DUALCOOL
AIR CONDITIONER DEMAND REDUCTION SYSTEM

SAVINGS VERIFICATION REPORT

Measurement and Evaluation
Customer Energy Efficiency Policy & Evaluation Section
Pacific Gas and Electric Company
San Francisco, California

Prepared for:
Mary Kay Gobris
Project Manager
Pacific Gas and Electric Co.
245 Market Street
San Francisco, CA 94105

Report Prepared by:
Douglas Mahone
Principal
Heschong Mahone Group, Inc.
11626 Fair Oaks Blvd. #302
Fair Oaks, CA 95628

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EXECUTIVE SUMMARY

This report summarizes the independent verification, conducted by the Heschong Mahone Group Inc., of "DualCool " unit installations for the "Cross-Cutting Demand-Reduction Program" of the Pacific Gas and Electric Company (PG&E). DualCool is an add-on evaporative section for packaged roof top units that provides direct evaporative cooling of the condenser air and indirectly precools outdoor ventilation air. Precooling outside air reduces cooling coil loads, and precooling condenser air reduces the compressor loads due to reduced refrigerant head. When the DualCool system is added to an RTU, the installers also reduce the supply fan speed which saves fan energy. The intended market for DualCool is packaged rooftop cooling units (RTUs) that are commonly applied to low-rise non-residential buildings. The DualCool system has been developed by the Davis Energy Group (DEG), under contract to PG&E.

The Heschong Mahone Group, Inc. (HMG) conducted an independent verification of the savings estimates generated by DEG to verify the savings potential of the units. HMG also conducted site inspections of the installations to verify installation and maintenance details and to note any potential problems with the execution of the system. HMG also conducted interviews with the building owners / owner representatives to gauge their level of satisfaction with the DualCool system, along with any recommendations.

The site inspections as well engineering analysis of the site data reveals that the DualCool system is capable of saving significant amounts of energy (16-24%), which are slightly lower than the DEG estimates, but still substantial enough to warrant further action. HMG also provide a set of recommendations for better analysis of the DualCool system capabilities. HMG also identified some important water quality issues at the sites that can cause scaling of the evaporative media and water damage to the roof surface, and recommend some preventive measures.

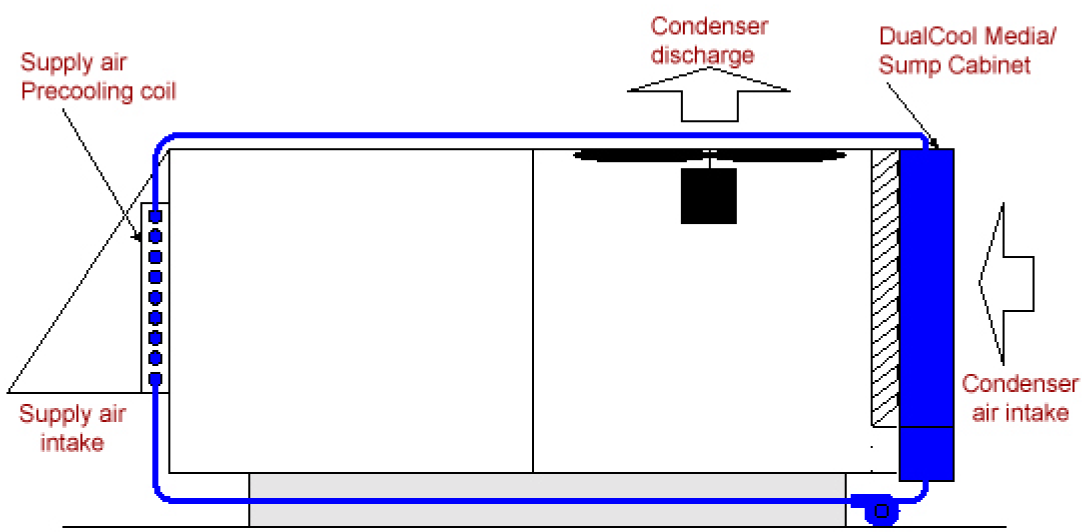
DualCool Savings Evaluation

There are two sections of this report, with the first one reporting on the monitored energy consumption and water usage data recorded on various DualCool units during the summer of 2002. The second part reports findings of the onsite surveys of the installations.

How the DualCool System Works

The DualCool schematic (Figure 1) shows key system components, including evaporative media/cabinet, water sump, circulating pump, ventilation air coil, and piping.

Figure 1: DualCool System Schematic



The operation of a DualCool unit has several aspects:

- Condenser air is cooled as it passes through the wetted evaporative media in the DualCool cabinet, which is mounted over the condenser air intake grill on the RTU.
- This cooled air then passes through the RTU's condenser coil, where the heat extracted by the system from inside the building is rejected to the outside. The cooler air makes this heat rejection process more efficient.
- The evaporatively cooled water which drips off the evaporator medium is collected in a sump at the bottom of the unit. This sump water is circulated through a cooling coil mounted at the ventilation air inlet. As the outside air being drawn into the building passes through this coil, it is cooled. This is a closed coil, so the water doesn't contact the air and no moisture is added to the air supply.
- That air then passes over the main cooling coil in the RTU before delivery to the conditioned space below. Because this supply air is pre-cooled by the sump water, the load on the air conditioner is reduced.
- After passing through the ventilation air-cooling coil, the water then goes to the distribution header at the top of the evaporative media and begins the cycle anew.

The DualCool system, then, uses one evaporative cooling cycle to make two contributions to cooling the building: reducing condenser air temperatures, and reducing supply air temperatures. DualCool is operated by a dedicated controller that initiates DualCool pump operation, and hence evaporative cooling, when the outdoor air temperature exceeds 70º F during RTU compressor (air conditioning) operation.

As the DualCool system continues to operate, the mineral content of the water increases in concentration, because the minerals are left behind when the water evaporates. If the concentration becomes too great, then minerals are deposited as scale on the evaporative medium and other surfaces in the unit. To prevent scaling, the controller is programmed periodically to drain the sump and allow it to refill with fresh water (there is a float valve to provide fresh water and maintain a constant water level in the sump). In areas with higher mineral content, the frequency of sump dumping is increased.

Two other changes to the RTUs are made in conjunction with the DualCool operation: the number of operating condenser fans is reduced, and the speed of the main system supply air fan is reduced. Both reductions in air flow are possible because of the reduced temperatures produced by the DualCool system, and both save additional fan energy.

DEG Data Collection Procedures

The following section summarizes the DualCool installation and data collection efforts undertaken by the contractors, Davis Energy Group (DEG), and borrows from the final report submitted by DEG to the program managers.

DualCool Installations & Monitoring Locations

Table 1 summarizes DualCool installations that have been installed through PG&E program auspices, including the Cross-Cutting Demand Reduction project, PG&E's commercial new construction program and, earlier, PG&E supported R&D efforts. The first three installations in Table 1 were completed in 2001, and the others were completed in spring 2002.

Table 1: PG&E-Supported DualCool Installations

Building Type	Location	HVAC Brand	RTU Unit Sizes	Total Tons
Office	Rocklin	Brand 1	One 8.5 ton	8.5
Office *	Fremont	Brand 1	5 – 130 ton	650
Lab	Sunnyvale	Brand 1	One 25 ton	25
Retail	Davis	Brand 1	One 10 ton unit	10
Retail *	Fresno	Brand 2	2- 10 ton, 11- 15 ton	185
Retail *	Santa Rosa	Brand 2	1- 10 ton, 2- 16 ton; 3- 20 ton	102
* Units monitored at these sites			**Total tons installed**	**980.5**

DEG concentrated their data collection efforts on the two retail sites in Fresno and Santa Rosa and the office building in Fremont. On each of these three sites, DEG monitored all units for their power consumption and cumulative energy use, and in addition conducted detailed monitoring of water usage, energy consumption and condenser temperatures on two units each per site. Blower fan power was measured on the two retail units both before and after DualCool conversion. The Fremont office site was a new construction project, so there were no "before" data to be collected. Due to data collection complications on the office building, savings data from the site was not available for a complete analysis and therefore the savings analysis concentrated on the two retail stores. A more detailed explanation of the analysis process is presented later in this report. Table 2 summarizes the monitoring points at each site.

Table 2: DualCool Monitoring Points

Sensor Type	Location / Description
Overall site monitoring	
Water flow meter	Monitors water use for all DualCools
HOBO temperature and relative humidity	Located in shielded outdoor sensor (manually downloaded each month)
Detailed monitoring on selected units	
Water flow meter	Monitors dedicated water use for 1 unit
Shielded outdoor air sensor	One shielded sensor per store
Power monitor	Total unit kWh and instantaneous kW
Sump temperature	Outdoor air coil inlet water temperature
Distribution header temp.	Outdoor air coil outlet water temperature
Condenser outlet air temp	Condenser fan outlet
Pump status	DualCool operating time
Refill valve status	Monitors sump fill valve operating time
Purge valve cycles	Number of sump “purges”
Standard DualCool units	
Condenser inlet temperature	Pre-cooled air temperature
Outdoor air temperature	At each unit
Pump status	DualCool operating time
Refill status	Sump fill valve operating time
Purge valve cycles	Number of sump “purges”

While all standard units under the DEG program were converted to DualCool operation in late April 2002, the detailed units operated in base case mode until mid-summer, when they were converted to DualCool by adding the media and ventilation air coil, disabling one condenser fan, and reducing blower motor power. This approach allowed comparative energy and demand data to be collected on a “before and after” basis on the same unit. Table 3 summarizes base case and DualCool monitoring schedules for the four detailed units in the two retail sites.

DEG downloaded data via dedicated phone line at least twice each week. DEG verified DualCool operation by comparing condenser inlet and outdoor dry bulb temperatures. During hot summer day conditions, the condenser inlet air is much cooler than outdoor air if the DualCool unit is operating properly.

Table 3: Detailed Unit Monitoring Data

			Base Case Monitoring		DualCool Monitoring	
Location	**RTU #**	**Tons**	**Begin**	**End**	**Begin**	**End**
Fresno	7	15	July 29th *	August 7th	August 8th	October 14th
Fresno	18	10	July 5th	August 7th	August 8th	October 14th
Santa Rosa	6	20	June 9th	July 15th	July 17th	October 14th
Santa Rosa	17	16	June 9th	July 15th	July 17th	October 14th

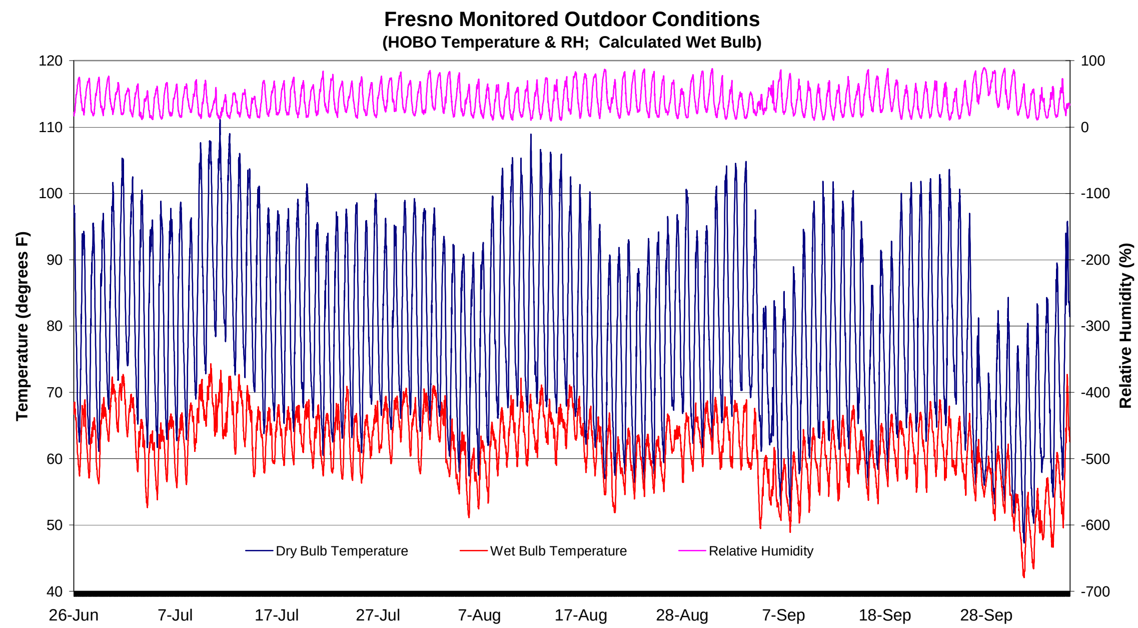
Weather Data

Summers are warmer in Fresno than in Santa Rosa, which is influenced by coastal fog. Table 4 summarizes monitored daily maximum dry bulb temperatures during the 2002 monitoring period from June 26th through September 30th. Also, there are minor differences in the outdoor dry bulb temperatures at each site between the base case and DualCool monitoring periods. Figure 2 shows the monitored outdoor temperatures for the Fresno site, and shows an average of 5°F lower temperatures for the DualCool monitoring period as compared to the base case monitoring period. Similarly, Figure 3 shows the monitored outdoor temperatures for the Santa Rosa site. Additional weather data can be found in Appendix B of the DEG final report submitted to PG&E.

Table 4: Monitored Daily Maximum Temperatures

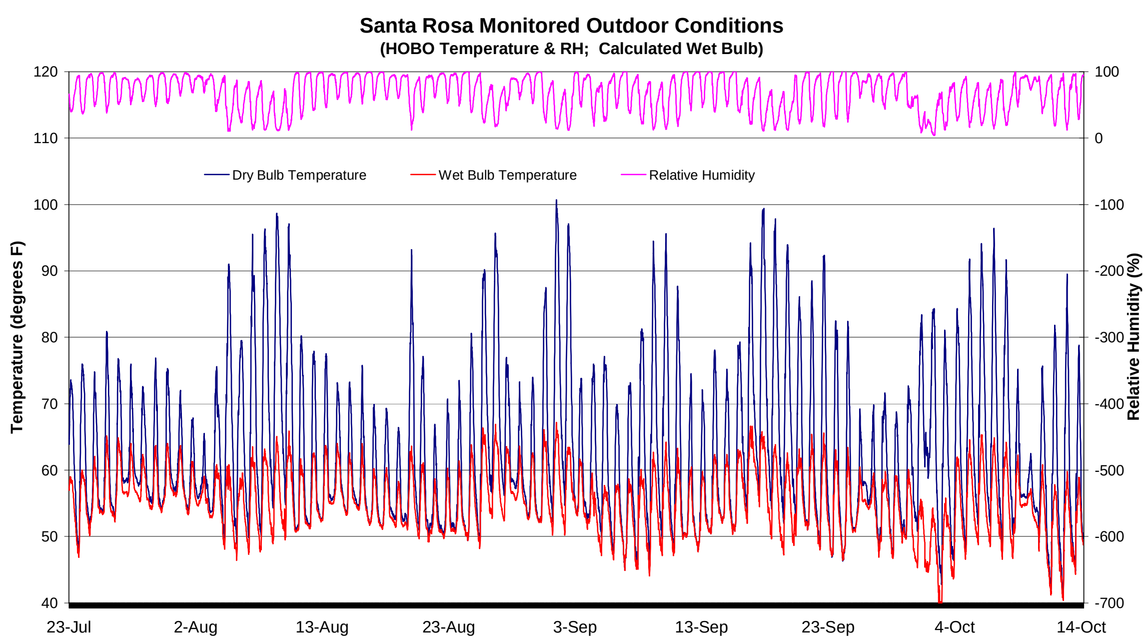
	Fresno	Santa Rosa
# of Days > 100ºF	38	1
# of Days > 90ºF	87	25
# of Days < 85ºF	6	69

Figure 2: Fresno Monitored Weather Data



Note: colors are readable on screen in the electronic version of this report.

Figure 3: Santa Rosa Monitored Weather Data



Energy Consumption Data and Savings Calculations

The Heschong Mahone Group (HMG) conducted an independent verification of the data collection procedures and the energy savings estimation procedures used by DEG. HMG used data recorded by DEG on the three sites monitored to verify the savings estimates that DEG produced. Upon review of the installed data acquisition systems, and of a sample of raw data that was collected, there was no reason to doubt the validity of the data.

HMG used a different methodology than DEG to calculate savings on each site. While both HMG and DEG used a temperature correlation equation to calculate savings based upon outdoor dry bulb temperature at the site, each used different methods for arriving at the temperature correlation. These correlations were then applied, in both methods, to the temperature data for a typical weather year (as defined by California Energy Commission weather data (known as CEC WYEC2 datasets) for the appropriate climate zone). The result was an estimate of the expected average annual energy savings. Actual savings will, of course, vary depending on actual temperature conditions in a given year. Further details of the two approaches are provided below.

Recorded data for both pre and post DualCool installations from the two retail sites in Santa Rosa and Fresno were made available to HMG by DEG in an Excel readable format, along with a description of their analysis procedures. Similar data was not available for the office building in Fremont, and DEG supplied a simplified methodology for estimating savings at this site based upon the analysis of the two retail sites. Independent verification of this methodology was not possible due to lack of data on pre-DualCool operation at this site.

DEG Analysis Procedures

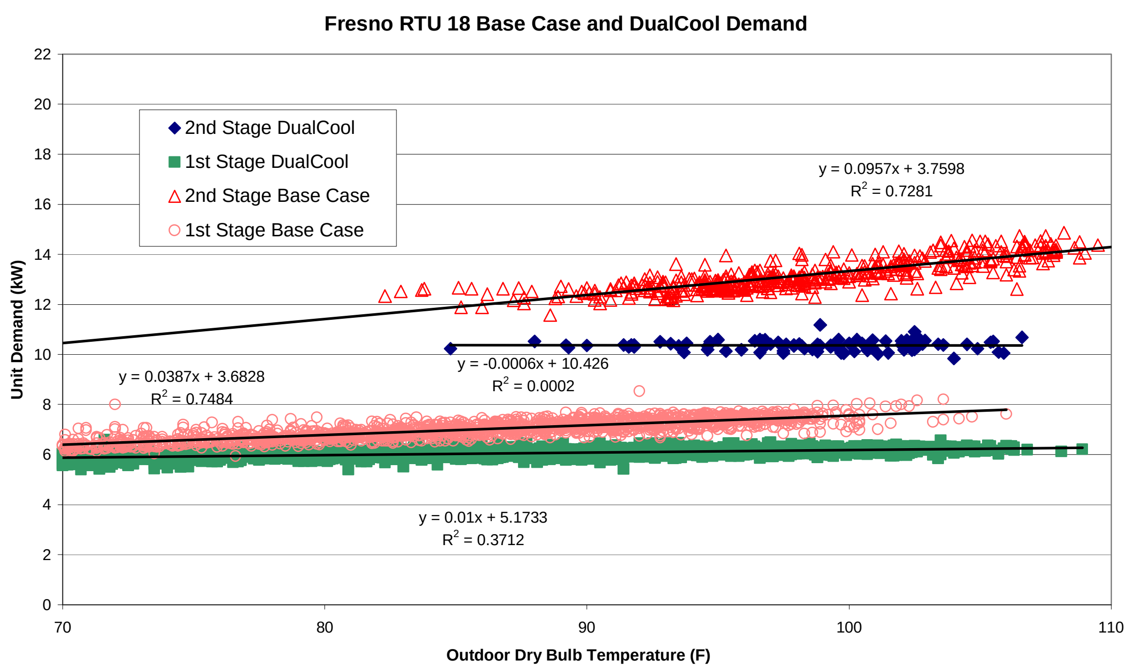
The following methodology was used by DEG to calculate savings at the two retail sites in Fresno and Santa Rosa.

The savings in energy consumption due to installation of the DualCool features on each of the units is obtained by noting the difference between the pre and post DualCool installation energy consumption numbers for similar outdoor dry bulb temperatures at the site. Since the base case (no DualCool installation/operation) and DualCool operations take place at different times, there is no concurrent data on both these conditions. Hence, DEG calculated the difference in base case and DualCool energy consumption with a regression analysis of the kW consumption of the unit against the outdoor dry bulb temperature at the site.

For each of the units monitored, there are two stages of operation for the compressor, and the unit can run either with only the first stage or both the stages running. The second stage operates during hot conditions, when there is insufficient cooling capacity from the first stage to meet the building load. There is a distribution of 1st and 2nd stage operation across the outdoor temperature range encountered in the monitoring period, for both the base case as well as the DualCool operation case. In each case, DEG separated the two stages based upon the kW consumption of the unit. If the kW consumption was below a certain threshold, the unit was assumed to run with only the 1st stage of compressor, otherwise 2nd stage operation was assumed. Thus, there is 1st and 2nd stage base case operation and 1st and 2nd stage DualCool operation of the units across a range of temperature conditions encountered in the monitoring period. Each of these four operating conditions was then plotted against the outdoor dry bulb temperature recorded at the site to generate a regression curve for each of the conditions against the temperature.

A sample regression analysis is presented in Figure 4 below, and shows the four separate operation modes plotted, along with a regression formula for each of the four operation modes. It is generally observed that the units run a lesser amount of time with the two-stage operation with the DualCool system installed.

Figure 4: DEG Savings Regression Analysis Plot for Fresno unit #18



Once the four regression curves were developed, DEG used historic temperature data from a typical meteorological year to estimate the expected, yearly average energy savings. DEG used the following assumptions to calculate the delta between the base kW consumption to the DualCool kW consumption –

If the outdoor dry bulb temperature was:

- <75°F, DualCool savings = 26% supply fan kW savings (Based upon initial fan power testing done by DEG, where 26% supply fan kW savings were observed as a result of installing the DualCool features during mild weather conditions)
- <94°F, Base case kW is based on 1st stage regression line

- >= 94°F, base case kW is based on 2nd stage
- <98°F, DualCool kW is based on 1st stage regression line
- >98°F, DualCool kW is based on 2nd stage

It is apparent from these assumptions that DEG expected the DualCool units to operate under first stage cooling conditions for a longer time (to hotter outdoor temperatures) than the base case units.

Using these temperature correlations, DEG then estimated the DualCool operation savings by subtracting DualCool energy usage from the base case energy usage for the appropriate temperature range. For example, if the outdoor temperature was 96°F, the base case kW would be the kW consumption of the base case unit in 2nd stage operation at 96°F, and the DualCool kW would be kW consumption of the DualCool unit in 1st stage operation at 96°F.

DEG then calculated kW savings per ton of cooling capacity for one of the monitored units per site determined to be representative of the site with the above method. To estimate savings over the year, they used the monthly maximum temperature from the historical weather data (CEC WYEC2 datasets), and estimated monthly kW savings using the assumed temperature correlations as described above. Adding the monthly savings numbers, the annual savings numbers are estimated for this one monitored unit per site. To get the annual kWh savings, DEG used daily maximum temperature from the historical weather data (CEC WYEC2 datasets) to get daily kWh/ton values, which were then added up to get an annual kWh savings per ton number.

To project these savings from one unit to the rest of the units on the site, they use runtime data for each of the units, which monitored the number of hours each unit was in operation with either one or both the compressors running. Based on the number of hours the units were operating during the data-monitoring period, they developed an average operation profile for the units. DEG then applied necessary corrections for runtime and equipment sizing to the savings number from the one unit, and multiplied it by the number of units on the site to get annual site level savings.

HMG Analysis Procedures

HMG used the same dataset that DEG had used for their analysis but followed a slightly different procedure to calculate the annual savings estimate for the two sites. HMG maintained the basic approach of using one unit as a proxy for the other units at the site, and using runtime data to modify for the differences between various units. The main difference was the calculation of the kW savings between base case and DualCool operation.

It was observed in the DEG data that for many of the outdoor dry bulb temperatures experienced, there would be some hours with only 1st stage operation, and some with 2nd stage operation. This was true for both the base case as well as the DualCool operation data. There are certain errors associated with using the assumptions DEG made in regards to what constituted the base case kW and DualCool kW for any given outdoor dry bulb temperature – which affects the savings estimate. HMG therefore decided to use a temperature bin method to correlate outdoor dry bulb temperature at the site to the kW consumption of the unit regardless of what stage of compressor operation occurred. A regression curve was developed for each of the base case and DualCool operations that accounts for both 1st and 2nd stage operation in each of the temperature bins.

HMG then applied this regression equation to the hourly outdoor dry bulb temperature data from the CEC WYEC2 datasets to get hourly kW and kW savings numbers for the entire year (Figure 5and Figure 6). Similar to the DEG methodology, HMG assumed that below 70 degrees outdoor dry bulb temperature, the unit essentially is saving fan energy due to DualCool and used the recorded fan power reduction numbers from DEG. These fan power reduction numbers were based upon the recorded fan power measurements at the time of installing the DualCool features on the fan, and compared the before and after DualCool installation power consumption of the fans alone.

Figure 5: HMG kW Savings Regression Analysis for Fresno unit # 18

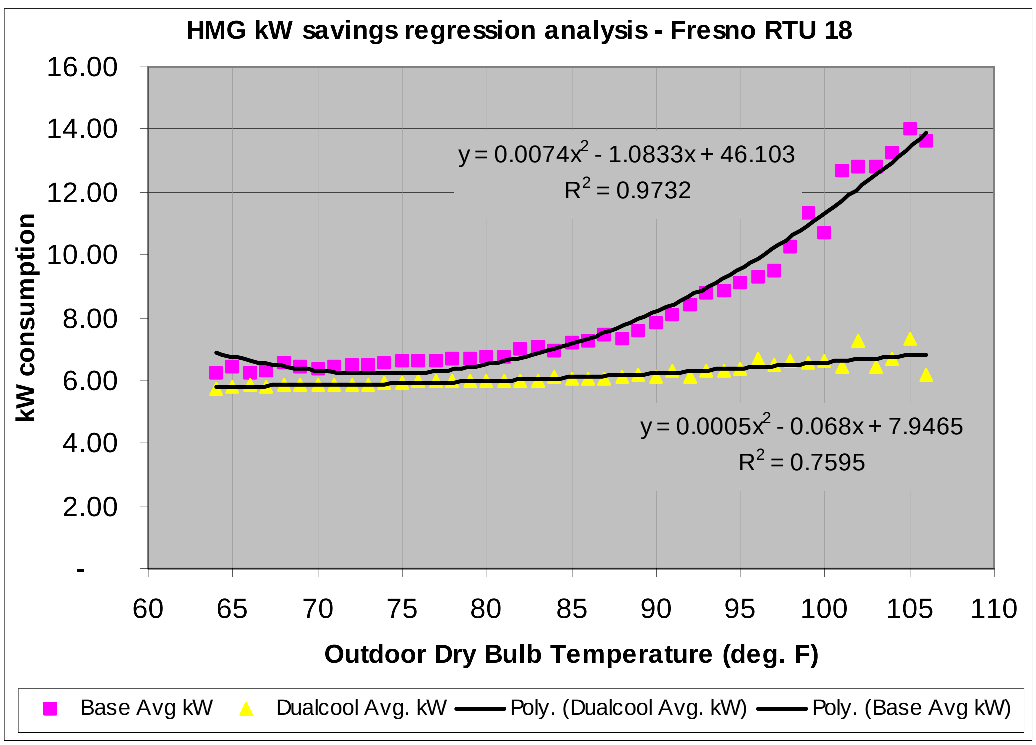
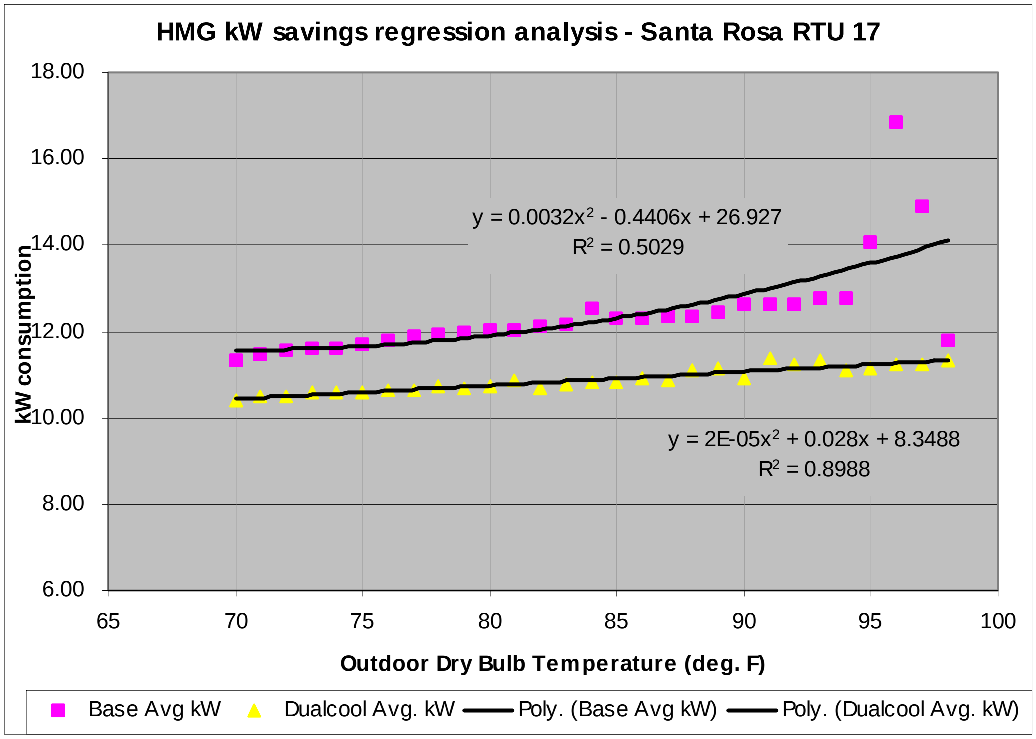


Figure 6: HMG kW Savings Regression Analysis for Santa Rosa unit # 17



Adding the hourly savings numbers, we get an annual kWh savings estimate for one unit on each site. We then look at the runtime hours of all the DualCool units on the site, and apply a runtime correction factor for each unit. We also apply an equipment sizing correction factor to each unit. Applying these correction factors, and using the savings from one unit as a base, we arrive at site level savings at the site level.

Figure 7: HMG Site Total Energy Savings Analysis for Fresno

	Capacity (Tons)	Capacity factor	Run-time	Runfactor	Annual DualCool kWh savings	Annual BaseCase kWh
Unit 4	15	1.5	772	1.07	13,058	55,011
Unit 5	15	1.5	790	1.09	13,369	56,322
Unit 6	15	1.5	765	1.06	12,941	54,520
Unit 7	15	1.5	425	0.59	7,187	30,279
Unit 8	15	1.5	740	1.02	12,511	52,707
Unit 10	15	1.5	124	0.17	2,093	8,819
Unit 11	15	1.5	683	0.95	11,560	48,699
Unit 13	15	1.5	0	-	-	-
Unit 14	15	1.5	442	0.61	7,471	31,476
Unit 15	15	1.5	475	0.66	8,027	33,817
Unit 16	15	1.5	492	0.68	8,315	35,030
Unit 17	10	1	722	1.00	8,148	34,324
Unit 18	10	1	531	0.73	5,986	25,219
total	185		Total kWh/yr savings		110,668	466,225
			Total kWh/ton/yr savings		598	2,520

Figure 8: HMG Site Total Energy Savings Analysis for Santa Rosa

	Capacity (Tons)	Capacity factor	Run-time	Runfactor	Annual DualCool kWh savings	Annual BaseCase kWh
Unit 4	10	0.63	472.71	1.03	4,228	26,097
Unit 5	20	1.25	502.43	1.09	8,987	55,476
Unit 6	20	1.25	398.56	0.87	7,129	44,007
Unit 11	16	1.00	388.23	0.84	5,556	34,293
Unit 17	16	1.00	459.75	1.00	6,579	40,611
Unit 19	20	1.25	402.23	0.87	7,195	44,413
total	102		Total kWh/yr savings		39,675	244,898
			Total kWh/ton/yr savings		389	2,401

As displayed in Figure 7 and Figure 8 above, the detailed savings analysis was done on one unit at each site. Then a series of correction factors were applied to each of the other units to account for different equipment sizes and runtime. Capacity factor is a measure of how any given unit is bigger or smaller than the reference unit; runtime is the amount of time each of the units was in operation during the monitoring period and runfactor is the multiplier to account for the differences in runtime between any given unit and the reference unit at the site. Thus multiplying the kW consumption for the reference unit as described earlier in this section with capacity factor and runfactor, we get kW consumption for all the units (both base case and DualCool operations). Adding the base case and DualCool kW consumption numbers for all the units, we get site level kWh savings numbers. Unit 13 in Fresno is shown to have zero savings due to the fact that it had almost no run-time during the monitored period.

Annual Energy Savings Comparison

Table 5 details the savings per site as calculated by HMG, and also states the equivalent savings estimates used by DEG. The kWh savings are the difference in pre and post DualCool installation energy consumption calculated for each temperature bin in the analysis.

Table 5: Site Level Annual kWh Energy Savings

Location	# Units	Annual Dualcool kWh Savings		% savings	
		HMG	DEG	HMG	DEG
Santa Rosa	6	39,675	43,600	16%	24%
Fresno	13	110,668	86,910	24%	30%

As seen in Table 5, the % savings estimates by HMG are lower than the DEG estimates for both sites by about 25%. It should be noted that the annual DualCool savings number for the Fresno site is higher in the HMG estimate than the DEG estimate. This number is misleading though as the kWh savings numbers are relative to the base case savings numbers and HMG estimates for base case energy consumption are higher than the DEG estimates, resulting in lower % savings.

The different analysis procedures used by HMG and DEG as described earlier account for the differences in the results. While the DEG analysis method gave good ballpark estimates of savings using assumptions for when the system would be in 1st stage versus 2nd stage of operation, the HMG methodology accounts for the various operating conditions of each unit under the base case and DualCool operations, as well as differences between units. HMG also used hourly weather data for the particular climate zones to generate their annual savings estimate, making the savings analysis robust by using known weather parameters as used in energy efficiency analysis for statewide codes and standards and energy efficiency analysis by the California Energy Commission. By contrast, the DEG methodology did not use hourly temperature values, but instead used daily peak temperatures to calculate peak daily kWh savings, and use these peak daily values to calculate annual kWh savings. This approach by DEG yields savings numbers that are higher than the ones obtained by HMG using hourly-recorded historical weather data.

In addition to the annual energy savings estimate HMG also estimated the peak kW savings for unit 17 in Santa Rosa and unit 18 in Fresno – the two units deemed to be typical for the two sites respectively. The peak kW savings are defined as the maximum savings achievable by the unit at any given hour during the PG&E defined peak usage hours (summer peak period is defined as May 1 to October 31, noon to 8 pm, Monday through Friday, excluding holidays). For Fresno unit 18, the kW peak savings occurred at 2:00 pm on July 28th and were 8.22 kW; for Santa Rosa unit 17, the peak savings occurred at 2:00 pm on August 20th and were 3.31 kW.

Extrapolating these peak kW savings for one unit per site to the other units on the site, HMG used a simplified approach of calculating peak kW/ton savings by accounting for differing run-time for all the units in the monitoring period. Similar to the analysis used for calculating annual kWh/ton savings estimates explained earlier, the reference unit kW savings peak number was multiplied by the runfactor to get the peak kW savings for each of the units. Adding up the peak kW savings and dividing by the total tonnage of the units, we estimate a peak kW/ton savings number for the site. (Figure 9) Greater peak savings are seen in Fresno than in Santa Rosa, which is expected due to the higher potential for evaporative cooling in the hot-dry Fresno climate as opposed to the Santa Rosa climate affected by coastal effects.

Figure 9: Estimate of peak kW savings for Fresno and Santa Rosa

Fresno		**Santa Rosa**	
Unit #	**peak savings kW /ton**	**Unit #**	**peak savings kW /ton**
Unit 4	8.78	Unit 4	3.40
Unit 5	8.99	Unit 5	3.62
Unit 6	8.70	Unit 6	2.87
Unit 7	4.83	Unit 11	2.79
Unit 8	8.41	Unit 17	3.31
Unit 10	1.41	Unit 19	2.89
Unit 11	7.77		
Unit 13	-		
Unit 14	5.02		
Unit 15	5.40		
Unit 16	5.59		
Unit 17	8.22		
Unit 18	6.04		
total kw/ton savings per site:			
Fresno	0.43	Santa Rosa	0.19

Of the three sites monitored, only the office building in Fremont was a new construction project, and the units at the site had the DualCool features activated at the time of installation. Thus there was no baseline operation of the units on this site rendering a savings analysis based upon a post and pre operation data impossible. The only way to get baseline data for this site would be to deactivate the DualCool features, and collect data over a suitably warm period comparable to the data already collected onsite. In absence of such a baseline data, DEG used a simplified analysis approach, which we are unable to comment on due to lack of detail. In any case, it is at best a guestimate of savings, if the only available guestimate.

It is seen from the two retail sites that the units perform better in the hotter and dryer climate (Fresno – central California) as compared to the milder and more humid climate (Santa Rosa – Coastal influence), which is to be expected of a unit based upon evaporative pre-cooling.

Water Quality and Consumption

The site visit observations (see site reports below) indicated that there were some water quality problems (scaling of the evaporative media) at the sites. The same is documented in the final report sent by DEG, and is seen in places with harder water. Since the DualCool units would be most ideally suited for the central valley climates, water quality would be a big issue. (Anecdotal and empirical evidence suggests that the central valley has much harder water than the rest of the state)

Currently, the methodology for taking care of the scaling problem is to increase the water drain rate. At the Fresno site the drain cycle was increased from once a day to about 5 times a day to get rid of the scaling. This increases the water consumption of the units, though water is significantly less expensive in the central valley than other places in California. This increased water usage therefore does not result in an economic penalty when compared to other areas.

A secondary water issue is related to disposal of the water once it is dumped from the units. At the Fresno site, the units were originally configured to dump water directly onto the roofing membrane, with the thought that it would simply provide an added evaporative cooling effect. As it turned out, however, the daily water dumps caused streaking on the membrane, and encouraged rather substantial algae growth where it puddled in local depressions on the roof surface. Plumbing the drain dumps into existing drain pipes located adjacent to each of the RTUs solved this problem. The Fremont installations had drainage piping installed from the outset. However, as described in the site visit report, the Fremont site has significant leakage out of the access door that has created similar algae build-up on the roof. The other retail site in Santa Rosa dumps water onto the roof surface without apparent problems.

DEG monitored the water consumption on each of the sites using a water flow meter on each of the units used for the analysis. DEG also monitored the number of sump 'purges' on each of the detailed monitored units.

DEG obtained Fresno and Santa Rosa water charge rates and projected annual water costs per ton of DualCool capacity. Current Fresno commercial rates per DEG are $0.616 per 1000 gallons and Santa Rosa rates are $2.43 per 1000 gallons. For Santa Rosa, DEG estimates that sump purging amounts to 21-24% of the monitored water use compared to 55-61% in Fresno. On a typical 90ºF Santa Rosa day, DualCool uses about 800 gallons (7.8 gallons/ton-day), with a resulting daily cost of $1.95 ($.019/ton-day) as per DEG data. For a typical 100ºF Fresno day, average use of 3,440 gallons (18.6 gallons/ton-day) costs $2.12 ($.0115/ton-day) as per DEG data. Thus even though water consumption is much higher in Fresno as compared to Santa Rosa there is no great economic penalty. HMG did not conduct independent verification of the water consumption numbers, and the above figures are quoted from the final report submitted to PG&E by the Davis Energy Group.

The issue of water chemistry is beyond the scope of this analysis. Clearly, high mineral content in the water can cause scaling problems. A comprehensive solution would be to develop a method to determine, based on water district water quality reports, whether a potential for scaling exists at a given site. A simpler solution would be to inquire at the water district whether scaling problems are common with traditional evaporative cooling (swamp cooler) systems. In either case, the solution to the problem will be the same as was done at the Fresno retail site: increase the rate of sump dumps until the problem is minimized. If these units are to achieve high market penetration, a workable method for predicting and preventing water quality problems will need to be developed.

Recommendations

Based upon the analysis done for these two sites recommendations for the future M&V activities related to DualCool include:

- Collect data on supply air temperatures and airflow rates: The current analysis is based upon power consumption versus outdoor dry bulb temperature. There is no data on the actual performance in terms of supply air temperatures and airflow rates to the space. Collecting this data would allow determination of the efficiency and capacity of the units at the recorded power consumption and outdoor temperature values.
- Collect data on effects of load sharing amongst units: Since there are multiple units per site, it is possible that the load-sharing characteristics of the units change especially if multiple units serve the same zone or space. In other words, if one unit is not completely meeting its load, adjacent units may be picking up the difference. If the deficient unit were a DualCool unit, then this analysis would be overestimating savings. Collecting the actual supply, return and mixed air temperatures and airflow from each unit would greatly enhance the analysis capabilities in this regard.
- Increase frequency of power measurements: The current data collection device for the DualCool units records instantaneous power consumption at every 15 minutes. Since the unit can potentially cycle multiple times during this interval, a more accurate means of capturing the data would be to average the power data over the 15 minutes, with the sub-sampling done at every minute. For the analysis approach that we used, however, the existing data collection method was adequate.
- Develop a methodology for assessing water quality at site: Water quality monitoring is potentially the most important issue to be addressed if the DualCool units are to be used on a mass scale. During the start-up phase of any new project, the water quality and scaling potential at the installation should be carefully evaluated, and the flushing cycle adjusted to avoid problems. A more elaborate approach would entail onboard monitoring devices that can track the concentration of solids in the water and operate the sump drains based upon preset control levels.
- Include costs for sump water drainage in cost analysis: There are costs associated with providing adequate drainage from the DualCool units to a drain line onsite. On sites where no drain lines exist, there is the added cost of installing drain lines on the roof. These added costs should be considered when assessing the cost effectiveness analysis of a particular application.

The overall analysis showed that the DualCool units performed satisfactorily in terms of saving energy on both of the sites analyzed. In terms of large-scale deployment of the units, the main barrier seems to be convincing building owners and operators to install this new technology, as evidenced by the fact that DEG was only able to install prototypes on a much smaller number of sites than they had anticipated. If backed by comprehensive support and ongoing maintenance, either by DEG, by the installer, or by some other agency, the DualCool technology has potential to save substantial amounts of energy for rooftop air conditioners in California.

ON-SITE VERIFICATION PROCESS

This section reports on field visits conducted by Douglas Mahone on November 14 and 15, 2002 to the three active DualCool installations in the PG&E territory:

1. Santa Rosa retail store (6 units totaling 102 tons)
2. Fresno retail store (13 units totaling 185 tons)
3. Fremont office building (5 units totaling 650 tons)

These three projects have been monitored by the Davis Energy Group (DEG) for Steve Blanc at PG&E. The conditions and presence of monitoring equipment appeared to be as reported in by DEG. In general, the equipment appeared to be in working order. On the dates of the site visits, however, the weather was mild and the units were not working hard, so we were not able to observe all units under full cooling load. Examination and analysis of the monitoring data provided by DEG allowed a more thorough review of the performance of the systems.

The following activities were carried out at each of the sites:

1. Observation of the condition of the equipment and its installation, supplemented (in the case of the Fremont site) with information from the facility manager. Neither of the retail stores had on-site personnel who were familiar with the units. All units were photographed.
2. Spot checks of unit model numbers and capacities
3. Spot measurements of amperage draws

Summaries of the field observations follow.

Site 1: Santa Rosa – retail store

There are DualCool units retrofitted onto 6 of the 20 rooftop air-conditioning units on this store. These include three 20 Ton units, two 16 Ton units, and a 10 Ton unit. Apparently two of these units have monitoring data collected by DEG. In addition, there is a master water meter on the supply line serving the units.

In general, the units appeared to be in good condition. Only one slight drip leak was observed. These units drain water directly to the roof surface, rather than to a piped drainage system as at the other two sites; this did not appear to be a problem (no visible algae or staining), although for the most part the units were not operating when we observed them.

Photographs:

Access to the inner workings of these units was straightforward - an access panel was lifted and slid out. This photo shows the sump and its associated pumps at the bottom, and the DualCool control unit at the top. The evaporative medium at the right shows minor corrosion and scaling, which is to be expected. The pipe stub sticking out at the lower left corner is the drainage pipe from the sump onto the roof surface. In other installations, this was connected to a drainage piping system.

The second photo shows a typical installation, in this case on a 16 Ton RTU. The DualCool unit is the square evaporator unit on the left side, attached to the downward sloping air intake and condenser coil of the RTU.

The third photo shows the air intake at the top left, with its pre-cooling coil and the associated two pipes (supply and return from the sump at the bottom of the DualCool unit on the right. The white covered, insulated pipe entering from the lower right is the fresh water supply piping. The piping on the left side is the natural gas supply to the furnace. The square opening on the bottom left of the unit is the exhaust with its gravity damper - it is shut in this photo because the unit was not operating.

The fourth photo shows the condition of a typical evaporator surface. It shows slight corrosion and staining from mineral deposits. This did not appear to be excessive or problematic. None of the units was observed to be operating while we were there, so we were not able to observe whether or not there is spray or

leakage from any of the units, but there was no evidence of damage or algae on the rooftop.

Site 2: Fresno- retail store

The site was visited on November 15th. The installations were nearly identical to those observed at the Santa Rosa retail store, described above. There were DualCool units attached to 11 of the 15 Ton units, and 2 of the 10 Ton units, manufactured by the same company as the units at the Santa Rosa retail store.

We had been forewarned that there were problems with mineral deposits on the evaporator media, and with mineral deposits on the roof from dumping sump water onto the roof surface, but this did not appear to be the case. As seen in the photo at right, the evaporative media appeared to have a similar degree of scaling and corrosion to the other sites, which was minor and did not appear severe enough to restrict airflow or function.

The only indications of problems with the roofing were some staining/streaking on the roof surface, and a few instances of puddles at local flat spots. The puddles were associated both with units that did not have DualCool installations and some that did, so it did not appear to be a DualCool problem. There was a great deal of algae growth at the low end of the roof, where a large area of roof surface was slightly lower than the roof drains and so water accumulated there. The retail chain's Energy Manager said that this was caused initially by the dumping of sump water from the DualCool units. The problem had extended down to the ground where the roof drains discharged. This problem has been solved, because all water discharge from the DualCool units is now piped directly

to drainage piping which penetrates the roof and goes down into the building adjacent to the units. The photo on the left with the roof hatch shows a local puddle, and shows the large area of algae growth in the background. The photo on the right shows the sump discharge piping joining the main unit drain. It also shows some mineral deposits and streaking from past water discharges onto the roof surface. These may have been due to sump discharges before the drainage piping was installed. We will investigate further to determine the sequence of events - whether the drainage piping was installed at the time of the DualCool installation, or whether it was retrofitted later.

We understand that the rate of flushing of the DualCool sump was increased in order to prevent scaling on the evaporative medium. DEG reports that, other than some brushing of scale off the surfaces when the dump cycle was changed, there has been no extra maintenance of the evaporative media.

The operation of the Fresno DualCool units was not observable, because nearly all of the RTUs were not in cooling mode on the day of the site visit (weather was 65°F and skies were hazy).

In addition to site visits at the two retail stores, we interviewed the retail chain's Energy Manager. He was generally happy with the DualCool units, and indicated that they were considering installing units on other stores where it would be appropriate. He described the water problems that they had had at the Fresno site, but did not feel they were anything more serious than understandable start-up problems. He also was satisfied with the way DEG had cooperated with the retail chain to resolve the problems. He had read the DEG report on energy savings and believed it, although he had not done any of his own analysis of the utility bills to see if he could observe savings there. Overall, he is satisfied.

Site 3: Fremont - office building

The Fremont site consists of two office/manufacturing buildings in Fremont. The three-story main building, at 6900 Paseo Padre, has two 120 Ton packaged VAV rooftop units. The adjacent building where the manufacturing takes place, at 6801 Kaiser Blvd., has three such units. These are very large units, and the DualCool installations are likewise large, compared to the units on the retail stores. In addition to these units, the rooftops had a variety of other kinds of HVAC equipment, including water chillers and small, local air conditioners.

The facilities manager was knowledgeable and available to discuss the DualCool installations. He was unhappy with the installations. He felt that the workmanship was poor, and that they had poor serviceability and access features. One of the units was persistently leaking water onto the roofing, promoting algae growth, and he fears he will have to repair the roof as a result. An outdoor sensor installed by DEG, with a large plastic shielding enclosure, was placed so that it interfered with the opening of the access door to the electrical controls. He mentioned problems with four of the units not receiving water, and problems with the modem/monitoring units. He felt that the installers had not provided good customer service and had been poor at responding to his problems with the units, despite repeated complaints from him. He has not received any information or reporting on how well or poorly the units are performing, or whether his company is actually saving any money. As a result, he said he has been refusing to sign the agreement he was asked to sign (presumably by DEG).

Photographs:

The biggest problems appeared to be associated with ACU-6 on the 6900 Paseo Padre building. The adjacent photograph shows the DualCool evaporative medium in its frame attached to the outside of the condensing unit (right side of photo). The vertical streaks are water leaking/spraying out of the unit. The roof deck below is wet from the leakage, and has algal growth (see detail in next photo). The white sensor unit above the flex conduit on the end of the DualCool unit impedes the opening of the access door (the surface with the red Trane label). The DualCool control unit was apparently installed someplace behind the evaporator panel - we were unable to access and observe it. Within the other electrical access panel (left side of photo), we were able to observe the clamp-on ammeter probes and, in some of the units, the telephone modem connection.

This photo shows the algae and water on the roof surface below the leaking DualCool unit. This is the condition which the facility manager fears will require roofing repair. Also shown is an electrical service box attached to a flexible conduit. It was left lying loose on the roof surface, rather than attached to the a/c unit and off the deck.

The other details of the installations and condition of these units at Fremont appeared normal. The photos below show a typical rooftop unit with the DualCool equipment attached (near end of the unit). The close-up shows the condition of the evaporative medium on the condenser. There is some minor

corrosion and scaling, but this does not appear to be unusual or problematic.

The piping detail shows the water supply and drainage connections, as well as the water consumption meter, at the condenser.