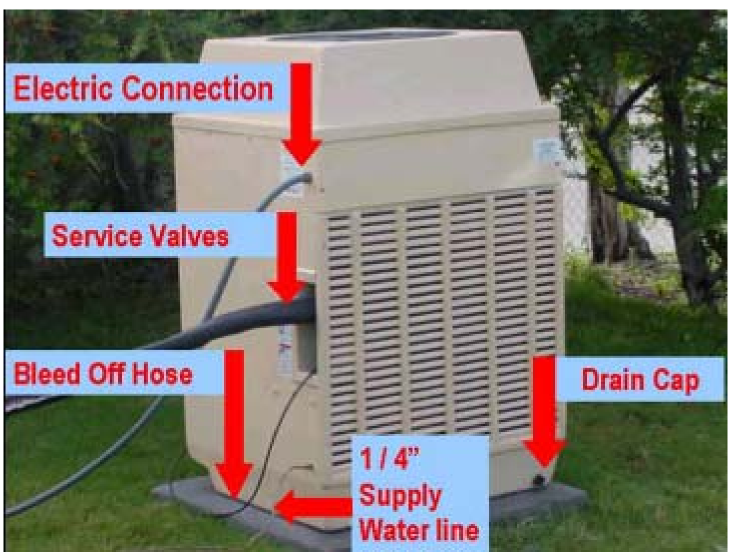
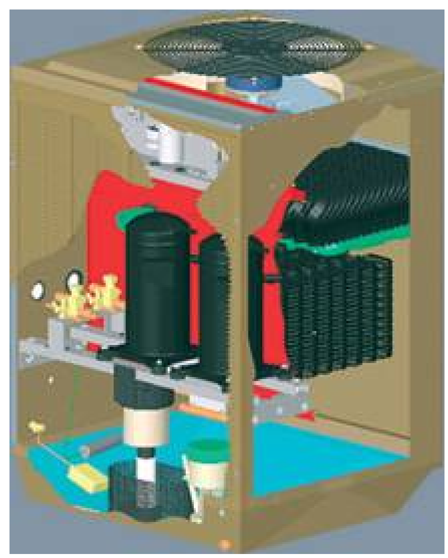
Final Report for Field Evaluation of PATH Technologies

March 2006

Comparative Evaluation of a Freus Evaporative Condenser with a High-Performance Air Cooled Condenser





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Executive Summary

In 2003, Steven Winter Associates conducted a field evaluation of the Freus evaporative condenser in a Las Vegas home with funding from the Partnership for Advancing Technologies in Housing (PATH). While performance benefits were demonstrated relative to an adjacent standard practice home, the installation was far from ideal due to sub-optimal specification of AC system indoor components. Specifically, low air handler fan airflow (less than 400 CFM per ton), an inefficient PSC air handler fan motor and a standard sized evaporator coil reduced system cooling efficiency. Specification of these indoor system components was particularly detrimental to sensible cooling efficiency. In Las Vegas and most of the Western U.S., there is no latent load due to infiltration for the vast majority of the cooling hours of the year. As has been recognized by researchers in the California Energy Commission funded hot-dry climate AC project (www.hdac-des-pier.com/project.html), AC systems that maximize sensible cooling are optimal for this climate zone. Increasing air handler airflow and evaporator coils surface area are two indoor equipment specification changes that can be used to increase sensible cooling efficiency.

In 2004, SWA specified and oversaw the installation of another Freus evaporative condenser in a home built by the Community Development Corporation of Utah in Magna, Utah. In this house, high performance indoor equipment optimized for sensible cooling was matched with the Freus condenser. This same indoor equipment was also specified in an adjacent house with a mirror image floor plan. The outdoor condenser in this second house was an efficient air cooled unit that resulted in a nominal SEER 14 combination rating. In August of 2005, SWA performed steady state Energy Efficiency Ratio (EER) testing with a portable data logger of the Freus and SEER 14 systems. The intent of this study was therefore to compare the performance of the Freus evaporative condenser to a high performance (SEER 14) air cooled AC system.

At mild outdoor conditions, there was not found to be a dramatic difference in performance between the two systems. This result may be explained by the fact that air cooled equipment tends to be optimized for mild outdoor temperatures (SEER ratings are performed at 82 ^{o}F outdoor temperature). The Freus realizes improved efficiency with evaporative cooling that is most significant at high outdoor air temperatures. Thus as outdoor temperature rises above 95 ^{o}F, the benefit of the Freus system compared to the SEER 14 system becomes more significant. Since the performance benefits of a Freus AC system compared to a SEER 14 AC system depend significantly on outdoor air temperature, climate, the availability of time of use electricity rates and utility financial incentives for peak demand reductions are all important factors to consider for any builder deciding between these two high performance AC system alternatives.

Overview of Test Houses

Architectural renderings of the side-by-side Community Development Corporation of Utah houses are presented in Figure 1 below. The floor plans of both houses are mirror images of each other. Both houses featured identical building envelope specifications. Both houses also featured the same indoor AC equipment.

Figure 1. Side-by-side Community Development Corporation of Utah Houses

The only significant difference between the two houses is the outdoor AC condenser. One house (Unit A) featured a 2-ton Freus evaporative condenser. The other house (Unit B) featured a 2-ton Carrier air cooled condenser.

Figure 2. Freus Evaporative Condenser (Unit A)

Figure 3. Air Cooled Condenser (Unit B)

AC System Characteristics

The characteristics of the AC systems tested in the two houses are presented in the tables below. The indoor components are identical in both cases and were specified in order to optimize system performance when combined with the two outdoor condensers being evaluated. The furnaces feature ECM fan motors, evaporator coils were oversized in order to maximize heat transfer efficiency and TXVs were specified in order to minimize the effects of over or under charging on system performance.

Table 1. Freus House System Components (Unit A)

Condenser	Furnace	Evaporator	Metering Device
Freus 2-ton 10M0327	Carrier Variable Speed MVP040-14	Carrier 3-ton CK5BXW036021AAAA	TXV

Table 2. Air Cooled System Components (Unit B)

Condenser	Furnace	Evaporator	Metering Device
Carrier 2-ton 38TRA 024340	Carrier Variable Speed MVP040-14	Carrier 3-ton CK5BXW036021AAAA	TXV

The ARI rating for the 2-ton Freus condenser matched with Carrier's 3-ton CK5B evaporator coil is EER 13.4 Btu/hr/watt. This standard ARI test is performed with outdoor conditions of 95 ^{o}F DB / 75 ^{o}F WB and indoor conditions of 80 ^{o}F DB / 67^{o}F WB. ARI does not provide a SEER rating for water cooled condensers. The ARI ratings for the Carrier condenser and furnace installed in Unit A is presented in the table below for different evaporator coil and accessory combinations.

Table 3. ARI Combination Ratings for Carrier 2-ton 38TRA 024340 with MVP040-14

	SEER	SEER w/ TXV	EER @ 95 ^{o}F DB
2-ton CK5B Evaporator coil	12	12	11.15
2.5-ton CK5B Evaporator coil	12.2	12.2	11.15
2-ton CK5B Evaporator coil w/ factory Time Delay Relay (TDR)	13	13	12.35
2.5-ton CK5B Evaporator coil w/ factory Time Delay Relay (TDR)	13.5	13.5	12.35

Since equipment is perfectly charged in ARI laboratory testing, a TXV does not improve SEER rating. The accessory that does significantly improve SEER and EER ratings is a factory installed Time Delay Relay (TDR). By keeping the air handler fan running for a fixed interval after the compressor shuts off, a TDR allows condensed moisture on the evaporator coil to re-evaporate into the supply airflow, resulting in "free" sensible cooling. In dry climates such as Utah, the resulting degradation in latent capacity is not a problem. ARI ratings are not available for an oversized 3-ton evaporator coil matched with the Carrier condenser in Unit B. However based on the ratings that are presented, it is clear that SEER increases with evaporator coil size. Therefore the equipment installed in Unit B can be considered to have a nominal SEER 14 rating with a TDR.

Performance Testing Protocol

SWA has developed a portable data logger system that can be used to conduct short term testing of HVAC system performance. In Magna, this system was used to measure the steady state EER of the split AC systems in prototype house Units A and B. For a steady state EER test, the portable data logger is used to continuously monitor both return air temperature and RH and average supply air temperature and RH. The duct return air and supply air sensors are connected to leads that plug directly into the data logger and require no on-site wiring. In addition, a differential pressure transducer hard wired to the data logger is used to monitor the output from a TrueFlow® pressure plate inserted into the return air plenum. A simple Campbell Scientific software program is used to calculate airflow rate based on the TrueFlow® pressure reading. The software program then combines airflow measurements with temperature and RH measurements in order to calculate sensible, latent and total cooling capacity. During the test, air handler power and condenser power are recorded with a hand held power meter and outdoor air temperature at the condenser is recorded with a hand held thermocouple meter. This test was designed in order to yield a relatively sophisticated "snap-shot" of AC system performance without the significant effort associated with the installation of long term monitoring equipment.

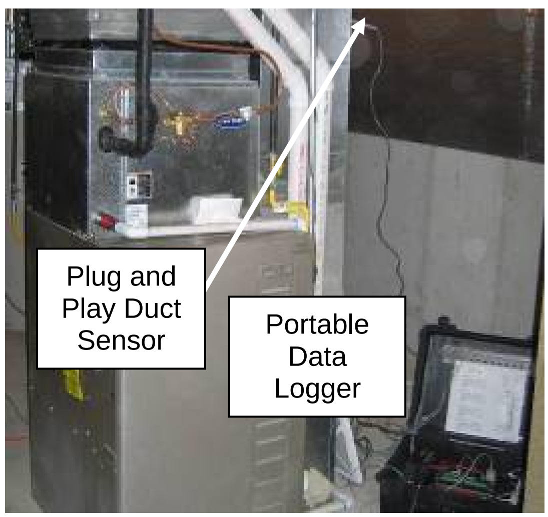

Figure 4. SWA Portable Data Logger for HVAC System Testing

It is important to distinguish the efficiency measurement provided by a steady state EER test and the efficiency measurement provided by a SEER rating. The SEER rating procedure accounts for both condenser performance and the performance of indoor AC equipment but is only applicable to air cooled systems. In addition, the SEER rating procedure is based on relatively mild outdoor conditions and relatively warm and humid indoor conditions compared to what is often encountered in the field. Finally, as a laboratory test, the SEER rating procedure assumes that equipment has been installed to manufacturer's specifications in regards to refrigerant charge and airflow across the evaporator coil. The steady state EER test is applicable to any AC system (air cooled or evaporatively cooled) and is a true measure of installed system efficiency. However since the steady state EER test does not take place in a controlled laboratory environment, indoor and outdoor environmental conditions cannot be controlled.

Performance Testing Results

The portable data logger system was used to take performance snapshots of the two AC systems on consecutive afternoons in August of 2005. In both cases, the furnace air handler fan pin settings were adjusted in order to investigate system performance at different airflow rates. The indoor and outdoor conditions on the two testing days are presented in the tables below. While the outdoor conditions were relatively similar on both days, the indoor conditions were significantly different. Before testing was performed, a kink in the liquid line between the Freus and the evaporator coil was repaired. This problem was due to a poor quality installation by the HVAC contractor and was unrelated to the Freus equipment itself. The restricted refrigerant flow reduced cooling capacity to less than 1-ton resulting in relatively warm and humid indoor space conditions in the house. As soon as this problem was addressed, the cooling capacity of the system increased to over 2-tons. However, as a result of the past performance of the equipment, the house was still relatively warm and humid during SWA's testing.

Table 4. Indoor and Outdoor Conditions for Freus System Testing on 8/10/05

Outdoor DB	Outdoor WB	Indoor Return Air DB	Indoor Return Air WB
88 ^oF	68 ^oF	81 ^oF	66 ^oF

Table 5. Indoor and Outdoor Conditions for SEER 14 System Testing on 8/11/05

Outdoor DB	Outdoor WB	Indoor Return Air DB	Indoor Return Air WB
85 ^oF	67 ^oF	73 ^oF	59 ^oF

In addition, one-time refrigerant line measurements were made with a Honeywell HVAC Service Assistant in order to check refrigerant charge levels.

Table 6. Refrigerant Measurements for Freus System on August 10, 2005

Time	Fan Mode	Suction Pressure	Suction Temp.	Liquid Pressure	Liquid Temp.	Liquid Sat. Temp.	Sub-cooling
4:30 PM	860 CFM	79 psia	64 ^oF	167 psia	80 ^oF	84 ^oF	4 ^oF
5:10 PM	1000 CFM	81 psia	64 ^oF	169 psia	80 ^oF	84 ^oF	4 ^oF

Table 7. Refrigerant Measurements for SEER 14 System on August 11, 2005

Time	Fan Mode	Suction Pressure	Suction Temp.	Liquid Pressure	Liquid Temp.	Liquid Sat. Temp.	Sub-cooling
1:20 PM	780 CFM	-	67 ^oF	197 psia	99 ^oF	95 ^oF	4 ^oF
1:54 PM	930 CFM	-	69 ^oF	202 psia	102 ^oF	97 ^oF	5 ^oF

The measured cooling capacity for the two systems is presented in the following two figures. The tables combine this cooling capacity information with one-time power measurements in order to calculate steady state EER. The Freus system was tested with a furnace air handler flow of 860 CFM (conventional ~400 CFM per ton) and then 1000 CFM (high fan speed). The nominal SEER 14 system was tested with a furnace air handler flow of 800 CFM (conventional ~400 CFM per ton) and then 920 CFM (high fan speed).

The 1000 CFM supply airflow mode increased Freus system EER by 3% compared to the 860 CFM mode. At the same time, the higher supply airflow mode decreased the nominal SEER 14 system EER by 4%.

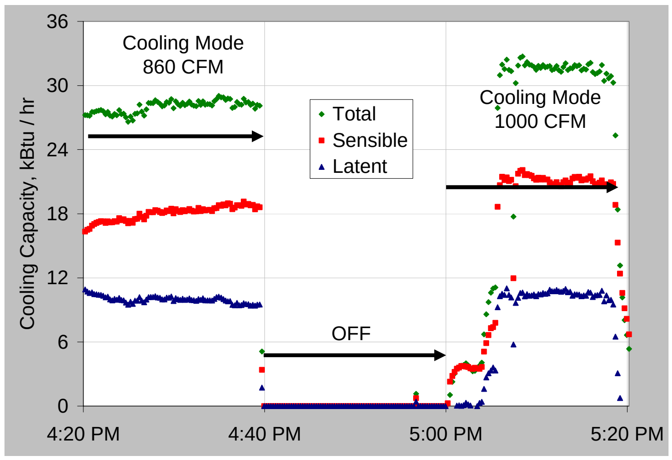

Figure 5. Freus System Cooling Capacity on August 10, 2005

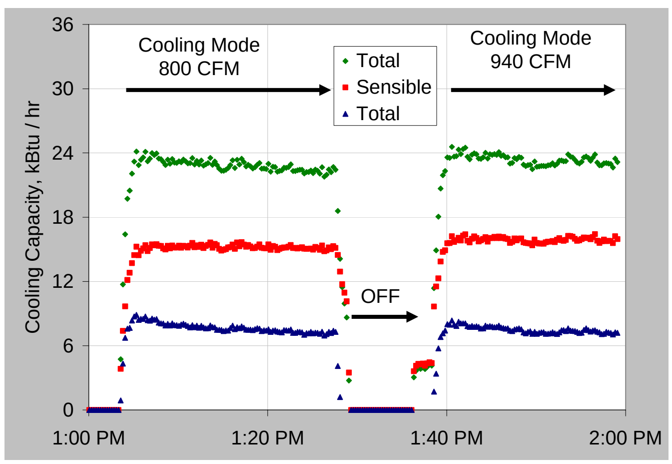

Figure 6. SEER 14 System Cooling Capacity on August 11, 2005

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Table 8. Steady State Performance of Freus System on August 10, 2005

Fan Mode CFM	Condenser Power Watts	Fan Power Watts	Total Power Watts	Total Capacity Btu/hr	Sensible Capacity Btu/hr	Latent Capacity Btu/hr	SHR	EER Btu/hr/W
860	1,850	290	2,140	28,000	18,100	9,900	0.65	13.1
1000	1,870	450	2,320	31,400	21,000	10,400	0.67	13.5

Table 9. Steady State Performance of SEER 14 System on August 11, 2005

Fan Mode CFM	Condenser Power Watts	Fan Power Watts	Total Power Watts	Total Capacity Btu/hr	Sensible Capacity Btu/hr	Latent Capacity Btu/hr	SHR	EER Btu/hr/W
800	1,700	230	1,930	22,900	15,200	7,700	0.66	11.9
920	1,730	360	2,090	23,400	15,900	7,500	0.68	11.2

Data Analysis and Discussion

While outdoor conditions for the testing of the two systems were similar, indoor conditions were relatively different and prevent a direct comparison between the measured EER results for the Freus system and the nominal SEER 14 system. The efficiency of any air conditioning system increases with warmer and more humid return air. Return air was significantly warmer and more humid in the Freus test house than in the SEER 14 test house. It is therefore necessary to normalize the measured EER results for the different return air conditions in the two test houses.

Performance data for the EER of their equipment over a wide range of indoor and outdoor conditions is readily available from Carrier. The red and blue dashed lines in Figure 7 represent Carrier's published EER performance data for the SEER 14 system in Unit B over a range of outdoor temperatures. The red dashed line represents this systems performance for the indoor air conditions in Unit B (59 ^{o}F return air wet bulb temperature). The blue dashed line represents this systems performance for the indoor air conditions in Unit A (66 ^{o}F return air wet bulb temperature). Upon comparison of the red and blue dashed lines, it is clear that increasing return air wet bulb from 59 ^{o}F to 66 ^{o}F increases the efficiency of the SEER 14 system by approximately 10%. The single red data point in Figure 7 represents the "snapshot" EER measurement of the SEER 14 system in Unit B at a 780 CFM airflow rate, an outdoor temperature of 85 ^{o}F and an indoor return air wet bulb temperature of 59 ^{o}F. The snap shot EER measurement is slightly lower than Carrier's published data for these Unit B test conditions (the red dashed line at 85 ^{o}F outdoor air temperature). It is reasonable to infer that the EER performance of the SEER 14 system at the Unit A indoor conditions would be slightly lower than the blue dashed line. EER measurement of AC system field EER tends to be lower than manufacturer's data because there is significantly less resistance to airflow (and therefore lower fan motor power draw) in ARI laboratory test rigs than what occurs in typical residential supply and return ductwork.

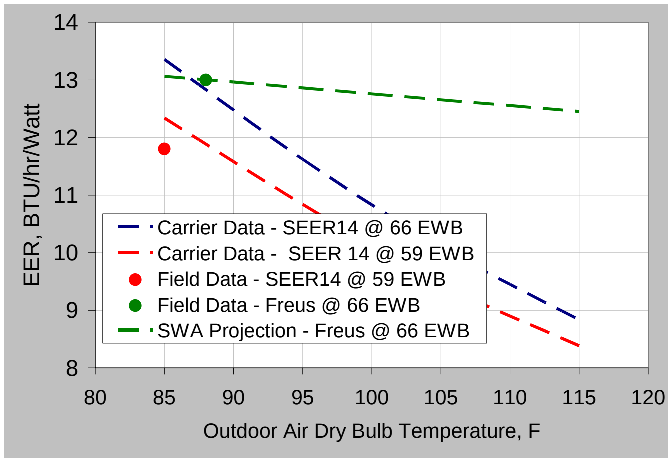

Figure 7. EER vs. Outdoor Air Temperature – Conventional Fan Mode ~400 CFM/ton

The single green data point in Figure 7 represents the "snapshot" EER measurement of the Freus system in Unit A with an 860 CFM airflow rate, an outdoor temperature of 88 ^{o}F and an indoor return air wet bulb temperature of 66 ^{o}F. The green dashed line represents the projected performance of the Freus over a range of outdoor conditions based on the Davis Energy Group's findings that in a dry climate, the Freus EER decreases by 0.20 Btu/hr/Watt for every 10 ^{o}F increase in outdoor air temperature[1].

Upon comparison of the two AC systems, it is evident that there is not a dramatic difference in performance between the Freus and SEER 14 system at mild outdoor conditions. This result may be explained by the fact that air cooled equipment tends to be optimized for mild outdoor temperatures (SEER ratings are performed at 82 ^{o}F outdoor temperature). The Freus realizes improved efficiency with evaporative cooling that is most significant at high outdoor air temperatures. Thus as outdoor temperature rises above 95 ^{o}F, the benefit of the Freus system compared to the SEER 14 system becomes more significant.

Figure 8 is identical to Figure 7 except that it includes field measured snapshot EER data at the higher fan speed mode. As was the case at the lower (400 CFM per ton) indoor airflow rate, the performance gap between the Freus and SEER 14 system is much more significant at higher outdoor temperatures.

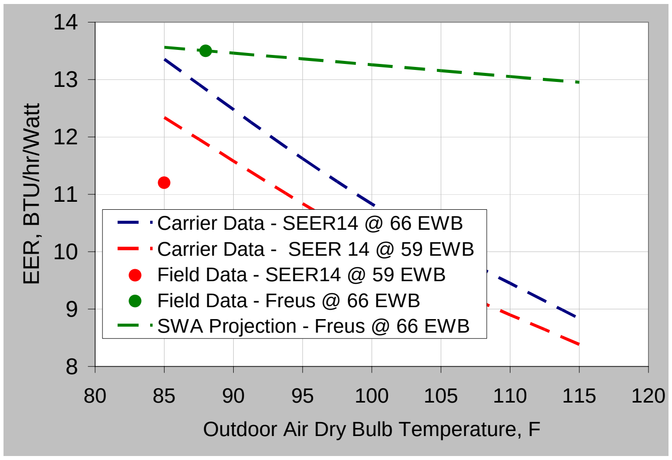

Figure 8. EER vs. Outdoor Air Temperature – High Fan Speed Mode ~500 CFM/ton

Since the performance benefits of a Freus AC system compared to a SEER 14 AC system depend significantly on outdoor air temperature, climate is an important factor to consider for any builder deciding between these two high performance alternatives. In a mild climate with few cooling hours above 85 ^{o}F, the choice of a Freus condenser over a high performance air cooled condenser may not be justified. In hotter climates, the Freus may make more sense as a viable alternative to significantly reducing a homeowner's electricity bills. The impact of the Freus on a homeowner's electricity bills will be even greater in the case of time of day electricity rates that charge more per kWh during summer afternoons. Finally, since the performance benefits of the Freus condenser are most significant during extreme outdoor conditions, financial incentives available from many utilities should be considered as a means of offsetting the first cost of this system.

[1] Advanced Residential Building Systems: Advanced Residential System Research. U.S. Department of Energy Building America Program. Task Order KAAX-3-33411-08.

Summary and Conclusions

SWA evaluated the efficiency of a Freus evaporative condenser compared to a high performance (SEER 14) air cooled AC system in two similar Utah houses. At mild outdoor conditions, there was not found to be a dramatic difference in performance between the two systems. This result may be explained by the fact that air cooled equipment tends to be optimized for mild outdoor temperatures (SEER ratings are performed at 82 ^{o}F outdoor temperature). The Freus realizes improved efficiency with evaporative cooling that is most significant at high outdoor air temperatures. Thus as outdoor temperature rises above 95 ^{o}F, the benefit of the Freus system compared to the SEER 14 system becomes more significant. Since the performance benefits of a Freus AC system compared to a SEER 14 AC system depend significantly on outdoor air temperature, climate, the availability of time of use electricity rates and utility financial incentives for peak demand reductions are all important factors to consider for any builder deciding between these two high performance AC system alternatives.