Pacific Gas and Electric Company

Emerging Technologies Program

Application Assessment Report # 0605

Evaluation of the Freus Residential Evaporative Condenser System in PG&E Service Territory

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Executive Summary

Residential evaporative condensers offer efficiency advantages over conventional air-cooled air conditioners by utilizing evaporative cooling to improve condensing unit performance. The evaporative cooling process results in a 30-40°F reduction in peak refrigerant condensing temperatures relative to a conventional air-cooled system, resulting in increasing demand savings as outdoor temperatures rise, as well as more stable cooling capacity and efficiency. Currently the only product on the market is the Freus system. As of 2006, Freus has sold approximately 6,500 units, with the bulk of sales in the southwestern United States. Major HVAC manufacturers have yet to embrace the technology as a viable option with two key reasons being concerns about maintenance and product longevity, as well as a strong desire to market products to larger national, not regional markets.

This study involved detailed monitoring at two residential sites in California's Central Valley during the 2007 summer. One site was a 1,750 ft^2 Sacramento-area production home built in the 1990's, and the second was a new 2,440 ft^2 energy-efficient custom home located in Redding, CA. Monitoring data from the sites were used to develop a performance algorithm for use with hourly house cooling loads generated by the MICROPAS hourly building simulation model. Freus full-year savings projections were developed relative to SEER 13 air conditioning for both new and retrofit house types under varying thermostat setpoint assumptions and non-thermal electrical usage assumptions. Several local HVAC contractors were also informally surveyed to assess their perceptions on the Freus unit in terms of product quality and expected lifetime, installation and commissioning requirements, and quality of manufacturer product literature and factory support capabilities.

<u>Conclusions</u>

Project conclusions include:

1. Simulation projections, based on project monitoring results, suggest cooling energy savings of 21-33% for typical Central Valley applications[1] relative to conventional 13 SEER air conditioning. Average savings are estimated at 725 kWh/year, resulting in typical homeowner cost savings of $203 annually. Coincident peak cooling demand savings over the Noon to 7 PM summer period range from 22-35%. Projected peak hour savings will be higher since the evaporative condenser performance advantage increases as outdoor temperatures rise. (Projected percentage savings for the new construction cases are higher since cooling loads are more concentrated in the hottest part of the day, but absolute savings are higher for the retrofit due to higher loads.)
2. Monitoring results from the Elk Grove site indicate that evaporative condensers reduce condensing unit peak demand by ~50% relative to a 9.5 SEER air-cooled unit monitored at the same site. This level of peak demand reduction is likely representative for retrofit applications, but is high for new construction applications where 13 SEER units are typically installed.

[1] Results were generated based on an 1,882 ft^2 single-story prototype house modeled both as a new Title 24 compliant case, as well as a 20 year old existing house with lower quality glazing, less ceiling insulation, and leakier attic ducts.

3. The two evaporative condensers monitored demonstrated less capacity and efficiency degradation with outdoor temperature relative to the 9.5 SEER air-cooled unit. On average, the reduction of evaporative condenser sensible cooling capacity, per degree of outdoor temperature rise, was only 18% that of the 9.5 SEER unit. At 90°F outdoor temperature, the evaporative condenser average sensible EER was 100% higher than the 9.5 SEER air-cooled unit; at 100°F the EER was found to be 112% higher.
4. Attention to design and installation detail is critical with evaporative condensers, as well as with conventional HVAC equipment. The Redding site demonstrated average full-season cooling EER's of 12.0, or 14% higher than the Elk Grove site. The Redding site installation had 23% higher supply airflow, installation of the liquid line/suction line refrigerant heat exchanger, and careful refrigerant charging, all of which contributed to the improved performance.
5. Contractor feedback suggests general satisfaction with the product, although improved factory support and parts availability are needed. Several of the contractors surveyed aggressively promote maintenance plans to their Freus customers. This is valuable for ensuring adequate performance, but the cost negatively impacts homeowner economics. One of the four contractors surveyed experienced component failures on one unit within one month of installation.
6. The technology is currently affected by many of the barriers common to emerging technologies. Low production volume equates to high equipment prices, discouraging introduction in the new construction market. A lack of a proven track record also raises uncertainty as to longer-term maintenance requirements and overall service life affecting both builder and homeowner confidence. Improved factory training of HVAC contractors is important for success of the technology. Despite these barriers, the technical potential of evaporative condensers is attractive. A viable manufacturing entity and utility incentives are the key ingredients for initial market success.
7. Water use for the two monitored sites ranged 41 to 54 gallons per day during the summer monitoring period. Water efficiency will become increasingly critical in the years ahead and should be carefully addressed.

Recommendations

The evaporative condenser technology is an important technology for PG&E since it offers both energy and peak demand savings. Unfortunately the technology is currently only available from one manufacturer who is struggling to get past the market barriers of first cost, demonstrated reliability, and manufacturer support and training. Given the uncertainty in the marketplace, it is not clear how aggressively PG&E should support the technology. Incentives, such as the $1,100 per unit offered by the Sacramento Municipal Utility District (SMUD), represent one approach to stimulating demand in the marketplace.

To support the evaporative condenser technology development in the future, PG&E should:

1. Continue discussions with Freus (and other potential manufacturers) to develop a mutually beneficially strategy to promote the technology. Support activities could include incentives, PG&E sponsored contractor training, and/or consumer education information.

2. Support a small Freus residential pilot installation that is monitored over an extended period (five or more years) to assess maintenance, reliability, and customer satisfaction issues. An alternative would be to track these issues on a subset of the currently installed Freus units.
3. Monitor and support statewide efforts to develop an integrated water-energy evaluation. This issue is important for evaporative technologies as to how water and energy are valued and will help in reaching consensus with water/environmental agencies on the benefits of energy-efficient water consuming appliances.

Project Background

Evaporative cooling is a powerful natural cooling process that achieves its greatest potential during hot (and dry) summer hours when the outdoor wet bulb depression[2] is greatest. Evaporative cooling can be used to either directly condition outdoor air for delivery to conditioned space, or indirectly cool the air, where the moisture addition doesn't negatively impact indoor comfort. Since indirect cooling processes do not affect indoor humidity levels, technologies that incorporate indirect cooling will likely have increased market acceptance. One such technology is residential-scale evaporative condensers. These systems utilize cooling tower technology to replace the typical air cooled condenser[3] with a system that generates refrigerant condensing temperatures lower than the outdoor dry bulb temperature. Reduced refrigerant condensing temperatures translate to higher cooling capacity and reduced compressor demand, resulting in higher operating efficiencies. Equally as significant as the improved performance is the resulting stable cooling capacity with outdoor temperature. Unlike air-cooled systems that lose cooling capacity at a rate of roughly 5% per ten degrees of outdoor temperature rise, evaporative condensers demonstrate much more stable performance. Since heat storm weather spells in California and other dry Southwestern climates are characterized by very low outdoor humidities, the relative benefit of evaporative condensers actually increases during heat storm events when the electrical grid is most heavily taxed.

The only residential evaporative condenser currently positioned in the marketplace is the Freus unit which first appeared in 2000. Freus is headquartered in Anthony, Texas and has produced approximately 6,500 by mid-2006 (Esource, 2006) with plans for sales of several thousand units in 2007. Mainstream HVAC manufacturers are well aware of the technology, but have shied away from it largely due to two reasons: First, a concern over long term reliability of HVAC equipment that introduces water and the associated scale deposits from evaporation, and second, a perception that the technology represents a product suited for regional, not national markets. The technology should expect increased attention in the years ahead based on the expected energy and peak demand savings of 30-40% touted by proponents.

Figure 1 provides a schematic of the Freus evaporative condenser. A water sump at the base of the unit collects water that is circulated from the sump to the water spray system. The condenser fan pulls air through the base of the unit past the sprayed condenser coil. The impact of improved condenser to water heat transfer and the powerful evaporative cooling effect contributes to the enhanced heat transfer and improved efficiencies. A product brochure can be found in Appendix A.

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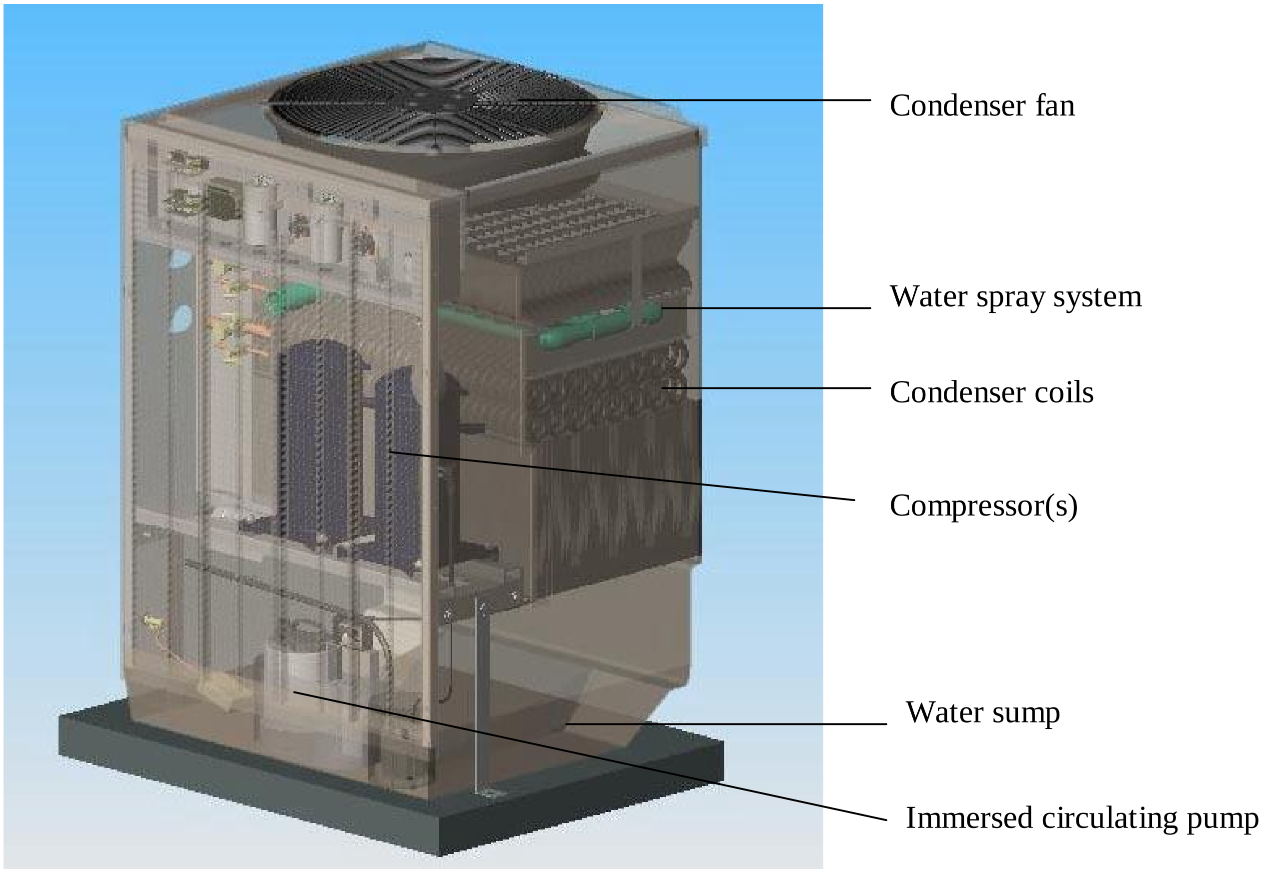
[2] The difference between dry bulb and wet bulb temperatures

[3] Typical residential air-cooled condensing units operate at refrigerant condensing temperatures 20-25°F higher than the outdoor dry bulb temperature.

Figure 1: Representation of Evaporative Processes on a Psychrometric Chart



Courtesy: Freus (http://www.freus.com/products.htm)

Market Issues

Evaporative condensers offer significant potential as an energy efficient alternative to air-cooled systems since they provide identical comfort to standard vapor compression systems. The key issues affecting market acceptance are:

Incremental installed cost: Freus is currently being manufactured in moderate volumes, but not at sufficient levels where manufacturing processes can be optimized for cost reduction. This scenario is common to many emerging technologies that struggle to achieve the market penetration necessary to favorably influence production costs. Current Freus pricing is comparable to high-end two-speed air conditioning systems (SEER 17+).

Overall economics: The Freus unit is more costly to purchase and install than conventional air-cooler equipment, but combined utility rebates and cooling operating cost savings can result in favorable homeowner economics. With PG&E's tiered residential electric rate structure, high consumption households in hot climates can realize savings with a Freus unit by reducing the marginal cost of their consumed electricity. Finding and targeting these homeowners is critical to early product success. Some form of incentives is needed to reduce the current high incremental cost.

Maintenance requirements: Additional maintenance (relative to air-cooled systems) is essential to maintain the Freus performance advantage over time, and to ensure system components do not fail prematurely. Hard water, common to many Central Valley cities, contributes to excessive scale build up in systems that evaporate water. Basic maintenance, performed either by homeowners or HVAC technicians, is essential for product reliability.

Long-term reliability: The Freus unit has been on the market since 2000, with most of the units sold over the past three or four years. With added maintenance requirements for the system, product reliability and service life are certainly real issues.

Education in the Marketplace: Builders, homeowners, and HVAC contractors need to be educated on the benefits and issues related to evaporative condensers. Contractors in particular need to understand the design, sizing, and installation issues related to the technology.

California Title 20 Appliance and Title 24 Building Standards Requirements

"Evaporatively-Cooled" air conditioners (with cooling capacities less than 65,000 Btu/hour) are required by the California Title 20 Appliance Standards to achieve a minimum EER of 12.1 at the standard rating conditions of 95°F dry bulb and 75°F wet bulb. Currently the six Freus models shown in Table 1 are listed in the Title 20 database[4].

In October 2006 the Energy Commission approved a compliance option[5] for evaporative condensers. The compliance option includes algorithms for modeling of evaporative condenser performance. Evaporative condensers provide Title 24 cooling compliance credits of roughly 30-40%, with savings increasing in the hotter climate zones.

Table 1: Current Freus Title 20 Listings

Model	Capacity (Btu/hr)	EER
10M0318	19,800	14.1
10M0327	26,000	14.5
10M0336	35,400	15.1
10M0342	41,500	15.1
10M0348	48,500	14.5
10M0360	59,000	14.5

Water Use Issues

In the past ten years evaporative condensers and other evaporative technologies have received increasing interest as concerns about energy efficiency and peak electrical demand has increased. At the same time, water agencies and environmental groups have started to express concerns

[4] http://www.energy.ca.gov/appliances/appliance/excel_based_files/central_air/
[5] http://www.energy.ca.gov/2006publications/CEC-400-2006-003/CEC-400-2006-003-SF.PDF

about products that consume water, especially during peak periods when water demand is high. This tension between water vs. energy efficiency is an important issue in dry Southwestern climates where water resources are limited, but evaporative technologies also have the greatest energy savings potential.

A compliance option approach proposed by Freus to the California Energy Commission under the Title 24 Residential Building Standards was delayed at least partially due to water use concerns expressed by the California Urban Water Conservation Council (CUWCC). These issues were finally resolved with the key evaporative condenser requirement being manufacturer certification that system water use does not exceed 9.0 gallons per ton-hour of cooling capacity. Water use is dependent on several factors, including the method used by the cooler to refresh water and prevent scale (mineral) build-up on evaporative media, outside air temperature and humidity, and system operating hours. The Freus application requires that an eligible system must use a pump down system to fully purge the sump on an eight hour run-time interval.

Product Warranties

The current Freus residential product warranty is 15 years on the fiberglass cabinet, ten years on the compressor and copper condenser coil, and five years on other parts. Labor is not included under the warranty terms. The warranty terms are consistent with conventional air-cooled equipment.

Prior Research

The Freus unit and its predecessors (the AC2 and AC2000) have been around for over ten years. Several recent studies are highlighted below:

"Freus Water-Cooled Air Conditioners", SMUD Customer Advanced Technologies Program Technology Evaluation Report. April 20, 2006.

This report provides an overview of how the Freus system works in contrast to conventional air-cooled air conditioners. The report also presents EER measurements completed on six Freus retrofit installations tested in 2003 (ranging from 7.7 to 11.8 at outdoor temperatures ranging from 91° to 101°F), all of which were determined to have insufficient supply air flow. Lower than expected EER's were partially attributed to installation defects. The study also summarizes results of field inspections of 16 units. The units were inspected for mechanical issues and also evaluate the level of scale deposits on the copper heat exchanger. Homeowner satisfaction surveys indicated general satisfaction with their systems. The report can be found at:

http://www.smud.org/education-safety/images-safety/cat_pdf/Freus%20(SMUD%20Report).pdf

"Evaluation Project for Freus Evaporative Condenser Air Conditioners", Prepared for SMUD by ADM Associates, March 2006.

This report presents energy use simulation projections for the Freus system relative to three conventional system alternatives: a standard 13 SEER unit, a "typical" efficiency existing unit (7 EER assumed), and a premium efficiency 16 SEER unit. Simulations were completed on a 1,600 ft^2 house in Sacramento. Simulation results indicate annual cooling energy savings of 50.5% (764 kWh) and SMUD operating cost savings of $95 a year relative to the standard 13

SEER unit. Survey responses from thirteen SMUD customers[6] with Freus units indicated the following:

- 70% of customers were satisfied with the performance of the Freus unit
- 60% would replace their current Freus unit with another Freus, upon system burnout
- 85% of the customers felt their unit was properly installed

"Projected Benefits of New Residential Evaporative Cooling Systems: Progress Report #2", NREL/TP-550-39342, October 2006.

This report presents field results and DOE2 simulation projections for the Freus unit in southwestern climates including Los Angeles, CA, Borrego Springs, CA and Las Vegas, NV. Simulations were completed on a 1,936 ft^2 energy-efficient house (R-23 SIP walls, R-42 ceiling, and high performance spectrally selective glazing). The Freus unit was simulated as a 13 SEER air conditioner coupled with a 100% effective condenser pre-cooler[7]. Projected Freus savings vs. a 13 SEER air conditioner ranged from 5% in Los Angeles to 21% in Borrego Springs, and averaged approximately 15%. http://www.nrel.gov/docs/fy07osti/39342.pdf

Objectives

The primary goal of this project was to develop a current assessment of the Freus evaporative condenser system in terms of field performance, projected homeowner economics, and market issues. To complete this work, Davis Energy Group completed the following tasks:

1. Identify candidate sites and secure monitoring access agreements with two field test sites in the Central Valley.
2. Develop a monitoring plan for collecting detailed 15-minute interval data at the sites.
3. Install and maintain data acquisition systems at each of the sites with a minimum of three months of mid-summer data collection.
4. Analyze field data.
5. Evaluate energy and peak demand impacts for evaporative condenser systems relative to conventional 13 SEER air conditioning on both new and retrofit house types.
6. Survey HVAC contractors and homeowners on acceptance, marketability, and level of manufacturer support.
7. Summarize project results.

Experimental Procedure and Results

The overall monitoring approach was developed to document the in-situ performance and comfort implications of the various tested technologies to assess their applicability to a broader range of the residential market. Specific monitoring objectives included measuring energy consumption, water use, and cooling efficiency of the system.

[6] Of the thirteen units, six were installed in 2003, five in 2004, and two in 2005.
[7] The 100% effective pre-cooler would adjust condenser air inlet temperature to be equal to the outdoor wet bulb temperature. The authors felt that this resulted in a conservative performance assessment for the Freus unit.

A monitoring plan was developed to satisfy these objectives. The monitoring plan specified equipment and procedures for installation of monitoring hardware. Individual monitoring systems were installed at each site to obtain, store, and transfer data. The installed monitoring and test equipment included:

- Data Electronics DT-50 dataloggers for temperature, power, flow, and relative humidity measurement
- On-site modems for downloading data to the host monitoring computer
- Solid state or RTD temperature sensors for indoor, outdoor, and supply air temperatures
- Solid state relative humidity sensors for supply air, return air, and outdoor air relative humidity
- Immersion thermocouple for sump water temperature
- True RMS power monitors
- Flow meters for measuring system water usage
- TrueFlow airflow measurement grid for one-time airflow measurement

Table 2 lists the types of sensors used and their performance specifications. All temperature and humidity sensors were received with factory calibration certificates from a NIST-traceable device.

Table 2: Sensor Specifications

Application	**Manufacturer/Model Number**	**Accuracy**
Indoor temperature	Automation Components, Inc. A-TTM100-(50-90)	±0.7 °F
Outdoor temperature and relative humidity	Automation Components, Inc. A/RH2-TTM100-(50-120)	±1.0 °F ±2% RH
Water consumption	ISTEC pulsing water meter #1702	±1.5%
Supply/Return air temperature and relative humidity	Automation Components, Inc. A/RH2-TTM100-(50-90)	±0.7 °F ±2% RH
Electrical energy usage	Rochester Instrument Systems True RMS power monitors #PM1001-240	±0.5%
Sump water temperature	Gordon 20CTOUH Immersion Thermocouple	±0.4%

The DT50 datalogger was programmed to scan all sensors every 15 seconds, and data were summed (or averaged) and stored in datalogger memory on 15-minute intervals. Datalogger memory was sufficient to store at least five days of data, so that loss of modem communications would not interrupt the stream of data. Low voltage power supplies were used to power dataloggers with battery backup to protect against data loss during power outages.

Data, in comma-delimited ASCII format, was downloaded daily to a central computer and screened using software to review data quality. Out-of-range data was noted and further investigated visually to determine whether a sensor or monitoring error exists or equipment has failed. Data review was performed using an EXCEL spreadsheet that allows for loading and graphing of all key monitoring parameters in a weekly time series format. Weekly performance reports were developed for each site and emailed to the PG&E project manager. The reports included plots of temperature, relative humidity, unit power, water consumption, effectiveness, and EER. A sample report is included in Appendix B.

Sensible cooling delivered by the evaporative condenser was determined on a 15 second interval as shown in Equation 1. Total cooling (sensible plus latent) was also calculated based on the change in air enthalpy[8] between the return airstream measurement and the supply air measurement (see Appendix B). Historically these enthalpy measurements have not always produced reasonable results due to sensor accuracy limits and the inherent variations in temperature and humidity that occur downstream of an evaporator coil. In this project we focused on the sensible cooling measurement as the key performance descriptor. For dry California climates, the impact of ignoring latent is typically small (<5%), since indoor conditions are generally not humid enough to result in significant dehumidification at the evaporator coil.

Equation 1: $Q_{sensible,\ clg}$ (Btu/15-second) = $\rho_{air} * C_p * (CFM/4) * (T_{return} - T_{supply})$

where: ρ_{air} = density of air (lb/ft3)

C_p = specific heat of air (Btu/lb-°F)

CFM = measured airflow (ft^3/minute)

T_{return} = return air temperature (°F)

T_{supply} = supply air temperature (°F)

The 15-minute $Q_{sensible,clg}$ summation was then divided by energy consumed over the 15-minute period to determine the sensible cooling Energy Efficiency Ratio, or EER.

Description of Monitoring Sites

Two monitoring sites were selected in California's Central Valley. The first site was located in Elk Grove, approximately 15 miles south of Sacramento. The Elk Grove house is a 1,750 ft^2 single-story home built in 1991. Walls were insulated to R-11 and the attic was insulated to R-19. The installed windows are standard dual pane clear glazing. The original air conditioning system was a 3-ton 9.5 SEER unit. This unit was previously monitored in the summer of 2005 under a DOE Building America sponsored project prior to installation of a 2.5 ton Freus unit in late July 2005.

[8] Enthalpy can be calculated based on air temperature and relative humidity.

The second house was located on the outskirts of Redding located at the northern end of the Sacramento Valley. This 2,440 ft^2 single-story custom house was completed in 2006. The house insulation work and HVAC installation was performed by a specialty energy efficiency contractor. The home includes a range of energy efficiency measures including:

- 2x6 exterior walls insulated to R-21 (with R-4.6 exterior sheathing)
- R-38 attic insulation
- High performance glazing (U-value = 0.33 and SHGC = 0.33)
- Ducts in conditioned space
- Condensing water heater (for space and domestic water heating)
- Compact duct system (air handler centrally located in the house)
- Photovoltaic system

The high level of energy efficiency incorporated in the house, as well as attention to installation details, allowed the installing contractor to aggressively size the Freus evaporative condenser at 1.5 tons, or 1,600 ft^2 per ton. The sizing of the Redding house system contrasts with the more typical Elk Grove sizing of 700 ft^2 per ton.

Project Results

Evaporative condensers utilize an evaporative process to enhance system performance. The evaporative cooling effect is dependent upon the "effectiveness[9]" of the process and the difference between the outdoor dry bulb and wet bulb temperature (the wet bulb depression). Because of the evaporative cooling effect, evaporative condenser performance is more strongly tied to outdoor wet bulb conditions rather than dry bulb. This is in contrast to standard air-cooled vapor compression equipment where outdoor unit performance is dependent largely on outdoor dry bulb temperatures.

Table 3 summarizes the monitoring data collected during the 2007 summer. Both datasets include data from June 15 through September 15th. For the full 2007 summer, Redding National Weather Service data indicates a slightly warmer than average summer (1838 cooling degree days vs. an average of 1739), while Sacramento data indicates a slightly cooler summer (1131 vs. 1243 average)[10].

The data in Table 3 shows comparable indoor temperatures at the two sites with average outdoor temperatures approximately three degrees higher in Redding. The 2.5 ton Elk Grove Freus unit achieved a supply airflow of 434 cfm/ton, or slightly higher than the industry standard level of 400 cfm/ton. The intent of the Redding HVAC design was to achieve maximum airflow through careful duct design and central location of the air handler to minimize duct run length to each room. The Redding system achieved 534 cfm/ton, resulting in increased sensible cooling

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[9] Effectiveness is used in describing the performance of evaporative coolers. Effectiveness represents the amount of the wet bulb depression, the evaporative cooler can achieve. For example, under 100°F dry bulb and 70°F wet bulb conditions, an 80% effective cooler would deliver 76°F air.

[10] During the summer there were a total of 38 days in Redding with outdoor temperatures at or above 100°F and ten days in Sacramento.

capacity, increased efficiency, and reduced latent cooling capacity[11]. Cooling energy usage ranged from 10.4 to 12.6 kWh/day, although "per ft^2" usage was roughly 13% lower for the home in the hotter Redding climate. The Redding peak cooling demand per thousand ft^2 of conditioned floor area was less than half that of the Elk Grove house, demonstrating the benefits of both quality construction techniques and precise HVAC sizing and installation.

Table 3: Monitoring Data Summary

	Elk Grove	**Redding**
Time Period	June 15 – Sept 15	June 15 – Sept 15
Average Indoor Temperature	75.8º	76.8º
Average Outdoor Temperature	76.3º	79.5º
Supply Airflow (cfm)	1087	801
Supply Airflow per ton (cfm/ton)	434	534
Condensing Unit kWh	729	846
Indoor Fan kWh	235	326
Total Cooling kWh (per ft^2)	964 (0.55)	1172 (0.48)
Total Cooling kWh / day	10.4	12.6
Peak Cooling Demand (kW)	2.5	1.7
Peak Cooling kW per 1000 ft^2	1.43	0.70
Operating hours / day	4.8	8.9
Total water use (gallons)	2543	3279
Gallons / operating hour	5.7	4.0
Gallons / ton-hour	3.5	2.8
Average EER	10.5	12.0

Figure 2 plots 15-minute interval data for the August 29th peak Elk Grove day. Outdoor temperatures ranged from a low of a 70 to a high of nearly 107°F. The Freus unit ran briefly during the night, followed by cycling operation from 10 AM to 4 PM. From 4:30 PM to nearly 8 PM, the unit ran continuously and maintained indoor temperatures at ~76°F. Sump water temperatures tracked outdoor wet bulb temperatures well (~10-15°F higher), nearly 20°F lower than the outdoor dry bulb temperature at peak. The peak system cooling demand was ~2.5 kW.

[11] In dry California climates, latent cooling is rarely needed to maintain comfort. Higher supply airflows result in warmer evaporator temperatures, increased sensible cooling, and reduced latent cooling.

Figure 2: Elk Grove House Peak Day Operation

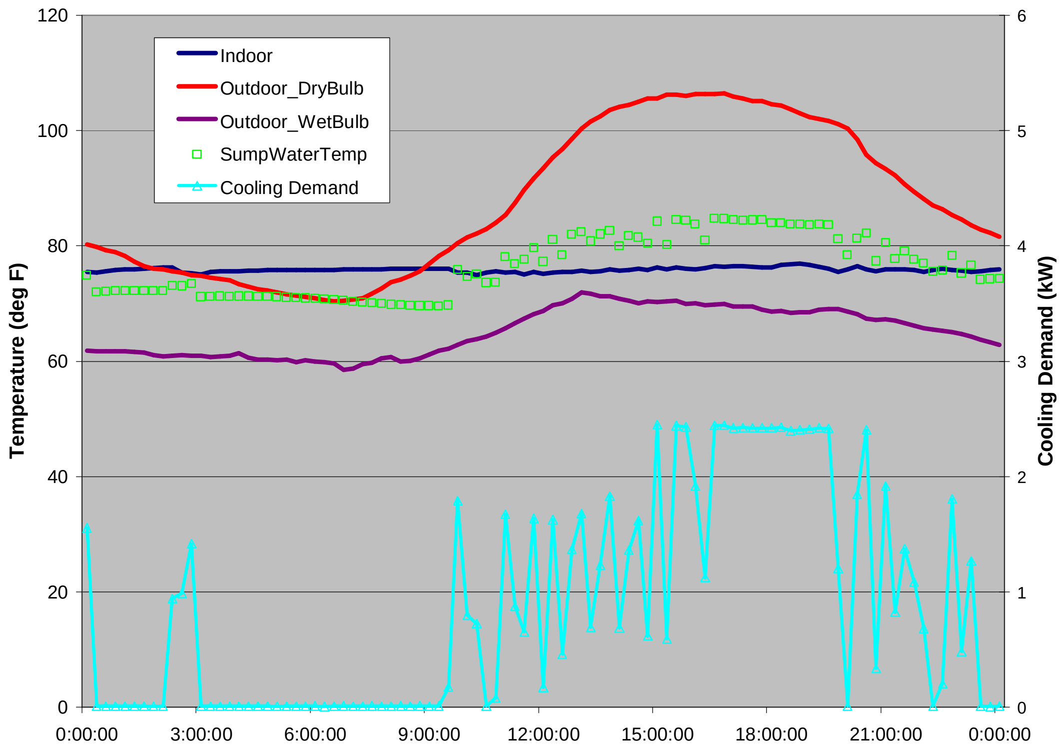


Figure 3 provides a similar plot for the peak Redding day (July 4th). Outdoor temperatures reached a low of 74°F and a peak of 112°F. The air conditioner cycled through the night to maintain the 78°F setpoint. Around 10 AM, the thermostat schedule entered the pre-cooling period[12] and the unit ran continuously until Noon. From Noon to 6 PM, the indoor setpoint is raised to 80°, and on this peak day, the system cycles to maintain the setpoint. At 6 PM, the setpoint is reduced to 76°F, and the unit runs continuously for 6 hours to pull down the indoor temperature. The peak cooling demand is an impressive 1.6 kW. The sump temperature is thirty degrees lower than the outdoor peak temperature, highlighting the efficiency advantage of the evaporative condenser.

Figures 4 – 6 plot all summer data collected where the Freus system operated for the full 15-minute data logging interval. The three plots show data for sensible cooling capacity, condensing unit power, and overall sensible cooling efficiency (EER). Data are shown for each of the two field sites, as well as 2005 data collected during pre-monitoring completed on the 9.5 SEER air-cooler unit. The air-cooled data is included to demonstrate the performance variations common to air-cooled equipment relative to the evaporative condenser.

[12] Since the house is on a PG&E time-of-use rate, the homeowner attempts to maximize delivery of his PV output during the Noon to 6 PM peak period. The pre-peak cooling setpoint from 10 AM to noon is 74°F in an attempt to pre-cool the house to allow it to coast through the upcoming peak period. This approach generally works well, but on the peak day the Freus unit is unable to effectively pre-cool.

Figure 3: Redding House Peak Day Operation

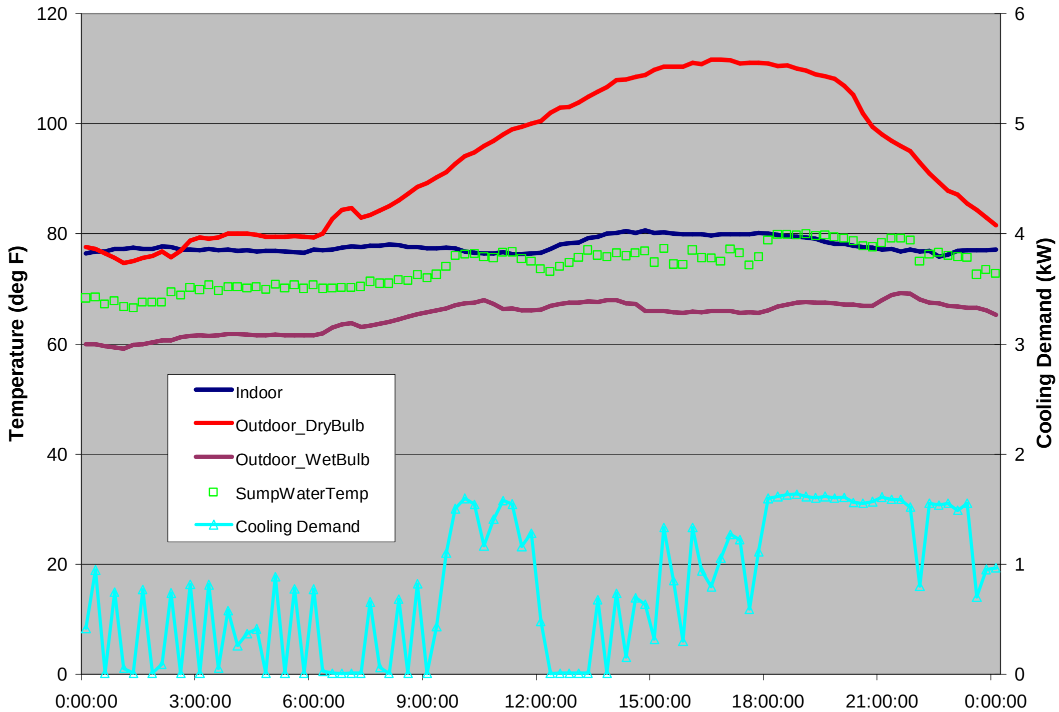


Figure 4 trend lines indicate a much greater rate of sensible cooling capacity reduction with outdoor temperature for the air-cooled unit than for either the Elk Grove or Redding Freus unit. The air-cooled unit trend line shows a 2.8% reduction in sensible cooling capacity between 90° and 100° relative to 0.8% for the Elk Grove Freus and essentially 0% for the Redding Freus.

Figure 5 plots condensing unit demand for the three system types. All three units demonstrate increasing demand with outdoor temperature, although the slope of the trend line for the air-cooled unit is 3 to 4 times as steep as that of the Freus units. The plot clearly shows the demand reduction potential that was achieved at the Elk Grove site with the air-cooled unit demand roughly double that of the Freus unit at 105°F outdoor dry bulb temperature.

Figure 6 plots efficiency in terms of sensible EER. The fifteen year old 9.5 SEER air-cooled unit originally installed at the Elk Grove home was found to only achieve sensible EER's in the 5 to 6 range[13]. Freus monitored EER's were found to be roughly twice as high as the 9.5 SEER unit. The Redding unit's efficiency advantage of ~15% over the Elk Grove unit is likely due to higher supply airflow per ton and to performing the installation detail of thermally connecting the refrigerant suction and liquid lines[14].

[13] The performance of older units often degrades due to improper refrigerant charge, evaporator coil fouling, etc.
[14] This process, described in the installation manual, allows for improved refrigerant system performance.

Figure 4: Comparison of Full-Load Sensible Cooling Capacity

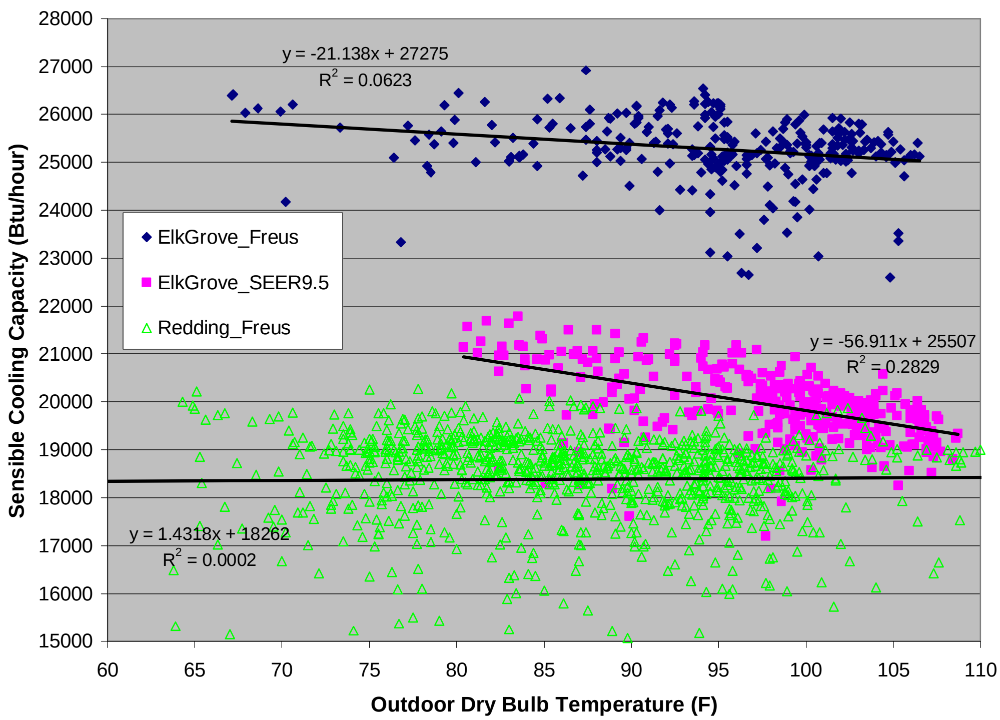


Figure 5: Comparison of Full-Load Condensing Unit Demand

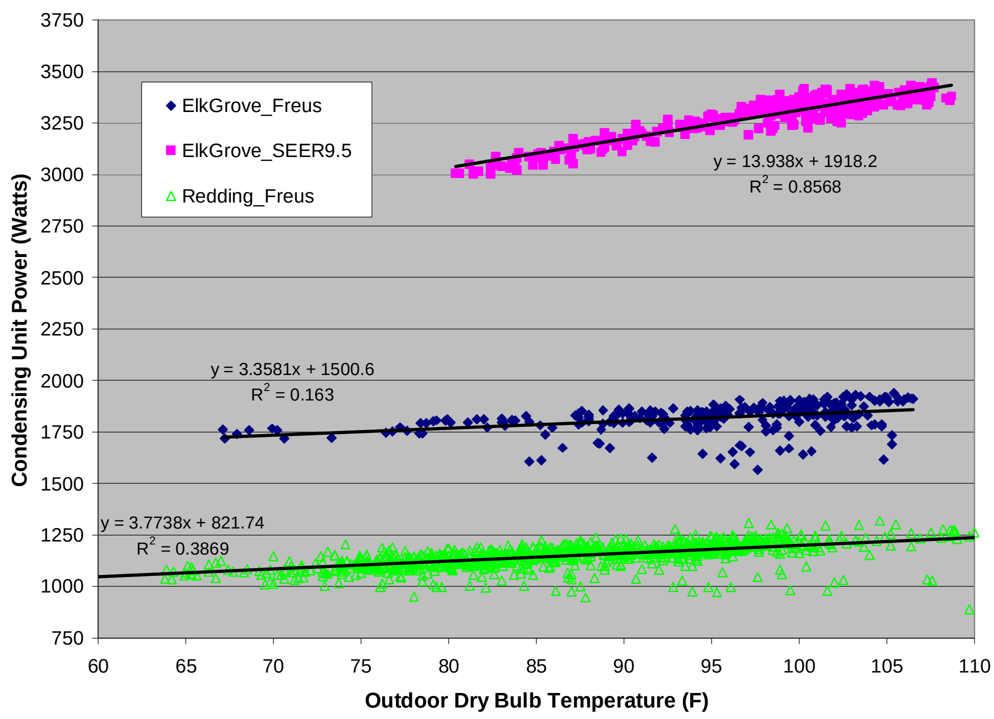
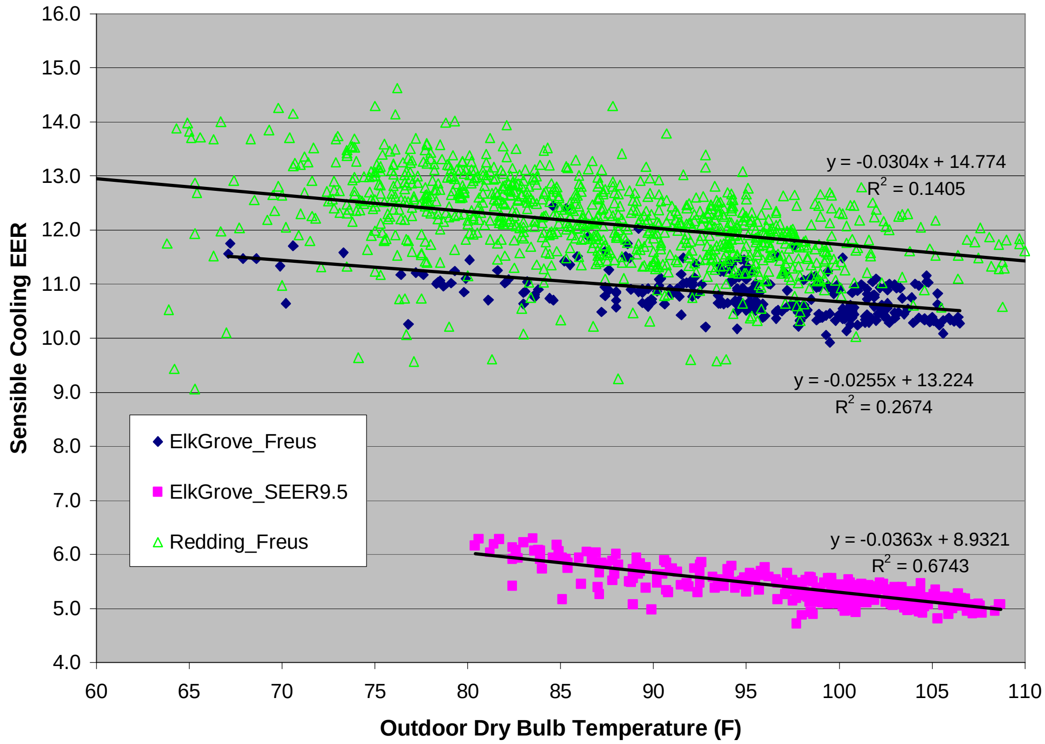


Figure 6: Comparison of Full-Load Sensible Cooling EER



Performance Projections

Simulation runs were completed to generate hourly cooling load profiles using the MICROPAS7 computer program for a prototypical 1,882 ft^2 single-story house. Simulations were completed for both new and retrofit cases for the three Central Valley climate zones (11-13) that represent the climates of Red Bluff, Sacramento, and Fresno, respectively. Table 4 summarizes key envelope characteristics of the new and existing house types. In addition to varying the envelope characteristics, thermostat setpoints and daily non-cooling electrical usage assumptions were varied to assess how these factors would affect savings estimates. Higher cooling setpoints reduce cooling loads and higher non-cooling electrical usage affects the marginal rate for electricity under PG&E's five-tiered residential rate E-1. Cooling thermostat setpoints of 76°F and 80°F were modeled for both house types; daily non-cooling energy use estimates of 10 kWh/day were assumed for the 80°F setpoint case, and 12 and 16.5 kWh for the 76°F setpoint case[15]. Hourly loads from the simulation runs were used to determine Freus energy consumption. The Freus efficiency relationship from the Redding site was used to characterize performance for any hour where the cooling load exceeded 75% of the nominal unit capacity. For hours where the cooling load was less than 75% of nominal, a 12.5% degradation was assumed to approximate equipment cycling effects.

[15] The varying non-cooling energy use estimates were tied to setpoint to represent higher overall consumption for homeowners that have lower cooling setpoints.

Table 4: Modeled House Characterization

Characteristic	New House	Existing House
Wall R-value	R-13, with R-4 exterior rigid insulation	R-13
Ceiling R-value	R-38, with attic radiant barrier	R-30, no attic radiant barrier
Glazing	Vinyl frame, dual pane, low SHGC	Vinyl frame, dual pane, clear glass
Ducts	Attic, R-6, tested low leakage (<6%)	Attic, R-4.2, not tested

Table 5 presents annual cooling energy use projections from the MICROPAS7 simulation model. Climate zone 12 (Sacramento) demonstrates considerably lower cooling energy use than the northern (CZ 11) and southern (CZ 13) portions of the Central Valley where both summer maximum and minimum temperatures are higher. Projected savings relative to 13 SEER air conditioning range from 21% to 33% with the higher percentage savings in the lower load situations (new house, higher setpoint) where cooling loads tend to be concentrated during the hottest part of the day when evaporative condenser performance benefits are greatest.

Annual electric costs under PG&E's standard E-1 rate are summarized in Table 6 for the modeled scenarios. Since E-1 includes a tiered rate structure, savings increase as usage moves into the more expensive tiers. Projected annual savings range from $21 to $425, or 4-24% of the annual electric bill. Clearly high electrical users will benefit most from the Freus due to the high marginal cost of the electrical energy saved.

Table 5: Projected Cooling Energy Use and Freus Savings

	76°F Setpoint			80°F Setpoint		
Climate Zone (CZ)	SEER 13 AC	Freus	Freus % Savings	SEER 13 AC	Freus	Freus % Savings
New						
CZ 11	2509	1742	31%	1449	968	33%
CZ 12	1386	998	28%	550	368	33%
CZ 13	3827	2711	29%	2578	1753	32%
Retrofit						
CZ 11	4078	3076	25%	2739	2025	26%
CZ 12	2814	2226	21%	1628	1250	23%
CZ 13	5539	4241	23%	3959	2971	25%

Table 6: Projected Annual Electrical Energy Costs and Freus Savings

	76°F, 12 kWh/day			76°F, 16.5 kWh/day			80°F, 10 kWh/day		
Climate Zone	Annual Base$	Freus$ Savings	% Bill Savings	Annual Base$	Freus$ Savings	% Bill Savings	Annual Base$	Freus$ Savings	% Bill Savings
New									
CZ 11	$920	$172	19%	$1208	$202	17%	$606	$76	13%
CZ 12	$702	$74	11%	$959	$87	9%	$480	$21	4%
CZ 13	$1250	$304	24%	$1563	$328	21%	$830	$175	21%
Retrofit									
CZ 11	$1314	$275	21%	$1645	$308	19%	$861	$160	19%
CZ 12	$1021	$155	15%	$1327	$169	13%	$648	$72	11%
CZ 13	$1701	$383	23%	$2080	$425	20%	$1159	$268	23%

PG&E is particularly interested in the peak demand implications of alternative cooling technologies such as the evaporative condenser. Using the hourly energy usage data, average peak cooling demand (defined as Noon to 7 PM average for the months of June through September) is tabulated in Table 7. Sacramento projected annual cooling use for the 13 SEER air conditioner is ~40% that of Fresno's and similarly Sacramento peak demand is less than half.

Table 7: Projected Coincident Peak Demand and Freus Savings

	76°F Setpoint			80°F Setpoint		
Climate Zone	SEER 13 AC	Freus	Freus % Savings	SEER 13 AC	Freus	Freus % Savings
New						
CZ 11	2.17	1.46	33%	1.44	0.95	34%
CZ 12	1.34	0.95	29%	0.60	0.40	33%
CZ 13	2.75	1.81	34%	2.20	1.44	35%
Retrofit						
CZ 11	3.12	2.28	27%	2.47	1.80	27%
CZ 12	2.41	1.87	22%	1.62	1.24	23%
CZ 13	3.54	2.54	28%	2.98	2.14	28%

Limitations in Applicability

The evaporative condenser technology has the potential to transform the residential air conditioning market since the system is a drop-in replacement for the existing air-cooled condensing unit. Unlike other efficient evaporative technologies, indoor comfort conditions are equal to or better than conventional air-cooled systems.

Incremental Costs

Pricing for the Freus unit appears to be fairly fluid. There have been general price increases over the past year or two, with apparently lower pricing levels in the Las Vegas market where sales activity is higher. Contractor pricing for a 3 ton Freus unit was found to be $2,560 in the Las Vegas market and $4,200 in the California market. The discrepancy is difficult to explain other than Freus may be targeting the Las Vegas market since an incentive of ~ $350/ton is currently in place.

Current California contractor pricing for the Freus unit is in the neighborhood of high-end two-stage cooling systems with SEER ratings of 16 to 20 and EER ratings ranging from 12 to 14. Freus incremental costs to the contractor are roughly $750 per ton relative to 13 SEER equipment. In today's market where Freus represents a niche product, incremental costs to the homeowner are likely in the $1,000 to $1,300 per ton range. SMUD is currently offering per unit Freus incentives of $1,100. These incentive levels should continue through 2008.

Product Service Life

A key factor affecting the ability of evaporative condensers to penetrate the market relates to how long the product will last and what level of maintenance will be needed over the years. To date, insufficient data exists to adequately address this issue. SMUD's experiences in the field suggest Freus has made modifications to correct problems that existed in earlier units[16]. The introduction of water to the condensing unit increases maintenance needs relative to conventional air-cooled equipment. In recognition of this increased maintenance need, Freus suggests semi-annual maintenance. Two of the Sacramento-area HVAC contractors contacted in this project offer maintenance agreements to the homeowners who purchase Freus units. Although most homeowners can perform the basic maintenance, a skilled HVAC technician should provide a better assessment of potential near term problems that may be corrected. The cost of an ongoing HVAC service contract does negatively impact homeowner savings, and in some cases may exceed the cooling energy savings.

Discussion

Contractor Feedback

Four Northern California HVAC contractors were informally surveyed to gather input on their perceptions of the Freus unit in terms of manufacturer support, installation and commissioning requirements, maintenance concerns, and overall product reliability. Results of the survey are summarized in Table 8. One of the contractors (Contractor "A") is a specialty HVAC contractor who strongly advocates a holistic approach to energy efficiency. Contractor "B" is a high volume HVAC contractor who focuses on the new construction production home market. The

[16] An example relates to cracked pump housings on units manufactured prior to 2005. In February 2005, Freus changed the design to stainless steel submersible pumps with flexible hoses to eliminate the vibration problem that contributed to the cracked pump housings.

remaining two contractors ("C" and "D") perform primarily retrofit and custom home installations. Contractors A and B have installed less than ten Freus units each, while C and D have each installed between 30 and 60 units.

Table 8: HVAC Contractor Survey Responses

Characteristic	Contractor Feedback
Manufacturer Instructions/ Service Manual Thoroughness	A. More information on equipment sizing and TXV sizing; better instructions on refrigerant charge and differences vs. conventional air-cooled equipment B. Missing service detail on water spray head access C. & D. Essentially complete
Additional Commissioning Procedures	A. Added complexity of refrigerant charging were identified. B. Properly setting the float assembly C. Charge multi-compressor units, one at a time D. Can't recall any
Equipment Sizing	A. Noted stable Freus capacity with outdoor temperature. Indicated ~1/3 sizing advantage vs. air-cooled. Oversizes indoor coil and air handler to achieve supply airflow of ~450 cfm/ton or more. Need to upsize TXV by ~ 1 ton. B. & C. Similar comments to A. D. Generally doesn't downsize relative to existing tonnage. Both C&D exclusively have done retrofits; both always replace indoor coil
Timely Factory Support	A. Has had bad factory support experiences (not very responsive) B. Hasn't needed support C. Recently improved D. Poor quality training from distributor
Maintenance Program	A. Homeowners provide basic maintenance at beginning/end of cooling season B. Offers a maintenance program with at an annual cost of $75-$85 C. Twice a year maintenance at a cost of $214 annually. Successful at getting virtually all customers to take the maintenance plan D. Twice a year maintenance at a cost of $135 annually. Roughly half of customers take the maintenance plan
Overall Reliability and Lifetime	A. Expects equipment to last 75% as long as a conventional system B. Will last longer than conventional C. & D. Same as conventional
Product/ Component Reliability	A. Pump and condenser fan failure in one unit within a month of installation B. & C. No problems. D. Doesn't like quality of the cabinet

Customer Feedback

One of the two homeowners (Elk Grove) returned a brief survey that was developed to assess their perceptions of the Freus technology, product quality, and overall satisfaction. Overall the homeowner was satisfied with the system performance and comfort that they experienced since the unit was installed in late summer 2005. They also commented on noticing the impact of the Freus unit on their summer utility bills relative to the SEER 9.5 air-cooled unit that was previously installed on their house. In terms of assessing the value of the technology, this particular homeowner indicated that they would be willing to pay $600 per ton incremental cost for the Freus unit.

The homeowner felt that in terms of overall product quality there was room for improved manufacturing capability. They felt the quality of the cabinet could be improved from both an aesthetic viewpoint and also that the top of the cabinet was slightly deformed and collected rainwater. One operational problem related to a defective wire running to the condenser fan that ultimately needed to be replaced.

The homeowner mentioned that they have performed all the basic maintenance on the unit to date. This includes sump cleaning and rinsing in the spring and fall. No additional maintenance has been performed on the unit to date.

Feasibility for Widespread Implementation

Evaporative condensers are an intriguing emerging technology since the quality of the cooling delivered to the indoor space is equal to, if not better[17], than conventional air-cooled air conditioners. The Title 24 Building Standards provide a significant energy credit that should be attractive to builders and also homeowners completing significant retrofits on their existing homes. If the Freus, or a competing product, can achieve lower costs and demonstrated reliability, the potential for significant market penetration is good. Current market barriers relate to cost (i.e homeowner economics), maintenance issues and service life, and presence of a viable manufacturing entity.

Estimated Market Size and Market Potential

According to the Residential Appliance Saturation Survey (RASS), 78% of homes built in California since 1996 have central air conditioning. In addition 53% of central air conditioners are older than nine years (RASS, 2004). For the retrofit market, expected condensing unit demand savings of ~50% (see Figure 5) are certainly achievable. Based on averaging the savings projections shown in Tables 5-7, estimated savings of 725 cooling kWh/year ($203/year) are projected relative to 13 SEER air conditioning for typical Central Valley households under the current PG&E E-1 electric rate. Coincident demand savings (average of Noon to 7 PM for the months of June through September) of 0.65 kW are also projected relative to 13 SEER air conditioning. Actual peak hour savings will be higher since the evaporative condenser performance advantage increases at higher outdoor temperatures.

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[17] Since evaporative condensers offer more stable cooling capacity at high outdoor temperatures, the quality of comfort during extreme heat spells should surpass conventional air-cooled systems.

Market Barriers and Installation Challenges

Freus is currently struggling against many of the market barriers common to emerging technologies. The key market barriers to greater implementation of evaporative condensers are incremental cost, long-term product reliability, and development of a robust manufacturer support network for contractor training, field support, and parts availability. The cost issue is the classic chicken-and-egg problem, since increased volume is needed optimize production capabilities and reduce supplier costs. Utility or Public Utilities Commission incentives extending over a multi-year period would be beneficial in spurring the market. Production homebuilders will move cautiously until they see evidence of demonstrated product reliability and favorable economics. As with any emerging technology, education for homeowners and HVAC contractors is needed to ensure that the expected performance is achieved in the field. Manufacturer training and certification of HVAC contractors would be a valuable step in properly training contractors on system sizing, coil and expansion valve selection, refrigerant charging, and other installation details.

Conclusions

Residential evaporative condensers offer significant benefits for California and other hot/dry climates. By effectively limiting refrigerant condensing temperatures through evaporative processes, significant energy and demand savings exist relative to 13 SEER air conditioning. In addition, evaporative condensers provide identical indoor comfort to standard air-cooled equipment, allowing the technology to be acceptable to a broader segment of the residential market than other efficient evaporative systems that create higher indoor humidity levels.

This project monitored two Freus installations in PG&E territory; completed simulation projections to assess energy, demand, and cost savings; and assessed contractor and homeowner satisfaction with the unit. Specific project conclusions include:

1. Simulation projections, based on project monitoring results, suggest cooling energy savings of 21-33% for typical Central Valley applications[18] relative to conventional 13 SEER air conditioning. Average savings are estimated at 725 kWh/year, resulting in typical homeowner cost savings of $203 annually. Coincident peak cooling demand savings over the Noon to 7 PM summer period range from 22-35%. Projected peak hour savings will be higher, as the evaporative condenser performance advantage increases as outdoor temperatures rise. (Projected percentage savings for the new construction cases are higher since cooling loads are more concentrated in the hottest part of the day, but absolute savings are higher for the retrofit due to higher loads.)
2. Monitoring results from the Elk Grove site indicate that evaporative condensers reduce condensing unit peak demand by ~50% relative to a 9.5 SEER air-cooled unit monitored at the same site. This level of peak demand reduction is likely representative for retrofit applications, but is high for new construction applications where 13 SEER units are typically installed.

[18] Results were generated based on an 1,882 ft^2 single-story prototype house modeled both as a new Title 24 compliant case, as well as a 20 year old existing house with lower quality glazing, less ceiling insulation, and leakier attic ducts.

3. The two evaporative condensers monitored demonstrated less capacity and efficiency degradation with outdoor temperature relative to the 9.5 SEER air-cooled unit. On average, the reduction of evaporative condenser sensible cooling capacity, per degree of outdoor temperature rise, was only 18% that of the 9.5 SEER unit. At 90°F outdoor temperature, the evaporative condenser average sensible EER was 100% higher than the 9.5 SEER air-cooled unit; at 100°F the EER was found to be 112% higher.
4. Attention to design and installation detail is critical with evaporative condensers, as well as with conventional HVAC equipment. The Redding site demonstrated average full-season cooling EER's of 12.0, or 14% higher than the Elk Grove site. The Redding site installation had 23% higher supply airflow, installation of the liquid line/suction line refrigerant heat exchanger, and careful refrigerant charging, all of which contributed to the improved performance.
5. Contractor feedback suggests general satisfaction with the product, although improved factory support and parts availability are needed. Several of the contractors surveyed aggressively promote maintenance plans to their Freus customers. This is valuable for ensuring adequate performance, but the cost negatively impacts homeowner economics. One of the four contractors surveyed experienced component failures on one unit within one month of installation.
6. The technology is currently affected by many of the barriers common to emerging technologies. Low production volume equates to high equipment prices, discouraging introduction in the new construction market. A lack of a proven track record also raises uncertainty as to longer-term maintenance requirements and overall service life affecting both builder and homeowner confidence. Improved factory training of HVAC contractors is important for success of the technology. Despite these barriers, the technical potential of evaporative condensers is attractive. A viable manufacturing entity and utility incentives are the key ingredients for initial market success.
7. Water use for the two monitored sites ranged 41 to 54 gallons per day during the summer monitoring period. Water efficiency will become increasingly critical in the years ahead and should be carefully addressed.

Recommendations for Future Work

The evaporative condenser technology is an important technology for PG&E since it offers both energy and peak demand savings. Unfortunately the technology is currently only available from one manufacturer who is struggling to get past the market barriers of first cost, demonstrated reliability, and manufacturer support and training. Given the uncertainty in the marketplace, it is not clear how aggressively PG&E should support the technology. Incentives, such as the $1,100 per unit that SMUD is offering, are certainly one approach that will stimulate demand in the marketplace.

To support the evaporative condenser technology development in the future, PG&E should:

1. Continue discussions with Freus (and other potential manufacturers) to develop a mutually beneficially strategy to promote the technology. Support activities could include incentives, PG&E sponsored contractor training, and/or consumer education information.

2. Support a small Freus residential pilot installation that is monitored over an extended period (five or more years) to assess maintenance, reliability, and customer satisfaction issues. An alternative would be to track these issues on a subset of the currently installed Freus units.
3. Monitor and support statewide efforts to develop an integrated water-energy evaluation. This issue is important for evaporative technologies as to how water and energy are valued and will help in reaching consensus with water/environmental agencies on the benefits of energy-efficient water consuming appliances.

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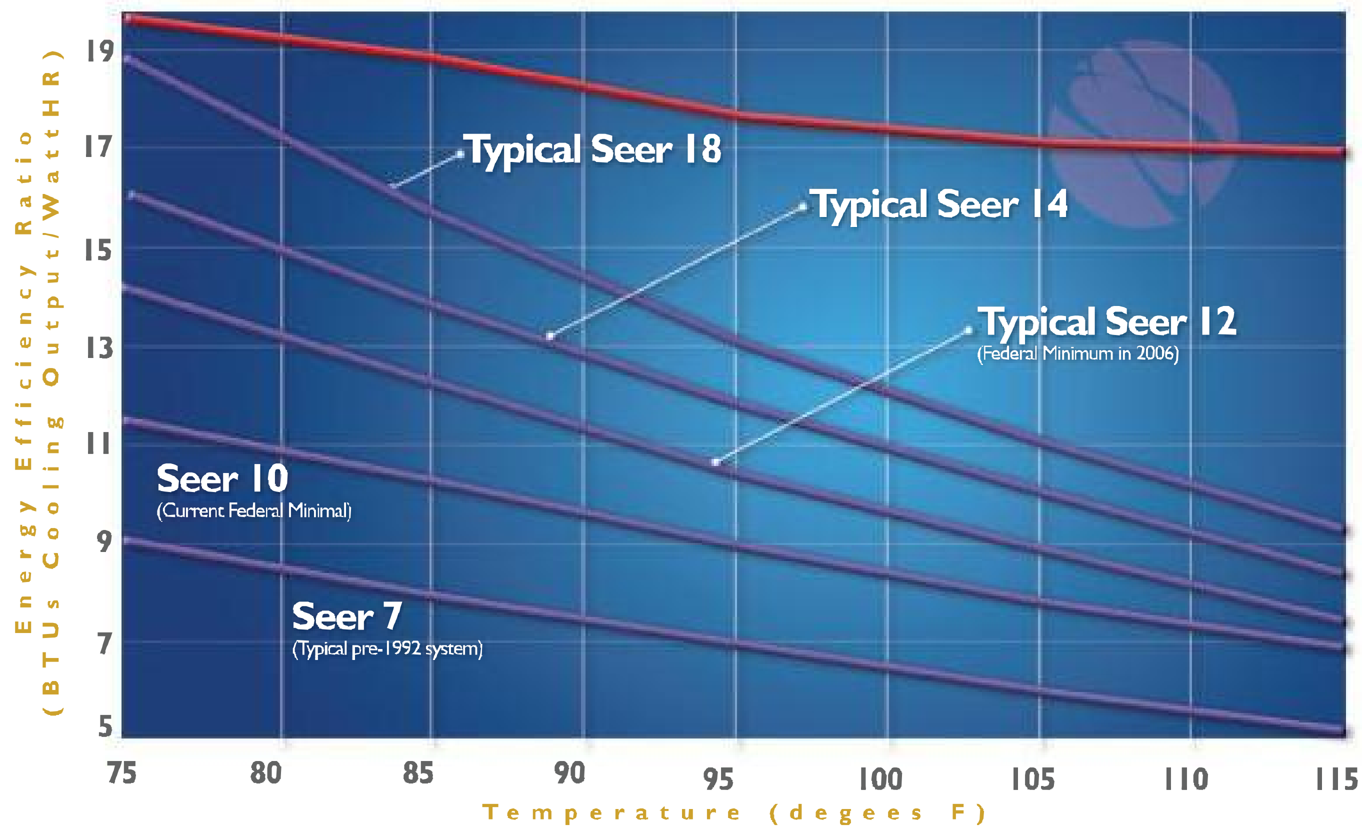
Appendix A:

Freus Product Brochure

ULTIMATE EFFICIENCY

UP TO 250% MORE EFFICIENT
THAN EXISTING 7 EER UNITS (AT 105 F/65WB)

AIR CONDITIONING ENERGY EFFICIENCY RATIO
FREUS WATER COOLED VS. AIR COOLED



FREUS WATER COOLED VS. AIR COOLED UNITS

Air cooled Units are rated in SEER, which is a cooling efficiency standard at lower outside air temperatures (82 degrees). The Freus water cooled units are rated in EER, an efficiency standard at higher outside temperature (95 degrees). The graph above demonstrates that air cooled units have a big reduction in efficiency and capacity at higher temperatures. Compare the efficiency of Freus water cooled vs. air cooled for the climate you live in and what will be best for you home.

WATER COOLED DOMINATES IN LARGE BUILDINGS

Using water for refrigerant heat transfer is a quantum step more efficient than using hot air. A gallon of water absorbs about 3,500 times more heat than a gallon of air (per degree of heat added). This allows the Freus water cooled unit to be more compact and have higher efficiencies. Water cooled technology is dominate in large commercial buildings due to the energy savings and now Freus brings those efficiency advantagbes to residential and light commercial applications at an affordable price.

SUPERIOR LIFESPAN

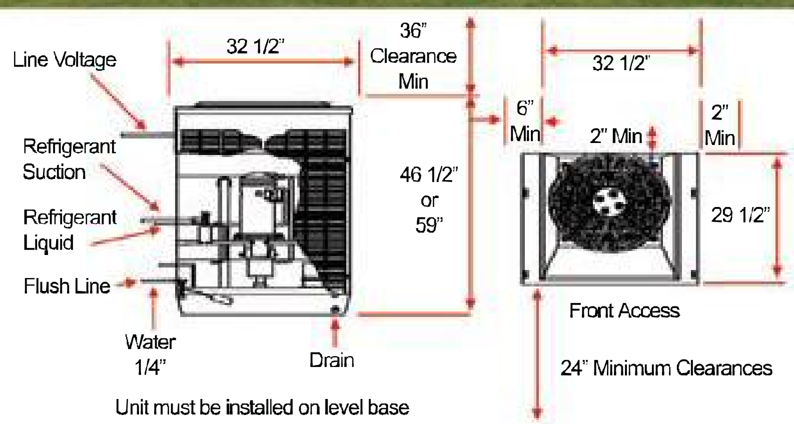
1. Coated Fan Grille.
2. One piece Fiberglass cabinet.
3. Commercial PVC Drift Eliminator.
4. Large 1" PVC distribution piping.
5. Low pressure clog-resistant 1/4" syntheyic spray nozzles (not shown).
6. Intertwined Helical Condenser Coil is made of commercial evaporative condenser grade air conditioning copper, and coated to add a corrosion barrier. The double helix shape allows the coils to expand and contract with normal operating temperature changes thereby inherently shedding mineral deposits. It is so superior it carries a 10 Year limited Warranty* versus just 1 year on most residential air cooled condenser coils.
7. Sloped Sump to aid in cleaning and to aid in prevention of freeze damage to the sump.
8. Air Cooled totally enclosed PSC energy efficient pump with a large area intake screen to keep debris out of the spray nozzles.
9. Brass Drain with hose threads (fits a garden hose).
10. Flush Pump - drains minerals and debris to automatically keep the sump cleaner.
11. Magnesium Anode - provides sacrificial corrosion protection.
12. Float Valve - maintains the water sump level.
13. Refrigerant Filter Dryer.
14. Copeland Scroll Compressor (s).
15. Zone Systems - One to three systems can share the evaporative condenser cabinet. Each system has its own independent (a Compressor, b) Refrigerant Circuits/ Valves/ Dryer, and c) Electrical/ Controls. Any system calling for cooling will turn on the fan and pump which are shared by all systems.
16. Sweat Type Service Valves.
17. Electrical Panel.
18. Louvered Intake - the louvers angle down to shed rain/ block sunlight. The intake is screened to keep out debris

15 YEAR LIMITED WARRANTY

BUILT FOR DURABILITY AND EASY MAINTENANCE!

Service and maintenance are simple. Removal of the front access louver provides direct access to its interior. Simply flush the basin clean with a garden hose. The Freus owner's manual includes a 30 year maintenance schedule which shows the expected life of various components in residential operation. Most air cooled units are out of warranty in one to five years and don't even provide a maintenance schedule!

* See warranty for details



ONE TO THREE UNITS IN ONE

The compact size of a Freus unit fits in a 29.5" x 32.5" footprint within 2" from the building, which can be 75% less than the requirements of air cooled units. The Freus standard cabinet allows for (1 - 2 systems) up to 7 tons and stands 46.5" high. The Freus tall cabinet allows for (2 - 3 systems) up to 10 tons and stands 59" high.

PREMIUM COMFORT

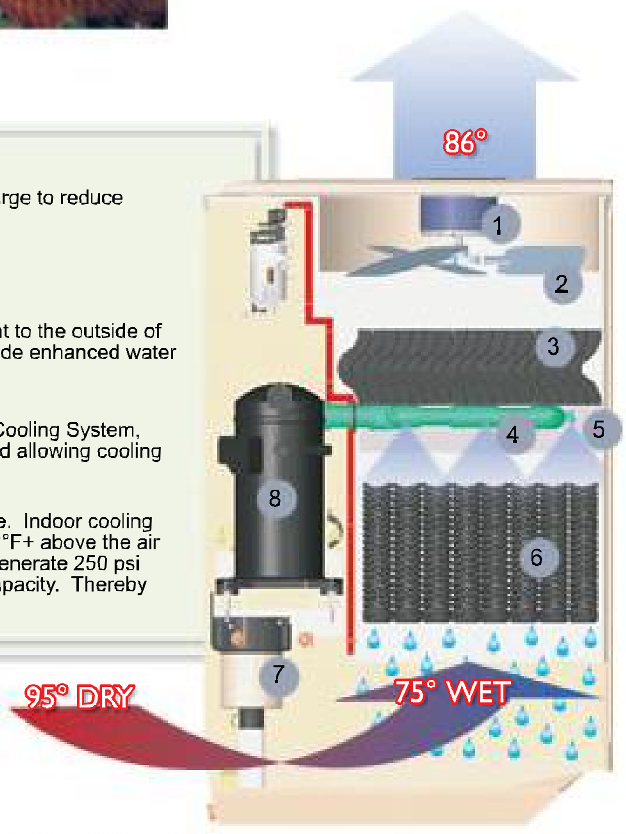
Air Cooled Condensers can lose 20% of their capacity as outdoor temperature increases from 70°F to 100+°F compared to only about 4% for a Freus™ system.

This capacity change forces air cooled units to be sized for hot temperatures and cycle to maintain temperature during milder conditions, causing indoor drafts with hot spots, cold spots and drastically reduced dehumidification performance (in other words - fluctuating comfort).

Freus' consistent capacity allows indoor air volume sizing closer to load requirements, with higher CFM in arid locations to maximize high temperature capacity without overheating the compressor lower CFM in humid climates to optimize dehumidification without freezing the coil. This leads to consistent dehumidifica tion performance, and provides premium comfort

1. Titally Enclosed High Efficiency Condenser Fan Motor
2. Efficiency optimized fan blades in a tubaxial volume with vertical discharge to reduce noise.
3. Commercial Grade Low Pressure Drift Eliminator.
4. Large 1"PVC distribution piping.
5. Low pressure clog-resistant 1/4" synthetic spray nozzles.
6. Intertwined Helical Condenser Coil which centrifugally throws refrigerant to the outside of the tube to enhance heat transfer. The tubes are offset spaced to provide enhanced water flow contact and superior refrigerant to water heat transfer.
7. Air Cooled totally enclosed PSC energy efficient pump.
8. One to three separate Copeland Scroll Compressor(s) - One for each Cooling System, can share the evaporative condenser cabinet, thereby saving space and allowing cooling to be directed only where needed.

Summary:
Compressing refrigerant simultaneously raises its pressure and temperature. Indoor cooling requires expelling heat outdoors and achieving a refrigerant temperature 20°F+ above the air or water cooling the refrigerant. With 95°F air a "dry" condenser needs to generate 250 psi while a "wet" condenser only needs 180psi to generate the same cooling capacity. Thereby the compressor in the "wet" Freus system uses remarkably less power



FREUS REQUIRES LESS POWER, LAST LONGER

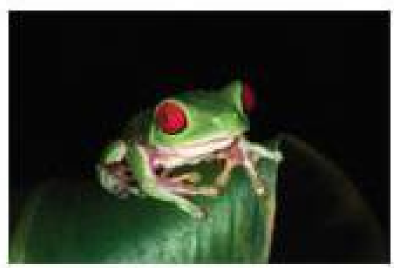
The Freus water cooled units operate at much lower pressures and temperatures than air cooled units. Motors and compressors that operate at lower pressures and temperatures require less power and last longer

BENEFITS FOR YOUR HOME

Freus™ offers 1 - 3 systems in one cabinet with low noise levels to make it almost invisible so your home's beauty shines forth.

CONSERVE OUR NATURAL RESOURCES

Freus™ saves energy and water to provide a responsible way to get the home cooling comfort you want, and the utility savings you need, while being responsible to our environment. Energy savings has a positive impact on global warming, and reduces the demand placed on our utility companies to help keep electric rates and pollution down.



Patents **#5,832,739 #5,992,171**
Designed and Built in North America.

Due to Freus' policy of continuous product development and improvement, we reserve the right to change design specifications without notice. See your Dealer for important energy cost and efficiency information.

freus™ AIR CONDITIONING

Freus Inc.
P.O. Box 3048
Sunland Park, N.M. 88063
www.freus.com

ULTIMATE AIR CONDITIONING

ULTIMATE EFFICIENCY

SUPERIOR LIFE SPAN

EXTREMELY QUIET

freus™

AIR CONDITIONING

Appendix B:

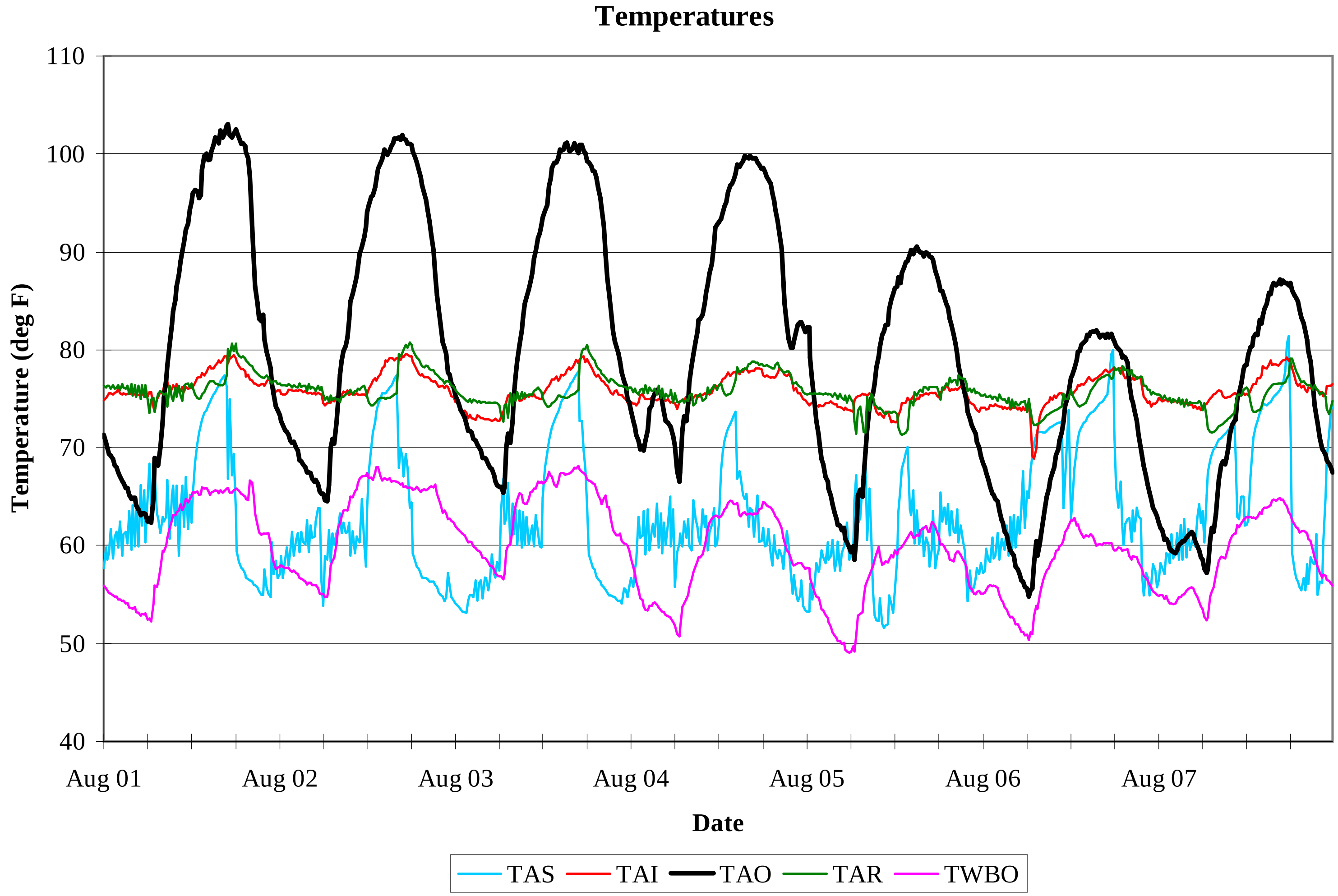
Sample Weekly Data Report

Start Date: August 01 00:00 Site:

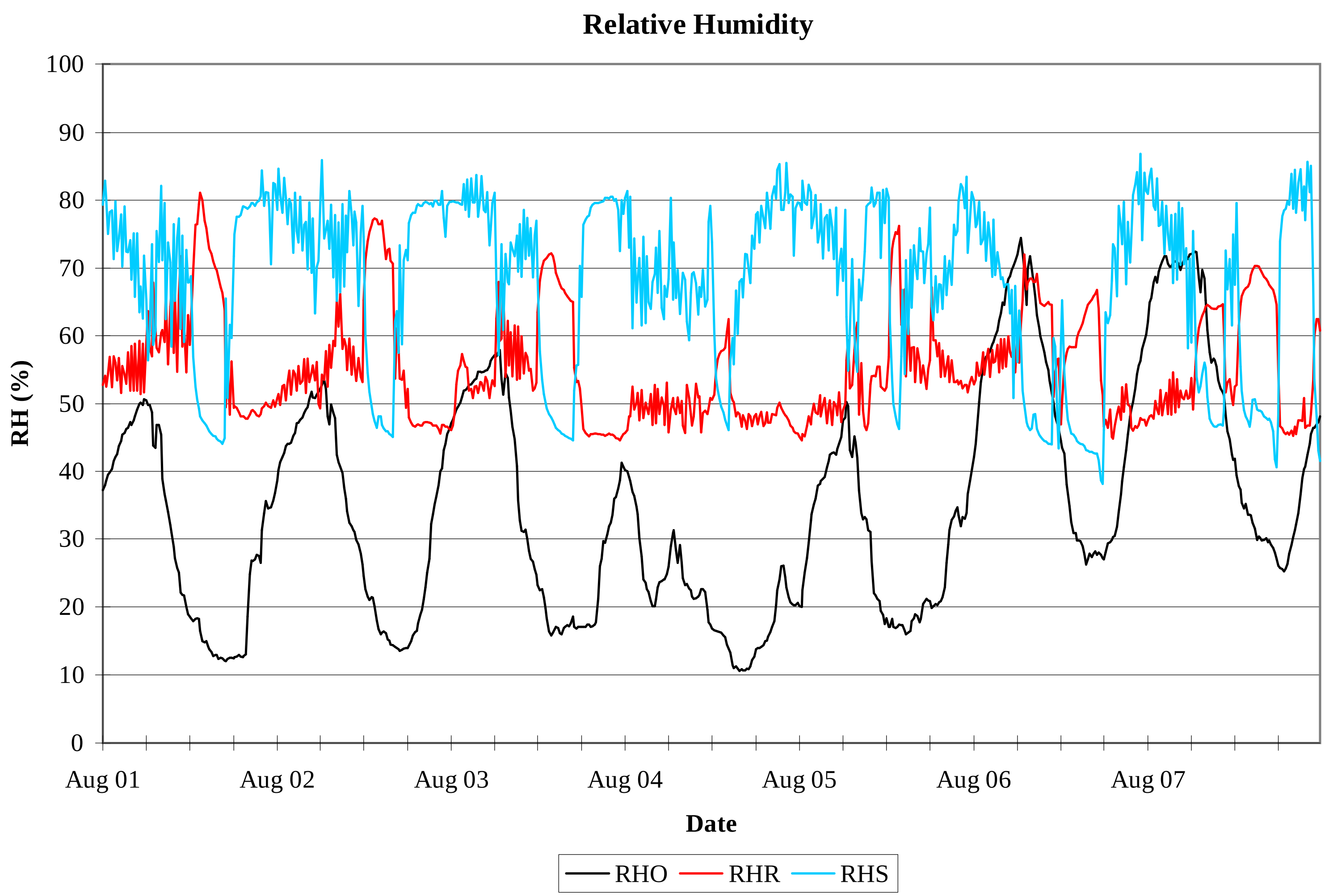
Stop Date: August 07 23:45

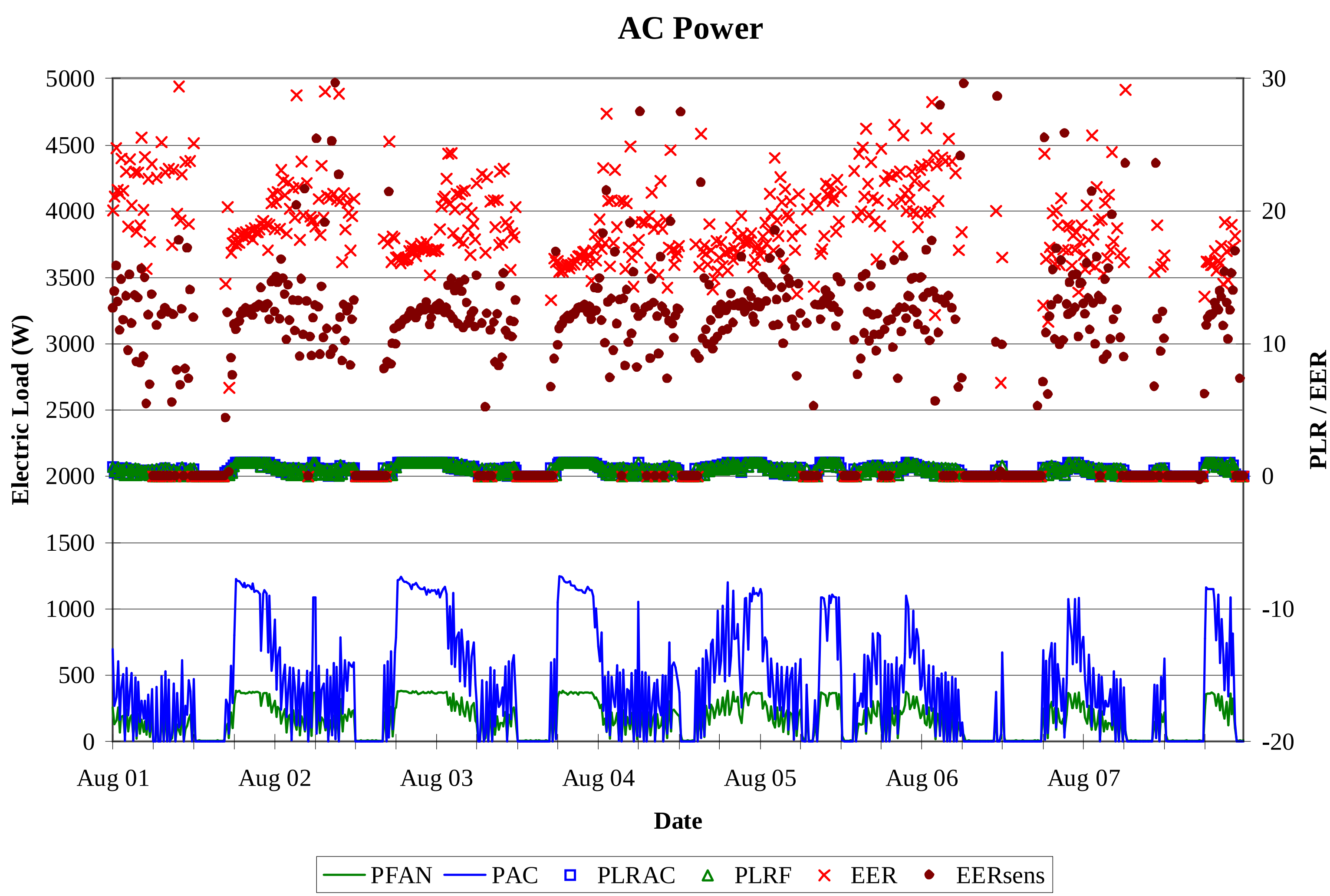
Missing: 0

Point	Units	Average	Min	Time of Min	Max	Time of Max
TAI	deg F	75.8	68.9	Aug 6 07:00	79.6	Aug 2 17:15
TAO	deg F	79.4	54.8	Aug 6 06:15	103.1	Aug 1 17:00
RHO	%	35.1	10.6	Aug 4 15:45	74.4	Aug 6 06:30
TAS	deg F	63.0	51.6	Aug 5 10:30	81.4	Aug 7 17:45
RHS	%	67.7	38.2	Aug 6 17:45	86.8	Aug 6 23:00
TAR	deg F	75.8	71.3	Aug 5 13:00	80.7	Aug 2 17:45
RHR	%	55.3	44.6	Aug 3 23:15	81.0	Aug 1 13:30
TSUMP	deg F	69.4	58.7	Aug 6 08:45	82.6	Aug 3 16:45
EFAN	kWh/Wh	27.2	1.500	Aug 6 16:15	96	Aug 1 18:15
PFAN	W	161.8	6.000	Aug 6 16:15	384	Aug 1 18:15
PLRF	hours/frac	73.6	0	Aug 1 06:00	1	Aug 1 18:15
EAC	kWh/Wh	71.1	0.000	Aug 1 06:00	312	Aug 3 18:15
PAC	W	423.4	0.000	Aug 1 06:00	1246	Aug 3 18:15
PLRAC	hours/frac	69.3	0	Aug 1 06:00	1	Aug 1 18:15
QCS	kBtu/Btu	-1215	-4844	Aug 2 22:30	1	Aug 7 17:15
QCT	kBtu/Btu	-1831	-8340	Aug 3 01:30	0	Aug 1 06:00
FWMU	Gallons	292	0	Aug 1 01:00	16	Aug 1 20:45
Calculated						
LatentFrac	%	34%	-8%	Aug 4 05:15	101%	Aug 7 17:15
EER	BTU/W	20.6	6.7	Aug 1 17:15	68.3	Aug 6 17:15
EERsens	BTU/W	13.5	0	Aug 7 17:15	48	Aug 6 05:15
PCCH	kWh/W	0.0	0	#N/A	0	#N/A
TWBO	deg F	59.8	49.0	Aug 5 05:45	68.1	Aug 3 16:45
Gals/kBtu_sens		0.24				

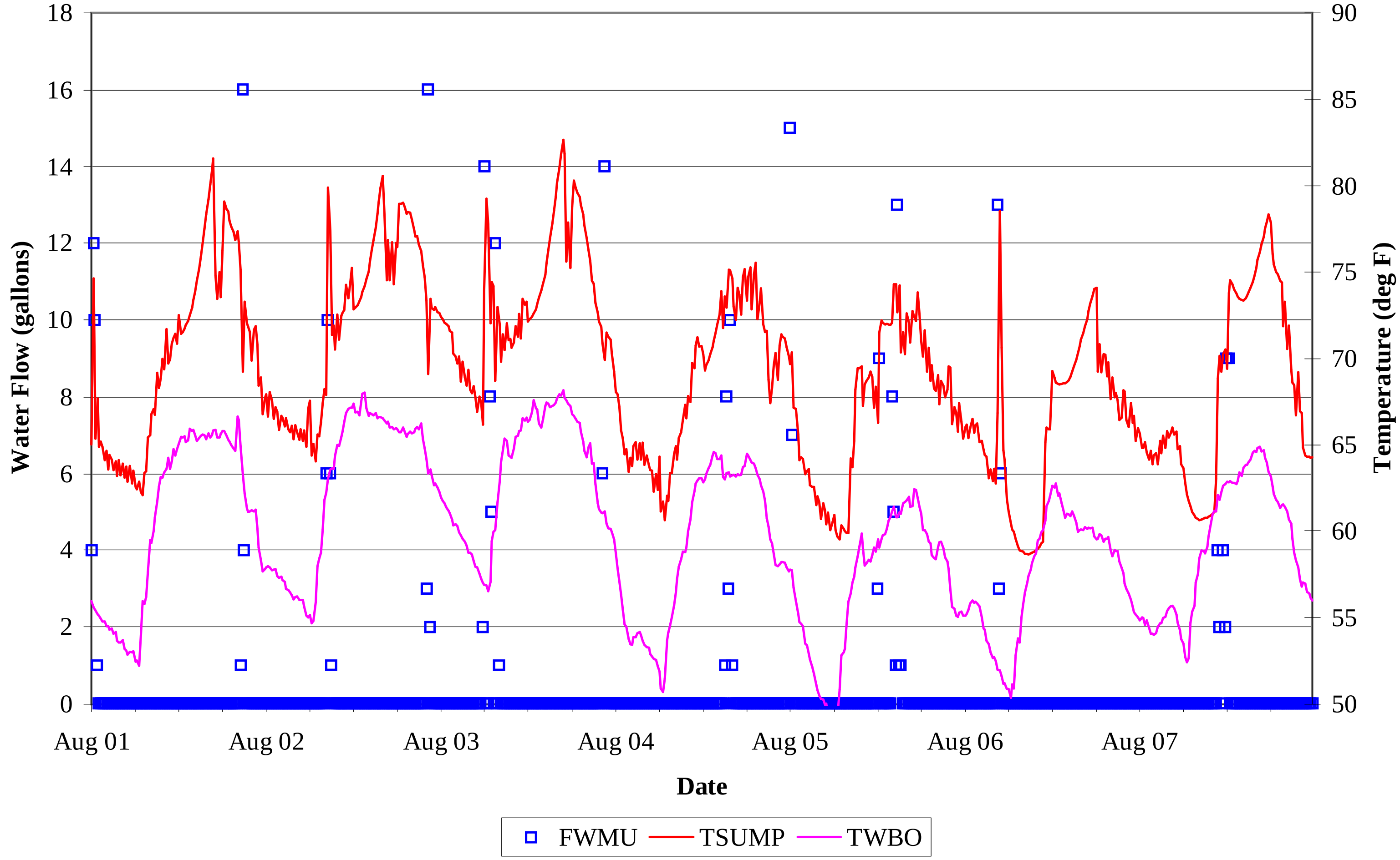


Temperatures
110
100
90
80
70
60
50
40
Temperature (deg F)
Aug 01
Aug 02
Aug 03
Aug 04
Aug 05
Aug 06
Aug 07
Date
TAS
TAI
TAO
TAR
TWBO


Relative Humidity
100
90
80
70
60
50
40
30
20
10
0
RH (%)
Aug 01
Aug 02
Aug 03
Aug 04
Aug 05
Aug 06
Aug 07
Date
RHO
RHR
RHS


AC Power
Electric Load (W)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
PLR / EER
30
20
10
0
-10
-20
Aug 01
Aug 02
Aug 03
Aug 04
Aug 05
Aug 06
Aug 07
Date
PFAN
PAC
PLRAC
PLRF
EER
EERsens

Sump Water


Sump Water
18
16
14
12
10
8
6
4
2
0
Water Flow (gallons)
90
85
80
75
70
65
60
55
50
Temperature (deg F)
Aug 01
Aug 02
Aug 03
Aug 04
Aug 05
Aug 06
Aug 07
Date
FWMU
TSUMP
TWBO

Appendix C:

Enthalpy Calculations for Determining Total Cooling

Equations 1 through 6 are a non-iterative approximation of enthalpy (h) based on supply and return air temperature and relative humidity. Enthalpy is calculated for both the supply and return airstreams on a 15 second basis, and summed over a 15 minute logging interval.

Equation 1: $X = (18.678 - Tc / 234.5) * Tc / (Tc + 257.14)$

Equation 2: $Y = 1 + X + 0.5*X^2 + 0.16393*X^3 + 0.041667*X^4 + 0.0123457*X^5$

Equation 3: $Z = RH \times 6.112 * Y / 100$

Equation 4: $W = 0.6219 * Z / (1013.26 - Z)$

Equation 5: $h = 0.24 * Tf + W * (1060.9 + 0.443 \times Tf)$ in Btu/lbm

where, Tc = supply or return air temperature in °C
Tf = supply or return air temperature in °F
RH = percent relative humidity

Total delivered cooling can then be calculated using Equation 6.

Equation 6: $Qttl = (h_{return} - h_{supply}) \times Dair \times CFM_{sup}$

Where,

Dair = air density (lb/ft3)
CFM_{sup} = measured airflow (cfm)