Pacific Gas and Electric Company

Emerging Technologies Program

Application Assessment Report #0724

Hot Dry Climate Air Conditioner Pilot Field Test Phase II

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EXECUTIVE SUMMARY

California's electric peak demand is almost completely caused by summer-time air conditioning loads that show sharp peaks.

2002-2012 Electricity Outlook Report
CEC, February 2002 P700-01-004F

California and other states with hot dry climates need air conditioners that maximize indoor temperature reductions for the expended energy. This is particularly true at high outdoor temperatures.

Commercially available air conditioners are designed to meet national performance standards that are roughly based on "average" cooling season weather conditions across the United States. The current design process gives little or no attention to the performance of the air conditioners at the conditions prevalent in California. As a result, substantial energy is wasted by California air conditioners, particularly on peak days.

The PIER program commissioned a project to promote air conditioners specifically selected to perform well at hot dry conditions (the HDACs). Pacific Gas and Electric Company funded a side-by-side field test of standard SEER 13 air conditioners and major manufacturers' HDACs. The study was completed during the summer of 2006. The two best performing HDAC units were monitored again in 2007 to ensure improved performance was maintained at hot temperatures. An additional unit produced by a small manufacturer, and containing a microchannel condenser coil, was installed and monitored in 2007.

The study found that:

1. Existing single speed air conditioners utilizing outdoor units, indoor coils, and furnaces selected to meet the performance standards set in the HDAC project can produce peak electrical power reductions and annual cooling energy savings of 20%.
2. The common characteristics of combinations that perform well are brushless DC fan motors and more effective coils.
3. Control modifications to the fan timing can reduce annual electric consumption and peak consumption an additional 9% to 17%, for total savings of 29% to 37%. The highest savings are accomplished on air conditioners with brushless fan motors.
4. The "refrigerant of the future" R-410A results in a 5% increase in peak watt draw for every air conditioner[1]. Over the next 15 years, as the market penetration of R-410A machines increases, there will be an increase of 1.13 GW in peak electrical consumption in California, the equivalent of nearly four 300 MW power plants. This increase will have to be met by new capacity at a cost of approximately 0.563 billion dollars.
5. Aggressive adoption of HDAC standards could more than compensate for the effects of 410A.

[1] Compared to a similar machine with the same ratings using R-22.

6. On average, R-22 units performed closer to their manufacturers' expanded performance tables than the R-410A machines. This points out a weakness in determining the performance of air conditioners from published expanded performance tables.
7. The best performing unit contained a microchannel condenser coil. This agrees with results from the PIER project, providing further evidence that microchannel heat exchangers may improve air conditioner performance in hot dry climates.

This study recommends that:

1. An additional test point should be created for certification of air conditioners selected for use in hot dry climates. This is particularly important for R-410A units, which lose more efficiency at hot temperatures than R-22 units.
2. The peak AC test point should be an essential part of utilities programs to control or reduce peak loads.
3. In order to achieve market penetration with air conditioners that perform well at high temperatures, the utilities in hot dry areas should offer substantial incentives for the installation of units that meet or exceed the HDAC specification.
4. A standard and accurate method of predicting the performance of combinations of equipment, including third party coils should be developed. The predictions need to be based on laboratory testing and supported by random testing of OEM and 3rd Party coil certified systems.
5. Emerging technologies capable of improving efficiency at hot conditions, such as microchannel heat exchangers, should be further studied and promoted to the manufacturers as a means of achieving the hot/dry specification.

I. PROJECT BACKGROUND

California is a summer peaking utility region and air conditioning is the foremost cause of the peaks. Residential air conditioning has a ratio of peak load to average load of 3.5 to 1. This is the highest ratio of all end uses. A residential air conditioner produces a peak watt draw 23 times as great as residential lighting with the same annual consumption.

Air conditioning is the driver of the peak energy consumption that results in the highest marginal cost of electricity.

> **California's electric peak demand is almost completely caused by summer-time air conditioning loads that show sharp peaks.**
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California's peak electric demand dominates the need for additional power plants, transmission infrastructure and related environmental issues. Even high-performance air conditioning systems are not optimized to maximize indoor temperature reduction for each watt-hour of consumption under hot and dry ambient conditions. Reducing peak-electric demand by 20% in residential and small commercial air conditioners could save California as much as 71 megawatts per year at a 20% market penetration.

Commercially available air conditioners are designed to meet national performance standards that are roughly based on "average" cooling season weather conditions across the United States. For residential air conditioners, the performance metric is the Seasonal Energy Efficiency Ratio (SEER). SEER is based on providing significant dehumidification and is measured at an outdoor temperature of only 82ºF. For commercial air conditioners larger than 5 tons, the metric is Energy Efficiency Ratio (EER), which also credits dehumidification, but is rated at 95ºF, closer to the performance needed in California. The current design process gives little or no attention to the performance of the air conditioners at higher temperatures. The only mandatory test for high temperature is a Maximum Operating Conditions test at 115 ºF. The manufacturers do not certify or report the performance of their air conditioners at that temperature.

The Hot Dry Air Conditioner Program

The California Energy Commission under the PIER program funded a project to build peak reducing split and package system air conditioners for hot/dry climates and to subsequently produce and promote a performance standard for air conditioners with superior performance in these climates. These air conditioners were designated the proof of concept HDACs.

Split and package air conditioners were designed, developed, and tested to provide a basis for the performance specification. The performance was specified at two indoor test conditions to cover the range of conditions found in the field. These air conditioners met the goals of the program and produced the efficiencies shown in Table 1.

Table 1. PIER Hot Dry Air Conditioner Performance and Draft Specification

	Split HDAC Proof of Concept Machine	Package HDAC Proof of Concept Machine	Draft Specification
Condition #1	**Hot Dry 115°F outdoor, 80°F indoor with 38.6% Rh (63 WB)**		
Net Sensible PEER	8.22	8.60	8
Gross Sensible PEER	9.11	9.56	
Condition #2	**Hot Medium 115°F outdoor, 80°F indoor with 51.1% Rh (67 WB)**		
Net Sensible PEER	6.91	7.08	6.8
Gross Sensible PEER	7.67	7.93	

Net efficiencies include the effect of the indoor fan energy while gross efficiencies do not include the energy of the indoor fan.

Technical Metric - Peak Energy Efficiency Ratio - Sensible

Air conditioners produce two effects. They lower the temperature (known as sensible cooling) and they remove moisture (latent cooling). In hot dry climates only the sensible cooling is beneficial under most conditions. For hot dry climates, the appropriate metric of performance is the Peak Energy Efficiency Ratio - Sensible (PEERs) that would be measured at high temperatures and low to moderate indoor humidity. Since this addresses the cause of system electrical peak, this metric is of particular importance.

The CEC Program selected 115°F as the appropriate outside temperature. Two sets of indoor conditions were selected: 75°F with 38.6% relative humidity and 75°F at 51.1% relative humidity.

The PG&E HDAC Field Test

The purpose of the PG&E HDAC field test was to determine the field performance of air conditioners selected to meet (or approach) the draft HDAC specifications. The design of the PIER project anticipated a number of the differences between standard laboratory tests and field conditions. The PIER project tested the proof of concept HDACs at the duct airflow restrictions common to the field, at temperatures approached or achieved at peak conditions, and under both moderate and dry indoor conditions. Nevertheless laboratory testing does not cover the full range of conditions experienced in the field, including occupant behavior, duct system performance, thermostat effects, and most importantly – air conditioner cycling.

Once the draft specification was produced, a number of manufacturers were approached to provide air conditioners that would meet the draft specifications by selection of existing components or modifications to their existing equipment. Three major manufacturers responded with combinations of existing components that, on paper, approached within 3% of the draft specifications[2].

Four HDAC units were tested in 2006. Two showed significant improvement over standard SEER 13 units, while the other two (both produced by the same manufacturer) showed no improvement. The two best performing HDAC units were monitored through summer 2007, along with a third unit selected because it had a microchannel condenser coil – an emerging technology identified in the PIER HDAC project as beneficial at hot temperatures.

[2] The specifications require less efficiency than was achieved in the PIER HDAC units.

II. PROJECT OBJECTIVES

The objectives of this project were to:

1. Evaluate the annual and peak performance of currently available air conditioners chosen for their superior functioning at conditions common to hot dry climates such as those in California.

2. Compare the selected air conditioners to standard SEER 13 units.

3. Engage smaller manufacturers of air conditioning equipment in the production of units with superior performance in hot dry climates, and evaluate the performance of those units relative to the HDAC specification.

4. Determine the effect of these air conditioners on occupant comfort.

5. Evaluate the performance improvement potential of extending the fan time delay to deliver evaporative cooling after the compressor turns off.

6. Produce recommendations on how to move high performance HDAC units into the mainstream.

III. METHODOLOGY

Proctor Engineering Group completed a field test to compare the performance of standard air conditioners to air conditioners selected for hot and dry climates (HDACs), and to evaluate the performance of an additional air conditioning unit relative to the HDAC specification. The field test consisted of site and AC selection, installation and replacement, performance monitoring, and data analysis. In 2006, standard (baseline) SEER 13 air conditioners were first monitored and then replaced with HDACs. In 2007, monitoring was continued for the two best performing HDAC units and one additional unit produced by a small manufacturer.

Site and AC Selection

Proctor Engineering Group consulted with PG&E staff to determine criteria for inclusion in the sample. The final selection procedure assessed the house size, AC usage characteristics and climate zone. PEG collaborated with PG&E in recruiting, selecting and securing agreements for the test houses. The characteristics of the homes and air conditioners used in the 2007 project are listed in Table 2.

Table 2. Site Characteristics

House Specifications			
Site	Madera	Yuba	Fresno
House Size (square feet)	1650	1600	1700
Year Built	2002	1991	1992
Air Handler Location	Attic	Attic	Attic
California Climate Zone	13	11	13
Standard Air Conditioner Specifications[3]			
Rated SEER without furnace	13	13	-
Rated Sensible EER	7.5	8.3	-
Rated EER	10.8	11.6	-
Sensible Heat Ratio (temperature reduction fraction)	0.70	0.72	-
Rated Capacity	47000	35000	-
Nominal Size (Tons of Cooling)	4	3	-
Nominal Evaporator Coil Capacity (Btuh)	48000	36000	-
Refrigerant	R-22	R-22	-
Metering Device	Piston	Piston	-
Fan Motor Horsepower	1/2	1/4	-
Fan Motor Type	PSC	PSC	-

[3] With ARI furnace default assumptions and at standard 95/80/67 conditions.

Since the sensible heat ratio is the fraction of the cooling that reduces the indoor temperature, it is evident that these standard units wasted almost a third of their cooling capacity removing water rather than reducing the temperature. Designs capable of sensible heat ratios of 0.80 or higher are possible and the installed HDACs at the Madera and Yuba sites approached this ratio.

Sensible heat ratio can be further increased by increasing the airflow across the evaporator coil. Fan power increases approximately as the cube of the flow, so higher airflow can result in significantly higher fan watt draw. The PIER project found that in typical duct systems higher airflow decreases sensible EER, even as sensible capacity increases. For the split unit laboratory tested in the PIER project, the optimal airflow was 350 cfm/ton at 0.5 IWC external static pressure.

A more effective means of increasing sensible heat ratio is through fan control modification. By continuing to run the fan for a period of time after the air conditioner turns off, water collected on the indoor coil is re-evaporated. The evaporating water cools the air, thereby converting latent capacity back into sensible capacity at the end of each cycle. Variable speed fans can be run at low speed to produce the additional sensible capacity at very low watt draw.

HDAC Air Conditioner Specifications[4]			
Site	Madera	Yuba	Fresno*
Rated SEER	14	14.2	NA
Rated Sensible EER	9.4	9.2	9.2
Rated EER	12.3	11.7	12.6
Rated Sensible Heat Ratio (temperature reduction fraction)	0.77	0.79	0.73
Rated Capacity (Btuh)	50730	35200	35025
Nominal Size (Tons of Cooling)	4	3	3
Nominal Evaporator Coil Capacity (Btuh)	60000	42000	36000
Refrigerant	R-410A	R-410A	R-22
Metering Device	TXV	TXV	TXV
Furnace Fan Specifications	Replaced	Replaced	-
Fan Motor Hp	1/2	1/2	1/2
Fan Motor Type	ECM	ECM	PSC

*Fresno HDAC specifications are unpublished modeled performance results provided by the manufacturer for the specified condensing unit and evaporator coil.

The standard ACs were SEER 13 R-22 units either already in place or selected by the contractor and installed for this test. No standard AC unit was tested at the Fresno site.

The HDAC air conditioners consisted of components (outside unit, inside coil, and furnace) selected because they approached the draft HDAC performance specification. The selections were based on manufacturer supplied performance data on the outside unit and coil combination, the coil air pressure drop, and the furnace blower. The components were standard production equipment that fit into the existing locations with some minor duct system modifications. These units were selected to approach the draft HDAC performance specifications.

[4] with ARI furnace default assumptions and at standard 95/80/67 conditions.

HDAC Performance Specifications

The HDAC specifications are that the combination of the furnace, outside unit, and indoor coil meets the criteria shown in Table 3.

Table 3. Hot Dry Air Conditioner Draft Specifications

Condition #1	Hot Dry 115/80/63
Gross Sensible Capacity (sensible btuh)	75% or greater than the gross total capacity at ARI test A (95/80/67)
Net PEERs	at least 8 btu/watthr
Condition #2	Hot Medium 115/80/67
Gross Sensible Capacity (sensible btuh)	65% or greater than the gross total capacity at ARI test A (95/80/67)
Net Sensible PEER	at least 6.8

Table 3 Notes:

1) With the External Static Pressure from the return plenum to the supply plenum downstream of the evaporator coil is defined by $\left(\frac{CFM\ \ per\ ton}{495\ CFM\ \ per\ ton}\right)^2$

An air conditioner system (furnace, outside unit, and evaporator coil) with a flow of 400 CFM per ton would be tested at 0.653 IWC.

2) Net PEERs is the net sensible capacity divided by the total unit watt draw.

Production and Advanced HDAC Units

The Production HDAC unit installed at the Fresno site is a new model produced by a small manufacturer. It is designed to be a SEER 14 unit, but performance specifications have not yet been published and it is not yet ARI rated. The unit was of particular interest because of its microchannel condensing coil. Microchannel coils were identified in the CEC/PIER HDAC study as an emerging technology with great potential benefit for air conditioners in hot dry climates. Research conducted by the manufacturer indicates that the units with microchannel condenser coils lose less efficiency at hot temperatures than similar units with standard tube and fin condenser coils. Microchannel coils have greater heat exchanger surface area compared to a standard tube and fin coil of similar dimensions.

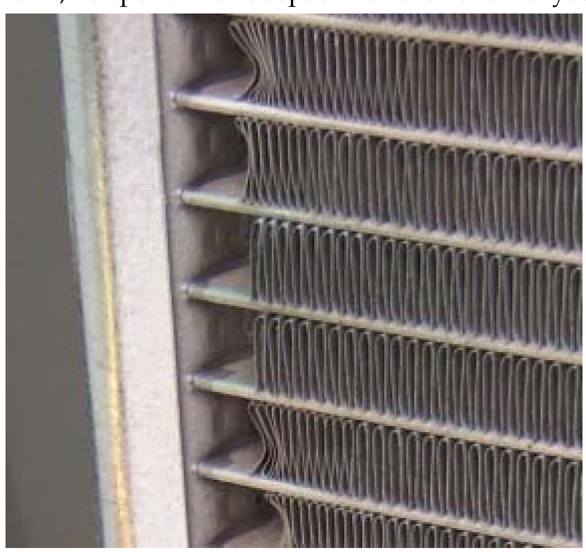


Figure 1. Microchannel Condenser Coil

A second small manufacturer was approached to work with Proctor Engineering Group to build an Advanced HDAC unit exceeding the HDAC specification. The manufacturer builds high efficiency heat pumps, but was unable to provide evidence that their units would perform efficiently at hot/dry conditions. This task was dropped from the project due to lack of manufacturer participation.

Installation and Replacement

Each air conditioner was commissioned prior to the beginning of the monitoring periods. This commissioning included checking and setting refrigerant levels using manufacturers' recommended methods, determining airflow and adjusting airflow to the degree available, and making sure the duct leakage was less than California Title 24 specifications for existing duct systems when an air conditioner is being replaced.

The selected air conditioning systems were able to approach the performance of the HDAC specification by closely matching the performance of the indoor coil, outdoor unit, and furnace. This included replacing the furnace with a new unit listed as providing higher airflow at lower watt draws for the specified external static pressure. At Madera and Yuba, the furnaces barely fit into the attics through the attic access. In one location, furnace cabinet screws were removed to get it through the access.

In Fresno, a furnace with an efficient fan motor was unavailable from the manufacturer. The unit was installed and tested with the furnace provided by the manufacturer and data were adjusted during analysis to estimate performance with a more efficient fan motor. The evaporator coil box for the Fresno unit was very large, and required a custom sheet metal transition.

Even with close attention to the work of the HVAC contractors, we had to have contractors replace evaporator coils because they installed substitutes. It is very common for contractors to substitute alternate components that they judge as comparable to the specified equipment. This is done without thorough analysis of the effects of the substitutions. In most cases the substitutions are made due to availability or cost. This practice can substantially alter the delivered efficiencies from those expected. In the case of third party evaporator coils there are generally no expanded performance tables to estimate the expected performance under hot dry conditions. This is one reason why combinations need to be certified by the manufacturers (including third party manufacturers) at hot dry conditions.

One Time Measurements

A number of one-time measurements were taken at the time of installation, replacement, and project conclusion. Two methods were used for measuring the evaporator airflows, an Energy Conservatory TrueFlow plate and the pressure matching method as specified in California's Title 24. Airflows, static pressures, and watt draws were recorded at various blower settings.

Monitoring System

A Campbell Scientific CR10X data logger monitored each air conditioner. The data logger includes an AMT-25 multiplexer, a COM210 modem, a sealed lead acid battery, and a battery changer, within a water- tight enclosure. Each data logger and its sensors were prewired and tested at the Proctor Engineering Group Laboratory before installation. This data acquisition system has the flexibility to perform many data capture and analysis functions and is capable of being downloaded or reprogrammed via modem. The temperature probes were bare wire 36 gauge type T thermocouples, RTDs, or thermistors. Condensate flow from the indoor coil was measured with a tipping bucket gauge attached to the termination of the condensate drain. Data points are summarized in Table 4.

Table 4: Monitored Parameters

Measurement	Sensor Type	Sensor Location
Supply Air Dry Bulb Temperature	4 Point RTD Grid	After Coil In Supply Plenum
Supply Air Dry Bulb Temperature	Thermocouple	After Coil In Supply Plenum
Supply Air Dry Bulb Temperature	Thermocouple	Supply Register
Supply Air Relative Humidity	Humidity Transmitter	With Supply Air Thermocouple
Return Air Dry Bulb Temperature	4 Point RTD Grid	Return Plenum Before Furnace
Return Air Dry Bulb Temperature	Thermocouple	Return Plenum Before Furnace
Return Air Dry Bulb Temperature	Thermocouple	Return Grill
Return Air Relative Humidity	Humidity Transmitter	With Return Thermocouple
Return Air Relative Humidity	Humidity Transmitter	Return Grill
Temperature Drop Across Coil	Thermopile	With Return and Supply RTD Grids
Outside Air Temperature	Thermister (Shielded)	Outside Near Condensing Unit
Outside Air Relative Humidity	Humidity Transmitter	With Outside Air Thermister
Indoor Air Temperature	Thermister	Near Thermostat
Compressor Discharge Temperature	Thermocouple	Surface Mounted To Compressor Gas Discharge Line (Insulated)
Liquid Line Temperature	Thermocouple	Surface Mounted To Liquid Line at Evaporator Coil (Insulated)
Suction Line Temperature	Thermocouple	Surface Mounted To Suction Line at Evaporator Coil (Insulated)
Condenser Saturation Temperature	Thermocouple	Surface Mounted to Condenser Refrigerant Circuit
Evaporator Saturation Temperature	Thermocouples	Surface Mounted to Evaporator Refrigerant Circuit
Evaporator Condensate Flow	Tipping Bucket	Evaporator Condensate Line
Condensing Unit Power	Pulse Watt Transducer	Electrical Supply To Unit
Condensing Unit Power	Analog Watt Transducer	Electrical Supply To Unit
Furnace Blower Power	Pulse Watt Transducer	Electrical Supply To Furnace Unit
Furnace Blower Power	Analog Watt Transducer	Electrical Supply To Furnace Unit

Data were gathered every 5 seconds. Instantaneous data were gathered at all sensors at the beginning and end of all cycles. This includes compressor cycles, fan cycles, and off cycles. The data were also averaged or summed over each cycle and recorded. Additionally, data were gathered and averaged/summed every hour on the hour.

A dedicated computer in the PEG office called the CR10X daily to download data. These data were transformed into graphs and reviewed daily by PEG staff.

Potential Measurement Errors

When air conditioners are tested in a laboratory, where measurements can be extremely accurate, the applicable ASHRAE Standard[5] allows for up to 6% difference between capacity measurements.

In this field monitoring, the largest potential sources of error are the supply humidity reading and the supply temperature reading. Even high quality humidity sensors are subject to drift and low accuracy at high relative humidities such as those in the supply air stream. While the return air stream is generally well mixed, the supply air stream is not. Measurements in one part of the air stream are not necessarily representative of the mixed values.

In order to reduce measurement error, humidity sensors were calibrated using a closed container and salt slurries. Salt slurries produce fixed relative humidities at each temperature, providing an accurate calibration for humidity sensors. Four pure salt slurries were used, Sodium Chloride, Magnesium Chloride, Potassium Sulfate and Magnesium Nitrate. In order to reduce measurement error of the supply and return temperatures, an averaging RTD grid was used in both the supply and return plenums. The temperature difference across the coil was measured using a thermopile grid, which consists of two grids of thermocouples connected to output a temperature difference. This is a highly accurate method for measuring temperature differences and, when combined with airflow produces sensible capacities with little potential error.

Calculations

System Seasonal and Average Peak Performance

This field test was performed in two stages during the summer of 2006. The first stage tested standard SEER 13 units. This took place from mid-June to early August. The second stage began when the HDAC units replaced the standard units. This stage was from early August through the end of September. Monitoring was continued through the summer of 2007 for the two best performing HDAC units. A third HDAC unit was installed in Fresno in August 2007 and monitored through September.

The primary performance measures were the change in annual energy consumption and reduction in peak electric demand. Electric demands were calculated for both coincident and non-coincident peaks.

The energy consumption was normalized to the local hourly temperature profiles from the 2005 California Energy Commission Standards version of Micropas. The analysis is based on 5°F temperature bins for each hour of the day, in the following manner:

1. The Sensible EER was modeled as a function of outside, return air dry bulb and return air wet bulb temperatures for each air conditioner from the monitored data. The models were used to calculate the sensible EER for each air conditioner in each temperature bin at the conditions measured during summer 2007.

[5] ANSI/ASHRAE Standard 37-1988

$$Sensible\ EER = \frac{Sensible\ Capacity\ with\ Compressor\ On(Btu) + Sensible\ Capacity\ with\ FanOnly\ (Btu)}{Energy\ Used\ with\ Compressor\ On(Wh) + Energy\ Used\ with\ FanOnly\ (Wh)}$$

The full cycle of an air conditioner consists of the portion of the cycle with the compressor and indoor fan on, the portion of the cycle with the compressor off and the indoor fan on, and finally the portion with both the compressor and the indoor fan off.

2. The Sensible load for each site for each hour was calculated from the 2007 monitored data.

3. The Sensible loads were grouped by outside temperature bins of 5°F and a function was derived based on hour of the day for each temperature bin. This function is assumed to be the sensible load of the structure at that hour and temperature. The function is of the form:

$$SensibleLoad_{ij} = A_i \times \sin(\frac{2\pi(hour+8)}{24}) + B_i \times \sin(\frac{2\pi(hour+2)}{24}) + C_i$$

   Where the independent variable, *hour,* is the hour of the day ranging from 1 to 24 and *i=temperature bin (60°F-110°F) and j=hour bin (1-24)*

4. The actual load seen by the air conditioner is dependent on outside temperature, but also on solar position and occupant behavior among other variables. To account for occupant behavior in this analysis the monitored data was analyzed to determine the ratio of the hours in which the air conditioner operated to the total hours in the temperature/hour bin. This ratio is the on fraction.

$$OnFraction_{ij} = \frac{Number\ of\ Monitored\ Hours\ That\ AC\ Was\ Used_{ij}}{Total\ Number\ of\ Monitored\ Hours_{ij}}$$

5. The equivalent sensible load was calculated as the product of the OnFraction and the SensibleLoad for each temperature/hour bin.

$$EquSensibleLoad_{ij} = OnFraction_{ij} \times SensibleLoad_{ij}$$

6. The kWh (annual or average peak[6]) in each temperature bin was compiled.

$$kWh_i = \sum_{j=1}^{24} \frac{EquSensibleLoad_{ij} \times \#of\ Micropas\ Hours_{ij}}{SensibleEER_i}$$

[6] Where average peak consists of the hours between noon and 7PM on weekdays from June 1 through September 30.

Figure 2 displays the fit of the function in Step 3 to the measured sensible load for one temperature bin and one location. Step 3 projects the load of the structure for temperature/hour bins that have little monitored data.

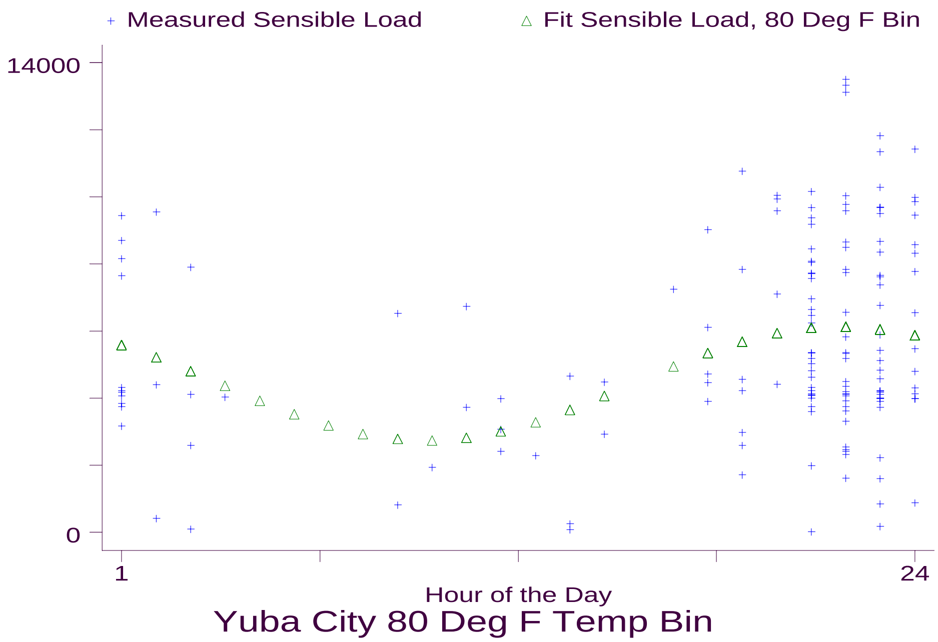


Figure 2. Curve Fit to Monitored Sensible Load

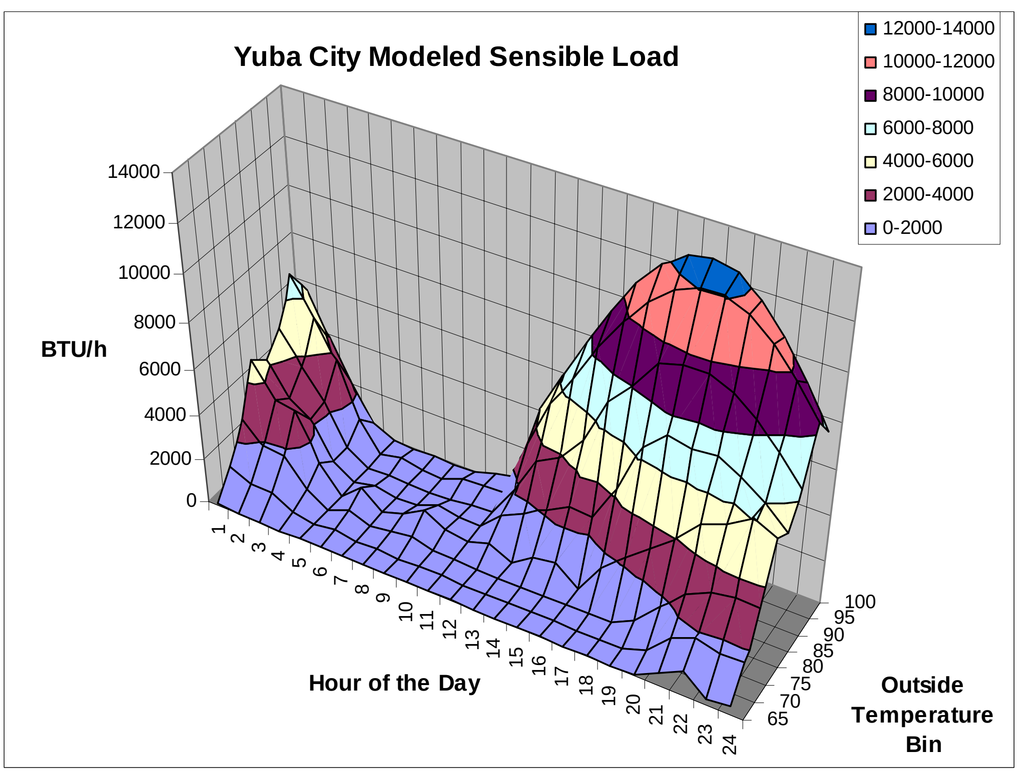


Figure 3. Modeled Equivalent Sensible Load

Unit Annual Energy Savings

Unit Annual Energy Savings were determined by taking the difference between the normalized Annual Energy Usage of the HDAC and the normalized Annual Energy Usage of the standard unit.

Annual energy savings for the Fresno site was estimated using the average measured sensible efficiencies of the Madera and Yuba Standard units.

Average Peak Demand

Average Peak Demand (APD) was calculated by dividing the total normalized kilowatt-hours of cooling used during the 2007 cooling season peak demand period[7] (*Energy Usage*) by the total number of hours in the Micropas profile that occurred during the peak demand period. The peak demand reduction is the difference between the APD of the HDAC and the standard unit.

Peak demand reduction for the Fresno site was estimated using the average measured sensible efficiencies of the Madera and Yuba Standard units.

Coincident Peak Demand

Coincident peak demand was derived from the hourly data set. The days with highest watt draws during peak hours were examined to determine whether the unit was cycling or running continuously. For units that were cycling, the connected load was calculated as the recorded outside unit kWh/hr divided by the compressor duty cycle plus the recorded fan kWh/hr divided by the fan duty cycle. The recorded kWh/hr is reported for the hours ending in 4PM, 5PM, and 6PM for matched peak days[8].

Coincident peak demand reduction for the Fresno site was estimated using the average measured sensible efficiencies of the Madera and Yuba Standard units.

Field Test vs. Manufacturer Comparison

The standard and HDAC units were compared against the manufacturer's published performance matrices. The manufacturers' published data for condensing unit watt draw, gross capacity, and gross EER were modeled as a function of outside, return air dry bulb and return air wet bulb temperatures and evaporator airflow. The modeled performance specification was applied to the measured temperatures and airflows. Performance was compared at 95 °F outside temperature. Measured evaporator airflows were lower than those listed on the manufacturer's performance matrices. Specified performance at the measured airflow is an extrapolation of the manufacturer's performance table.

The HDAC unit installed at the Fresno site is a new model and published performance matrices are unavailable. The manufacturer provided unpublished modeled performance for the condensing unit and evaporator coil.

[7] Where average peak consists of the hours between noon and 7PM on weekdays from June 1 through September 30.

[8] Where coincident peak demand reduction is now defined as: "“The average grid level impact for a measure between 2 pm and 5 pm during the three consecutive weekday period containing the week day temperature with the hottest temperature of the year”

Control Modifications – Fan Time Delay

Refrigerant cooled air conditioners not only cool the inside air, they also remove moisture (latent capacity). In humid climates this is desirable, as high indoor relative humidity is uncomfortable and can also result in mold growth. In dry climates however, it is not necessary to remove moisture and additional sensible cooling capacity can be gained by evaporating the water left on the evaporator coil after the compressor has turned off. This is accomplished by using a fan time delay or 'tail' to continue running the indoor fan for a time after the compressor turns off.

The optimal time delay at each site was determined by recording data every minute through a complete air conditioner cycle. After the compressor turned off, the fan was allowed to run on low speed until cooling was no longer being provided. The one-minute data were analyzed to determine the optimal fan time delay for maximum average sensible EER. Measured sensible capacity and watt*hours during the fan cycle were added to each cycle throughout the monitoring period to estimate performance with the optimal time delay.

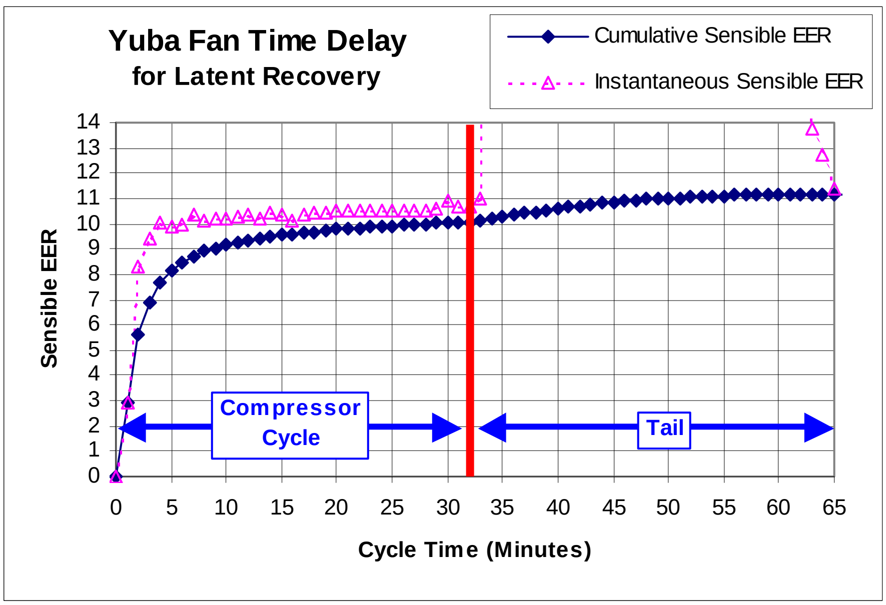


Figure 4. Yuba City Fan Time Delay

At the Madera site, the indoor fan was run continuously and data were collected every 2 minutes over the final 42 days of monitoring. Data collected during this period were analyzed to determine the optimal fan time delay.

R-22 vs. R-410A Efficiency Correction

It is well known that the efficiency of R-410A degrades faster with increased outdoor temperature compared to R-22. This degradation in one set of laboratory experiments is displayed in Figure 5.

The same trend of performance degradation at higher temperatures for R-410A vs. R-22 is evident in the testing by Davis and D'Albora 2000. Those tests included two SEER 14 air conditioners, one R-410A and one R-22. The measured SEERs of the two units were within 2% of each other. However the EER of the R-410A machine was more than 12% below the R-22 machine at 115°F.

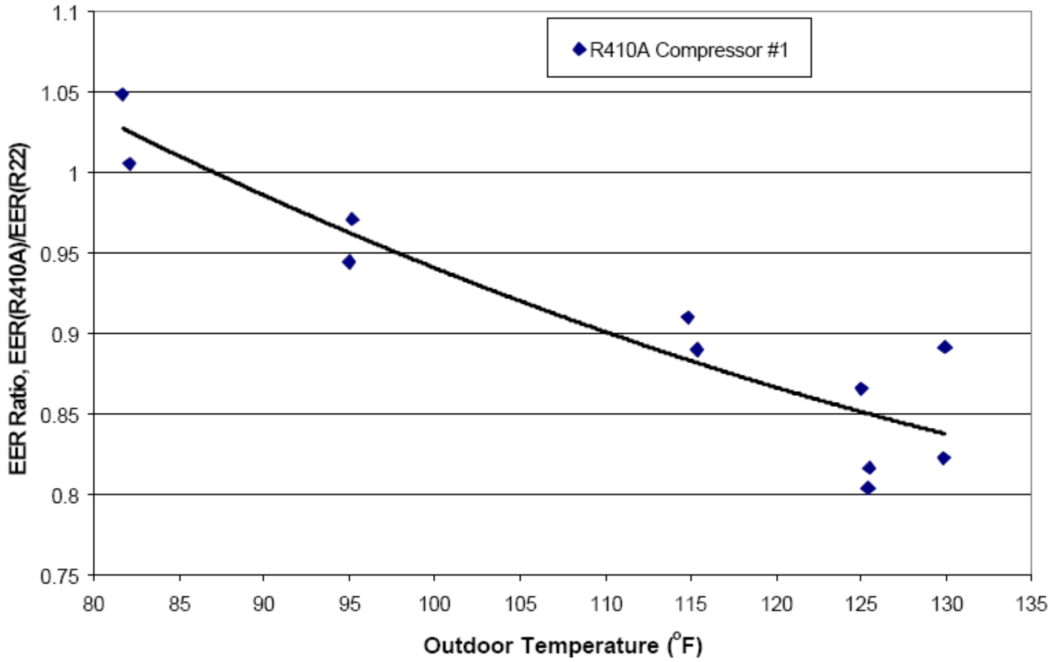


Figure 5. Cooling EER of R-410A System Relative to R-22 System (Domanski & Payne 2002)

This data indicates that R-410A may perform better than R-22 at temperatures below about 87 °F, but performs significantly worse at hot temperatures. Figure 5 shows a difference in performance of less than 5% at the SEER and EER test points. The difference increases to 12% at 115 °F.

The Fresno HDAC as well as the Madera and Yuba Standard units used R-22 refrigerant. To adjust for the effect of refrigerant type in comparing the performance of HDAC and Standard units, the measured results were adjusted to predict performance with refrigerant R-410A. The performance correction was calculated by multiplying the measured EER by the R-410A/R-22 EER ratio measured by Domanski and Payne in 2002 (Figure 5).

It should be noted that the performance degradation documented in the aforementioned studies was measured using standard tube and fin heat exchangers.

Fresno HDAC Furnace

The furnace provided with the Fresno HDAC unit was equipped with a PSC motor, rather than a more efficient ECM motor. Results were adjusted during analysis to estimate performance with the more efficient ECM furnace fan motor. ECM furnace watt draw was estimated by calculating the watt draw of furnaces equipped with ECMs or equivalent motors that were tested by Proctor Engineering Group at similar airflow and static pressure to the Fresno site. The lowest watt draw measured in the furnace tests (at the same airflow and static pressure) was 311 W. The adjusted watt draw for the Fresno HDAC unit was conservatively estimated at 350 W, a significant improvement over the measured watt draw of 614 W with the PSC motor.

Performance with the more efficient furnace fan motor was calculated for each air conditioner cycle as follows:

Adjusted Total W*h = Measured compressor W*h + 350W * cycle length (h)

Avoided Fan Heat (BTU/h) = (614W – 350W) * 3.412 BTU/W*h = 901 BTU/h

Sensible Capacity = Measured Sensible Capacity + Avoided Fan Heat * cycle length (h)

Sensible EER = Sensible Capacity/Total W*h

Occupant Survey

During the monitoring period, comments by the occupants concerning the performance of their air conditioners were recorded as they naturally occurred. At the end of the field test each occupant was surveyed to determine their perception of the HDAC compared to the standard SEER 13 unit. Open-ended survey questions were used to elicit any applicable information. The survey questions were:

- How is your air conditioner working?
- Did you notice any changes when the original unit was replaced?
- Have you noticed any changes in comfort after the replacement?
- If yes, what changes have you noticed?
- Is your Air Conditioner keeping you cool?
- Does it feel more or less humid inside the house?
- Have you noticed any change in the noise level from the air conditioner?
- Are there any other comments you would like to make?

IV. RESULTS

Results were obtained for seasonal cooling energy consumption (kWh) as well as coincident and average peak power draw (average kWh per hr). These results are presented for standard operation and for operation with an extended fan run time after the compressor is off (latent recovery mode). The tables show annual results and results by 5ºF temperature bins. Complete results are displayed in the Appendices.

Weather Normalized Seasonal Cooling Energy Consumption

The seasonal cooling energy consumption of each unit and the annual energy savings are shown in Table 5.

Table 5. Standard vs. HDAC Performance

	Madera	Yuba	Fresno
R-22 Standard Unit Annual Energy Usage (kWh)	1490	1385	1298
R-410A Standard Unit Annual Energy Usage (kWh)	1510	1387	1323
R-410A HDAC Unit Annual Energy Usage (kWh)	1329	1111	847
Energy Savings vs. R-22 Standard Unit (kWh)	161	274	451
Annual Energy Savings vs. R-22 Standard Unit based on Sensible EER (%)	**11%**	**20%**	**35%**
Energy Savings vs. R-410A Standard Unit (kWh)	181	276	476
Annual Energy Savings vs. R-410A Standard Unit based on Sensible EER (%)	**12%**	**20%**	**36%**

Madera and Yuba showed substantial Annual Cooling Energy Savings of 12% and 20% respectively. The new unit in Fresno showed the best performance compared to the standard units originally in Madera and Yuba.

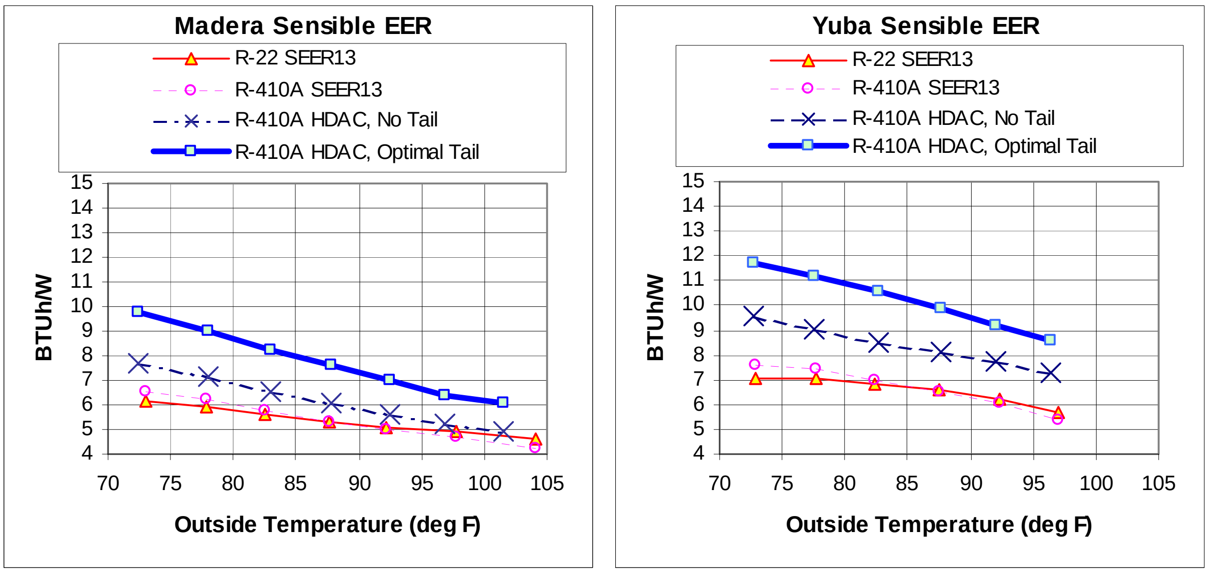
The sensible cooling loads measured in 2007 were lower than in 2006. In 2006, the datalogger was able to override the thermostat to maintain a constant indoor temperature, or to operate the air conditioner in various control modes. In 2007, the datalogger had no control over the air conditioner and only the building occupant determined the cooling load. The 2007 cooling loads were used for analysis.

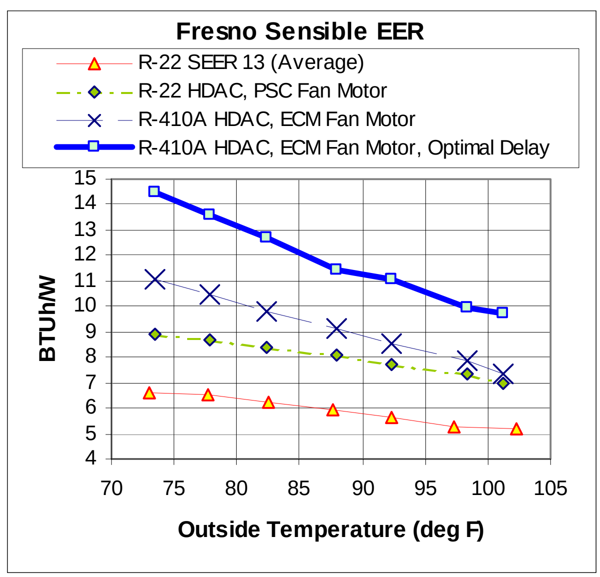
The Madera occupant operated the AC with a continuous fan. The sensible EER used to calculate annual and peak energy usage is the sensible EER measured during the compressor cycle only (no tail).

The supply plenum temperatures were significantly higher than the return plenum temperatures when the Madera unit was operated in fan-only mode for extended periods. The temperature gain increased with increasing attic temperature, and is likely the result of air leaking from the attic into the furnace cabinet or connection to the plenum. The furnace was replaced when the HDAC was installed, and the leak was not present during monitoring of the Standard unit. Based on the amount of temperature gain corrected for heat generated by the fan motor, the leak is estimated to be 7% of the cooling airflow. Without the leak, Madera energy savings over the R-410A SEER 13 unit would increase to an estimated 257 kWh, or 17%.

The primary focus of the HDAC projects is the performance at high temperatures. Each location was analyzed for the performance of the air conditioners in temperature bins. The results of those analyses are shown in Figure 6.

Figure 6. Performance by Outside Temperature





Discussion

The R-410A HDAC units lost efficiency more quickly with increasing outside temperature compared to the R22 units. This result agrees with the trend documented by Domanski and Payne in 2002 and Davis and D'Albora in 2000. It also highlights the importance of performance ratings at hot outside temperatures as a consideration in selecting air conditioners, especially R-410A units, for use in hot/dry climates.

Cooling Peak Electrical Demand

Peak demand savings followed the same trend as the annual energy savings.

Coincident Peak Demand

The peak demand of major importance occurs on hot afternoons and is driven by the diversified air conditioner demand. The diversified peak demand of air conditioners is generally coincident with the peak demand of the system. The hours from 3PM to 6PM are of particular significance. The coincident peak demand for matched peak days are shown in Table 6.

Table 6. Standard vs. HDAC 4PM to 6PM Coincident Peak Demand Summary

	Madera	Yuba	Fresno
Standard Unit Connected Load Watts (at °F)	5211 (105)	2960 (105)	-
HDAC Unit Connected Load Watts (at °F)	4724 (105)	3222 (105)*	3567 (105)*
3PM to 4PM			
Average Outside Temperature (°F)	104	98	100
R-22 Standard Unit Peak Demand (W)	1657	2047	1802
R-410A Standard Unit Peak Demand (W)	1767	2160	1912
Peak Demand Increase due to R410A	111	112	110
R-410A HDAC Unit Peak Demand (W)	1610	1722	1253
Peak Demand Reduction (W)	157	438	659
4PM to 5PM			
Average Outside Temperature (°F)	105	99	101
R-22 Standard Unit Peak Demand (W)	1792	1878	2337
R-410A Standard Unit Peak Demand (W)	1916	1986	2491
Peak Demand Increase due to R410A	124	108	154
R-410A HDAC Unit Peak Demand (W)	1749	1577	1650
Peak Demand Reduction (W)	167	409	842
5PM to 6PM			
Average Outside Temperature (°F)	105	99	101
R-22 Standard Unit Peak Demand (W)	1734	1897	2065
R-410A Standard Unit Peak Demand (W)	1849	2004	2201
Peak Demand Increase due to R410A	115	107	136
R-410A HDAC Unit Peak Demand (W)	1682	1582	1465
Peak Demand Reduction (W)	167	421	736

Notes to Table 6:

1) * = extrapolation to higher than monitored temperatures. Extrapolations can be subject to significant errors because they extend the results outside the observed data.
2) Madera's and Yuba's second highest watt draw occurs in the 6PM to 7PM hour. This is a characteristic of residential air conditioners where the occupants turn down the thermostat when they arrive home from work.
3) The connected load for the HDAC unit in Yuba is higher than the Standard unit because the capacity is larger on the HDAC unit (Connected load is Sensible Capacity/PEER). The Yuba HDAC unit ran for a shorter time and at a higher PEER resulting in a lower peak load.
4) "Coincident Peak Demand" The metered or estimated demand of a device, circuit, or building that occurs at exactly the same time as the system peak for a given year and weather condition. *Energy Efficiency Policy Manual version 3.1 updated 11/2/2007, page 32*

Two items of significance from Table 6 are:

- The introduction of R-410A is illustrated in the cells with gray shading. R-410A will result in a 5% Coincident Peak if no compensating changes are made.

- The three HDAC units performed significantly better than Standard R-410A SEER 13 units. The reductions were between 9% and 34% as shown in the cells with the green shading.

Average Peak Demand

The average peak demand is over a much larger period[9], including periods where the watt draw is considerably less. The average peak demand of each unit and the average peak reductions are shown in Table 7.

Table 7. Standard vs. HDAC Average Peak Demand

	Madera	Yuba	Fresno
R-22 Standard Unit (W)	706	676	625
R-410A Standard Unit (W)	723	689	646
R-410A HDAC Unit (W)	639	548	414
Average Peak Demand Reduction vs. R-22 Standard Unit (W)	67	128	211
Average Peak Demand Reduction vs. R-22 Standard Unit (%)	**9%**	**19%**	**34%**
Average Peak Demand Reduction vs. R-410A Standard Unit (W)	84	141	232
Average Peak Demand Reduction vs. R-410A Standard Unit (%)	**12%**	**20%**	**36%**

Air leakage from the attic into the furnace cabinet or return plenum interface created when the HDAC unit was installed hides some of the peak demand improvement at Madera. The estimated reduction without the leak is 125 W, or 17% compared to the R-410A Standard Unit.

[9] Noon to 7 p.m. Monday through Friday, June 1 through September 30.

Discussion

Within the residential population there are three significant modes of air conditioner demand as follows:

- Residences where the air conditioners are off during the hours between 4PM and 6PM.
- Residences where the air conditioners run continuously from 4PM to 6PM. The continuously running AC group consists of air conditioners that cannot meet the load either because they are small or the load is excessive (such as is caused by a thermostat adjustment to a lower temperature).
- Residences that have air conditioners that are cycling during these hours.

The approximate breakdown of these groups from a sample of 100 monitored units in PG&E's Central Valley is: Off Group 20%, Continuously On Group 36%, and Cycling Group 44%. (Peterson & Proctor 1998)

The peak reduction for the continuously on group is the difference between the connected loads at the peak temperature. This is the group wherein resizing the air conditioners would have a major peak reduction effect.

The peak reduction for the cycling group is the difference in watt draws shown in Table 6.

The monitored sites had the following characteristics at coincident peak:

- Madera used a constant thermostat setting and was cycling.
- Yuba was cycling on some peak days and continuous running on other peak days, due to thermostat adjustment.
- Fresno was cycling, but experienced thermostat adjustments that influenced peak load.

Fan Time Delay Seasonal Cooling Energy Consumption and Peak Watt Draw

Table 8 shows estimated performance of each air conditioner with an optimal fan time delay. The sensible capacity and fan watt*hours during the optimal delay were measured for one cycle, then added to each cycle measured throughout monitoring to estimate performance with the delay.

Table 8. Standard vs. HDAC Performance with Control Modifications

	Madera		Yuba		Fresno	
Control Mode	Standard Tail	Optimum Tail	Standard Tail	Optimum Tail	Standard Tail	Optimum Tail
HDAC Unit Tail Length (minutes)	1.5	7*	0	20	0.75	5**
R-410A Standard Unit Annual Energy Usage (kWh)	1510		1387		1323	
R-410A HDAC Unit Annual Energy Usage (kWh)	1329	1068	1111	926	847	720
Energy Savings (kWh)	181	442	276	461	476	603
R-410A Standard Unit Annual Average Sensible EER	5.2		6.5		5.8	
R-410A HDAC Unit Annual Average Sensible EER	5.9	7.3	8.1	9.7	9.1	10.7
Annual Energy Savings based on Sensible EER (%)	**12%**	**29%**	**20%**	**33%**	**36%**	**46%**
Average Peak Demand Reduction (%)	**12%**	**29%**	**20%**	**34%**	**36%**	**45%**

* The optimal time delay for Madera was shorter than expected. Air leakage from the attic into the furnace cabinet or connection to the return plenum reduced the sensible capacity delivered during the fan cycle and limited the length of the optimal tail. Data collected during a cycle when the attic temperature was approximately the same as the return air temperature (so there was no heat gain due to the leak) indicated the optimal tail would be 10 minutes or longer.

** The furnace at the Fresno site was not equipped with an ECM motor and was unable to run at low speed, as at Madera and Yuba. A 5-minute tail is optimal for the actual fan speed. An ECM or equivalent motor would allow the fan to run longer at much lower speed and watt draw increasing the efficiency.

No fan time delay was standard for the SEER 13 units. The table above lists Standard Unit results with no time delay.

Discussion

The Optimum Tail mode describes the tail length resulting in the highest measured Sensible EER for the given unit. Use of an extended fan time delay can significantly improve the average efficiency as well as annual and peak energy use. The ability of the control changes to reduce peak watt draw at coincidence is limited by the operating mode of the air conditioner (Continuously On or Cycling). For Continuously On units there is no tail since the compressor is on continuously over the peak hour. The extended fan time delay is particularly effective for oversized units that are cycling at peak.

Monitored Efficiency vs. Manufacturers' Steady State Published Data

Performance of outdoor unit with indoor coil

The End of Cycle (EOC) data are obtained by taking the sensor measurements at the end of each compressor cycle. This point is used to compare performance to the manufacturers' steady state ratings because it is the point in the cycle closest to steady state operation. For the cleanest comparison, we have separated the Gross performance[10] of the unit from the performance of the furnace as an air handler. Table 9 compares the measured EOC Gross Sensible EER for each unit to the Manufacturer's rating at an outside temperature of 95 °F.

Table 9. Gross Performance Comparison to Published Data

	HDAC		
	Madera	Yuba	Fresno*
Outdoor Power (Watts)	105%	105%	123%
Sensible Capacity (Btuh)	76%	85%	100%
Sensible EER (Btuh/W)	73%	81%	81%
Flow (cfm)	1052	1111	1003
Cycle Length (min)	5.8	18.2	6.6
	Standard		
	Madera	Yuba	Fresno
Outdoor Power (Watts)	102%	95%	-
Sensible Capacity (Btuh)	86%	92%	-
Sensible EER (Btuh/W)	84%	96%	-
Flow (cfm)	1259	972	-
Cycle Length (min)	3.8	18.3	-

* Manufacturer's specified performance for the Fresno HDAC unit is based on unpublished modeled gross performance provided by the manufacturer. The model includes the condensing unit and evaporator coil installed at the Fresno site at 1200 cfm evaporator airflow.

[10] Gross capacities and efficiencies do not include the effect of the furnace fan watt draw or the fan heat.

Discussion

On the average the Standard units performed closer to their published data both for power draw and capacity. The R-410A HDAC units showed inferior performance to the Standard units compared to the Manufacturers' published data on the Sensible EER. On average, the R-410A HDAC units were 13% less efficient than the Standard units when compared to the Manufacturers' published data. The predominant difference was in the Sensible Capacity, which is the important metric for dry climates.

There are differences in the average cycle lengths between the Standard units and the HDAC units, but these differences are unlikely to account for the differences observed. It is possible that the difference is related to performance degradation of R-410A at high ambient temperatures.

Performance of Furnace as an Air Handler

The average watt draw of the indoor fan was taken whenever the fan was on. The average watt draw when the compressor is on and the fan is at full flow was used to compare fan watt draw per 1000 CFM. Table 10 shows the measured watt draw for each furnace and compares it to the Manufacturer's rating when those ratings are available[11].

Table 10. Furnace Air Handler Performance

Fan Power (W/1000 CFM)	Madera	Yuba	Fresno
HDAC	472	369	614*
Manufacturers' Listing	371	NA	NA
Standard Unit	518	509	-
Manufacturers' Listing	NA	NA	-

* The HDAC unit at Fresno was equipped with a PSC furnace blower motor. The estimated watt draw for a furnace with an ECM blower motor at the airflow and static pressure measured at the Fresno site is 349 W/1000 cfm.

Discussion

The average connected fan load was reduced by the HDAC installations due to lower resistance evaporator coils and, in two cases, changing the PSC motor furnace with an ECM motor furnace.

The furnace fan motor can significantly impact the sensible efficiency of an air conditioning system. Inefficient fan motors not only use more energy, the extra energy heats the air that the air conditioner is cooling. Inefficient fan motors increase system watt draw, and decrease capacity. Another benefit of ECMs and other brushless DC motors is their efficiency at low airflow, which increases the positive effect of an extended fan time delay.

[11] For most manufacturers the fan watt draws are not listed for standard PSC-motor driven fans.

To illustrate, Figure 7 shows the average end of cycle sensible EER of the Fresno HDAC unit with existing PSC motor, and estimated performance with a more efficient fan motor. On average, the fan motor in Fresno drew 616 watts. A furnace with an ECM or equivalent motor would draw approximately 350 watts at the same airflow and static pressure. The more efficient motor not only decreases watt draw by 266 W, it also increases sensible capacity by 908 BTU/hour. The average improvement in end of cycle (steady state) sensible EER at Fresno is 13.5%.

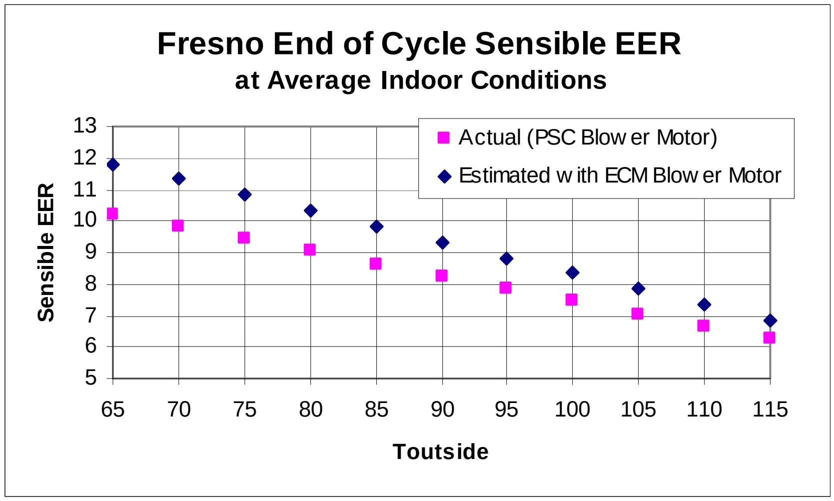


Figure 7. Fresno Blower Motor Improvement

Fresno Production Unit Performance Relative to HDAC Specification

The Fresno unit performance was extrapolated to the HDAC specification points by regression of measured sensible EER against outside, return air dry bulb, and return air wet bulb temperatures. Measured outside temperature did not exceed 105 °F during monitoring so performance at 115 °F is an extrapolation beyond the measured data. Measured return air temperatures ranged from an average of 77/63 (dry bulb/wet bulb) at 80 °F outside, to 82/67 at 105 °F outside.

Table 11: Fresno Production Unit Peak Energy Efficiency Ratio – sensible (PEERs)

			Predicted PEERs (% of HDAC Specification)				
Condition Out/Dry/Wet (°F)	HDAC Specification Net Sensible EER	Mfg. Specification (*Unpublished*) Net Sensible EER (% of HDAC Specification)	Installed, R-22 (End of Cycle)	R-22, With Efficient Fan Motor (End of Cycle)	R410A With Efficient Fan Motor (End of Cycle)	R-22 With Efficient Fan Motor, Optimal Tail (Cycle Average)	R-410A With Efficient Fan Motor Optimal Tail (Cycle Average)
115/80/63	8.0	106%	86%	95%	79%	103%	88%
115/80/67	6.8	91%	81%	88%	72%	96%	79%
Average		98%	84%	92%	75%	99%	83%

CAUTION: This is an extrapolation beyond the measured data and may contain significant error.

Discussion

Modeled performance provided by the manufacturer predicts PEERs exceeding the HDAC specification at dry conditions, but falling short at humid conditions (with an ECM furnace). Predicted performance of the unit as installed (with a PSC furnace) was 16% below the HDAC specification.

Upgrading the furnace blower motor improves estimated performance to 95% and 88% of the dry and humid specification, respectively. The use of an optimal fan time delay increases estimated average performance to within 1% of the HDAC specification with R-22.

Estimated performance with refrigerant R-410A is well below the specification due to performance degradation at high temperatures. The estimated performance degradation associated with R-410A was measured on standard tube and fin coils and may not accurately represent the performance of this unit, which has a microchannel condenser coil. Microchannel coils have greater heat transfer surface area compared to tube and fin coils, so performance degradation may be less.

Occupant Survey

The occupant surveys were performed by interview as described in the Methodology Section.

Table 12. Occupant Satisfaction Survey Results

	Comfort	Humidity	Noise	Occupant's Comments
Madera	No Difference	No Difference	HDAC Quieter	HDAC had less fluctuation in inside temperatures. Summer electric bill is approximately half of what it used to be.
Yuba City	No Difference	No Difference	HDAC Quieter	The HDAC provided better cooling in back rooms
Fresno	Acceptable	Acceptable	HDAC is Quiet	HDAC is quiet and cools the house well.

All homeowners were happy with the HDAC unit.

The homeowners at the Madera site stated that their electric bill in the summer is about half of what it used to be. Since the fan is operated continuously, it is likely that much of the improvement is the result of a more efficient furnace fan motor. The original furnace had a PSC motor, while the furnace installed with the HDAC unit had an ECM motor with much lower watt draw at fan only speed.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Existing single speed air conditioners utilizing outdoor units, indoor coils, and furnaces selected to meet the performance standards set in the HDAC project can produce peak electrical power reductions and annual cooling energy savings of 20%.
2. The common characteristics of combinations that perform well are brushless DC fan motors and more effective coils.
3. Control modifications to the fan timing can reduce annual electric consumption and peak consumption an additional 9% to 17%, for total savings of 29% to 37%. The highest savings are accomplished on air conditioners with brushless fan motors.
4. The "refrigerant of the future" R-410A results in a 5% increase in peak watt draw for every air conditioner[12]. Over the next 15 years, as the market penetration of R-410A machines increases, there will be an increase of 1.13 GW in peak electrical consumption in California. This increase will have to be met by new capacity at a cost of approximately 0.563 billion dollars.
5. Aggressive adoption of HDAC standards could more than compensate for the effects of 410A.
6. Both the SEER 13 R-22 air conditioners and the HDAC R-410A air conditioners performed below the manufacturers' published data for gross sensible EER at 95°F. On average, R-22 units performed closer to their manufacturers' expanded performance tables than the R-410A machines. This points out a weakness in determining the performance of air conditioners from published expanded performance tables.
7. The manufacturer's published data are not of laboratory test results, but are rather the output from a model based on past history and limited laboratory tests. The results of this study indicate that the model may be less accurate for the R-410A air conditioners than it is for the R-22 air conditioners. As a result it appears that the current manufacturers' data sheets may not be sufficient for selecting HDAC air conditioners.
8. The best performing unit contained a microchannel condenser coil. This agrees with results from the PIER project, providing further evidence that microchannel heat exchangers may improve air conditioner performance in hot dry climates.
9. Customers were universally satisfied with the HDAC air conditioners. In general they saw little difference between the standard SEER 13 units and the HDACs.

[12] Compared to a similar machine with the same ratings using R-22.

Recommendations

1. An additional test point should be created for certification of air conditioners selected for use in hot dry climates. This is particularly important for R-410A units, which lose more efficiency at hot temperatures than R-22 units.
2. The peak AC test point should be an essential part of utilities programs to control or reduce peak loads.
3. In order to achieve market penetration with air conditioners that perform well at high temperatures, the utilities in hot dry areas should offer substantial incentives for the installation of units that meet or exceed the HDAC specification.
4. A standard and accurate method of predicting the performance of combinations of equipment, including third party coils should be developed. The predictions need to be based on laboratory testing and supported by random testing of OEM and 3rd Party coil certified systems.
5. Emerging technologies capable of improving efficiency at hot conditions, such as microchannel heat exchangers, should be further studied and promoted to the manufacturers as a means of achieving the hot/dry specification.

APPENDIX A – REFERENCES

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APPENDIX B – ANNUAL RESULTS TABLES

Fresno Annual Results Tables

Table B1: HDAC Unit Fresno Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1003	1003/905	1003/905	1003/905	1003/905	1003/905	
Temperature Bin	Actual NO TAIL	Actual .75 Minute Tail	With ECM Motor .75 Minute Tail	ECM Motor and R-410A .75 Minute Tail	With ECM Motor 5 Minute Tail	ECM Motor and R-410A 5 Minute Tail	Normalized Sensible Load (kBtu)
70	0	0	0	0	0	0	0
75	17	16	14	13	12	11	147
80	89	86	74	72	63	61	764
85	94	91	78	78	67	66	772
90	241	232	202	204	172	174	1883
95	246	237	208	215	178	184	1834
100	227	219	193	205	166	176	1606
105	97	94	84	92	72	79	654
110	5	5	5	5	4	5	34
Total kWh/season	**1016**	**979**	**857**	**883**	**734**	**755**	**7694**
Seasonal Sensible EER	**7.6**	**7.9**	**9.0**	**8.7**	**10.5**	**10.2**	

Table B2: HDAC Fresno "Average Peak" Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1003	1003/905	1003/905	1003/905	1003/905	1003/905	
Temperature Bin	Actual NO TAIL	Actual .75 Minute Tail	With ECM Motor .75 Minute Tail	ECM Motor and R-410A .75 Minute Tail	With ECM Motor 5 Minute Tail	ECM Motor and R-410A 5 Minute Tail	Normalized Sensible Load (kBtu)
70	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0
80	4	4	3	3	3	3	34
85	23	22	19	19	16	16	185
90	123	119	103	104	88	89	964
95	176	169	148	153	127	131	1310
100	157	152	134	142	115	122	1112
105	77	75	66	73	57	63	519
110	5	5	5	5	4	5	34
Total kWh/season	**565**	**545**	**479**	**499**	**411**	**428**	**4159**
Seasonal Sensible EER	**7.4**	**7.6**	**8.7**	**8.3**	**10.1**	**9.7**	

Madera Annual Results Tables

Table M1: Standard Unit Madera Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1259	
Temperature Bin	No Tail	Normalized Sensible Load (kBtu)
65	0	0
70	3	21
75	52	317
80	96	561
85	260	1460
90	323	1731
95	357	1821
100	263	1272
105	129	593
110	7	32
Total kWh/season	**1490**	7808
Seasonal Sensible EER	**5.2**	

Table M2: Standard Unit Madera "Average Peak" Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1259	
Temperature Bin	No Tail	Normalized Sensible Load (kBtu)
70	0	0
75	7	45
80	28	167
85	119	666
90	148	795
95	224	1144
100	178	861
105	103	472
110	7	32
Total kWh/season	**816**	4183
Seasonal Sensible EER	**5.1**	

Table M3: HDAC Unit Madera Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1054	1054/417	
Temperature Bin	No Tail	7 Minute Tail	Normalized Sensible Load (kBtu)
65	0	0	0
70	3	2	21
75	42	32	317
80	79	62	561
85	221	175	1460
90	282	227	1731
95	322	261	1821
100	246	200	1272
105	127	103	593
110	8	6	32
Total kWh/season	**1329**	**1068**	7808
Seasonal Sensible EER	**5.9**	**7.3**	

Table M4: HDAC Unit Madera "Average Peak" Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1054	1054/417	
Temperature Bin	No Tail	7 Minute Tail	Normalized Sensible Load (kBtu)
70	0	0	0
75	6	5	45
80	24	18	167
85	101	80	666
90	130	104	795
95	203	164	1144
100	167	136	861
105	101	82	472
110	8	6	32
Total kWh/season	**738**	**595**	4183
Seasonal Sensible EER	**5.7**	**7.0**	

Yuba City Annual Results Tables

Table Y1: Standard Unit Yuba Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	972	
Temperature Bin	NO TAIL	Normalized Sensible Load (kBtu)
65	12	93
70	43	325
75	86	624
80	131	921
85	200	1355
90	303	1971
95	349	2180
100	205	1227
105	55	316
Total kWh/season	**1385**	9012
Seasonal Sensible EER	**6.5**	

Table Y2: Standard Unit Yuba "Average Peak" Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	972	
Temperature Bin	NO TAIL	Normalized Sensible Load (kBtu)
70	0	0
75	1	10
80	22	152
85	96	647
90	181	1178
95	216	1350
100	144	861
105	44	253
Total kWh/season	**705**	4452
Seasonal Sensible EER	**6.3**	

Table Y3: HDAC Unit Madera Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1111	1111/512	
Temperature Bin	NO TAIL	20 Minute Tail	Normalized Sensible Load (kBtu)
65	9	7	93
70	32	27	325
75	65	54	624
80	102	84	921
85	157	131	1355
90	242	202	1971
95	285	238	2180
100	171	143	1227
105	47	39	316
Total kWh/season	**1111**	**926**	9012
Seasonal Sensible EER	**8.1**	**9.7**	

Table Y4: HDAC Unit Madera "Average Peak" Projected Energy Use in a Typical Season (kWh)

Flow (CFM) Compressor Cycle /Tail	1111	1111/512	
Temperature Bin	NO TAIL	20 Minute Tail	Normalized Sensible Load (kBtu)
70	0	0	0
75	1	1	10
80	17	14	152
85	75	63	647
90	145	121	1178
95	176	147	1350
100	120	100	861
105	38	32	253
Total kWh/season	**572**	**477**	4452
Seasonal Sensible EER	**7.8**	**9.3**	