If the coil has a supplemental waterside economizer, the
c              economizer may be either wet or dry.

c              For a wet coil, the algorithm modifies the air specific
c              heat (CpAir) to include the latent condensation. This
c              correction generates small errors as the coil approaches
c              a dry state, but overall yields robust performance.

*CA /JJHSDG/
*CA /BLANK/
*CA /FILES/
*CA /KpxSys/
      Equivalence     (Kpx, KpxCoil)
```

```
*CA /MISCD/
*CA /TIME/
*CA /WEATH/
*CA /Wmoist/

      Real     Mh2o

*CA H
*CA Hliq
*CA BFfCFM
*CA BFfWr
*CA BFfWr2
*CA T
*CA WrWs
*CA WrWs2


      Jcu = <cc:Jcu>        ! condensing unit
      Khx = <cc:Khx>        ! heat exchanger
      Kah = <cc:Kah>        ! parent ahu
      Jsy = <ah:Jsy>        ! parent system
      Kcl = <ah:CoilWSE>    ! waterside economizer coil

c              Coil suction temperature
      IF (Jcu) THEN  ! attached to condensing unit
        <cc.Tfluid> = <cu.SSTcoil>
      ELSE  ! attached to refrigeration system (future)
      ENDIF

      SELECT CASE (Mode)
c
c
c============= HOURLY LOAD ====================================================
      CASE (31:34)

c              Calculates the coil output for a given outlet T or W
c              Setpoint is transmitted via cc.Toutlet or cc.Woutlet;
c              will be modified if overloaded

c              Mode  31  Capacity, given T
c                    32  Load,     given T
c                    33  Capacity, given W
c                    34  Load,     given W

c              Check if coil running.  If called for dehumidification,
c              it is assumed the unit must run.
      GUESS
        IF (<cc.Enable> .eq. 0.)                       Quit
        IF (Mode .lt. 33  .and.
     &      <cc.Toutlet>+0.01 .gt. <cc.Tinlet>)        Quit
        IF (Jcu .gt. 0  .and.  <cu.EnableCl> .eq. 0)  Quit
        IF (<cc.Tfluid> .ge. <cc.Tinlet>)              Quit
      ADMIT  ! coil is off
        Call CoilOff(Kcc)
        Return
      END GUESS

c              Airflow when fan on
      CFMon     = <cc.CFM> / <cc.Enable>
      <cc.CFM'> = CFMon
      IF (ModeDD) THEN
        <cc.CFM'> = <cc.CFM'> * <sy:COOL-SIZING-RATI>
        IF (<cc;SizeCoil> .eq. 0)
     &    <cc.CFM'> = Min(<cc.CFM'>, Max(<cc;CFM>, CFMon))
      ENDIF
c              entering wetbulb temperature
      <cc.Tewb> = WBFS(<cc.Tinlet>, <cc.Winlet>, Patm)

c              Coil capacity
      Execute CoilCapRfg

c              Surface conditions at setpoint
      CoilOn = 1.
```

```
       IF (Mode .lt. 33) THEN  ! Coil controlled on temperature
c               Load at setpoint
         Tsurf   = <cc.Tinlet> + (<cc.Toutlet>-<cc.Tinlet>)/CoilEff
         Wsurf   = Wfunc(Tsurf, 100., Patm)
         Wsurf   = Min(Wsurf, <cc.Winlet>)
         Hsurf   = H(Tsurf, Wsurf)
         Houtlet = Hinlet + (Hsurf-Hinlet)*CoilEff
         Woutlet = <cc.Winlet> + (Wsurf-<cc.Winlet>)*CoilEff
         dQh2o   = (<cc.Winlet>-Woutlet) * Hliq(Tsurf)
         <cc.Qsetpt> = <cc.Mair'> * (Hinlet-Houtlet-dQh2o)

c               Actual outlet temperature
         <cc.Toutlet> = Max(<cc.Toutlet>, ToutMin)
c               surface temperature
         IF (<sy:RFG-COIL-CTRL> .eq. 0)  THEN  ! coil cycles on/off
c               coil runtime necessary to provide average setpoint
           CoilOn  = (<cc.Tinlet>-<cc.Toutlet>) / (<cc.Tinlet>-ToutMin)
           CoilOn  = Min(1., CoilOn)
           CoilEff = CoilEff * CoilOn
           <cc.Tsurf> = TsurfQcap               ! calcd in CpNewRfg
         ELSE
           <cc.Tsurf> = <cc.Tinlet> + (<cc.Toutlet>-<cc.Tinlet>)/CoilEff
         ENDIF
         IF (<cc.Tsurf> .lt. TsurfSST) THEN  ! CoilEff too low
           CoilEff    = (<cc.Tinlet>-<cc.Toutlet>)/(<cc.Tinlet>-TsurfSST)
           CoilEff    = Min(0.99, CoilEff)
           <cc.Tsurf> = TsurfSST
         ENDIF
c               surface and outlet humidity
         <cc.Wsurf>   = Wfunc(<cc.Tsurf>, 100., Patm)
         <cc.Wsurf>   = Min(<cc.Wsurf>, <cc.Winlet>)  ! if dry
         <cc.Woutlet> = <cc.Winlet> - (<cc.Winlet>-<cc.Wsurf>)*CoilEff

       ELSE   ! Coil controlled on humidity
c               Load at setpoint
         Wsurf   = <cc.Winlet> + (<cc.Woutlet>-<cc.Winlet>)/CoilEff
         Tsurf   = Dewpt(Wsurf, Patm)
         Hsurf   = H(Tsurf, Wsurf)
         Houtlet = Hinlet + (Hsurf-Hinlet)*CoilEff
         dQh2o   = (<cc.Winlet>-<cc.Woutlet>) * Hliq(Tsurf)
         <cc.Qsetpt> = <cc.Mair'> * (Hinlet-Houtlet-dQh2o)

c               Actual outlet W
         <cc.Woutlet> = Max(<cc.Woutlet>, WoutMin)
         IF (<sy:RFG-COIL-CTRL> .eq. 0)  THEN  ! coil cycles on/off
c               Wsurf is constant when running; bypass factor varies
c               with cycling
           <cc.Wsurf> = WsurfQcap
           IF (Kcl .eq. 0  .or.  <cl.Woutlet> .eq. <cl.Winlet>) THEN
c               no WSE, or WSE is dry
             <cc.CoilBF'> = BFfWr(<ah.WretMax>, WsurfQcap)
           ELSE  ! WSE exists and is wet
             <cc.CoilBF'> = BFfWr2(<ah.WretMax>, WsurfQcap,
      &                           <cl.CoilBF'>, <cl.Wsurf>)
           ENDIF
           <cc.CoilBF'> = Max(<cc.CoilBF'>, <cc.CoilBF>)
           EffNew       = 1.-<cc.CoilBF'>
           CoilOn       = EffNew / CoilEff
           CoilEff      = EffNew
         ELSE  ! coil modulates
           <cc.Wsurf> = <cc.Winlet> + (<cc.Woutlet>-<cc.Winlet>)/CoilEff
         ENDIF
         IF (<cc.Wsurf>  .lt. WsurfSST  .and.     ! CoilEff too low
      &      <cc.Winlet> .gt. WsurfSST) THEN      ! coil is wet
           CoilEff    = (<cc.Winlet>-<cc.Woutlet>)/(<cc.Winlet>-WsurfSST)
           CoilEff    = Min(0.99, CoilEff)
           <cc.Wsurf> = WsurfSST
         ENDIF
         <cc.Tsurf>   = Dewpt(<cc.Wsurf>, Patm)
         <cc.Toutlet> = <cc.Tinlet> - (<cc.Tinlet>-<cc.Tsurf>)*CoilEff
c               During sizing, do not let humidity-driven Toutlet require
c               a HX effectiveness > 0.90
         IF (<cc;SizeCoil>) THEN
```

```
            HXeff = (<cc.Tinlet>-<cc.Toutlet>)
     &            / (<cc.Tinlet>-<cc.Tfluid>)
            IF (HXeff .gt. 0.899) THEN
              <cc.Toutlet> = <cc.Tinlet> + (<cc.Tfluid>-<cc.Tinlet>)*0.899
              Ratio        = (<cc.Tinlet>-<cc.Toutlet>)
     &                     / (<cc.Tinlet>-<cc.Tsurf>)
              <cc.Woutlet> = <cc.Winlet> + (<cc.Wsurf>-<cc.Winlet>)*Ratio
            ENDIF
          ENDIF
        ENDIF

c               Skip if a capacity call
        IF (Mode .eq. 31  .or.  Mode .eq. 33)  Return

c               Coil total load (airside) and latent
        <cc.CoilBF'> = 1. - CoilEff
        Houtlet      = H(<cc.Toutlet>, <cc.Woutlet>)
        dQh2o        = (<cc.Winlet>-<cc.Woutlet>) * Hliq(<cc.Tsurf>)
        dQcoil       = Hinlet - Houtlet - dQh2o
        <cc.Qcoil'>  = <cc.Mair'> * dQcoil
        dTair        = <cc.Tinlet> - <cc.Toutlet>
        <cc.CpAir>   = dQcoil / dTair
        Qsens        = <cc.Mair'> * CpSens * dTair
        <cc.Qlat>    = Dim(<cc.Qcoil'>, Qsens)

c               Part load ratio
        IF (<cc;SizeCoil>) THEN
          <cc.PLR> = 1.
        ELSE
          <cc.PLR> = <cc.Qcoil'> / <cc.Qcap>
        ENDIF

c               Return humidity
        IF (<cc:Level> .lt. 3) THEN  ! ahu coil
          IF (<cc.Woutlet> .lt. <cc.Winlet>) THEN  ! wet coil
            IF (Kcl .eq. 0  .or.  <cl.Woutlet> .eq. <cl.Winlet>) THEN
c               No WSE, or WSE is dry
              <ah.Wret> = WrWs(<cc.Wsurf>, <cc.CoilBF'>)
            ELSE  ! WSE exists and is wet
              <ah.Wret> = WrWs2(<cc.Wsurf>, <cc.CoilBF'>,
     &                        <cl.Wsurf>, <cl.CoilBF'>)
c                 check if WSE really is wet
              IF (<cl.Wsurf> .ge. <ah.Wmix>)  ! WSE is dry
     &          <ah.Wret> = WrWs(<cc.Wsurf>, <cc.CoilBF'>)
            ENDIF
          ELSE  ! dry coil
c               IF a WSE, WSE has already set Wret
            IF (Kcl .eq. 0)  <ah.Wret> = WretDry
          ENDIF
        ENDIF

c               Adjust loads for fan time
        <cc.CoilOn> = CoilOn * <cc.Enable>
        <cc.Qcoil>  = <cc.Qcoil'> * <cc.Enable>
        <cc.Qlat>   = <cc.Qlat>   * <cc.Enable>
        <cc.Qloop>  = <cc.Qcoil>
        <cc.PLR1>   = <cc.PLR>  !  last non-zero hour or iteration
c               adjust external load for sizing ratio
        IF (ModeDD) THEN
          <cc.Qcoil> = <cc.Qcoil> / <sy:COOL-SIZING-RATI>
          <cc.Qlat>  = <cc.Qlat>  / <sy:COOL-SIZING-RATI>
        ENDIF
c
c
c============= REQUIRED SUCTION TEMPERATURE ===================================
        CASE (37)

c               Required suction temperature
        IF (<cc.CoilOn> .eq. 0.) THEN
          <cc.Treqd> = 88888.
        ELSEIF (<cc;SizeCoil>) THEN
          <cc.Treqd> = <cc.Tfluid>
        ELSE
```

```
          Call HeatExchanger(Khx, 5, <cc.Qsetpt>,
     &                          1.,  <cc.Treqd>, xSupTo,
     &                  <cc.Mair'>, <cc.Tinlet>, xAirTo)
        ENDIF
c
c
c============= HOURLY RECONCILIATION ==========================================
        CASE (39)

c              Store design-day sizing
        IF (iSaveDD .eq. 12  .and.  <cc.CoilOn> .gt. 0.) THEN
c              Check if design conditions possible
          HXeff = (<cc.Tinlet>-<cc.Toutlet>)
     &         / (<cc.Tinlet>-<cc.Tfluid>)
          IF (HXeff .gt. 0.90) THEN
            Jna = <cc:Parent>
            Call MsgSim(-1,II,II,II,II)
            Write (Ioutpt, 11101)  (<na:Name>,ii=1,8),
     &                            <cc.Tinlet>,<cc.Toutlet>,
     &                            <cc.Tfluid>
            Return
          ENDIF

          UA = HeatExchanger_UA(Khx, <cc.Qcoil'>,
     &                         1.0, 1.e20, <cc.Tfluid>,
     &                       <cc.Mair'>, 0., <cc.Tinlet>)
          IF (UA .gt. <cc;UAdd>) THEN
            <cc;UAdd>      = UA
            <cc;QcoilDD>   = <cc.Qcoil'>
            <cc;CFMdd>     = <cc.CFM'>
            <cc;CoilOnDD>  = <cc.CoilOn>
            <cc;TinletDD>  = <cc.Tinlet>
            <cc;WinletDD>  = <cc.Winlet>
            <cc;TewbDD>    = <cc.Tewb>
            <cc;ToutletDD> = <cc.Toutlet>
            <cc;CoilBFdd>  = <cc.CoilBF'>
            <cc;SHRdd>     = 1. - <cc.Qlat>/<cc.Qcoil>
            <cc;CpAirDD>   = <cc.CpAir>
            <cc;TfluidDD>  = <cc.Tfluid>
          ENDIF
        ENDIF
c
c
c============= DESIGN INITIALIZATION ==========================================
        CASE (100)

c              Restrictions on entering drybulb, wetbulb
        <cc:Tinlet> = Max(-40., Min(149., <cc:Tinlet>))
        <cc:Tewb>   = Max(-42., Min(<cc:Tinlet>-2., <cc:Tewb>))

c              Coil bypass factor is related to sensible heat ratio and
c              saturated suction temperature
        IF (<cc:SHR> .gt. 0.) THEN
          <cc:CoilBF> = CoilBFfSHR(Mode, Kcc, <cc.Tfluid>)
        ELSE
          <cc:SHR>    = CoilSHRfBF(Kcc, <cc.Tfluid>)
        ENDIF
c
c
c============= DESIGN RECONCILIATION - COIL SIZING ============================
        CASE (111)

c              The design airflow is cc;CFM and is set by the calling
c              routine.  If user-specified, it has been adjusted for
c              altitude.

c              Note that autosizing routine will not give exact same
c              result for coil UA as the user-specified calc, because of
c              errors between functions WBFS and WfDBWB cause the W to
c              not be exactly the same in both calcs

c              Coil size and heat exchanger UA
        IF (<cc:Capacity> .gt. 0.) THEN
```

```
c              User-specified capacity
        <cc;Qrated> = <cc:Capacity>

c              Airflow
        CFMmax = <cc;Qrated>/12000. * <sy:MAX-FLOW/CAPACIT>
        CFMmin = <cc;Qrated>/12000. * <sy:MIN-FLOW/CAPACIT>
        IF (<cc;CFM> .eq. 0) THEN  ! no airflow
c              flow/cap is at sea-level; adjust for altitude
          <cc;CFM> = <cc;Qrated>/12000. * <sy:FLOW/CAPACITY>
     &                                 * <ah;BPmult>
        ELSEIF (<sy:SIZING-METHOD> .eq. 1  .and.  ! size airflow on cap
     &                <ah:CFMcd> .eq. 0.) THEN  ! not user flow
          IF (CFMmax .gt. 0.  .or.  CFMmin .gt. 0.) THEN
c              max/min limits act as bounds on actual flow
            IF (CFMmax .gt. 0.)  <cc;CFM> = Min(<cc;CFM>, CFMmax)
            IF (CFMmin .gt. 0.)  <cc;CFM> = Max(<cc;CFM>, CFMmin)
          ELSE
c              flow/cap is at sea-level; adjust for altitude
            <cc;CFM> = <cc;Qrated>/12000. * <sy:FLOW/CAPACITY>
     &                                   * <ah;BPmult>
          ENDIF
        ENDIF
        IF (CFMmax .eq. 0.)  CFMmax = <cc;CFM>
        <cc.Mair'> = <cc;CFM> * <ah.Lb/CFM-Hr>  ! mass flow

c              Entering air conditions
        <cc.Winlet> = WfDBWB(<cc:Tinlet>, <cc:Tewb>, Patm)
        Hinlet      = H(<cc:Tinlet>, <cc.Winlet>)   ! inlet enthalpy
        CoilEff     = 1. - <cc:CoilBF>

c              coil surface conditions
        Hsurf = Hinlet - <cc;Qrated>/(<cc.Mair'>*CoilEff)
        Call CoilSurface(Hsurf, <cc.Tsurf>, <cc.Wsurf>)
        IF (<cc.Wsurf> .ge. <cc.Winlet>) THEN  ! dry coil
          Jna = <cc:Parent>
          Call MsgSim(-4,II,II,II,II)
          Write (Ioutpt, 11103)  (<na:Name>,ii=1,8)
          <cc.Wsurf> = <cc.Winlet>
          <cc.Tsurf> = T(Hsurf, <cc.Wsurf>)
        ENDIF
c              surface temperature must be above suction T
        TsurfMin = <cc;TfluidDD>
     &           + (<cc:Tinlet>-<cc;TfluidDD>)*<cc;Rsurf>
        IF (<cc.Tsurf> .lt. TsurfMin) THEN
          <cc.Tsurf> = TsurfMin
          <cc.Wsurf> = Min(<cc.Winlet>, Wfunc(TsurfMin, 100., Patm))
          Hsurf      = H(<cc.Tsurf>, <cc.Wsurf>)
        ENDIF

c              Wet coil specific heat
        dQh2o      = (<cc.Winlet>-<cc.Wsurf>) * Hliq(<cc.Tsurf>)
        <cc.CpAir> = (Hinlet-Hsurf-dQh2o) / (<cc:Tinlet>-<cc.Tsurf>)

c              Do not allow heat exchanger effectiveness to exceed 0.9
        GUESS  ! HX effectiveness
c              Outlet conditions
          dTair        = <cc;Qrated> / (<cc.Mair'>*<cc.CpAir>)
          <cc.Toutlet> = <cc:Tinlet> - dTair
c              HX effectiveness
          HXeff        = (<cc:Tinlet>-<cc.Toutlet>)
     &                 / (<cc:Tinlet>-<cc;TfluidDD>)
          IF (HXeff .gt. 0.9)  Quit
        ADMIT  ! HX effectiveness too large. Try increasing airflow
          IF (CFMmax .le. <cc;CFM>)  Quit  ! at upper limit
          <cc.Toutlet> = <cc:Tinlet>
     &                 - 0.9*(<cc:Tinlet>-<cc;TfluidDD>)
          dTair        = <cc:Tinlet> - <cc.Toutlet>
          <cc.Mair'>   = <cc;Qrated> / (<cc.CpAir>*dTair)
          <cc;CFM>     = <cc.Mair'> / <ah.Lb/CFM-Hr>
          IF (<cc;CFM> .gt. CFMmax)  Quit  ! insufficient flow
          CoilEff      = (<cc:Tinlet>-<cc.Toutlet>)
     &                 / (<cc:Tinlet>-<cc.Tsurf>)
          <cc:CoilBF>  = 1. - CoilEff
```

```
          ADMIT  ! insufficient flow; increase entering condition
            <cc;CFM>     = CFMmax
            <cc.Mair'>   = CFMmax * <ah.Lb/CFM-Hr>  ! mass flow
c                dTair = 0.9eff * (Ti-CHW)
            dTair        = <cc;Qrated> / (<cc.Mair'>*<cc.CpAir>)
            TinletNew    = <cc;TfluidDD> + dTair/0.9
c                slope of humidity ratio vs. T
            dWdT         = (<cc.Winlet>-<cc.Wsurf>)
     &                   / (<cc:Tinlet>-<cc.Tsurf>)
            <cc.Winlet>  = <cc.Winlet> + (TinletNew-<cc:Tinlet>)*dWdT
            <cc:Tinlet>  = TinletNew
            <cc:Tewb>    = WBFS(<cc:Tinlet>, <cc.Winlet>, Patm)
            <cc.Toutlet> = <cc:Tinlet> - 0.9*(<cc:Tinlet>-<cc;TfluidDD>)
            CoilEff      = (<cc:Tinlet>-<cc.Toutlet>)
     &                   / (<cc:Tinlet>-<cc.Tsurf>)
            <cc:CoilBF>  = 1. - CoilEff
          END GUESS  ! HX effectiveness

c                Coil UA
          Call HeatExchanger_Design(Khx, <cc;Qrated>,
     &                            1., 1.e20, <cc;TfluidDD>,
     &                    <cc.Mair'>,    0., <cc:Tinlet>)
          <cc;SizeCoil> = 0

c                Capacity at design conditions
          IF (<cc;QcoilDD> .gt. 0.) THEN
            <cc.CFM'>   = <cc;CFM>
            <cc.Tinlet> = <cc;TinletDD>
            <cc.Winlet> = <cc;WinletDD>
            <cc.Tfluid> = <cc;TfluidDD>
            Execute CoilCapRfg  ! sets cc.Qcap
            <cc;Qcoil>  = <cc.Qcap>
          ENDIF

        ELSEIF (<cc;QcoilDD> .gt. 0.) THEN  !  Design-day capacity
          <cc;Qcoil> = <cc;QcoilDD>
          SELECT CASE (<sy:SIZING-METHOD>)
          CASE (0)  ! default airflow/capacity
c                Scale design-day capacity to required flow
            <cc;CFM>   = Max(<cc;CFM>, <cc;CFMdd>)
            <cc;Qcoil> = <cc;QcoilDD> * <cc;CFM>/<cc;CFMdd>

          CASE (1)  ! size airflow on capacity
            IF (<ah:CFMcd> .gt. 0.)   Quit  ! User-specified airflow
            IF (<sy:MAX-FLOW/CAPACIT> .gt. 0.  .or.
     &          <sy:MIN-FLOW/CAPACIT> .gt. 0.) THEN
c                max/min limits act as bounds on actual flow
              IF (<sy:MAX-FLOW/CAPACIT> .gt. 0.)
     &          <cc;CFM> = Min(<cc;CFM>,
     &                        <cc;Qcoil>/12000. * <sy:MAX-FLOW/CAPACIT>)
              IF (<sy:MIN-FLOW/CAPACIT> .gt. 0.)
     &          <cc;CFM> = Max(<cc;CFM>,
     &                        <cc;Qcoil>/12000. * <sy:MIN-FLOW/CAPACIT>)
            ELSE
c                flow/cap is at sea-level; adjust for altitude
              <cc;CFM> = <cc;Qcoil>/12000. * <sy:FLOW/CAPACITY>
     &                                    * <ah;BPmult>
            ENDIF

          CASE (2)  ! size capacity on airflow
c                Scale design-day capacity to required flow.
            <cc;CFM> = Max(<cc;CFM>, <cc;CFMdd>)

            IF (<sy:MAX-FLOW/CAPACIT> .gt. 0.  .or.
     &          <sy:MIN-FLOW/CAPACIT> .gt. 0.) THEN
c                max/min limits act as bounds on altitude-adjusted flow
              IF (<sy:MAX-FLOW/CAPACIT> .gt. 0.)
     &          <cc;Qcoil> = Max(<cc;Qcoil>,
     &                          <cc;CFM>/<sy:MAX-FLOW/CAPACIT> * 12000.)
              IF (<sy:MIN-FLOW/CAPACIT> .gt. 0.)
     &          <cc;Qcoil> = Min(<cc;Qcoil>,
     &                          <cc;CFM>/<sy:MIN-FLOW/CAPACIT> * 12000.)
            ELSE
```

```
c              flow/cap is at sea-level
            <cc;Qcoil> = <cc;CFM>
     &                 / (<sy:FLOW/CAPACITY>*<ah;BPmult>)*12000.
          ENDIF
        END SELECT

c              Coil UA
        <cc.Mair'> = <cc;CFM> * <ah.Lb/CFM-Hr>  ! mass flow
        <cc.CpAir> = <cc;CpAirDD>
        Call HeatExchanger_Design(Khx, <cc;Qcoil>,
     &                            1., 1.e20, <cc;TfluidDD>,
     &                     <cc.Mair'>,    0., <cc;TinletDD>)

        <cc;Qrated>   = <cc;Qcoil>
        <cc;SizeCoil> = 0
      ENDIF  ! cc:Capacity .gt. 0.

      IF (<cc;SizeCoil> .eq. 0) THEN
c              refrigerant design load
        <cc;Qloop> = <cc;Qcoil>
      ENDIF
c
c
c============= ATTACHMENTS ====================================================

c              Second level of attachments
      CASE (202)

        SELECT CASE (<cc:SubType>)
        CASE (1)  ! Space cooling
          SELECT CASE (<cc:Level>)
          CASE (1)  ! Central AHU
            <cc:Capacity> = <sy:COOLING-CAPACITY>
            <cc:CoilBF>   = <sy:COIL-BF>
            <cc:SHR>      = <sy:SENS-HEAT-RATIO>
            <cc:Tinlet>   = <sy:RATED-EDB>
            <cc:Tewb>     = <sy:RATED-EWB>
            <cc:Jcu>      = <sy:CONDENSING-UNIT>
c              For single zone ahu, get the number of terminals in the
c              control zone
            IF (<ah:Type> .eq. 4) THEN
              Jzn           = <ah:ControlZone>
              <cc:Diversity> = Max(1., <zn:TERMINALS/ZONE>)
            ELSE
              <cc:Diversity> = 1.
            ENDIF
          CASE (2) ! Zonal AHU
            Jzn            = <cc:Parent>
            <cc:Capacity>  = <zn:COOLING-CAPACITY>
            <cc:CoilBF>    = <sy:COIL-BF>
            <cc:SHR>       = <sy:SENS-HEAT-RATIO>
            <cc:Tinlet>    = <zn:RATED-EDB>
            <cc:Tewb>      = <zn:RATED-EWB>
            <cc:Jcu>       = <zn:CONDENSING-UNIT>
            <cc:Diversity> = Max(1., <zn:TERMINALS/ZONE>)
          END SELECT
        CASE (2)  ! Precool
          <cc:Diversity> = 1.
        END SELECT

c              Coil heat exchanger
        <cc:Khx> = NewHX(<cc:Parent>, 1, 0., 0.001,
     &                   0.25, 0.80,          0,
     &                   0.45, 0.52, <#cc.CpAir>)

      END SELECT  ! Mode

      Return
c
c
c***************** CoilCapRfg *************************************************
      Remote Block CoilCapRfg
```

```
c             Calculates the full-load coil capacity.

c             Inlet air properties
      <cc.Mair'> = <cc.CFM'> * <ah.Lb/CFM-Hr>    ! mass flow
      Hinlet     = H(<cc.Tinlet>, <cc.Winlet>)   ! inlet enthalpy

c             Minimum coil specific heat (coil is dry)
      CpSens   = 0.24 + 0.444*<cc.Winlet>

c             Maximum coil capacity; performance is limited between
c             the minimum dry and maximum wet coil specific heat
      GUESS  ! coil capacity
        IF (<cc;SizeCoil> .eq. 0)  Quit

c             Design day; minimum coil surface conditions
        TsurfSST = <cc.Tfluid>                   ! surface T
     &           + (<cc.Tinlet>-<cc.Tfluid>)*<cc;Rsurf>
        WsurfSST = Wfunc(TsurfSST, 100., Patm)   ! surface W
        WsurfSST = Min(WsurfSST, <cc.Winlet>)    ! if dry

c             Coil bypass is rated
        <cc.CoilBF> = <cc:CoilBF>
        CoilEff     = 1. - <cc.CoilBF>

        IF (Mode .lt. 33) THEN  ! coil controlled on temperature
          TsurfQcap = <cc.Tinlet> + (<cc.Toutlet>-<cc.Tinlet>)/CoilEff
          IF (TsurfQcap .lt. TsurfSST) THEN
            TsurfQcap = TsurfSST
            WsurfQcap = WsurfSST
            CoilEff   = (<cc.Tinlet>-<cc.Toutlet>)
     &                / (<cc.Tinlet>-TsurfSST)
            IF (CoilEff .gt. 0.99) THEN
              CoilEff      = 0.99
              <cc.Toutlet> = <cc.Tinlet>
     &                     + (TsurfSST-<cc.Tinlet>)*CoilEff
            ENDIF
            <cc.CoilBF> = 1. - CoilEff
          ELSE
            WsurfQcap = Wfunc(TsurfQcap, 100., Patm)
            WsurfQcap = Min(WsurfQcap, <cc.Winlet>)
          ENDIF
          ToutMin = <cc.Toutlet>
        ELSE
          WsurfQcap = <cc.Winlet> + (<cc.Woutlet>-<cc.Winlet>)/CoilEff
          IF (WsurfQcap .lt. WsurfSST) THEN
            WsurfQcap = WsurfSST
            TsurfQcap = TsurfSST
            CoilEff   = (<cc.Winlet>-<cc.Woutlet>)
     &                / (<cc.Winlet>-WsurfSST)
            IF (CoilEff .gt. 0.99) THEN
              CoilEff      = 0.99
              <cc.Woutlet> = <cc.Winlet>
     &                     + (WsurfSST-<cc.Winlet>)*CoilEff
            ENDIF
            <cc.CoilBF> = 1. - CoilEff
          ELSE
            TsurfQcap = Dewpt(WsurfQcap, Patm)
          ENDIF
          WoutMin = <cc.Woutlet>
        ENDIF

      ADMIT  ! Coil is sized

c             Coil airflow ratio
        <cc.CFMr> = <cc.CFM'> / <cc;CFM>

c             Minimum coil surface conditions; adjust for airflow
        TsurfSST = <cc.Tfluid>                   ! surface T
     &           + (<cc.Tinlet>-<cc.Tfluid>)*<cc;Rsurf>*<cc.CFMr>
        WsurfSST = Wfunc(TsurfSST, 100., Patm)   ! surface W
        WsurfSST = Min(WsurfSST, <cc.Winlet>)    ! if dry

c             Effect of airflow ratio on coil bypass factor
```

```
          <cc.CoilBF>     = CoilBFfCFM(<cc:CoilBF>, Max(0.3, <cc.CFMr>))
          <cc.CoilBFfCFM> = <cc.CoilBF> / <cc:CoilBF>
          <cc.CoilBF>     = Min(0.8, <cc.CoilBF>)
          <cc.CoilBF'>    = <cc.CoilBF>   ! at part load
          CoilEff         = 1. - <cc.CoilBF>

c              Solve for capacity using iterative solution
c              for total specific heat (cc.CpAir) and capacity (cc.Qcap)
          <px.Mode>  = -2                     ! bounded parabolic
          dQh2o      = 0.                     ! no condensate energy
          <cc.CpAir> = CpSens                 ! dry boundary
          Execute CoilCapRfg2                 ! gets cc.Qcap & CpNew
          IF (CpNew .le. CpSens)  Quit        ! dry at max capacity

c              Maximum wet coil (total) specific heat and capacity
          HsurfSST = H(TsurfSST, WsurfSST)     ! surface H
          dQh2o    = (<cc.Winlet>-WsurfSST)    ! condensate energy
     &           * Hliq(TsurfSST)
          CpSST    = (Hinlet-HsurfSST-dQh2o)
     &           / (<cc.Tinlet>-TsurfSST)
          IF (Abs(1.-CpSens/CpSST) .lt. 0.0001)  Quit

          <cc.CpAir> = CpSST                  ! load wet SST boundary
          Execute CoilCapRfg2
          IF (CpNew .ge. CpSST)  Quit          ! at wet boundary

c              Coil is between dry and wet boundaries
          <cc.CpAir> = CpNew
          DO
            Execute CoilCapRfg2
            <cc.CpAir> = CpNew
            IF (AbsCpError .lt. 0.0001)  Exit
          ENDDO
          Quit

        ADMIT  ! Capacity has been found
c              Coil outlet conditions at max capacity
          dTair   = <cc.Qcap> / (<cc.Mair'>*<cc.CpAir>)
          ToutMin = <cc.Tinlet> - dTair
          Qsens   = <cc.Mair'> * CpSens * dTair
          Qlat    = Dim(<cc.Qcap>, Qsens)
          Qlat    = Qlat + <cc.Mair'>*dQh2o*CoilEff
          Mh2o    = Qlat / (1061. + 0.444*ToutMin)
          WoutMin = <cc.Winlet> - Mh2o/<cc.Mair'>

        END GUESS  ! coil capacity

        End Block  ! CoilCapRfg
c
c
c**************** CoilCapRfg2 ***********************************************
        Remote Block CoilCapRfg2

c              Predicts total specific heat (CpAir), including latent,
c              based on the last value of CpAir, the resulting coil
c              capacity, the resulting new CpAir, and the error between
c              the last value of CpAir and the new value

c              Coil capacity; based on cc.CpAir
        Call HeatExchanger(<cc:Khx>, 1, <cc.Qcap>,
     &                         1., <cc.Tfluid>, xSupTo,
     &                 <cc.Mair'>, <cc.Tinlet>, xAirTo)

c              Coil surface conditions based on Qcap
        Hsurf = Hinlet - <cc.Qcap>/(<cc.Mair'>*CoilEff)
        Call CoilSurface(Hsurf, TsurfQcap, WsurfQcap)

c              CpAir given these conditions
        dQh2o      = (<cc.Winlet>-WsurfQcap) * Hliq(TsurfQcap)
        CpNew      = (Hinlet-Hsurf-dQh2o) / (<cc.Tinlet>-TsurfQcap)
        CpError    = <cc.CpAir> - CpNew
        AbsCpError = Abs(CpError)
        IF (AbsCpError .lt. 0.0001)  Exit
```

```
      CpNew      = PredictX(Kpx, CpNew, CpError)

      End Block  ! CoilCapRfg2

c              Message formats
11101 Format(14x,'Rfg coil: ',8A4,' requires a heat'                  /
     &14x,'exchanger effectiveness greater than 0.90. You must either' /
     &14x,'raise the supply air temperature, or reduce the design'     /
     &14x,'suction temperature.'                                       /
     &14x,'Tair In:',F5.1,'F  Tair Out:',F5.1,'F  Tsuction:',F5.1,'F'  )
11102 Format(14x,'Rfg coil: ',8A4,' requires a surface'                /
     &14x,'temperature of',F5.1,'F which is less than the suction'     /
     &14x,'temperature of',F5.1,'F + 2F. Since the coil capacity was'  /
     &14x,'user-specified, you must either increase the supply flow,'  /
     &14x,'raise the RATED-EDB & EWB, reduce the design suction'       /
     &14x,'temperature and/or reduce the coil bypass factor.'          )
11103 Format(14x,'Rfg coil: ',8A4,' is dry at the rated'               /
     &14x,'conditions.'                                                )

      End  ! Coil_RfgCool
```

VRF Heating Coil

```
      Subroutine Coil_RfgHeat(Mode, Khc)

c              Simulates a condensing heating coil

*CA /JJHSDG/
*CA /BLANK/
*CA /FILES/
*CA /PtrSys/
*CA /TIME/


      Jcu = <hc:Jcu>        ! condensing unit
      Khx = <hc:Khx>        ! heat exhchanger
      Kah = <hc:Kah>        ! parent air handler
      Jsy = <ah:Jsy>        ! parent system

c              Coil condensing temperature
      IF (Jcu) THEN  ! attached to condensing unit
        <hc.Tfluid> = <cu.SCTcoil>
      ELSE  ! attached to refrigeration system (future)
      ENDIF

      SELECT CASE (Mode)
c
c
c============= HOURLY LOAD ====================================================
      CASE (21,22)

c              For a given outlet T, calculates the coil capacity (21)
c              or load (22)
c              Setpoint is transmitted via hc.Toutlet; will be modified
c              if overloaded

c              Check if coil running
      GUESS
        IF (<hc.Enable> .eq. 0.)                         Quit
        IF (<hc.Toutlet> .lt. <hc.Tinlet>+0.01)          Quit
        IF (Jcu .gt. 0  .and.  <cu.EnableHt> .eq. 0)     Quit
        IF (<hc.Tfluid> .le. <hc.Tinlet>)                Quit
      ADMIT  ! coil is off
        Call CoilOff(Khc)
        Return
      END GUESS

      <hc.Woutlet> = <hc.Winlet>

c              Airflow when fan is running
      CFMon     = <hc.CFM> / <hc.Enable>
```

```
       <hc.CFM'> = CFMon
       IF (ModeDD) THEN
         <hc.CFM'> = <hc.CFM'> * <sy:HEAT-SIZING-RATI>
         IF (<hc;SizeCoil> .eq. 0)
      &    <hc.CFM'> = Min(<hc.CFM'>, Max(<hc;CFM>, CFMon))
       ENDIF
       <hc.Mair'> = <hc.CFM'> * <ah.Lb/CFM-Hr>    ! mass flow fan on
       <hc.CpAir> = 0.24 + 0.444*<hc.Winlet>

 c              required load
       <hc.Qsetpt> = <hc.Mair'> * <hc.CpAir> * (<hc.Tinlet>-<hc.Toutlet>)

       IF (<hc;SizeCoil>) THEN
         <hc.Qcap>   = <hc.Qsetpt>
         <hc.Qcoil'> = <hc.Qsetpt>
       ELSE
         Call HeatExchanger(Khx, 1, <hc.Qcap>,
      &                      1., <hc.Tfluid>, xSupTo,
      &              <hc.Mair'>, <hc.Tinlet>, xDemTo)

 c              coil output
         IF (<hc.Qcap> .lt. <hc.Qsetpt>) THEN  ! modulating
           <hc.Qcoil'> = <hc.Qsetpt>
         ELSE  ! max capacity
           <hc.Qcoil'>  = <hc.Qcap>
           <hc.Toutlet> = <hc.Tinlet> - <hc.Qcap>/(<hc.Mair'>*<hc.CpAir>)
         ENDIF
       ENDIF

       IF (Mode .eq. 22)  <hc.CoilOn> = <hc.Enable>
       <hc.PLR>   = <hc.Qcoil'> / <hc.Qcap>
       <hc.Qcoil> = <hc.Qcoil'> * <hc.Enable>
       <hc.Qloop> = <hc.Qcoil>
 c              adjust external load for sizing ratio
       IF (ModeDD)  <hc.Qcoil> = <hc.Qcoil> / <sy:HEAT-SIZING-RATI>
 c
 c
 c============= REQUIRED CONDENSING TEMPERATURE ================================
       CASE (37)

 c              Required condensing temperature
       IF (<hc.CoilOn> .eq. 0.) THEN
         <hc.Treqd> = -88888.
       ELSEIF (<hc;SizeCoil>) THEN
         <hc.Treqd> = <hc.Tfluid>
       ELSE
         Call HeatExchanger(Khx, 5, <hc.Qsetpt>,
      &                      1.,  <hc.Treqd>, xSupTo,
      &              <hc.Mair'>, <hc.Tinlet>, xDemTo)
       ENDIF
 c
 c
 c============= HOURLY RECONCILIATION ==========================================
       CASE (39)

 c              Store design-day sizing
       IF (iSaveDD .eq. 12  .and.  <hc.CoilOn> .gt. 0.) THEN
 c              Check if design conditions possible
         HXeff = (<hc.Tinlet>-<hc.Toutlet>)
      &        / (<hc.Tinlet>-<hc.Tfluid>)
         IF (HXeff .gt. 0.90) THEN
           Jna = <hc:Parent>
           Call MsgSim(-1,II,II,II,II)
           Write (Ioutpt, 11101)  (<na:Name>,ii=1,8),
      &                           <hc.Tinlet>,<hc.Toutlet>,
      &                           <hc.Tfluid>
           Return
         ENDIF

         UA = HeatExchanger_UA(Khx, <hc.Qcoil'>,
      &                        1.0, 1.e20, <hc.Tfluid>,
      &                 <hc.Mair'>,    0., <hc.Tinlet>)
         IF (UA .gt. <hc;UAdd>) THEN
```

```
          <hc;UAdd>      = UA
          <hc;QcoilDD>   = <hc.Qcoil'>
          <hc;CFMdd>     = <hc.CFM'>
          <hc;CoilOnDD>  = <hc.CoilOn>
          <hc;TinletDD>  = <hc.Tinlet>
          <hc;WinletDD>  = <hc.Winlet>
          <hc;TewbDD>    = WBFS(<hc.Tinlet>, <hc.Winlet>, Patm)
          <hc;ToutletDD> = <hc.Toutlet>
          <hc;CpAirDD>   = <hc.CpAir>
          <hc;TfluidDD>  = <hc.Tfluid>
        ENDIF
      ENDIF
c
c
c============= DESIGN RECONCILIATION - COIL SIZING ============================
      CASE (111)

c              The design airflow is hc;CFM and is set by the calling
c              routine.  If user-specified, it has been adjusted for
c              altitude.

c              Specific heat of air
      IF (<hc;CpAirDD> .gt. 0.) THEN
        <hc.CpAir> = <hc;CpAirDD>                    ! for HX algorithm
      ELSE
        <hc.CpAir> = <ah.CpAir>
      ENDIF

c              Coil size and heat exchanger UA
      IF (<hc:Capacity> .lt. 0.) THEN
c              User-specified capacity
        <hc;Qrated> = <hc:Capacity>

c              Airflow
        IF (<hc;CFM> .eq. 0.)  <hc;CFM> = <hc;CFMdd>
        IF (<hc;CFM> .eq. 0.)  Quit
        <hc.Mair'> = <hc;CFM> * <ah.Lb/CFM-Hr>  ! mass flow

c              Do not allow heat exchanger effectiveness to exceed 0.9
        <hc.Toutlet> = <hc:Tinlet>
     &              - <hc;Qrated>/(<hc.Mair'>*<hc.CpAir>)
c              HX effectiveness
        HXeff = (<hc:Tinlet>-<hc.Toutlet>) / (<hc:Tinlet>-<hc;TfluidDD>)
        IF (HXeff .gt. 0.9)
     &    <hc:Tinlet> = <hc;TfluidDD>
     &               + (<hc;Qrated>/(<hc.Mair'>*<hc.CpAir>*0.9))

c              coil UA
        Call HeatExchanger_Design(Khx, <hc;Qrated>,
     &                            1., 1.e20, <hc;TfluidDD>,
     &                    <hc.Mair'>,    0., <hc:Tinlet>)
        <hc;SizeCoil> = 0

c              Capacity at design conditions
        IF (<hc;QcoilDD> .lt. 0.) THEN
          <hc.Mair'> = <hc;CFMdd> * <ah.Lb/CFM-Hr>  ! mass flow
          Call HeatExchanger(Khx, 1, <hc;Qcoil>,
     &                        1., <hc;TfluidDD>, xSupTo,
     &               <hc.Mair'>, <hc;TinletDD>, xDemTo)
        ENDIF

      ELSEIF (<hc:KccLink>) THEN  ! share a common coil with cooling
c              cooling coil was already sized
        Kcc = <hc:KccLink>
        IF (<cc;SizeCoil> .eq. 0) THEN  ! cooling sized
          Call HeatExchanger_Meld(Khx, <cc:Khx>)
          <hc;SizeCoil> = 0

c              Capacity at design conditions
          IF (<hc;QcoilDD> .lt. 0.) THEN
            <hc.Mair'> = <hc;CFMdd> * <ah.Lb/CFM-Hr>  ! mass flow
            Call HeatExchanger(Khx, 1, <hc;Qcoil>,
     &                          1., <hc;TfluidDD>, xSupTo,
```

```
     &                  <hc.Mair'>, <hc;TinletDD>, xDemTo)
          ENDIF
          <hc;Qrated> = <hc;Qcoil>
        ENDIF

      ELSEIF (<hc;QcoilDD> .lt. 0.) THEN
c              Scale design-day capacity to required flow
        <hc;CFM>   = Max(<hc;CFM>, <hc;CFMdd>)
        <hc;Qcoil> = <hc;QcoilDD> * <hc;CFM>/<hc;CFMdd>
        <hc.Mair'> = <hc;CFM> * <ah.Lb/CFM-Hr>  ! mass flow
        <hc.CpAir> = <hc;CpAirDD>
        Call HeatExchanger_Design(Khx, <hc;Qcoil>,
     &                            1., 1.e20, <hc;TfluidDD>,
     &                     <hc.Mair'>,    0., <hc;TinletDD>)

        <hc;Qrated>   = <hc;Qcoil>
        <hc;SizeCoil> = 0
      ENDIF

      <hc:SHR>      = 1.
c
c
c============= ATTACHMENTS ====================================================

c              Second level of attachments
      CASE (202)

        SELECT CASE (<hc:SubType>)
        CASE (-5)  ! Supp heat-pump
          <hc:Capacity> = -Abs(<sy:SUPP-HEAT-CAP>)
          SELECT CASE (<hc:Level>)
          CASE (1)  ! Central AHU
            <hc:Tinlet> = <sy:HT-RATED-EDB>
            <hc:Jcu>    = <sy:CONDENSING-UNIT>
c              For single zone ahu, get the number of terminals in the
c              control zone
            IF (<ah:Type> .eq. 4) THEN
              Jzn           = <ah:ControlZone>
              <hc:Diversity> = Max(1., <zn:TERMINALS/ZONE>)
            ELSE
              <hc:Diversity> = 1.
            ENDIF
          CASE (2,3) ! Zonal AHU
            Jzn            = <hc:Parent>
            <hc:Tinlet>    = <zn:HT-RATED-EDB>
            <hc:Jcu>       = <zn:CONDENSING-UNIT>
            <hc:Diversity> = Max(1., <zn:TERMINALS/ZONE>)
          END SELECT
        CASE (-2)  ! Preheat
          <hc:Capacity>  = -Abs(<sy:PREHEAT-CAPACITY>)
          <hc:Tinlet>    = <sy:PHT-RATED-EDB>
          <hc:Jcu>       = <sy:CONDENSING-UNIT>
          IF (<ah:Type> .eq. 4) THEN
            Jzn            = <ah:ControlZone>
            <hc:Diversity> = Max(1., <zn:TERMINALS/ZONE>)
          ELSE
            <hc:Diversity> = 1.
          ENDIF
        CASE (-1)  ! Space heat
          SELECT CASE (<hc:Level>)
          CASE (1)  ! Central AHU
            <hc:Capacity>  = -Abs(<sy:HEATING-CAPACITY>)
            <hc:Tinlet>    = <sy:HT-RATED-EDB>
            <hc:Jcu>       = <sy:CONDENSING-UNIT>
            IF (<ah:Type> .eq. 4) THEN
              Jzn            = <ah:ControlZone>
              <hc:Diversity> = Max(1., <zn:TERMINALS/ZONE>)
            ELSE
              <hc:Diversity> = 1.
            ENDIF
          CASE (2,3) ! Zonal AHU
            Jzn            = <hc:Parent>
            <hc:Capacity>  = -Abs(<zn:HEATING-CAPACITY>)
```

```
            <hc:Tinlet>    = <zn:HT-RATED-EDB>
            <hc:Jcu>       = <zn:CONDENSING-UNIT>
            <hc:Diversity> = Max(1., <zn:TERMINALS/ZONE>)
          END SELECT  ! hc:Level
        END SELECT

c              Coil heat exchanger
        <hc:Khx> = NewHX(<hc:Parent>, 3, 0., 0.001,
     &                   0.25, 0.80,               0,
     &                   0.45, 0.52, <#hc.CpAir>)

c              Links, lists
      CASE (205)
c              find cooling counterpart
        IF (<sy:HEAT/COOL-CONFIG> .eq. 1) THEN  ! common
          Kcc = Icl
          DO WHILE (Kcc)
            IF (   <cc:Type> .eq. -<hc:Type>     .and.
     &          <cc:SubType> .eq. -<hc:SubType>  .and.
     &           <cc:Parent> .eq. <hc:Parent>    .and.
     &            <cc:Level> .eq. <hc:Level>     .and.
     &              <cc:Jcu> .eq. <hc:Jcu>) THEN
              <hc:KccLink> = Kcc
              <cc:KhcLink> = Khc
              Exit
            ENDIF
            Kcc = <cc:Next>
          ENDDO
        ENDIF
      END SELECT  ! Mode
c
      Return

c              Message formats
11101 Format(14x,'Rfg Heat coil: ',8A4,' requires a heat'              /
     &14x,'exchanger effectiveness greater than 0.90. You must either' /
     &14x,'lower the supply air temperature, or increase the design'   /
     &14x,'saturated condensing temperature.'                          /
     &14x,'Tair In:',F5.1,'F  Tair Out:',F5.1,'F  SCT:',F5.1,'F'       )

      End  ! Coil_RfgHeat
```

APPENDIX 3. SIMULATION INPUT/OUTPUT

The DEER-based modified prototypical single-family home input and simulation files are quite large, and are included in a separate appendix to this report.

KEY TO FILES

INPUT FILES

The DOE-2 input files are the modified DEER-based single family prototypes, one for each climate zone. They are macro- and parameter-driven for thermostat schedules (5 schedules), and system type (5 system types).

SFM06.inp	CZ06
SFM08.inp	CZ08
SFM09.inp	CZ09
SFM10.inp	CZ10
SFM13.inp	CZ13
SFM14.inp	CZ14
SFM15.inp	CZ15
SFM16.inp	CZ16

INCLUDE FILES

Each of the above input files references the following include files, depending on the setting of the macros:

RESAC.inc	Conventional split-system AC/furnace, SEER-13 and SEER-16
RESHP.inc	Conventional split-system heat pump, SEER-13 and SEER-16
RESVRF.inc	Residential VRF system
SCE-TOU.inc	Utility-Rate components to generate TOU consumption

RUN GENERATOR FILES

The input files were driven by a spreadsheet-driven run generator, PRCMRUN.exe; written by Paul Reeves of the Partnership for Resource Conservation. The following files are used by this driver program:

VRFsfm.r22	A comma-delimited file that determines which input file will be used in a given run (SFM06.inp, etc.), and sets the macro and parameter definitions in that input file.
VRFsfm.grb	Specifies the DOE-2 simulation output reports and variables that will be grabbed by the PRCMRUN.exe post-processor

VRFsfm.prn	The comma-delimited file containing the output data for all runs captured in the post-processing.

A total of about 400 runs were generated for this study

DOE-2 OUTPUT FILES

For each input file and set of macros and parameters, the run generator produces building design language (bdl) output files (an echo of the input with diagnostic comments), and the simulation output (sim).

SFM06d01.bdl
  ^ climate zone, CZ06 etc.

SFM06d01.bdl
  ^ duct losses
- d 3% leakage on supply
- x no ducts
- h high leakage, 14% on supply

SFM06d01.bdl
  ^ the run number
- SEER-13 AC, 1- 5 for each of 5 thermostat schedules
- SEER-16 AC, 6-10
- SEER-13 HP, 11-15
- SEER-16 HP, 16-20
- VRF system, 21-25

SFM06d01.bdl
  ^ output
- bdl Building design language output
- sim simulation output

EXCEL POST-PROCESSING SPREADSHEET

The data from the simulation output reports (VRFsfm.prn) is imported into a spreadsheet, ResVRFResults.xls. Separate tabs are used to process the data and put it into the format used in the various tables in this document.

RawData	Imported from the VRFsfm.prn comma-delimited file
RawWgt	Weights the RawData for the 5 thermostats and stories
Weighted	Sums the weighted 5 thermostats of RawWgt
Normal	Normalization factors for tonnage
Wgt-Ton	Applies Normal to Weighted to normalize by tonnage
Summary	The SS-D, BEPU and TDV summary table
TOU	The electric consumption in SCE's TOU periods
Leakage	The table that presents leakage data
PartLoadBins	Not related to any of the above, part load bin data for the VRF outdoor unit in the 2-story north/south house