Hot Dry Climate Air Conditioner (HDAC)
Combined Field Test Report

Prepared for:
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Final Report, July 19, 2007

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Table of Contents

List of Figures

List of Tables

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, Nevada, Arizona, 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 air conditioners in hot dry climates, 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, Southern California Edison, and Nevada Power commissioned this side-by-side field test of standard SEER 13 air conditioners and major manufacturers' HDACs. The study consisted of field monitoring seven SEER 13 air conditioners and their HDAC replacements during the summer of 2006.

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 annual cooling energy savings of 20% or more.
2. These HDAC machines showed up to a 35% peak reduction at system critical peak times.
3. Fan time delays longer than provided by the manufacturers can significantly improve the performance of air conditioners in hot dry climates.

This study recommends that:

1. Two of the test units be monitored over a hot portion of 2007 to confirm that there is not any serious energy savings or peak reduction degradation at higher temperatures.
2. Two standard air conditioners be modified with the most effective items in the HDAC designs created for the PIER project and field-tested.
3. An additional test point should be created for certification of air conditioners selected for use in hot dry climates.
4. In order to achieve market penetration with high performance HDAC air conditioners, it is essential that the utilities in hot dry areas offer substantial incentives for the installation of these units.
5. Future air conditioner programs should require OEM certified systems or 3rd Party coil certified systems with extended tables.

I. PROJECT BACKGROUND

California is a summer peaking utility region and air conditioning is the primary 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 indoor conditions that require significant dehumidification and an outdoor temperature of only 82ºF. For commercial air conditioners larger than 5 tons, the metric is Energy Efficiency Ratio (EER) 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 or where dehumidification is not necessary. 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	Package HDAC	Draft Specification
Condition #1	**Hot Dry 115°F outdoor, 80°F indoor with 38.6% Rh (63 WB)**		
Net PEERs	8.22	8.60	8
Gross PEERs	9.11	9.56	
Condition #2	**Hot Medium 115°F outdoor, 80°F indoor with 51.1% Rh (67 WB)**		
Net PEERs	6.91	7.08	6.8
Gross PEERs	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 – PEERs (Peak Energy Efficiency Ratio $_{sensible}$)

Air conditioners produce two effects. They lower the temperature (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 outdoor temperatures with low to moderate indoor humidity. Since this addresses the cause of system electrical peak, PEERs 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.

II. INTRODUCTION

The purpose of the 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[1].

Units from those three manufacturers were installed and monitored in three utility company service areas by a team consisting of Paragon Consulting Services, ADM Associates, and Proctor Engineering Group (the Team).

Sites were selected in seven locations. Four of the locations were in Pacific Gas and Electric (PG&E) Company's service area; two locations were chosen in Southern California Edison's (SCE) service area; and one location was chosen in Nevada Power's (NP) service area.

This report is dependent upon, and borrows heavily from the NP Final Report Hot Dry Climate Air Conditioner (HDAC) Measurement and Verification (M&V) Residential Field Test by Paragon Consulting Services as well as the SCE Data Collection Report for Testing of Optimized Air Conditioner Design in Hot Dry Climates by ADM Associates.

An additional report, the PG&E Hot Dry Climate Air Conditioner Pilot Field Test by Proctor Engineering Group is available for details on the PG&E portion of the field test including the fan time delay tests.

[1] Specifications that, as shown in Table 1, were lower than the performance of the PIER HDAC units.

Normal air conditioner operation consists of two modes, continuous running (which is the connected load – the upper limit of the watt draw) and cycling (which is the normal consumption when the capacity of the unit is large enough to meet the load). These two modes are shown in Figure 1.

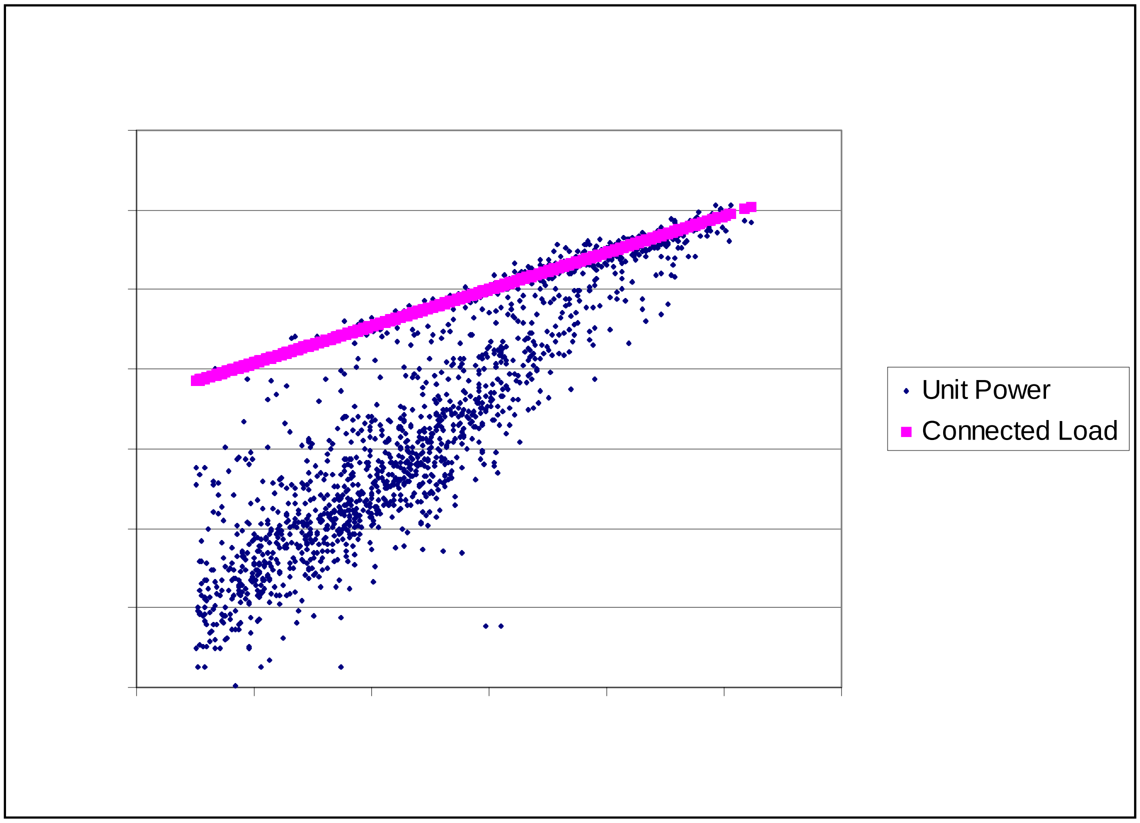

Figure 1. AC Power Draw (5 ton unit in Furnace Creek, CA)

The connected load is the power the air conditioner will draw on peak in houses where thermostat adjustments or system problems result in a cooling load higher than the cooling capacity of the air conditioner. In many locations, such as PG&E's Central Valley, thirty-six percent of the home air conditioners are running at their connected load on system peak.

The unit power under most conditions for most air conditioners is less than the connected load because the unit is cycling on and off over the hour. In areas such as the aforementioned California Central Valley forty-four percent of the home air conditioners are cycling during system peak.

In addition there are twenty percent of the home air conditioners that are off (0 power consumption) during system peak[2].

[2] These percentages are dependent on the characteristics of the local housing stock and occupancy patterns. (Peterson & Proctor 1998)

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

4. Evaluate the possibility of improved performance in hot dry climates by utilizing the cooling potential of the wet indoor coil at the end of the compressor cycle.

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

IV. METHODOLOGY

The Team completed a field test to compare the performance of standard air conditioners to air conditioners selected for hot and dry climates (HDACs). The field test consisted of site and AC selection, installation and replacement, performance monitoring, and data analysis. Standard (baseline) SEER 13 air conditioners were first monitored and then replaced with HDACs. Monitoring of the baseline and HDAC units were completed during the summer of 2006.

Site and AC Characteristics

The characteristics of the homes and air conditioners used in the project are listed in Tables 2, 3, and 4.

Table 2. Site Characteristics

Site	Bakers-field	Concord	Madera	Yuba	Furnace Creek	Victor-ville	Las Vegas
House Size (square feet)	1200	1400	1650	1600	1230	1600	1225
Year Built	1941	1970s	2002	1991	NA	2004	NA
Air Handler Location	Bedroom Closet	Hall Closet	Attic	Attic	Package Rooftop	Attic	Attic

All the locations except the Furnace Creek (Death Valley) site were occupied homes served by a single air conditioner. The Furnace Creek site was a modular structure used as a registration building. It was also served by four small window air conditioners. The Furnace Creek site was chosen for the severity of the conditions.

Table 3. Standard Air Conditioner Specifications

Site	Bakers-field	Concord	Madera	Yuba	Furnace Creek	Victor-ville	Las Vegas
Rated SEER	13	13	13	13	13	11.3 to 12.3[3]	13[4]
Rated Sensible EER[5]	8.3	8.0	7.5	8.3	8.18	NA	NA
Rated EER[5]	11.2	11.2	10.8	11.6	10.9	10 to 10.8	11
Sensible Heat Ratio (temperature reduction fraction) [5]	0.74	0.71	0.70	0.72	0.75	NA	NA
Rated Capacity [5]	34000	34000	47000	35000	54400	55000	35000
Nominal Size (Tons of Cooling)	3	3	4	3	5	5	3
Nominal Evaporator Coil Capacity (Btuh)	42000	48000	48000	36000	60000	NA	48000
Refrigerant	R-22	R-22	R-22	R-22	R-22	R-22	R-22
Metering Device	TXV	TXV	Piston	Piston	NA	NA	NA
Fan Motor Horsepower	1/2	1/2	1/2	1/4	3/4	NA	1/3
Fan Motor Type	ECM	ECM	PSC	PSC	PSC	PSC	PSC

Since the sensible heat ratio is the fraction of the cooling that reduces the indoor temperature, it is evident that these standard units wasted a quarter or more 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 some of the installed HDACs approached this ratio.

The standard ACs were SEER 13 R-22 units either already in place or selected by the contractor and installed for this test.

[3] Coil make and model unknown

[4] Best Estimate Coil and Outdoor unit Combination not listed

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

Table 4. HDAC Air Conditioner Specifications

Site	Bakers-field	Concord	Madera	Yuba	Furnace Creek	Victor-ville	Las Vegas
Rated SEER	13.25	13.5	14	14.2	14	13 to 13.7	15
Rated Sensible EER[6]	8.5	8.8	9.4	9.2	8.25	NA	NA
Rated EER[6]	11.2	11.3	12.3	11.7	11.7	10.7 to 11.2	12.5
Sensible Heat Ratio (temperature reduction fraction) [6]	0.76	0.78	0.77	0.79	0.73	NA	NA
Rated Capacity (Btuh) [6]	36400	44100	50730	35200	59000	52000 to 56000	35600
Nominal Size (Tons of Cooling)	3	3.5	4	3	5	5	3
Nominal Evaporator Coil Capacity (Btuh)	48000	60000	60000	42000	60000	NA	48000
Refrigerant	R-410A	R-410A	R-410A	R-410A	R-410A	R-410A	R-410A
Metering Device	TXV	TXV	TXV	TXV	TXV	NA	TXV
Fan Motor Horsepower	3/4	1/2	1/2	1/2	3/4	NA	3/4
Fan Motor Type	ECM	ECM	ECM	ECM	ECM	ECM	ECM

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 published performance data on the outside unit and coil combination, the coil pressure drop, and the furnace blower provided by the manufacturers. These units were selected to approach the draft HDAC performance specifications shown in Table 5.

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

Table 5. 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 PEERs	at least 6.8 btu / watthr

Table 5 Notes:

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

Nevada Power (NP) 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. Commissioning identified low refrigerant charge in the baseline unit. Refrigerant was added to bring the unit to the manufacturer's specification.

The HDAC specification was approached by the selected air conditioner systems 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.

The contractor did not install the furnace originally specified for the HDAC system. A larger furnace of the same model was installed instead. The contractor did not adjust the airflow to match the original specification. As a result, the HDAC furnace consumed more power than expected. Reducing the blower speed to more closely match the original specification reduced the furnace power consumption by 50%.

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.

Pacific Gas and Electric (PG&E) 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. When the monitored results indicated lower than expected performance, these items were rechecked. In the case of the Bakersfield HDAC unit, all the refrigerant was removed, the system evacuated to 500 microns, held to ensure there was no moisture in the system and recharged with fresh R410A. This procedure made no significant difference in the performance of the Bakersfield HDAC system.

The HDAC specification was approached by the selected air conditioner systems by closely matching the performance of the indoor coil, outdoor unit, and furnace. In all but Concord this included replacing the furnace with a new unit listed as providing higher airflow at lower watt draws for the specified external static pressure. In Concord the selected replacement furnace would not fit into the closet and the existing furnace remained in service. A sheet metal transition piece from the existing furnace to the new larger evaporator coil was used at this location. 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.

Even with a close attention to the work of the HVAC contractors, the Team 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[7] (including third party manufacturers) at hot dry conditions.

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.

Southern California Edison (SCE) Installation and Replacement

At the time of replacement, one-time measurements were taken of the airflows of the units. The Furnace Creek baseline airflow in the supply duct was 1,573 cfm. The HDAC unit airflow was 1,721 cfm. The Victorville baseline airflow in the supply duct was 1,284 cfm. This measurement was made at the end of the baseline period and the air filter was found to be very dirty. A measurement without the filter found 1,500 cfm flow. The airflow for the HDAC unit was 1,587 cfm.

[7] or independent third party test laboratory

Monitoring Systems

SCE Monitoring System. A multi-channel data logger (DataTrap) was used to record energy, temperature and relative humidity data. The data logger recorded averaged data in 15-minute intervals. A list of channel measurements is provided in Table 6.

Table 6. SCE Monitored Parameters

Channel	Measurement	At 15 minute intervals
1	Air Conditioner Power	Average kW
2	Supply Air Temperature, Dry-Bulb	Average Degree F
3	Supply Air Relative Humidity	Average % RH
4	Return Air Temperature, Dry-Bulb	Degree F
5	Return Air Relative Humidity	Average % RH
6	Ambient Air Temperature, Dry-Bulb	Degree F
7	Ambient Air Relative Humidity	Average % RH

NP Monitoring System: HOBO data loggers were used to monitor indoor and outdoor temperature and humidity, and temperatures in the return and supply plenums. Dent Instruments Elite PRO poly-phase power meter was used to monitor electrical current, voltage, power and energy for the condensing unit and furnace. 50A split core current transformers were used to monitor current. Voltage and current were monitored in each phase of the three-phase circuit. Data were stored in memory until the loggers were downloaded. Data points are summarized in Table 7.

Table 7 NP Monitored Parameters

Measurement	Sensor/Instrument	At 2 min intervals
kW of Outdoor AC Compressor/Fan	Dent Instruments Elite Pro	Average
kW of Indoor Blower	Dent Instruments Elite Pro	Average
Indoor Air Temperature at Thermostat	HOBO self-contained temperature data logger #H08-30-08	Instant
Air Temperature/Humidity at Return Grill	HOBO self-contained temperature and humidity data logger #H0832-08	Instant
Air Temperature at Farthest Supply Register	HOBO self-contained temperature data logger #H08-30-08	Instant
Air Temperature at Nearest Supply Register	HOBO self-contained temperature data logger #H08-30-08	Instant
Condenser Air Entering Temperature	External temperature probe connected to HOBO data logger #H08-006-04	Instant
Outdoor Ambient Air Temperature/Humidity	HOBO self-contained temperature and humidity data logger #H0832-08	Instant

PG&E 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 8.

Table 8 PG&E 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 Transducer	Electrical Supply To Unit
Condensing Unit Power	Analog Transducer	Electrical Supply To Unit
Furnace Blower Power	Pulse Transducer	Electrical Supply To Furnace Unit
Furnace Blower Power	Analog 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. These 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 office called the CR10X nightly to download data. These data were transformed into graphs and reviewed daily.

Potential Measurement Errors

When air conditioners are tested in a laboratory, where measurements can be extremely accurate, the applicable ASHRAE Standard[8] 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.

Calculations

System Seasonal Performance

This field test was performed in two stages during the summer of 2006. The first stage tested standard SEER 13 units. The second stage began when the HDAC units replaced the standard units.

The primary performance measures were the change in annual energy consumption and reduction in peak electric demand. Peak electric demands were calculated for both coincident and non-coincident[9] peak demand periods [10]. In clearer terms, the "non-coincident" peak demand period is the largest demand and for air conditioners it occurs on the hottest days at or near the few hours of the system critical peak demand.

The energy consumption was normalized to the local hourly temperature profiles from the 2005 California Energy Commission Standards version of Micropas or Bin Maker.

For the PG&E sites, the seasonal energy use was based on measured loads and measured efficiencies. In addition, each systems performance was calculated and compared to the manufacturers' data. These calculations are detailed in (Proctor Engineering Group 2007).

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[8] ANSI/ASHRAE Standard 37-1988

[9] Coincident (peak) demand reduction is the reduction of an electric load during the utility peak demand period. (Noncoincident (peak) demand reduction is the peak demand reduction of the technology, regardless of the time of the system peak.)

[10] Peak demand period, as defined in CPUC Energy Efficiency Policy Manual Version 2 (prepared by the Energy Division and dated August 2003) is noon to 7 p.m. Monday through Friday, June 1 through September 30.

For the NP and SCE sites, the seasonal energy use was based on regression of total hourly kWh against average hourly[11] outside temperature. Data from days where the thermostat setting was constant (as indicated by the temperature measured at the thermostat or in the return) were included in the analysis. This analysis assumes the loads are adequately represented as a linear function of outdoor temperature when known anomalies are excluded.

In the NP data, the following were excluded from the regression:

1. The building occupant turned the air conditioner off at various times during monitoring of the standard AC unit. Days where this occurred were excluded from the analysis.

2. The HDAC unit was installed with a larger than specified furnace. The blower speed was not adjusted properly during installation, resulting in higher than expected furnace watt draw. The blower speed was corrected midway through monitoring. Data before the blower speed was corrected were analyzed separately.

3. Data after 9/14/2006 indicated lower indoor temperature (measured at the thermostat) than previous data. Data after 9/14/2006 were excluded from the analysis.

4. Outside temperatures lower than 85 °F were excluded from the regression due to minimal air conditioner use.

5. Hours where the unit ran continuously were analyzed separately to establish the maximum power draw for those conditions.

In the SCE data, the following were excluded from the regression:

1. Outside temperatures lower than 80 °F were excluded from the regression due to minimal air conditioner use.

2. Hours where the unit ran continuously were analyzed separately to establish the maximum power draw for those conditions.

The regression results are presented in the form:

SEER 13 Unit kWh per hour = A*Ta + C1

HDAC Unit kWh per hour = A*Ta + C1 + B*Ta + C2

Where Ta = Average outside temperature for the hour

Variables B and C2 represent the difference in slope and y intercept, respectively, between the standard SEER 13 unit and the HDAC unit.

Connected load analysis was based on regression of measured kW against outside temperature for times when the units were running continuously.

The regression results are presented in the form:

SEER 13 Unit kW = A*To + C1

[11] For the Victorville site data were averaged over two hour periods to compensate for the substantial differences in cycle length between the baseline and HDAC units.

HDAC Unit kW = A*To + C1 + B*To + C2

Where To = Outside temperature

Variables B and C2 represent the difference in slope and y intercept, respectively, between the standard SEER 13 unit and the HDAC unit.

Unit Annual Energy Savings

Unit Annual Energy Savings were determined by applying energy use regression analysis results to TMY-2 temperature bin hours.

Coincident Peak Demand

Coincident Peak Demand (CPD) was calculated by dividing the total kWh predicted by application of the energy use regression to TMY-2 temperature bin hours occurring at peak times by the total hours occurring at peak times. Peak times were defined as 12 PM to 7 PM, Monday through Friday, June through September.

Non-coincident Peak Demand

Noncoincident peak demand was derived from the hourly data set. The days with hours showing the highest watt draws were examined to determine whether the unit was cycling or running continuously.

Connected load was calculated from the regression of measured kW against outside temperature.

The recorded kWh/hr is reported for the hours ending in 4PM, 5PM, and 6PM. Data for each unit is compared for days with similar weather.

Occupant Survey

In NP and PG&E, homeowners were surveyed to determine satisfaction with the HDAC unit. The survey addressed noise, vibration, cycling, airflow, general comfort, and overall satisfaction.

IV. RESULTS

Results were obtained for seasonal cooling energy consumption (kWh) as well as coincident and non-coincident peak power draw (average kWh per hr). These results are presented for standard operation[12].

Weather Normalized Seasonal Cooling Energy Consumption

The seasonal cooling energy consumption of each unit and the annual energy savings are shown in Table 9.

Table 9. Standard vs. HDAC Performance Summary.

Location	Standard Unit Annual Energy Usage (kWh)	HDAC Unit Annual Energy Usage (kWh)	Energy Savings (kWh)	**Annual Energy Savings (%)**
Las Vegas	2770	2291	478	**17%**
Furnace Creek	11086	9232	1854	**17%**
Victorville	3534	2498	1036	**29%**
Madera	1966	1618	348	**18%**
Yuba	1592	1256	336	**21%**
Bakersfield	3059	3262	-203	**-7%**
Concord	420	443	-23	**-5%**

Las Vegas, Furnace Creek, Madera, and Yuba all showed substantial Annual Cooling Energy Savings of 17% to 29%. Bakersfield and Concord showed increases in Annual Cooling Energy Use of 7% and 5% respectively. The units in Bakersfield and Concord were intensively monitored and it was determined that they performed well below the manufacturers' published data.

[12] The PG&E test included additional operating modes designed to obtain higher overall sensible cooling.

Cooling Peak Electrical Demand

Peak Demand Savings

Peak demand is determined by a combination of air conditioners that are running continuously for the whole hour at peak, air conditioners that are off for the full hour, and air conditioners that are cycling during the hour.

The units monitored in this field test were specifically selected to make sure they were used during peak periods. Their operation at peak was as follows:

- Bakersfield and Furnace Creek were continuous running.
- Concord, Victorville, Las Vegas, and Madera were cycling.
- Yuba used daytime thermostat setups and was cycling on some peak days and continuous running on other peak days (depending on the severity of the thermostat change).

Peak demand reductions at system peak depend on the operating conditions of the unit.

1. For units where the capacity is less than the load at peak, the savings will be the difference between the connected loads of the units (Connected load is Capacity/PEERs). For units with equal capacity then, the peak savings is 1 – PEERs std. / PEERs hdac.
2. For units where the capacity exceeds the connected load, the peak savings will again be 1 – PEERs std. / PEERs hdac.

Demand at System Super Peak

The peak demand of major importance occurs on hot afternoons and is driven by the diversified air conditioner demand. What is called the non-coincident peak demand of an air conditioner actually coincides with the peak demand of the system. The hours from 3PM to 6PM are of particular significance. The "non-coincident" peak demand for matched peak days are shown in Table 10.

Table 10. Standard vs. HDAC 4PM to 6PM "Non-Coincident" Peak Demand Summary.

	Las Vegas	Furnace Creek	Victor-ville	Bakers-field	Concord	Madera	Yuba
Standard Unit 3PM to 4PM Peak Demand (W)	1849	6245	4102	3156	2751	1975	1914
HDAC Unit 3PM to 4PM Peak Demand (W)	1612	6025	3040	na	na	1418	1293
Average 3PM to 4PM Peak Demand Reduction (W)	237	220	1062	0	0	557	621
	13%	4%	26%	0%	0%	28%	32%
Standard Unit 4PM to 5PM Peak Demand (W)	1934	6098	3935	3159	2624	2178	1960
HDAC Unit 4PM to 5PM Peak Demand (W)	1416	5935	2910	na	na	1562	1262
Average 4PM to 5PM Peak Demand Reduction (W)	518	163	1025	0	0	616	698
	27%	3%	26%	0%	0%	28%	36%
Standard Unit 5PM to 6PM Peak Demand (W)	1872	5962	3768	2902	2859	2254	2018
HDAC Unit 5PM to 6PM Peak Demand (W)	1541	5977	2780	na	na	1751	1302
Average 5PM to 6PM Peak Demand Reduction (W)	331	-15	988	est. 0	est. 0	503	716
	18%	0%	26%	0%	0%	22%	35%

na = insufficient higher temperature data with no reason to believe performance is better than standard.

The non-coincident peak loads were substantially reduced (between 237 and 1062 Watts) at four of the locations. At Bakersfield and Concord the HDAC units were performing well below the manufacturers' reported performance and no better than the standard units they replaced. At Furnace Creek both the standard and HDAC units were undersized to the load and had the same connected loads. The HDAC had more cooling capacity but, under peak conditions, it was still operating continuously.

Demand at Regulatory Peak

The coincident peak load is defined as the average over a much larger period, including periods where the watt draw is considerably less. The coincident peak demand of each unit and the coincident peak reductions are shown in Table 11.

Table 11. Standard vs. HDAC Average Coincident Peak Demand Summary.

	Standard Unit Average Coincident Peak Demand (W)	HDAC Unit Average Coincident Peak Demand (W)	Average Coincident Peak Demand Reduction (W)	Average Coincident Peak Demand Reduction (%)
Las Vegas	1630	1292	339	**21%**
Furnace Creek	4125	3632	493	**12%**
Victorville	2633	1903	729	**28%**
Madera	1080	902	177	**16%**
Yuba	1041	847	194	**19%**
Bakersfield	1888	2073	-186	**-10%**
Concord	297	312	-16	**-5%**

The regulatory coincident peak contains many hours when even the undersized air conditioner at Furnace Creek was cycling. As a result all five of the performing units showed significant peak reductions of 12% to 28%.

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
Bakersfield	No Difference	No Difference	HDAC Quieter	HDAC did not cool the house down as fast as the standard unit and ran longer periods. HDAC airflow was noticeably higher.
Concord	No Difference	No Difference	HDAC Quieter	
Madera	No Difference	No Difference	HDAC Quieter	HDAC had less fluctuation in inside temperatures.
Yuba City	No Difference	No Difference	HDAC Quieter	The HDAC provided better cooling in back rooms

It is interesting to note the difference between perception and reality. Monitored data from the Bakersfield home shows that the HDAC unit actually ran shorter periods than the Standard unit, and that there was no difference in "pull down time" or indoor temperatures. It is possible that the occupants comments about "running longer" might be translated to "more often" since the number of cycles per hour was greater with the HDAC unit.

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% or more.

2. Customers were universally satisfied with the HDAC air conditioners. In general they saw little difference between the standard SEER 13 units and the HDACs.
3. These HDAC machines showed up to a 35% peak reduction at system critical peak times.
4. Fan time delays longer than provided by the manufacturers can significantly improve the performance of air conditioners in hot dry climates.

Recommendations

1. The two PG&E units that performed well over the summer of 2006 should be monitored over a hot portion of Summer 2007 to confirm that there is not any serious degradation at the higher temperatures that were missing in the HDAC monitoring period.

2. We recommend that two standard air conditioners be modified with the most effective items in the HDAC designs created for the PIER project and field-tested.

3. We recommend that we elicit the support of the manufacturer of the two most under performing units to determine the cause of the underperformance.

4. An additional test point[13] should be created for certification of air conditioners designed for hot dry climates.

5. 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.

6. In order to achieve market penetration with high performance HDAC air conditioners, it is essential that the utilities in hot dry areas offer substantial incentives for the installation of these units.

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[13] 15°F outdoor, 80°F indoor with 38.6% Rh (63 WB) as well as the existing 80°F / 67 WB used in the durability test.

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