Maintenance and Advanced Controls Installation for Rooftop Units

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EXECUTIVE SUMMARY

In support of California's strategic plan to accelerate the penetration of energy efficiency technologies, San Diego Gas & Electric's Emerging Technology program funded a study of rooftop package unit maintenance and control retrofit technology at two fast food restaurant buildings. The primary goals for this project were to determine the energy savings potential and demand response (DR) capabilities of an advanced rooftop controller (ARC) for rooftop units (RTUs) and how a standardized operations and maintenance (O&M) protocol can complement the technology. In order to gain insight into the technology and the O&M procedure, a field test and subsequent analysis were conducted.

The measures were implemented at two San Diego area fast food restaurants with total building EUIs of 79.4 and 109.9 kWh/ft^2-yr. The restaurants were each served by three RTUs with total cooling capacities of 25 and 22.5 tons at each building. While one RTU had to be replaced prior to data collection, the remaining units were between 8 and 10 years old. The implementation consisted of several stages including RTU testing and diagnostics, repairs and maintenance, air balancing, and the installation of the ARC technology for a total measure cost of about $33,500 per site. The O&M measures were based on a standardized protocol and testing procedures as established by an industry training institute. The ARC technology included variable speed control of the supply fans, setpoint scheduling and control, DR load shedding capabilities, fault detection, and a user interface for tracking energy usage, projected savings, and unit operation. DR events were manually initiated for research purposes at both sites using two load shedding strategies: setpoint increases of 1 °F per hour for 6 hours and 2 °F per hour for 3 hours.

Data was collected using logging instrumentation over a period of several months, establishing a baseline and collecting at least two weeks of data after each stage of the implementation. Data collection included indoor air conditions and energy consumption of each RTU. In addition, whole-building, utility-metered data was used for data analysis of energy usage over a longer period of time.

The data showed that the buildings realized energy savings of about 16,481 kWh and 28,913 kWh per year for total building EUI reductions of 8.3% and 13.2%, respectively. Using the same convention as previous ARC reporting, the savings were about 0.304 and 0.615 kWh/hr-hp where hr is the annual RTU operating hours and hp is the supply fan horsepower. Demand response tests resulted in load decreases of 3.2 to 12.2 kW (8.1% to 25.9% of total building demand) depending on strategy. Both the energy savings and DR results agree with past research and suggest that vast market potential for savings and load shedding exists.

Site	Baseline Building Energy [kWh/year]	Energy Savings [kWh/year]	Avg Baseline Building On-Peak Demand [kW]	DR Reduction [kW]	Simple Payback with Incentives for Full Project Cost [yr]	Simple Payback with Incentives for ARC-only Cost [yr]
Escondido	198,476	16,481 (8.3%)	47.4	3.6 – 10.0 (8% - 20%)	12.0	4.8
Chula Vista	219,877	28,918 (13.2%)	43.4	3.2 – 12.2 (8% - 26%)	7.3	2.6

However, savings appear to have large variation and a high degree of uncertainty. Given the promising nature of the technology and O&M protocol, further research at a larger number of sites may be warranted for continued understanding of the potential. Program support or outreach for certain building types or RTU sizes may be appropriate if further research corroborates the findings. One certain conclusion is that even if a proper O&M protocol may not necessarily provide energy efficiency benefits, it is prudent to perform comprehensive O&M tasks along with ARC installation. This will maximize the benefits and persistence of the retrofit control technology. Conversely, the ARC installation can complement O&M procedures by providing fault detection and ongoing monitoring.

ABBREVIATIONS AND ACRONYMS

AESC	Alternative Energy Systems Consulting
ARC	Advanced rooftop controls
CBP	Capacity Bidding Program (SDG&E Program)
CPP-D	Critical Peak Pricing Default (SDG&E Program)
DEER	Database for Energy Efficient Resources
EE	Energy efficiency
EEBI	Energy Efficiency Business Incentives (SDG&E Program)
ET	Emerging technologies
EUI	Energy use intensity
EUL	Effective useful life
FDD	Fault detection and diagnostics
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
IPMVP	International performance measurement and verification protocol
kWh/(hr-hp)	kWh per annual operating hours and supply fan horsepower
M&V	Measurement and verification
O&M	Operations and maintenance
PF	Power factor
RTU	Roof-top unit (unitary package unit with heating and cooling)
T/RH	Temperature and relative humidity
SDG&E	San Diego Gas and Electric
VFD	Variable frequency drive

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INTRODUCTION AND BACKGROUND

This study was performed by Alternative Energy Systems Consulting (AESC) on behalf of San Diego Gas and Electric's (SDG&E) Emerging Technologies (ET) program. The ET program strives to increase the exposure and success of emerging and underutilized energy efficiency and demand side management technologies in California. AESC is an energy engineering consultancy specializing in utility programs, technology assessments, and measurement and verification (M&V). This field test was performed in order to study the effects and benefits of several measures aimed at optimizing the performance and enabling demand response capabilities of existing rooftop package units (RTUs) in restaurant buildings.

Although rooftop package units are accountable for a large portion of our national energy consumption, they remain particularly underserved in terms of energy efficiency and demand side management. Rooftop package units are used in 46% of all commercial buildings and serve over 60% of the associated commercial floor space in the United States (EIA, 2003), (DOE, 2012) . Annual site electrical energy for this end use is about 46,900 GWh for cooling and 20,500 GWh for heating via heat pumps (Wang, 2013). In California, it is estimated that commercial buildings consume 67,077 GWh of electricity per year and that about 26.8% of that is attributable to cooling and ventilation (Itron, 2006). Combining these statistics would suggest that RTUs consume about 10,790 GWh per year in California for ventilation and cooling purposes. By similar logic, RTU energy consumption for ventilation and cooling in the SDG&E territory is about 1,410 GWh per year. Furthermore, RTUs and other package units account for more than 50% of the peak electrical demand in California commercial buildings (EIA, 2015). This implies a large potential for load shedding when grid infrastructure is stressed.

Despite this massive energy consumption, efficiency measures for unitary package units have struggled to gain market traction, particularly for retrofit applications due to various market barriers. Energy efficiency efforts have largely focused on improving design point efficiency and function of new package units; however, the large existing RTU base is a prime target for improved energy efficiency at part load conditions. The measures studied in this report are a diagnostic and maintenance strategy and an advanced control retrofit designed to improve performance, efficiency, and enable demand response (DR) capabilities in existing units.

TARGET MARKET AND SETTING

Rooftop package units are very often used in standalone retail, education, restaurant, and small to medium size office buildings. Among other reasons, RTUs have this market dominance in small and medium commercial buildings because they require little site-specific design, can be dropped into position for space conditioning expansion or equipment replacement without impacting the remainder of the building, do not require auxiliary systems, require relatively little commissioning, and any downtime will impact only one zone rather than an entire building.

Rooftop package units are essentially a collection of all necessary heating, cooling, and ventilation components including compressors, supply fan, air dampers, condenser, refrigerant coils, and a gas furnace or heat pump function if the unit is also used for heating. Additionally, RTUs can have economizing outside air dampers which can have simple internal controls to provide increased outside air as a fraction of the total supply air in order to take advantage of "free" cooling power during certain weather conditions. Although there is often airflow interaction between zones through doorways, halls, and open spaces, RTUs typically serve a single zone and are controlled by a single thermostat. These thermostats can be programmable or smart thermostats with features such as scheduling, setpoint setbacks, occupancy sensors, learning algorithms, and remote control in some cases. However, many units are still controlled by analog or pneumatic thermostats and even programmable thermostats can easily become out of sync with occupancy patterns or be improperly programmed.

Rooftop package units have an estimated average lifespan of 15 years (DOE, 2012) and many existing and smaller size units in the marketplace do not have controls that meet recent California code revisions. The 2016 Title 24 building standards require new air-cooled package units and heat pumps to be at least 9.5 to 11.2 EER (depending on the size and type) and be controlled by thermostats with scheduling and setpoint setback capabilities (CEC, 2015). In some cases, economizer controls, 2-speed supply fans, and DR functionality are also required.

This study is particularly concerned with RTU energy use and demand in restaurant settings. As shown in Table 1, restaurants have much higher cooling and ventilation energy use intensity (EUI) than the average commercial building in California. Restaurants not only have the cooling and ventilation loads that other buildings experience through environmental and human heat gains, but also must counteract the substantial cooking heat output.

TABLE 1 – RESTAURANT AND GENERAL COMMERCIAL COOLING AND VENTILATION ENERGY USE (ITRON, 2006)

BUILDING TYPE	TOTAL EUI [KWH/FT^2-YEAR]	COOLING EUI [KWH/FT^2-YEAR]	VENTILATION EUI [KWH/FT^2-YEAR]
Restaurant	40.20	5.76	3.24
All Commercial	13.63	2.04	1.63

As a result, restaurants in California have nearly three times the average electrical EUI of commercial buildings in general. Restaurants have the highest cooling EUI of all building types and ventilation EUI second only to healthcare buildings. Cooling and ventilation account for about 22.4% of restaurant's electrical energy consumption (Itron, 2006). This would suggest that although all existing RTUs may be good targets for energy efficiency measures, restaurants may provide better return than most building types.

INCUMBENT TECHNOLOGY

The incumbent, baseline technology is two-fold: typical maintenance strategies and standard controls. The understanding of best operations and maintenance (O&M) practices for unitary HVAC systems has progressed from specific, widgetized measures to a more holistic, systems and whole-building approach. For instance, recommended periodic O&M practices include cleaning condenser and evaporator coils, ensuring proper refrigerant charge, cleaning fan blades, recommissioning controls, replacing filters, reducing package and duct leakage, replacing worn or maligned belts, and cleaning heat exchange surfaces (ASHRAE, 2012). Many existing RTUs are found to operating out of specification due to neglecting these various maintenance needs. Savings estimates for a proper O&M protocol range between 10% and 30% (Katipamula, 2004).

However, despite these established best practices, maintenance of unitary HVAC systems is often sorely lacking. It is more likely for maintenance to performed only when a unit malfunctions or stops working than for regular, periodic attention and upkeep (SCE, 2015). This has been recognized in the energy efficiency industry and is one of the major causes of uncertainty in the savings achieved by HVAC O&M programs. Customers and implementers are simply less motivated to spend resources on system upkeep when indoor air quality is being maintained and other business operations take priority. As a result, it is reasonable to consider the baseline maintenance protocol to be upkeep as needed whenever RTUs malfunction or are unable to maintain comfort conditions. As an example of this, the host sites used in this case study had RTUs that were operating well out of spec and required several iterations of tuning and equipment replacement before they could be considered fully functional. This highlights the need for ongoing remote monitoring with fault detection as a means of identifying maintenance needs before they become worse and costly.

Standard controls for existing RTUs typically include constant speed fans, constant speed compressors, and single setpoint or programmable thermostats. Units may also have economizing outside air dampers, multi-speed fans, or staged compressors. Most small and medium-size RTUs use constant speed fans and often provide more airflow than needed during much of the year since they are sized to meet design conditions at peak cooling load. They typically provide constant air volume regardless of operation mode (ventilation, heating, or cooling). One method of reducing the inefficiencies of this design flaw is to use demand control ventilation (DCV) to adjust the fraction of outdoor air and the associated heating and cooling power needed for that air. However, DCV is not effective in all situations and while it can reduce the cooling and heating power needed for the outdoor air, the constant speed fans still run at full power regardless.

Package units are most often controlled by a zone-level thermostat that triggers the furnace or compressor whenever there is need for heating or cooling. Although smart and programmable thermostats can improve the energy footprint of RTUs through scheduling, occupancy controls, or setpoint setbacks, these thermostats can easily fall out of sync with actual cooling and ventilation load patterns. Many buildings still use simpler thermostats such as pneumatic models or other models without scheduling or multiple setpoint controls, although these are rapidly becoming obsolete. If the RTU has economizer controls, it typically fully opens when the OAT drops below some threshold and either closes above that threshold or reduces outside air fraction as the temperature increases. However, economizer controls are notorious for malfunction and are sometimes purposefully disabled in anticipation of future comfort complaints.

EMERGING TECHNOLOGY

The advanced measures studied in this project are a combination of standardized RTU assessment and maintenance protocols and the installation of controls that enable remote monitoring, fault detection, setpoint control, VFD supply fan speed control, networked RTU interaction, and DR capabilities.

MAINTENANCE PROTOCOL

While all of those individual measures listed above (coil cleaning, filter replacement, recommissioning, recharging, etc.) are still necessary and prudent, higher-level approaches to O&M are taking shape. System monitoring, fault detection diagnostics (FDD), and building-level approaches have been recognized as necessary to achieve optimal HVAC performance and reduce the uncertainties in unitary system measures. A comprehensive study of California HVAC O&M programs in 2010 outlined the difficulties and uncertainties in unitary system maintenance programs targeting energy efficiency improvements, but was adamant that these types of programs could be economical and beneficial if refined (Hunt, 2010).

In order to address these difficulties, assessment techniques for HVAC technicians have been established and studied (Davis, 2002). Due to the wide range of conditions, equipment types, controls, and other parameters that HVAC professionals will encounter in the field, a standardized but flexible protocol for assessing RTU performance and maintenance needs is necessary to reduce the uncertainty associated with maintenance measures and improve the return on investment.

One such standardized approach developed by an institute that offers training to HVAC service providers aims to satisfy this need by establishing diagnostic testing and assessment procedures that can be used as a basis for maintenance efforts. In this project, this took the form of an initial assessment for RTUs that had not received regular maintenance and were expected to need significant tuning. For ongoing maintenance, the assessment would likely be an abbreviated version and be supplemented by monitoring capabilities, if installed. This protocol involves a series of steps including the following:

- Test air flow of exhaust fans, make up air, supply fans, and economizers.
- Test the performance of the RTU's refrigeration circuits.
- Test the RTU's performance at the equipment outlets, rated in BTUs.
- Test the ductwork performance (delivered efficiency) at the supply and return grills, rated in BTUs.
- Visually inspect ductwork sizing and connections.
- Check the thermostat operation, programming, and wiring.
- Check and record the operation of all refrigeration equipment.
- Compare all test-in data to manufacturer performance data to identify any deficiencies.
- Check air balance test-in and ductwork inspection and identify any deficiencies.
- Take deficiencies from test-in with known performance enhancements and conduct repairs which could include:
    - Chemically clean RTU blower wheels, indoor & outdoor coils, economizer, heating and electrical sections.
    - Replace or clean air filters.
    - Replace, realign, and tension fan belts.
    - Other repairs identified during the test-in analysis of all the HVAC equipment.
    - Perform an air balance to bring the building into a slightly positive pressure to eliminate unwanted unconditioned air infiltration and maintain the cooking area slightly negative to the dining room.

Advanced RTU Retrofit Controls

Once maintenance at the sites was complete, an advanced RTU controller was installed on each unit. These types of controllers have been called advanced rooftop control (ARC) retrofits in past research. ARC measures are intended to optimize RTU energy consumption by improving performance during part-load conditions that occur during the majority of annual operating hours for a properly sized system. In general, ARC technologies include some version of fan speed control, remote monitoring, FDD, advanced digital economizer control (ADEC), sensors (air temperatures, CO_2, etc.), and a digital controller to maintain and alter operation modes and setpoints as set through a BMS or similar user interface. DR capabilities are also enabled by allowing the RTUs to respond to external server signals during peak events. Furthermore, some ARC technologies include smart control of RTU networks by considering the coincident operation of multiple units and optimizing demand patterns while maintaining zone setpoints.

The ARC tested in this case study uses a VFD to set discrete, fixed speeds that vary the supply fan speed command value based on the mode of operation of the RTU (for example, 75% speed for 1st stage cooling, 90% speed for 2nd stage cooling or heating, and 40% speed for ventilation only mode). It also includes remote monitoring with fault detection algorithms, DR management, and setpoint controls.

Products that have features of the ARC category include but are not limited to Catalyst by Transformative Wave, Pelican solutions, Enerfit, and Digi-RTU by Bes-Tech. Similar systems that may not have all the functions of an ARC described above include PACE3 by Pace Controls, Swarm Logic by Encycle, and IntelliCon by Intellidyne. Although these products are all intended as retrofit controls, there are options for new OEM RTUs as well. New, top of the line products may have factory options similar to those provided by ARC technologies.

One study of RTUs at 8 buildings in the Pacific Northwest showed that savings for ARC installations varied between 0.4 and 0.7 kWh/(hr-hp) with an average of 0.515 kWh/(hr-hp), where hr is the annual operating hours and hp is the supply fan horsepower. Fan savings accounted for the majority of the savings (Wang, 2013). Per unit savings were between 22% and 90% with an average of 55%. The building types included offices, healthcare, and retail but did not include any restaurants. A second, smaller-scale field study showed RTU energy savings of 18-27% for units under cooling operation at an office building (White & Esser, 2013). Another study of ARC retrofits on office and retail buildings in Hawaii found savings between 0.16 and 0.30 kWh/(hr-hp) (Doebber, 2014).

These studies concluded that RTU maintenance and reparation should be an integral part of the controller retrofit process. Without maintenance and tuning prior to ARC installation, savings will not be fully realized and the interaction with the system could exacerbate pre-existing faults. These recommendations further justify the resources spent on the initial O&M procedures included as part of the total RTU optimization. This issue is compounded when RTUs are made even more complex by adding on retrofit technologies which require specialized training and knowledge, leading to fewer qualified service providers. In order to maximize benefits and persistence, ARC installation should include monitoring to provide insight into system performance so that maintenance can be scheduled when needed rather than too frequently or only when a unit malfunctions.

Field tests of the demand response capabilities of similar RTU controllers have been conducted on RTUs in the past. Reported percent load reductions have included 20% (Carrier Corporation, 2013), 7-18% (LBNL, 2008), 12-27% (Doebber, 2014), and 29% (SCE, 2012). Building types, controllers, and load shedding strategies varied, but tests did include fast food restaurants and the same ARC tested in this study.

Barriers to market adoption of advanced control measures for RTUs include high initial cost, unfamiliarity to customers and implementers, dependency on RTU performance and operation, and few visible distribution channels (SCE, 2015). One method to overcome barriers to market adoption is to target customers with the highest potential for energy savings as early adopters. This would provide the maximum returns while providing quality examples and precedent for less energy intensive building adoption down the road. This would suggest that restaurants are a prime target for early adoption of RTU retrofit technologies and O&M protocols.

Cost for ARC installations was previously estimated to start around $6,800 for smaller RTUs and increase slightly with increased unit size as shown in Table 2.

TABLE 2 – ESTIMATED ARC COSTS (WANG, 2013)

RTU Capacity (tons)	Supply Fan Size (hp)	Controller ($)	Controller Labor ($)	Metering ($)	Metering Labor ($)	Fixed Monitoring ($)	Variable Monitoring ($/Month)
≤5	1	2,200	750	1,071	375	2,403	50
> 5 and ≤ 10	2	2,600	750	1,071	375	2,403	50
> 10 and ≤ 15	3	3,500	750	1,071	375	2,403	50
> 15 and ≤ 20	5	4,000	750	1,071	375	2,403	50
> 20 and ≤ 25	7.5	4,142	750	1,071	375	2,403	50

Costs for the diagnostics, maintenance, and ARC installations for the sites in this study totaled about $11,160 per RTU. After removing maintenance costs, it is estimated that the ARC installations cost about $5,400 per unit for the six RTUs ranging from 5 to 10 tons.

TABLE 3 – PROJECT COSTS

TASK	COST PER RTU [$]
Testing and analysis	$1,360
Maintenance	$4,400
ARC installation	$5,400

Estimated useful life for the various measures included in the technology package varies from 3 to 15 years. Relevant DEER EULs are 5 years for RTU retrocommissioning (ExAnte2013), 11 years for reprogramming thermostats (ExAnte2013), 5 years for repairing economizers (DEER2014), 3 years for quality maintenance (DEER2014), 10 years for reducing overventilation and refrigerant charging (DEER2014), and 15 years for VFDs controlled by CO_2 variables (ExAnte2013).

ASSESSMENT OBJECTIVES

The goal of this technology assessment is to identify the demand reduction, energy savings, demand response potential, and operational benefits of an RTU optimization protocol comprising maintenance, air balancing, and advanced controls with supply fan VFDs. To this end several objectives were established:

- Evaluate existing RTU performance to establish a site-specific baseline.
- Sequentially perform deep maintenance, air balancing, and controls installation with short-term monitoring periods between each measure.
- Verify energy savings resulting from the technology during post-installation periods.
- Conduct a few DR events through the online user interface to measure load shedding capabilities.
- Generate an assessment report for the completed project that can be used as a case study for future upgrade opportunities and utility incentive program design.

In order to accomplish these objectives, AESC designed a measurement and verification (M&V) plan adhering to IPMVP principles. The M&V plan is outlined in the following section and was designed to directly measure energy effects and the relevant factors and performance characteristics.

MEASUREMENT AND VERIFICATION PLAN

A measurement and verification plan was established in order to capture all the necessary data for estimation of energy savings and demand response potential. The plan followed the principles of the IPMVP standards and used both Option B (Retrofit Isolation) and Option C (Whole Facility). M&V approaches. Retrofit isolation was exercised by monitoring the specific energy use of each RTU on an interval basis along with other variables to inform regression analyses. Whole facility M&V was exercised by analyzing utility metered interval data for a longer period of time before and after measure implementation and DR testing. The following sections outline the specifics of the M&V plan including host site descriptions, instrumentation, and measurement timeline.

In general, energy efficiency analysis was performed by monitoring RTU or whole building energy use on interval bases and using regressions to weather and business operations to project annual usage for the average weather year. DR events were simulated by initiating one of two load shedding strategies on particularly hot weather days in the summer of 2016. The DR strategies included increasing the setpoints for each RTU by either 1 degree F per hour for 6 hours (3 test days) or by 2 degrees F per hour for 3 hours (1 test day). The response was initiated using the ARC monitoring and control web user interface.

HOST SITES

The host sites for the field trial were two fast food restaurants in the SDG&E territory, one in Escondido and one in Chula Vista, CA. The building characteristics for both stores are listed in Table 4.

TABLE 4 - HOST SITE BUILDING CHARACTERISTICS

CHARACTERISTIC	ESCONDIDO SITE		CHULA VISTA SITE	
Building Type	Fast-food restaurant		Fast-food restaurant	
Business Hours	Wednesday	9:30AM–9:30PM	Wednesday	9:30AM–10:30PM
	Thursday	9:30AM–9:30PM	Thursday	9:30AM–10:30PM
	Friday	9:30AM–9:30PM	Friday	9:30AM–11:30PM
	Saturday	9:30AM–9:30PM	Saturday	9:30AM–11PM
	Sunday	10:30AM–9:30PM	Sunday	9:30AM–10PM
	Monday	9:30AM–9:30PM	Monday	9:30AM–10:30PM
	Tuesday	9:30AM–9:30PM	Tuesday	9:30AM–10:30PM
RTU Annual Operating Hours[1]	5,430		4,700	
Conditioned Floor Area [ft^2]	2,500		2,000	
CA Climate Zone	10		7	
Zip code	92025		91911	
Baseline EUI [kWh/ft^2-yr]	79.4		109.9	

[1] Estimated from monitoring data and includes hours during which calls for cooling were prominent. Escondido hours are greater despite fewer business hours than Chula Vista due to more cooling-intensive operation and climate zone.

Both buildings were conditioned by three RTUs with DX cooling and natural gas heating and 3-4 dedicated exhaust fans. The RTUs were all less than 10 years old at the start of the study, well within the estimate EUL of 15 years. The RTUs had the characteristics listed in Table 5.

TABLE 5 – RTU CHARACTERISTICS

CHARACTERISTIC	ESCONDIDO SITE			CHULA VISTA SITE		
RTU	1	2	3	1	2	3
Size [tons]	10	7.5	7.5	5	7.5	10
Economizer	Yes	Yes	Yes	No	Yes	Yes
Year of Origin	2007	2007	2007	2015	2005	2005
Supply Fan Size [hp]	4	3	3	3	3	4
Compressor stages	2	2	2	1	2	3
Nameplate Efficiency (EER)	11.0	11.0	11.0	11.0	11.0	11.0
Heating source	Gas	Gas	Gas	Gas	Gas	Gas
Burner stages	2	2	2	1	2	2
Heating input [kBtu/hr]	120/180	90/125	90/125	56	90/125	120/180
Nameplate AFUE	82%	82%	82%	82%	82%	82%

Two of the RTUs and baseline thermostat controls from the Escondido site are depicted in Figure 1.

FIGURE 1 – RTUS AND THERMOSTATS AT ESCONDIDO HOST SITE

INSTRUMENTATION

Relevant variables were continuously monitored and logged on an interval basis at the RTU circuit breakers and at various locations throughout the buildings. The measurement points and the associated instrumentation are listed in Table 6.

TABLE 6 - MONITORING INSTRUMENTATION

DATA POINT	MEASUREMENT	INSTRUMENT	ACCURACY	LOGGING INTERVAL
RTU Power	kW, kVA, A, V, pf	Dent ElitePro	<1%	1 minute
OAT and OARH	T/RH	HOBO U12	±0.63°F, ±2.5% RH	15 minutes
RAT and RARH	T/RH	HOBO U12	±0.63°F, ±2.5% RH	15 minutes

Energy data was captured on 1 minute intervals in order to have high resolution data and understand any compressor or fan cycling that may have occurred. The RTU energy metering and return air logger placement are shown in Figure 2 and Figure 3.

FIGURE 2 – RTU ENERGY METERING DURING AND AFTER INSTALLATION

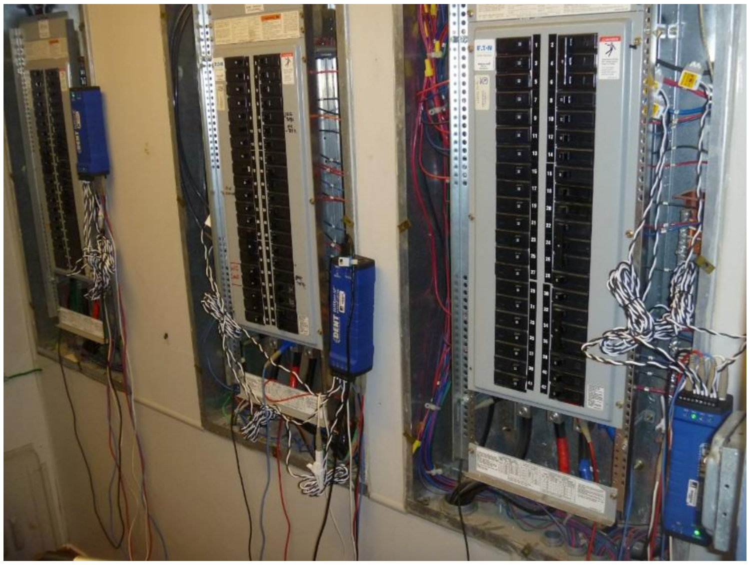


FIGURE 3 – RETURN AIR TEMPERATURE AND RELATIVE HUMIDITY DATA LOGGER PLACEMENT

Interval data from the facilities' utility grade smart meter were also used for analysis over a longer timeframe and for the DR testing. This data was recorded in 15 minute intervals but was also consolidated into hourly and daily intervals for energy use and demand calculations.

DATA COLLECTION PERIODS

Data collection was structured around the sequential implementation of the maintenance, air balancing, and controls installation measures. The measurement timelines for each site and IPMVP option are listed in Table 7 (specific measure task dates are listed in the Appendix).

TABLE 7 – MONITORING TIMELINE

PHASE	ESCONDIDO		CHULA VISTA	
	Dates	Length [days]	Dates	Length [days]
Monitoring baseline	7/14/2015 – 8/26/2015	43	8/25/2015 – 9/7/2015	13
Monitoring maintenance	9/1/2015 – 9/15/2015	14	9/8/2015 – 9/21/2015	13
Monitoring air balancing	9/15/2015 – 9/29/2015	14	9/22/2015 – 9/28/2015	6
Post Monitoring	10/1//2015 – 10/15/2015	14	11/11/2015 – 11/24/2015	13
Baseline utility meter data	5/1/2015 – 8/31/2015	123	5/1/2015- 8/10/2015	102
Post utility meter data	10/3/2015 – 7/1/2016	273	10/10/2015 – 7/1/2016	266

RESULTS

The analysis was five-fold: verification of consistent comfort levels in the conditioned space, regression of the raw power data to relevant independent variables, annualization to daily weather conditions, DR event analysis, and utility interval data analysis. Table 8 lists the total site energy consumption and savings as calculated through a combination of billing interval data and a heating and cooling degree day regression analysis. The savings agree with previously reported ranges.

TABLE 8 – BILLING DATA ENERGY SAVINGS ESTIMATES (WHOLE BUILDING)

SITE	BASELINE CONSUMPTION [KWH/YEAR]	BASELINE EUI [KWH/FT^2-YR]	POST CONSUMPTION [KWH/YR]	POST EUI [KWH/FT^2-YR]	ENERGY SAVINGS [KWH/YEAR]	TOTAL BUILDING SAVINGS	SAVINGS [KWH/HR-HP]
Escondido	198,476	79.4	181,995	72.8	16,481	8.3%	0.304
Chula Vista	219,877	109.9	190,959	95.5	28,918	13.2%	0.615

Although there was a high degree of variability in the data during the monitoring period due to uncontrollable factors, recurrent package unit issues which were corrected over time, and the test period extending into late fall, the effort clearly improved energy efficiency of the HVAC system at both sites. As noted in other studies, any future projects (research or implementation) should take time to clearly establish working RTUs via maintenance and repairs prior to ARC installation. This same issue posed some difficulties given the abbreviated monitoring period and shoulder season test.

Table 9 lists the total site demand reduction of the two DR test strategies. DR tests were conducted for 6 and 3 hour events with setpoint increases of 1 °F per hour 2 °F per hour, respectively.

TABLE 9 – DR EVENT RESULTS (AVERAGE OF 3 TESTS AT SETPOINT DECREASE OF 1 °F PER HOUR FOR 6 HOURS AND ONE TEST OF 2 °F PER HOUR FOR 3 HOURS)

SITE	DR EVENT BASELINE DEMAND [KW]	DR REDUCTION [KW]	DEMAND REDUCTION %
Escondido (Δ1F/hr)	43.90	3.54	8.1%
Escondido (Δ2F/hr)	50.98	10.02	19.7%
Chula Vista (Δ1F/hr)	39.58	3.20	8.2%
Chula Vista (Δ2F/hr)	47.13	12.22	25.9%

Annual energy savings, energy efficiency incentives, and demand response program participation cost benefits were calculated. Simple payback was calculated using the total project costs and ARC-only costs both with and without program incentives. Payback was calculated for ARC-specific costs since most of the savings appeared to derive from the control measure rather than the maintenance tasks. The calculation does not factor in additional ongoing O&M costs as may be warranted under a continuing O&M program. Table 10 shows a summary of these cost benefit and payback values.

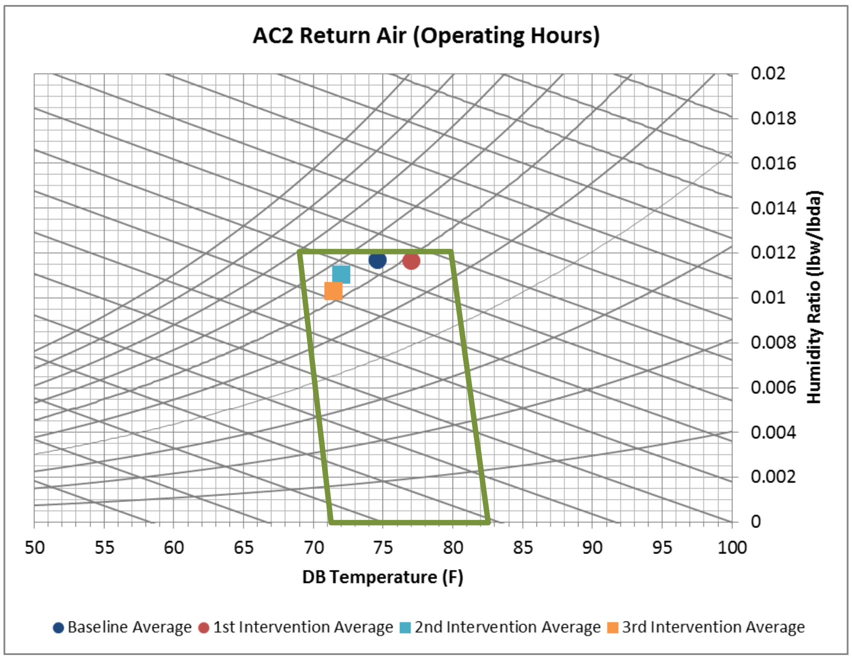
TABLE 10 – MEASURE COST, BENEFITS, INCENTIVE ESTIMATION, AND SIMPLE PAYBACK

SITE	TOTAL MEASURE COST [$]	ARC INSTALL COST [$]	ANNUAL SAVINGS [$]	ONETIME INCENTIVES [$]	ANNUAL DR INCENTIVE [$]	SIMPLE PAYBACK WITH INCENTIVES (FULL PROJECT COST) [YR]	SIMPLE PAYBACK WITH INCENTIVES (ARC-ONLY COSTS) [YR]
Escondido	$33.500	$16,200	$1,592	$4,512	$830	12.0	4.8
Chula Vista			$2,759	$6,652	$935	7.3	2.6

ESCONDIDO RESULTS

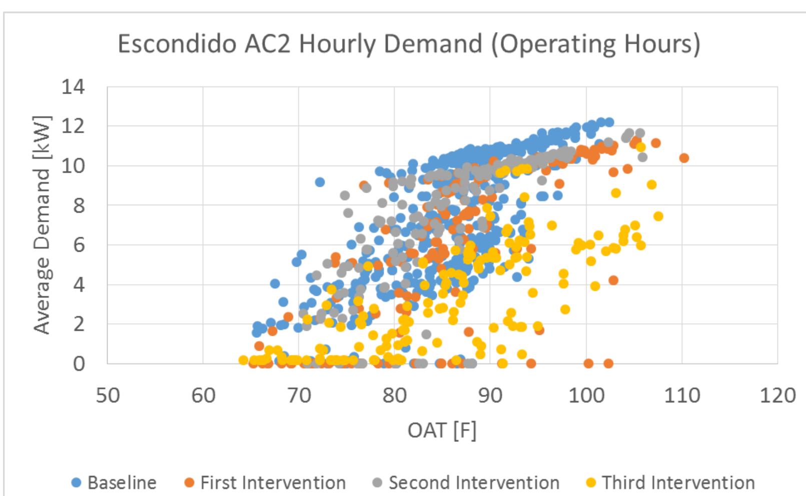
Average comfort levels during operating hours for the Escondido site show that comfort levels were relatively consistent over the course of the test despite reduced energy consumption. This information is important in order to verify that savings are not coming at the expense of occupant comfort and indoor air quality. The average indoor air conditions for one of the RTUs for each monitoring period is plotted in Figure 4 along with comfort zone boundaries. The remainder are included in the Appendices.

FIGURE 4 – AVERAGE RETURN AIR CONDITIONS FOR EACH MONITORING PERIOD WITH COMFORT ZONE BOUNDARIES (ESCONDIDO)



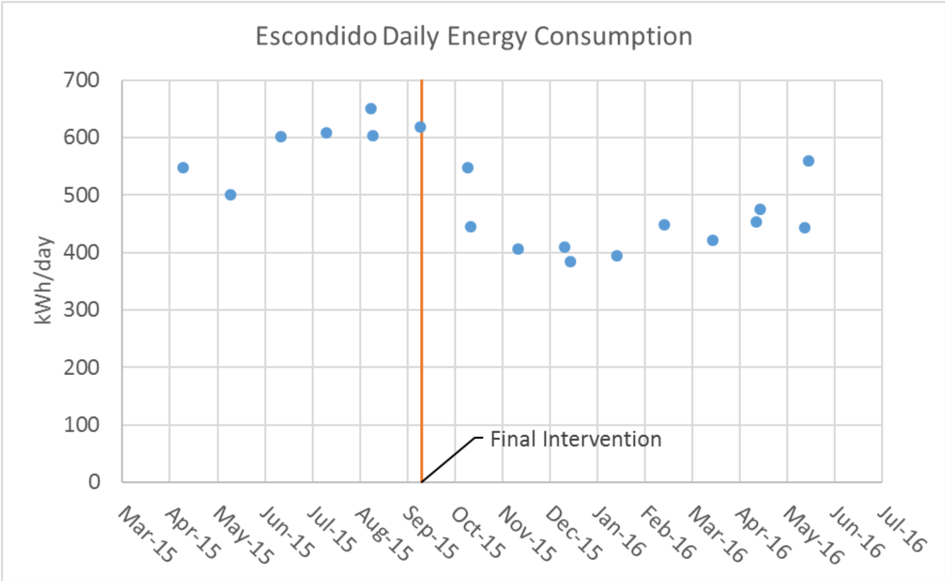
Although OAT is not the only variable affecting demand and energy consumption of the package units, plotting hourly demand against OAT clearly shows the improved energy efficiency and final variable speed control of the ARC as seen in Figure 5. Plots for the remaining units are shown in the Appendices.

FIGURE 5 – HOURLY SCATTER PLOTS OF RTU DEMAND AS A FUNCTION OF OAT (ESCONDIDO BUSINESS HOURS ONLY)



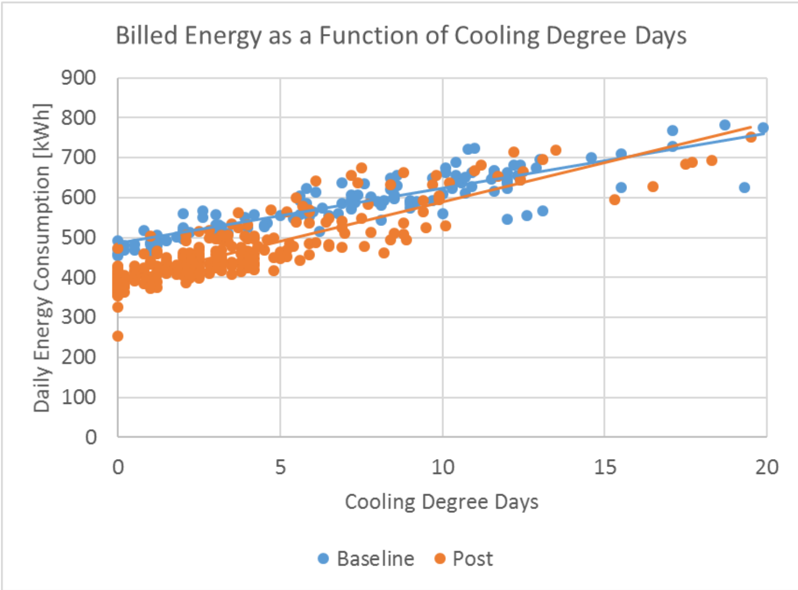
Billing data before and after the completion of the measures were compared in order to establish further estimates of energy savings. The plot of billing data kWh/day shows a clear energy use reduction after the measure implementation although the timeframe is limited and many other factors beyond HVAC could play a role (refrigeration, cooking equipment, customer behavior, etc.).

FIGURE 6 – ESCONDIDO SITE BILLING DATA ENERGY CONSUMPTION



In order to estimate annual savings using the utility metering data, a regression of daily energy consumption to daily heating and cooling degree days was established. There is a clear reduction in energy as seen in Figure 7. Note that the majority of system performance improvement is seen at part load performance days whereas peak cooling days see roughly the same energy consumption. No dependence on weekday was observed.

FIGURE 7 – BILLING DATA DAILY ENERGY CONSUMPTION AS A FUNCTION OF CDD



A multi-variable linear regression to CDD and HDD for daily billed energy consumption was established for the baseline and post-measure periods.

$$Daily\ energy\ [kWh] = a * CDD + b * HDD + c$$

This regression analysis resulted in an estimated annual total site baseline energy consumption of 198,476 kWh and 8.3% energy savings of 16,481 kWh.

DR events were initiated using the remote monitoring and control user interface during several hot weather days in the Summer of 2016. This was several months after the monitoring period concluded and all units were fully operational and well-commissioned at that time. Two DR strategies were employed: increasing the setpoint by 1 degree F per hour for 6 hours and increasing the setpoint 2 degrees F per hour for 3 hours. The first strategy was tested 3 times on consecutive days while the second was conducted once during a subsequent heatwave. All tests were initiated at 12 PM.

Analysis of the DR events was performed using hourly interval data from the utility smart meters for each site. A 10-in-10 baseline typical for SDG&E commercial DR programs was used for the analysis. This means that the 10 preceding eligible days were used for establishing the reference baseline. Additionally, since the preceding days had significantly cooler weather, a morning-of adjustment was applied to each baseline. The morning-of adjustment involves comparing the baseline demand and DR event day demand of the four hours before the event and applying an adjustment factor up to 20% to the 10-in-10 baseline.

The DR events for Escondido are shown in Figure 8 and Figure 9. Note that these plots use total site demand rather than only RTU power as shown in the earlier results. However since these events were manually called, the only end use that was being controlled for DR in this case was HVAC.

FIGURE 8 – DR DEMAND CURVES FOR THE 1F/HR TEST (ESCONDIDO)

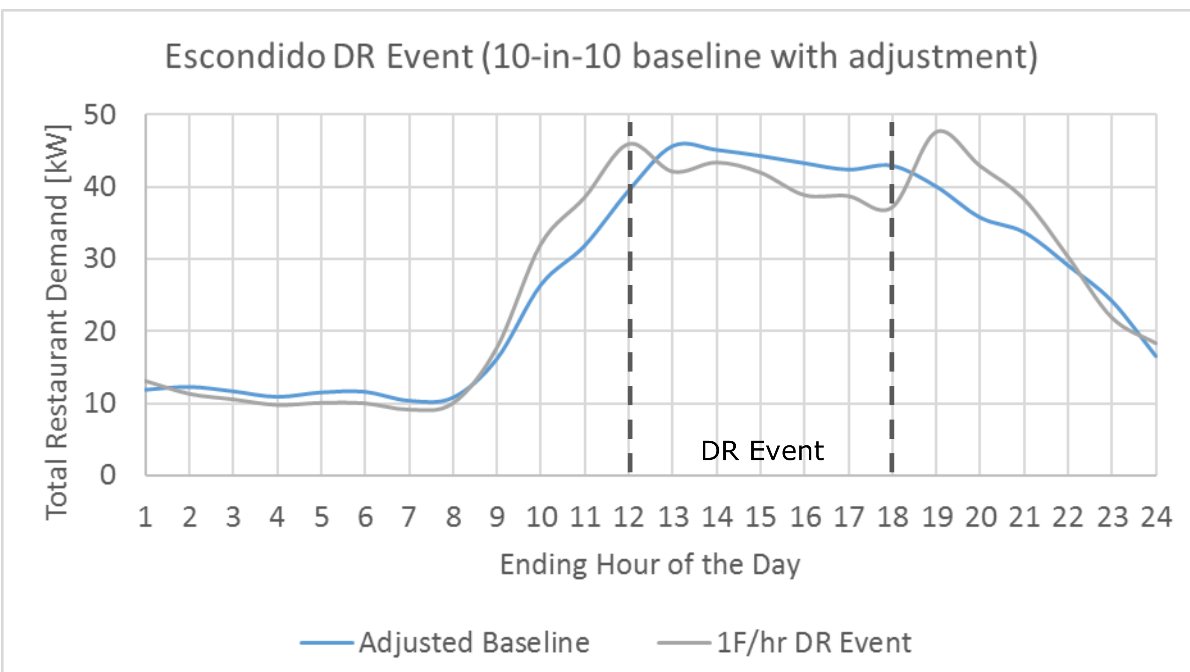
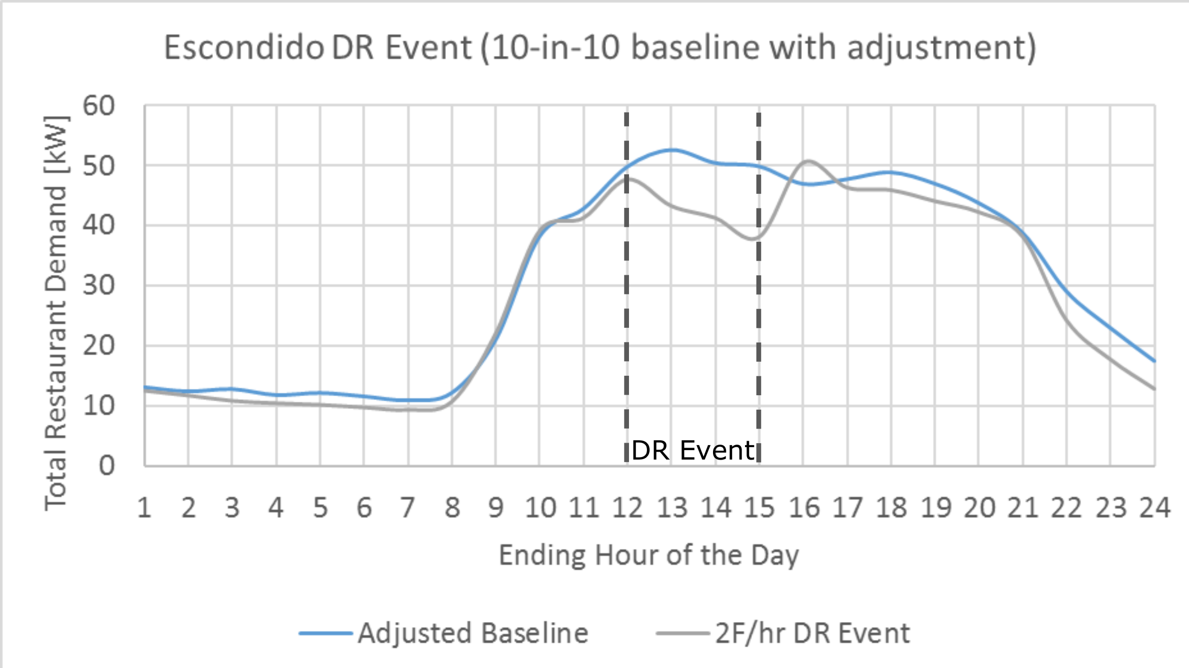


FIGURE 9 – DR DEMAND CURVES FOR THE 2F/HR TEST (ESCONDIDO)



The morning-of adjusted 10-in-10 DR reduction is shown by hour in Table 11.

TABLE 11 – ESCONDIDO DR TEST RESULTS

HOUR ENDING	AVG ADJUSTED BASELINE [KW]	1F/HR SETPOINT INCREASE DR REDUCTION [KW]	ADJUSTED BASELINE [KW]	2F/HR SETPOINT INCREASE DR REDUCTION [KW]
13	45.60	3.54	52.61	9.27
14	45.08	1.75	50.46	9.10
15	44.25	2.32	49.89	11.71
16	43.24	4.42	n/a	n/a
17	42.35	3.66	n/a	n/a
18	42.89	5.75	n/a	n/a
Avg	43.90	3.57	50.98	10.02
Average % reduction	n/a	8.1%	n/a	19.7%
Morning-of baseline adjustment factor	1.20	n/a	1.12	n/a

Chula Vista Results

Chula Vista encountered multiple equipment issues that delayed both the baseline period and the final intervention stage. As a result, the final intervention monitoring was not performed until November when the weather was significantly cooler than optimal. As a result, cooling demand patterns were not representative of when this technology achieves its best results. However, this issue was mitigated by relying on one year of billing data for energy savings analysis, in addition to the monitoring data.

The following psychrometric plot shows that indoor air conditions were not negatively impacted by the measures. Some data logging issues prevented reporting for the final post-period. The plots for the other RTUs are shown in the Appendices.

Figure 10 – Avg return air conditions for RTU3 for each period with comfort zone boundaries (Chula Vista)

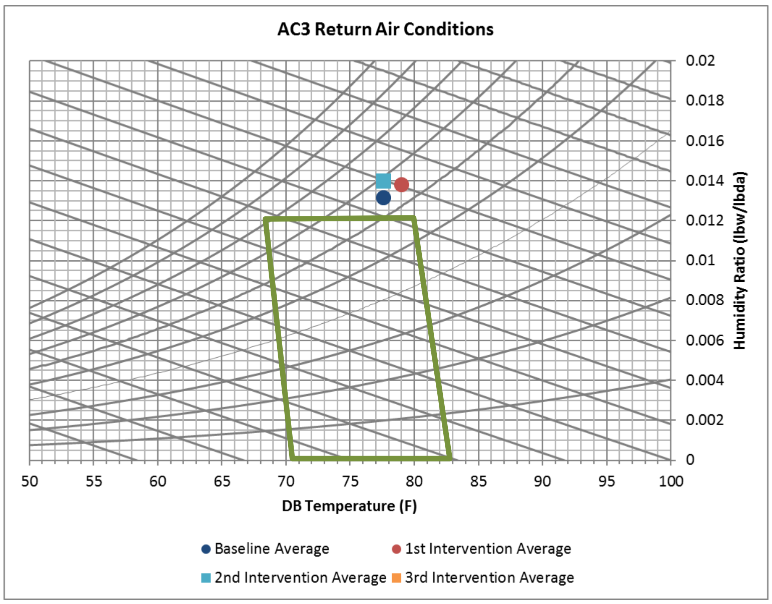
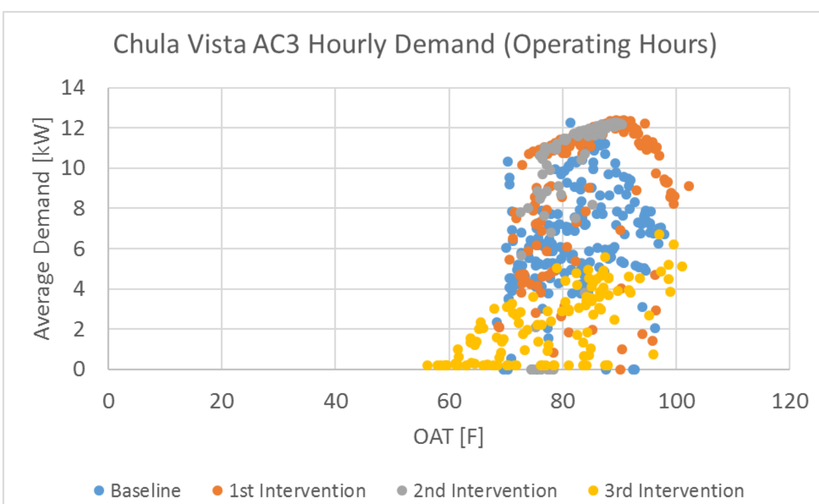


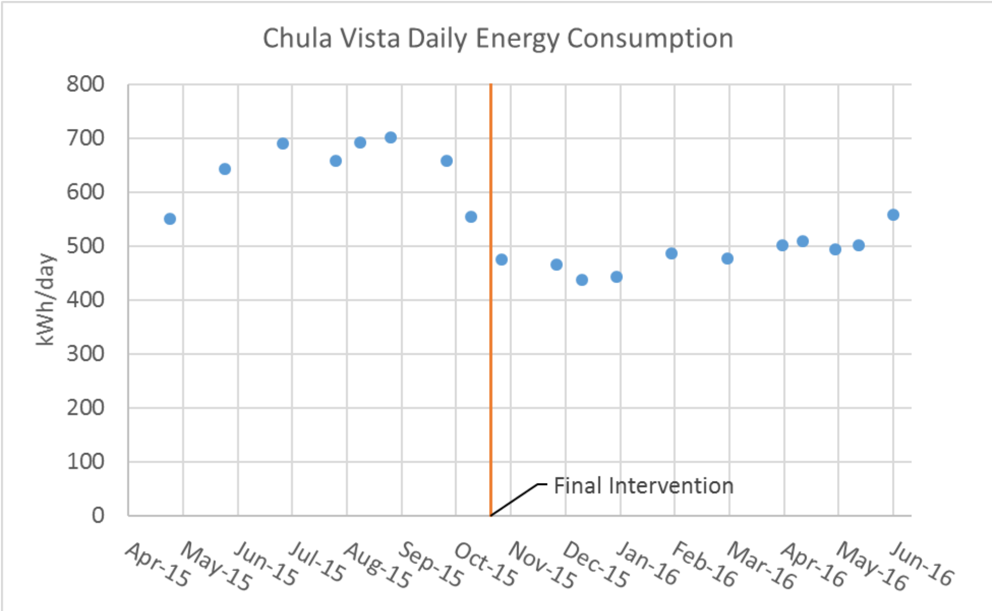
Figure 11 shows the hourly-averaged measured demand for each unit across each measurement period for RTU3. Plots for the remaining units are presented in the Appendices.

Figure 11 – Hourly scatter plot of RTU demand as a function of OAT (Chula Vista business hours only)



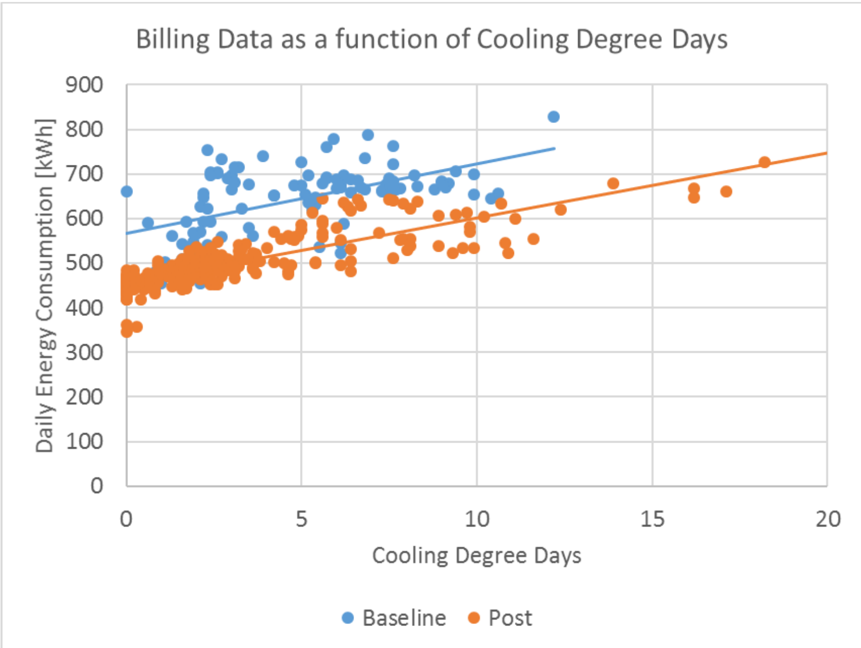
An analysis of the billing data was performed similar to the Escondido analysis described above.

FIGURE 12 – CHULA VISTA SITE BILLING DATA ENERGY CONSUMPTION



As was done for the Escondido sites, billing data was consolidated into daily intervals and correlated to cooling and heating degree days. Figure 13 shows the relationship between daily energy consumption and CDD for the Chula Vista site.

FIGURE 13 – BILLING DATA DAILY ENERGY CONSUMPTION AS A FUNCTION OF CDD DURING THE BILLING PERIODS



A multi-variable linear regression to CDD and HDD for daily billed energy consumption was established for the baseline and post-measure periods. This regression analysis resulted in an estimated annual total site baseline energy consumption of 219,877 kWh and 13.2% energy savings of 28,918 kWh.

DR events were initiated and analyzed similarly to those conducted for the Escondido site described above. Figure 14 and Figure 15 plot the demand profiles for the 10-in-10 baselines and DR event days based on the manually initiated tests.

FIGURE 14 – DR DEMAND CURVES FOR THE 1F/HR TESTS (CHULA VISTA)

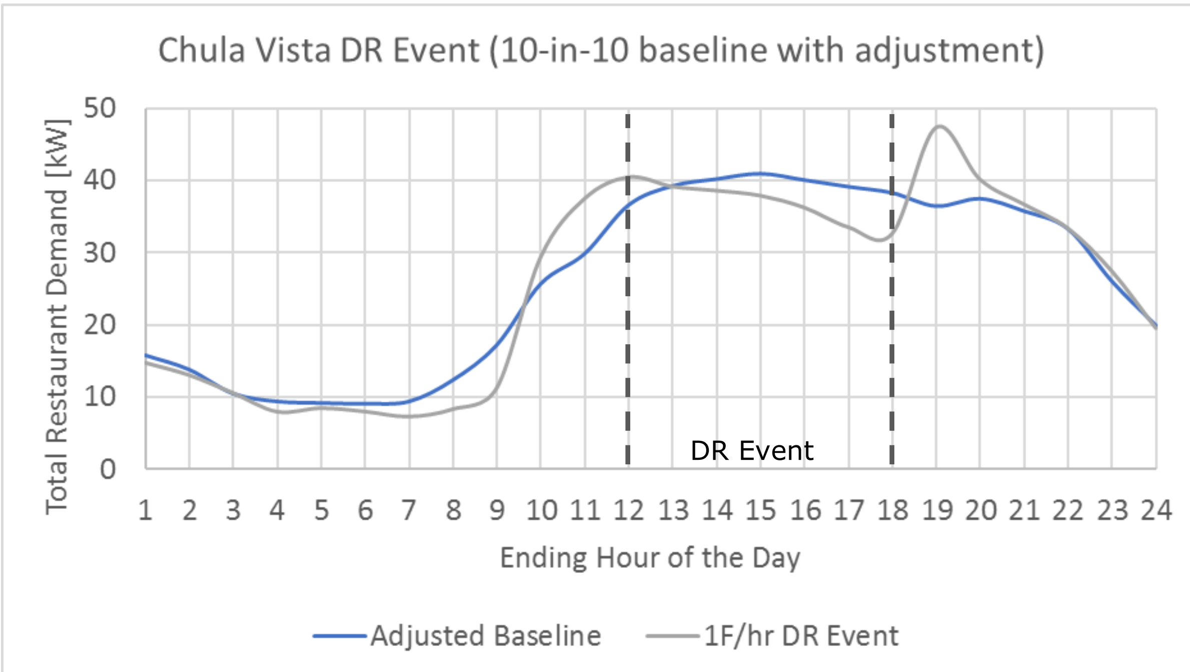
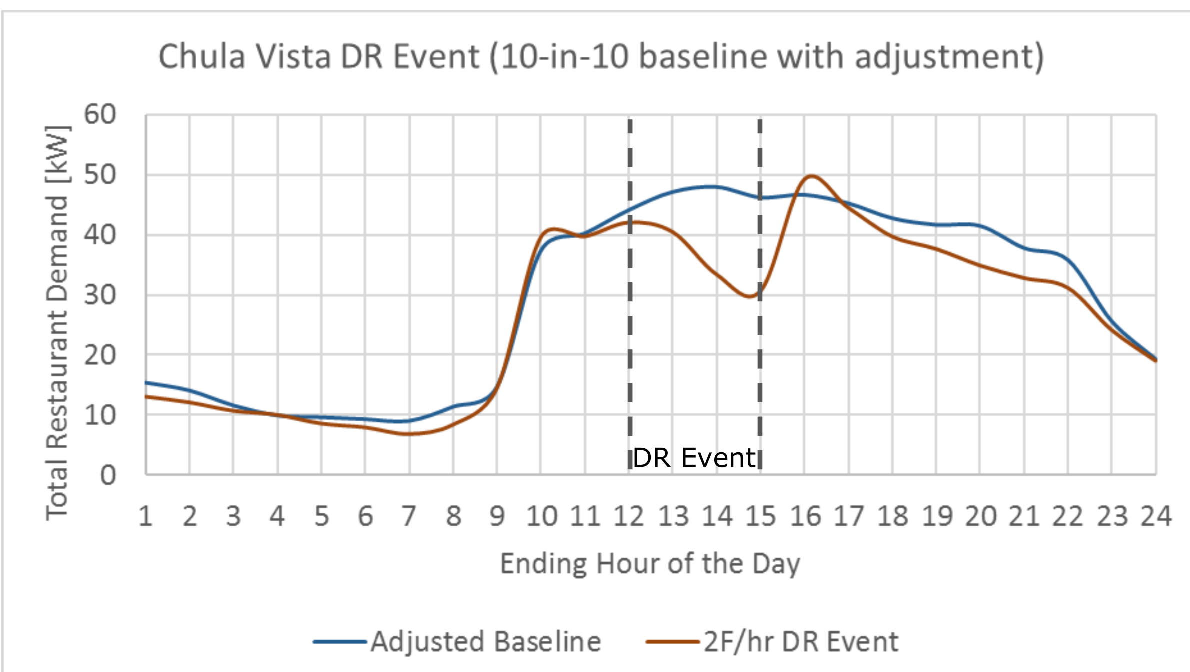


FIGURE 15 – DR DEMAND CURVES FOR THE 2F/HR TESTS (CHULA VISTA)



The morning-of adjusted 10-in-10 DR reduction by hour is shown in Table 12.

TABLE 12 – CHULA VISTA DR TEST RESULTS

HOUR ENDING	ADJUSTED BASELINE [KW]	1F/HR SETPOINT INCREASE DR REDUCTION [KW]	ADJUSTED BASELINE [KW]	2F/HR SETPOINT INCREASE DR REDUCTION [KW]
13	39.18	0.00	47.16	6.60
14	40.13	1.51	48.00	14.52
15	40.88	2.94	46.24	15.56
16	40.00	3.72	n/a	n/a
17	39.08	5.51	n/a	n/a
18	38.23	5.55	n/a	n/a
Avg	39.58	3.20	47.13	12.22
Average % reduction	n/a	8.2%	n/a	25.9%
Morning-of baseline adjustment factor	1.17	n/a	1.12	n/a

EFFICIENCY AND DEMAND RESPONSE PROGRAMS

SDG&E offers programs that can provide financial incentives to eligible customers in order to offset capital costs associated with measure implementation and to encourage peak load management. The ARC technology could apply to several of these programs, each of which is briefly described here.

ENERGY EFFICIENCY BUSINESS INCENTIVES PROGRAM

The Energy Efficiency Business Incentives Program (EEBI) provides non-residential customers the opportunity to receive payments for energy efficiency projects that do not fall under a standard rebate category. In general, the program supports energy efficiency measures that may apply to new loads, equipment replacements, or retrofits onto existing equipment. Project savings are evaluated by a combination of engineering calculations, modeling, measurement, and verification. Using these, the program provides a one-time incentive per annual kWh or therm savings per year.

TABLE 13 – EEBI INCENTIVE RATES (PER ANNUAL KWH AND THERM SAVINGS)

	Basic	Targeted
Lighting	$.03	$.08
Non-Lighting	$.08	$.15
Gas	$1.00	
Peak Reduction	$150/kW	
For a list of basic & targeted measures, please visit *sdge.com/businessincentives*		

If a particular site and project are eligible, an ARC installation could be supported by the EEBI program and would likely be categorized as a non-lighting targeted measure since it is an emerging, smart controls technology. Since ARC technologies are retrofit add-on measures, the incentive is limited to 50% of the project cost. Since EEBI-supported projects typically undergo inspections and must meet program rules, customers should contact and apply to SDG&E prior to purchasing the technology or entering into an installation contract with a service provider.

TECHNOLOGY INCENTIVES PROGRAM

The Technology Incentives (TI) program provides support for customers who install automated demand response (ADR) measures. Eligible measures must provide verifiable, dispatchable, on-peak load reduction at the customer facility and any non-residential customer on a time-of-use rate with a peak demand greater than 20 kW may apply. Additionally, the technology must be OpenADR 2.0 compliant and the customer must be enrolled in a demand response program such as the Capacity Bidding or Critical Peak Pricing programs. If those conditions are met by the technology and customer, the TI program provides an incentive of $300 per kW of verified on-peak load reduction.

CAPACITY BIDDING PROGRAM

The Capacity Bidding Program (CBP) provides non-residential customers a variety of options for receiving incentive payments when they reduce their demand during DR events from May through October. When an event is signaled, the customer reduces their demand during the event hours and receives an incentive based on the demand reduction and energy saved during the event. The demand reduction incentive rate is established by a selected program options. Notice time options include day-ahead, day-of, and 30 minutes prior to the event. The event timeframe options include 1-4 hours, 2-6 hours, and 4-8 hours. Additionally, the incentive rate varies for each month. Across these options and the months, the incentive rate can vary between $2.43 and $28.65 per kW-month reduced. The incentive also includes an energy usage reduction incentive based on the kWh saved during the events.

The program cannot call more than 44 hours of events per month and typically don't approach that limit. Incentives are paid monthly and continue as long as the customer is enrolled in the program. The penalty for customers who cannot meet their pledged load reduction is minimal (50% of the incentive that would have been received from the pledged reduction). Therefore, there is little risk to customers who are relatively assured of demand reduction or participate though an aggregator.

Although individual customers may directly enroll, the program is designed for customers to participate as a group through aggregators which manage load curtailment across the sites. A customer with a DR-enabling measure such as the emerging ARC technology joins an aggregator who pools together the participants' resources in order to maximize effectiveness and provide value to grid stability and to the participants.

CRITICAL PEAK PRICING

Critical Peak Pricing (CPP), also known as Time of Use Plus, is a time-of-use rate that is designed to encourage load curtailment during critical grid demand events and reflect the actual cost of energy during these peak events. Although optional, it is the default time-of-use rate for non-residential customers with peak demand consistently above 20 kW each month. Customers with smaller peak demand can adopt CPP at their discretion. Customers under CPP must elect a kW capacity reservation for peak days. A monthly charge is based on the capacity reservation and any energy consumption below that elected capacity is priced at a rate which is slightly lower than the alternative TOU schedule. However, any energy consumed above that capacity reservation during CPP events is charged at an elevated rate. The net effect is a motivation for customers to reduce their consumption during peak events in order to take advantage of the CPP structure and save energy costs.

CPP can serve as an alternative to CBP to meet demand response goals, although a customer can enroll in both as long as the day-of option of CBP is selected. For the ARC implementation at the host sites, CPP would provide more financial incentive than CBP. However, CPP requires more active participation by the customer and carries more financial risk for the customer. There is more potential for high cost penalties associated with exceeding the reserved capacity during peak events. To avoid this, the customer needs to remain highly aware of CPP event calls and be fully capable of managing the ARC system. Additionally, since setpoint control DR function has a less certain load shedding result than turning off constant or baseload equipment, shedding a target amount of load on call can be somewhat uncertain. As a result, reducing the facility demand to the reserved capacity may not always be a certainty. For these reasons, a facility such as the host site fast food restaurants may be better suited to use only CBP for DR purposes instead of CPP. Still, for the diligent customer willing to absorb some financial risk, CPP can improve the ROI of the ARC technology significantly.

OTHER PROGRAMS

In addition to the programs described above, several host site evaluation programs could consider recommending ARC measure installations. The Energy Advantage, Comprehensive Audit, and Business Energy Solutions programs all provide facility evaluation and measure identification services to non-residential customers. The program administrators of these programs could consider adding ARC measures to their lists of recommended measures for appropriate customers who use package HVAC units.

DISCUSSION

The improved maintenance efforts and ARC installations were very effective in reducing the buildings' energy consumption, improving RTU performance, and enabling DR capabilities. Since this study was small in scale and only involved two buildings, conclusions are limited. The two buildings realized an EUI reduction of 8.3% and 13.2% due to decreases in RTU energy consumption of 0.304 and 0.615 kWh/hr-hp, respectively. Based on several DR tests using setpoint increases of 1 or 2 degrees Fahrenheit per hour, 8.1% to 25.9% of the total site demand could be shed, on an hourly averaged basis. These findings agree with past research and suggest that continued utility support may be warranted.

Cost data for the field test covers the installed controls, commissioning, and all necessary maintenance needed to bring the RTUs into proper operation. However, there is inherent cost uncertainty due to unmeasured, ongoing maintenance costs and the high variability in how much maintenance and repair is needed for each unit. Furthermore, data presented in Appendix C – Monitoring Data Results suggests that the measured savings may come primarily from the ARC installation. Unfortunately, the data did not allow for savings to be separated by O&M phase or ARC installation. Thus, it can only be suggested that most of the savings are attributable to the ARC.

Simple payback was calculated for both base cost and incentivized project scenarios. Furthermore, payback was calculated for project costs based on the entire project and for ARC installation costs, only. This was done since most of the savings appeared to derive from the ARC installation as opposed to maintenance tasks. The project costs are based on actual investment in the sites for the O&M diagnostics, repair, and ARC installation. The electrical energy cost is based on the actual billing data for each site and does not include demand charges (electrical energy commodity rate only) since the peak demand was not significantly affected by the measures. Incentives from the programs described in the previous section were based on calculated annual energy savings, average demand response load shedding, and program parameters.

Table 14 lists the project costs, billing savings, incentives, and estimated simple paybacks for the host sites. The payback calculation does not include any non-energy cost savings such as improved RTU lifespan or the value of enhanced occupant comfort levels.

TABLE 14 – SIMPLE PAYBACK USING COST AND INCENTIVE ESTIMATES

	ESCONDIDO SITE	CHULA VISTA SITE
Total RTU capacity [tons]	25	22.5
Total project cost [$]	$33,500	$33,500
ARC install cost [$]	$16,200	$16,200
Annual energy savings [kWh]	16,481	28,918
Electrical commodity billing rate [$/kWh]	0.0966	0.0954
Annual energy cost savings [$]	$1,592	$2,759
Simple payback of full cost w/out incentives [yr]	21.0	12.1
Simple payback of ARC cost w/out incentives [yr]	10.2	5.9
EEBI incentive [$]	$2,472	$4,338
Technology incentive [$]	$2,040	$2,314
Annual CBP incentive [$]	$308	$343
Annual CPP incentive [$]	$522	$592
Simple payback of full cost with incentives [yr]	12.0	7.3
Simple payback of ARC cost with incentives [yr]	4.8	2.6

Energy savings from the O&M protocol are uncertain as has also been found by previous studies. The monitored data showed that energy usage per RTU could increase or decrease due to maintenance efforts and the uncertainty was too high to comment on O&M energy impacts. However, this is not necessarily a negative outcome as the maintenance is primarily meant to ensure proper operation and indoor air quality rather than provide energy savings. Rather, the maintenance is a necessary facet of RTU ownership and may be a prerequisite for quality ARC installation.

As has been discussed in at least three previous studies, the field test suggests that diagnostics and maintenance need to be performed and finalized before ARC installation to realize maximum benefits and control measure persistence. This claim is based on engineering judgement rather than empirical evidence, but all relevant studies have come to the same conclusion. It took significantly longer than anticipated to perform the repairs that were needed to bring the RTUs into proper operation. This is likely due to the sites not following the ASHRAE recommended O&M protocols through scheduled visits from HVAC technicians; thus extensive repairs and tuning was required prior to ARC installation. This is further evidence that RTUs benefit greatly from proper O&M attention with periodic checks as well as the addition of FDD to ensure future maintenance is proactively performed. Any new units brought into a combined O&M and ARC program may need significant attention before being in "full, efficient working order". The O&M step is critical to avoid any real or perceived issues with ARC installations that may reduce ARC persistence.

The ARC measure is effective at improving part load efficiency and enabling easily dispatchable DR load shedding capacity. The online interface for the ARC technology provides fault detection that can better inform service calls and prevent unit failure from unaddressed equipment issues that can progress over time. In this way, the O&M and ARC measures complement each other with the ARC requiring O&M in the early stages and ARC enabling better O&M services after installation. Additionally, the user interface provides an intuitive portal into RTU operation, energy visualizations, space conditions, empowering customers to better understand their own building energy use and performance.

RECOMMENDATIONS

Given the findings of this study, several future directions may be worth considering. These include:

- Further study at more sites and with longer monitoring periods and proper pre-ARC installation O&M is needed for reliable energy savings understanding. For instance, a test with energy data logging should include establishing a baseline for several months, managing initial O&M diagnostics and repairs until RTU operation reaches steady state, and more extensive post monitoring in cooling months. This should be performed at multiple sites in order to better understand building and climate zone variations.
- Multiple studies have concluded that proper O&M is necessary for full ARC benefits. However, this is largely based on engineering judgement and observation. For a more complete understanding of this factor, a study with a control group that only receives the ARC and no O&M could help support this claim.
- Certain utility jurisdictions outside of California provide deemed rebates for ARC-lite measures free of any O&M riders. ARC-lite measures are essentially VFD control of the supply fan. This is justified by the fact that the majority of energy savings come from fan speed control. However, this simplified measure will not provide DR capabilities. California could potentially consider providing support for ARC-lite and more comprehensive ARC and O&M measures.

- In order to ensure best outcomes, an ARC incentive program could provide a bonus or increased incentive rate if a standardized O&M contract is included in the measure package. Alternatively, a standardized O&M contract could be a requirement for an ARC incentive.
- The technology manufacturer should consider continuous speed control with the VFD.
- Incentives or rebates can likely be reliably based on RTU or supply fan size, building type, or operating hours as demonstrated by this and past studies. Additional study could provide better energy savings estimates based on these site variables.
- HVAC professionals will need training on specific ARC technologies, diagnostics, and O&M procedures before they can participate in any associated program offering.
- Public and service professional awareness campaigns could be useful, but further study is likely required before savings could be presented with confidence.
- ROI can be improved by selecting high HVAC EUI buildings (such as restaurants) and buildings with large RTU populations and long operating hours.
- RTU age is important to consider. Younger RTUs will have larger lifetime benefits from the ARC but older RTUs will have more immediately apparent benefits and needs from O&M protocols.
- Extended time for O&M is often needed in advance of ARC installation for proper implementation. Service providers should allow RTUs to operate for several weeks after any repairs so that they are confident that a steady state has been reached before proceeding to ARC installation.

The results of the study came with a degree of uncertainty but indicated that significant, persistent energy savings and DR load shedding capabilities are available. The large customer base, energy savings potential, and unaddressed market need all indicate that further research is warranted. Additional data collection based on longer monitoring, pilot programs, additional M&V, and better controlled O&M management could provide a better understanding of energy savings potential and how utility support could be improved.

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APPENDIX A – MEASURE TIMELINE

Chula Vista

7/21/15 – All AC's performance and delivered efficiency testing using software
8/11/15 – AC2 replaced failed condenser motor and repaired refrigerant leaks
8/11/15 – AC3 repaired refrigerant leaks and found failed condenser motor
8/13/15 – AC1 Replaced
8/17/15 – AC3 replaced failed condenser fan motor
9/8/15 – AC2 & 3 chemically cleaned condenser coils, replaced filters, belts and motor contactors
9/9/15 – AC2 & 3 removed economizers and refurbished, chemically cleaned evaporator coils
9/23/15 – All AC's performed air balance and retested performance and delivered efficiency
10/7/15 – AC3 replaced restrictive back of house supply air grills
10/7/15 – AC1 controls installation
10/8/15 – AC2 controls installation
10/9/15 – AC3 controls installation
10/13/15 – AC3 repaired loose supply air dampers restricting airflow
10/14/15 – AC2 replaced failed condenser fan motor (2 on this unit, other replaced 8-11)
10/14/15 – AC3 corrected condenser fan motor wiring to factory spec, bring on both fans together
11/4/15 – All AC's performed filter changes and checked unit operation

Escondido

8/3/15 – All AC's performance and delivered efficiency testing using software
8/31/15 – AC1 & 2 chemically cleaned condenser coils, replaced filters, belts and motor contactors
9/1/15 – AC2 chemically cleaned condenser coils, replaced filters, belts and motor contactors
9/1/15 – All AC's removed economizers and attempted to refurbished
9/16/15 – All AC's performed air balance and retested performance and delivered efficiency
9/29/15 – AC3 controls installation
9/30/15 – AC3 replaced restrictive back of house supply air grills
10/1/15 – AC2 controls installation
10/2/15 – AC1 controls installation
10/8/16 – All AC's retested airflows for complaints of doors blowing open
10/9/15 – AC1 repaired refrigerant leak and recharged
10/20/16 – AC1 & 2 doors still blowing open, disabled the economizers
10/22/16 – AC1 & 2 doors adjusted and economizers reconnected
11/4/15 – All AC's performed filter changes and checked unit operation
11/30/15 – AC1 replaced blown fuse and repaired burnt condenser motor wiring
12/16/15 – All AC's installed new economizers

APPENDIX B – RETURN AIR CONDITIONS

The following figures plot the hourly and average psychrometric indoor air conditions for each RTU and monitoring period in Escondido during operating hours.

FIGURE 16 – RETURN AIR CONDITIONS FOR EACH MONITORING PERIOD (ESCONDIDO – RTU1)

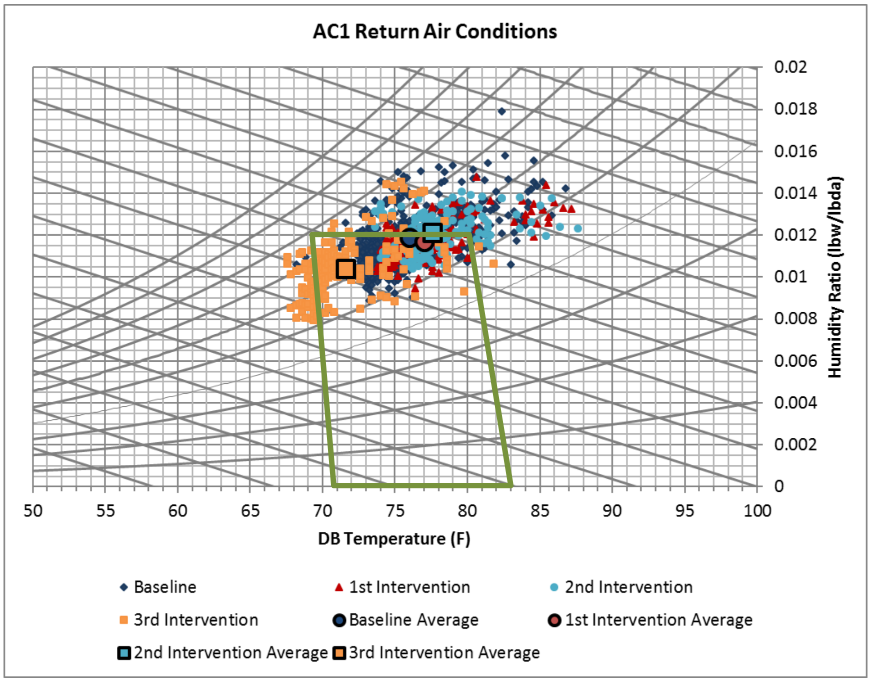


FIGURE 17 – RETURN AIR CONDITIONS FOR EACH MONITORING PERIOD (ESCONDIDO – RTU2)

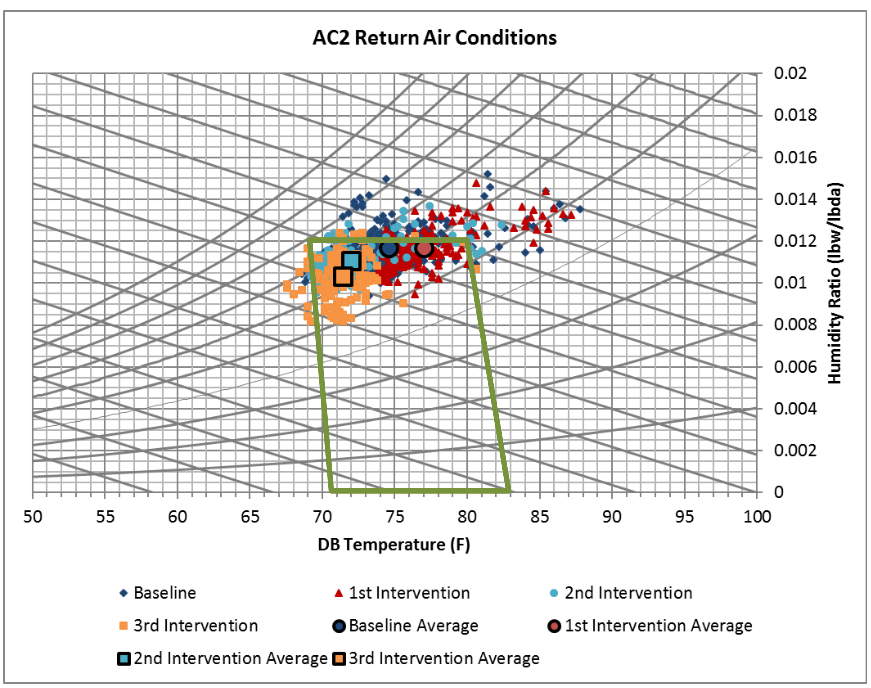
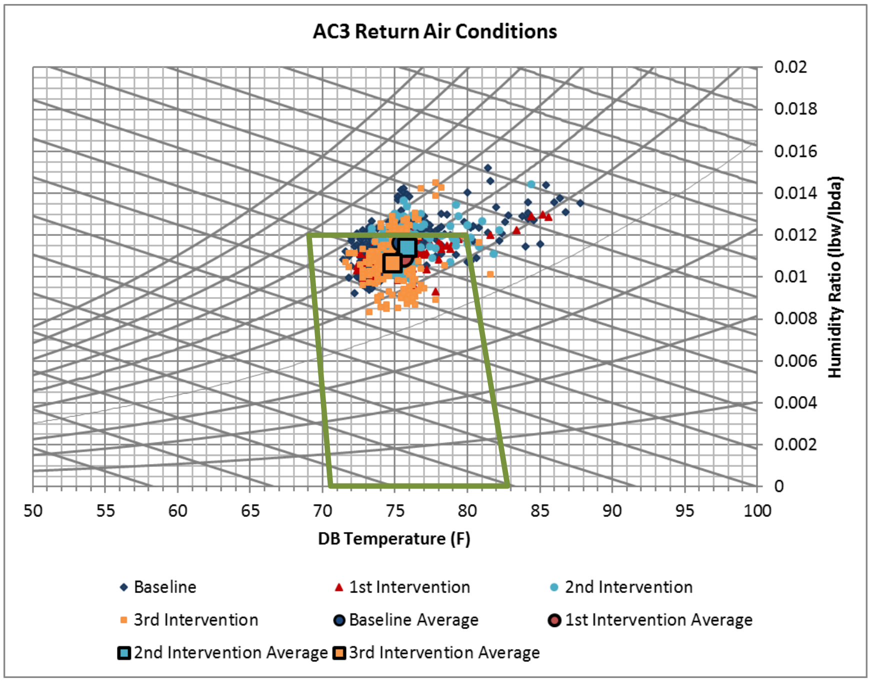


FIGURE 18 – RETURN AIR CONDITIONS FOR EACH MONITORING PERIOD (ESCONDIDO – RTU3)



The following figures plot the hourly and average psychrometric indoor air conditions for each RTU and monitoring period in Chula Vista during operating hours.

FIGURE 19 – RETURN AIR CONDITIONS FOR EACH MONITORING PERIOD (CHULA VISTA – RTU1)

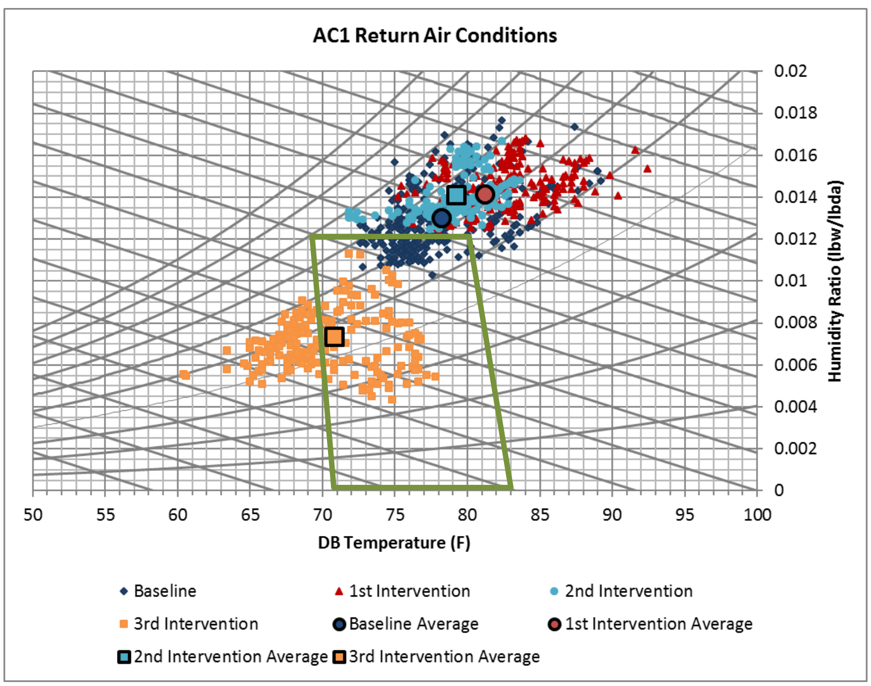


FIGURE 20 – RETURN AIR CONDITIONS FOR EACH MONITORING PERIOD (CHULA VISTA – RTU2)

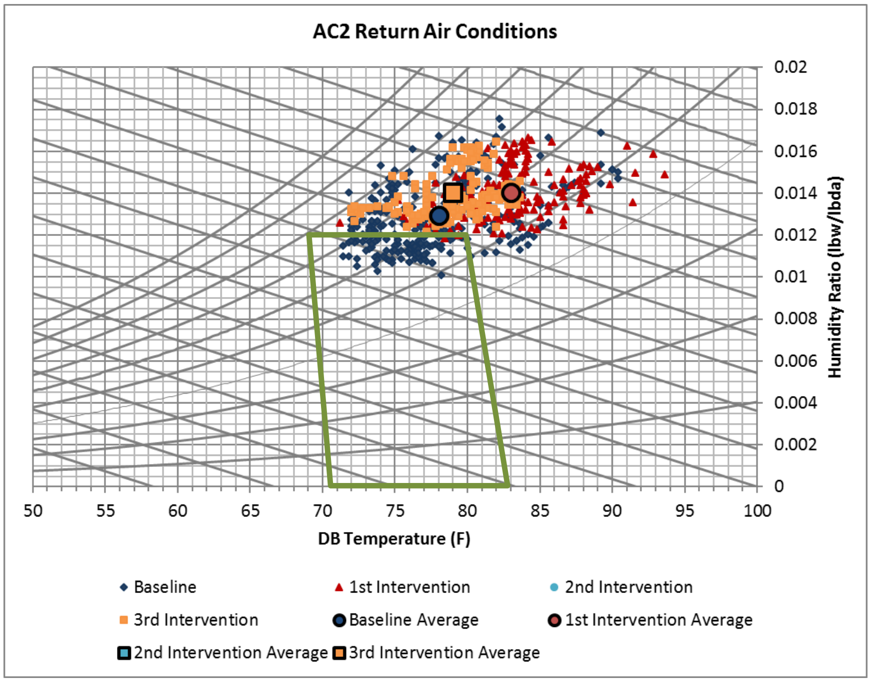
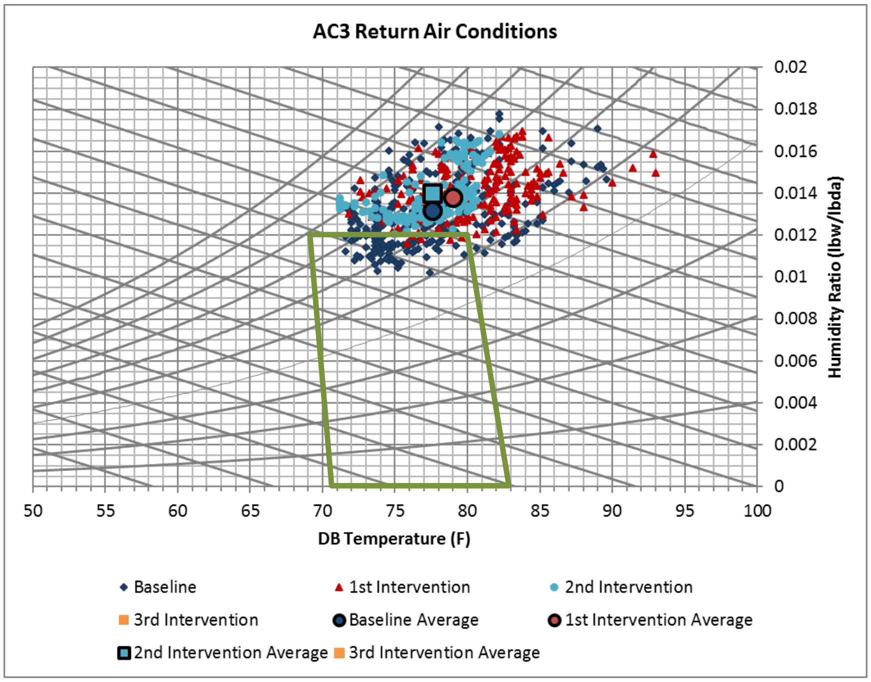


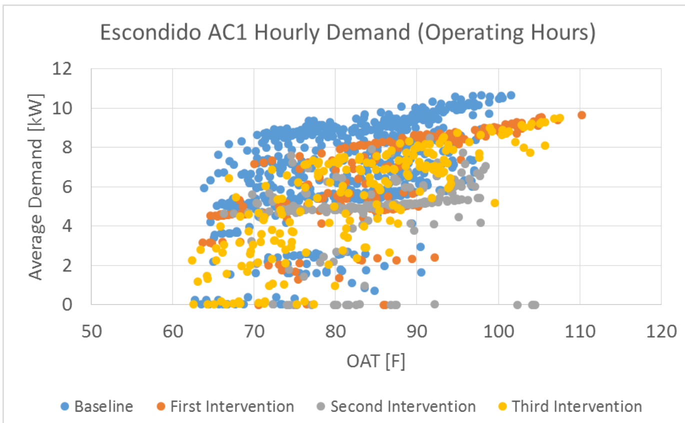
FIGURE 21 – RETURN AIR CONDITIONS FOR EACH MONITORING PERIOD (CHULA VISTA – RTU3)

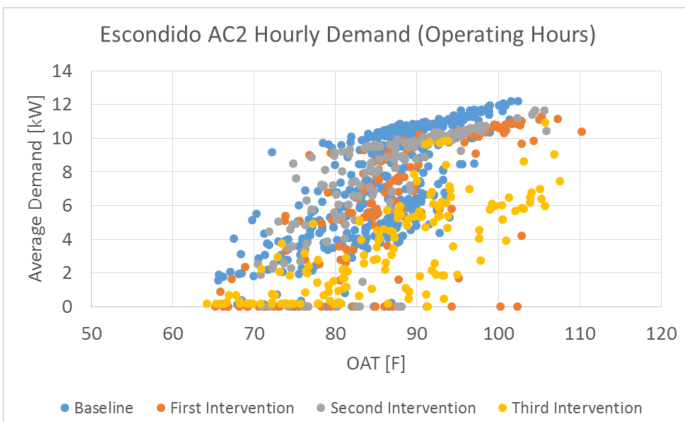


APPENDIX C – MONITORING DATA RESULTS

The following figures show the hourly scatter plots of RTU average demand for the three Escondido units. The scatter plot for RTU3 shows that the unit only operated in economizing or ventilation mode during the third phase. It is unclear whether this was a result of improved whole building performance or a failure in the unit. If the improved system performance and controls enabled units 1 and 2 to fully satisfy the buildings load, it could be that RTU3 mechanical cooling was not required although unlikely.

FIGURE 22 – HOURLY SCATTER PLOTS OF RTU DEMAND AS A FUNCTION OF OAT (ESCONDIDO BUSINESS HOURS ONLY)





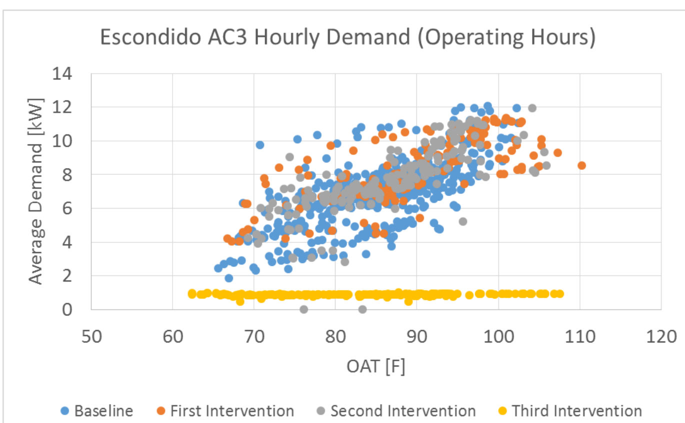
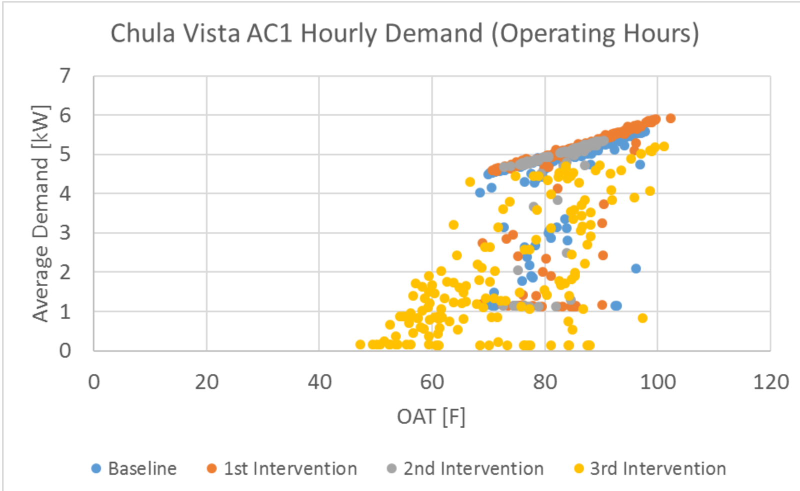
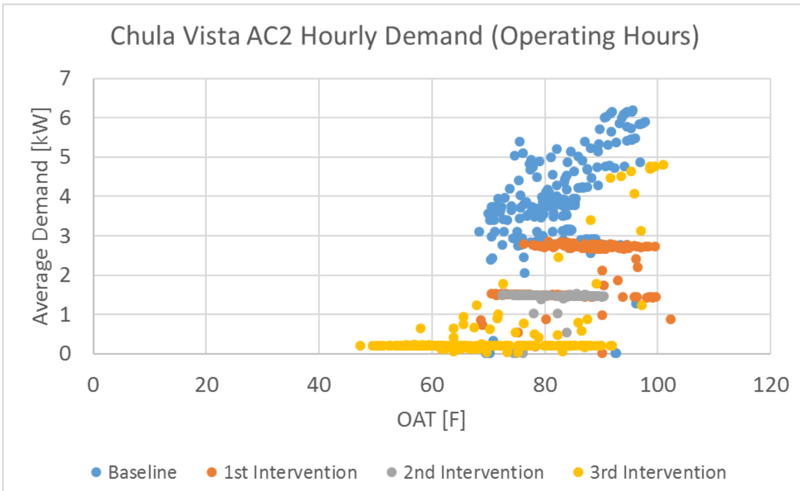
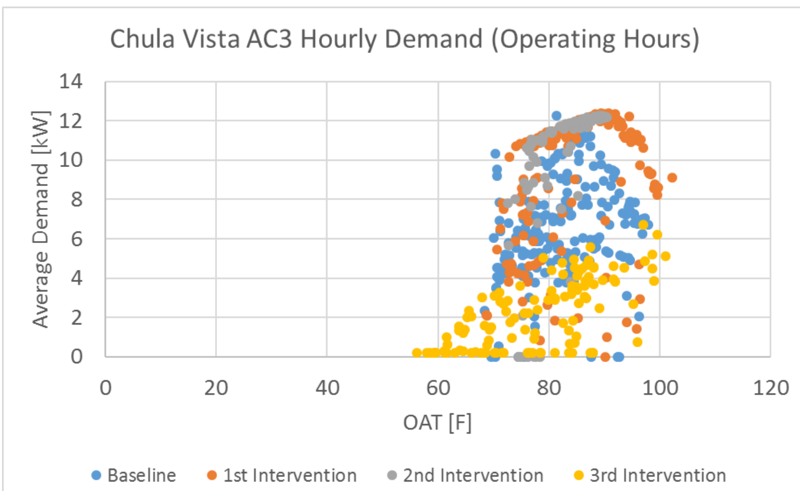


Figure 23 shows the hourly-averaged measured demand for each unit across each measurement period. Note that RTU1 was a unit that had to be replaced prior to the baseline. As a result, the first two stages (deep maintenance and air balancing) appear to have had little to no effect on the performance, as you would expect on a new unit.

FIGURE 23 – HOURLY SCATTER PLOTS OF RTU DEMAND AS A FUNCTION OF OAT (CHULA VISTA BUSINESS HOURS ONLY)







Power and operating condition variables were recorded in order to develop an annualized model for each RTU for the baseline and each stage of the optimization. The only regression that provided meaningful results was a simple regression of daily energy use to cooling degree days. Hourly data had too much variance to establish useful regressions on an hourly basis to monitored variables such as outside air conditions, operating hours, and humidity.

$$Daily\ energy\ [kWh] = a * CDD + b$$

where *a* and *b* are the regression coefficients and *CDD* is the total cooling degree days in the daily interval as measured from a 65F reference temperature. This regression was developed for each unit for both sites. Table 15 lists the annualized energy consumption for each stage of the monitoring period using the above regression form.

TABLE 15 – ESCONDIDO ENERGY SAVINGS[2]

	BASELINE CONSUMPTION [KWH/YEAR]	DEEP MAINTENANCE CONSUMPTION [KWH/YEAR]	AIR BALANCING CONSUMPTION [KWH/YEAR]	FINAL (CONTROLS) CONSUMPTION [KWH/YEAR]	TOTAL ANNUAL SAVINGS [KWH/YEAR]	TOTAL PERCENT SAVINGS
RTU1	30,603	24,394	26,600	21,565	9,038	29%%
RTU2	15,697	18,207	19,607	7,767	7,930	50.5%
RTU3	22,617	27,170	23,496	6.962	15,655	69.2%
All units	81,880	80,456	89,561	49,421	32,459	39.6%

Using similar regressions with average annual weather data as done for Escondido, the savings in the following tables were calculated.

TABLE 16 – CHULA VISTA ENERGY SAVINGS[3]

	BASELINE CONSUMPTION [KWH/YEAR]	DEEP MAINTENANCE CONSUMPTION [KWH/YEAR]	AIR BALANCING CONSUMPTION [KWH/YEAR]	FINAL (CONTROLS) CONSUMPTION [KWH/YEAR]	TOTAL ANNUAL SAVINGS [KWH/YEAR]	TOTAL PERCENT SAVINGS
RTU1	28,563	21,927	23,134	9,605	18,958	66.4%
RTU2	16,406	8,268	8,468	3,498	12,908	78.7%
RTU3	35,215	46,702	58,854	8,584	26.631	75.6%
All units	80,185	76,896	90,457	21,687	58,497	73.0%

The percent savings for each RTU agree with past research. However, given the uncertainty of unresolved maintenance issues during the monitoring period and the post data collection during late in the shoulder season, the billing data results presented in the main body of the report are considered more reliable.

[2] RTU3 operated unexpectedly during the monitoring period after the last interventions. The unit had constant demand which appears to have been only the supply fan operating.

[3] RTU2 operated unexpectedly during the monitoring period after the interventions. The unit had constant demand which could have resulted from a number of issues.

APPENDIX D – 3-IN-10 BASELINE DR RESULTS

FIGURE 24 – DR DEMAND CURVES FOR THE 1F/HR TEST (ESCONDIDO)

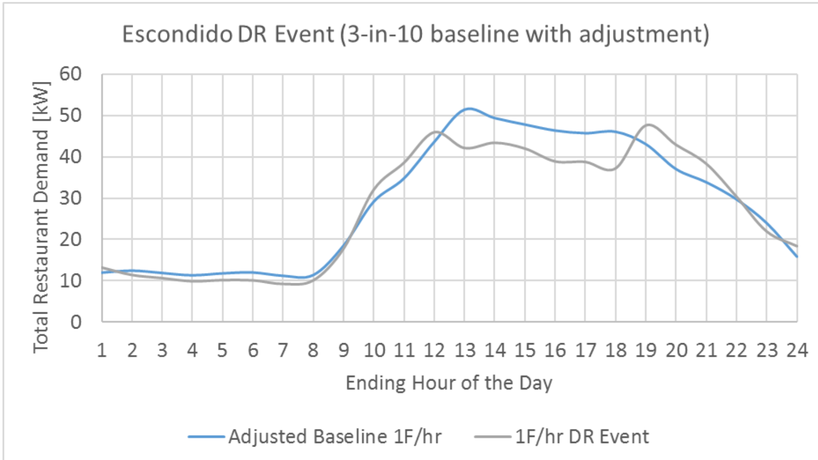


FIGURE 25 – DR DEMAND CURVES FOR THE 2F/HR TEST (ESCONDIDO)

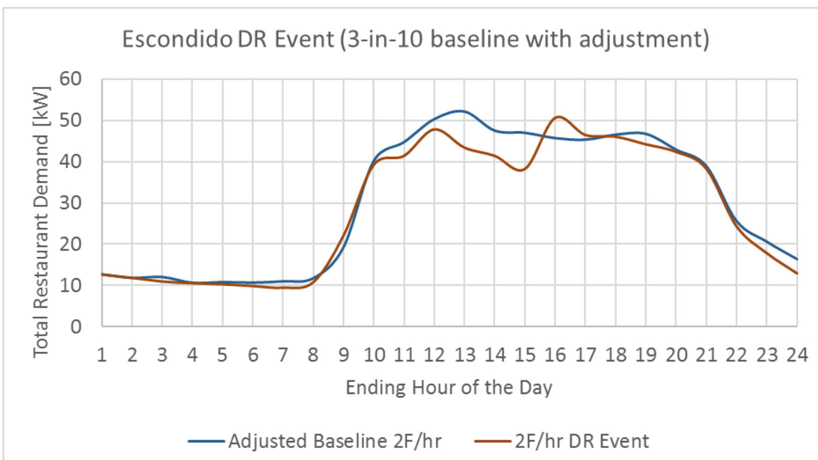


TABLE 17 – ESCONDIDO DR TEST RESULTS

HOUR ENDING	3-TEST AVG 3-IN-10 ADJUSTED BASELINE [KW]	1F/HR SETPOINT INCREASE DR REDUCTION [KW]	1 TEST 3-IN-10 ADJUSTED BASELINE [KW]	2F/HR SETPOINT INCREASE DR REDUCTION [KW]
13	45.60	9.28	52.08	8.74
14	45.08	7.04	47.46	6.10
15	44.25	4.47	46.94	8.76
16	43.24	6.61	n/a	n/a
17	42.35	5.88	n/a	n/a
18	42.89	6.22	n/a	n/a
Avg	43.90	6.58	48.83	17.87
Average % reduction	n/a	13.8%	n/a	16.1%
Morning-of baseline adjustment factor	1.20	n/a	0.989	n/a

FIGURE 26 – DR DEMAND CURVES FOR THE 1F/HR TESTS (CHULA VISTA)

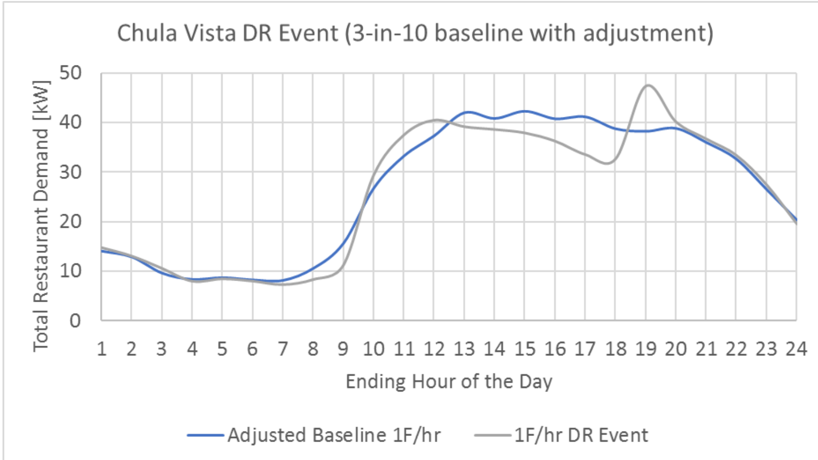


FIGURE 27 – DR DEMAND CURVES FOR THE 2F/HR TESTS (CHULA VISTA)

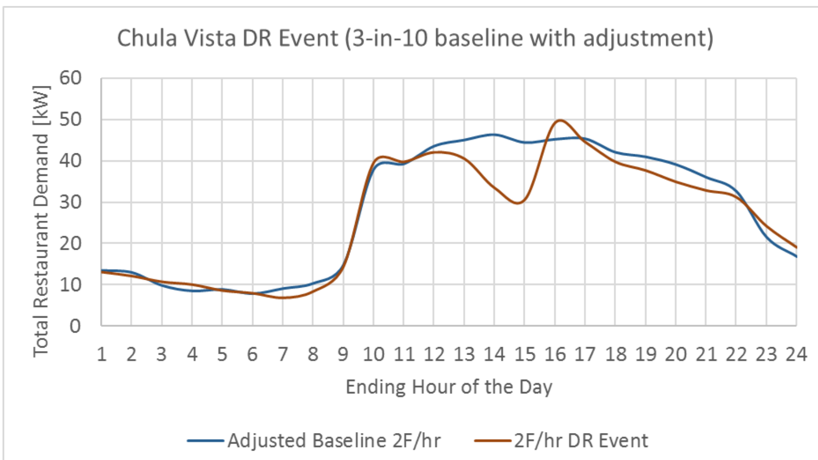


TABLE 18 – CHULA VISTA DR TEST RESULTS

HOUR ENDING	3-TEST AVG 3-IN-10 ADJUSTED BASELINE [KW]	1F/HR SETPOINT INCREASE DR REDUCTION [KW]	1 TEST 3-IN-10 ADJUSTED BASELINE [KW]	2F/HR SETPOINT INCREASE DR REDUCTION [KW]
13	42.03	1.65	45.09	4.53
14	40.86	1.33	46.37	12.89
15	42.32	2.76	44.47	13.79
16	40.80	1.13	n/a	n/a
17	41.20	6.75	n/a	n/a
18	38.79	4.64	n/a	n/a
Avg	41.0	3.02	45.31	10.40
Average % reduction	n/a	7.4%	n/a	23.0%
Mornin-of baseline adjustment factor	1.132	n/a	0.988	n/a