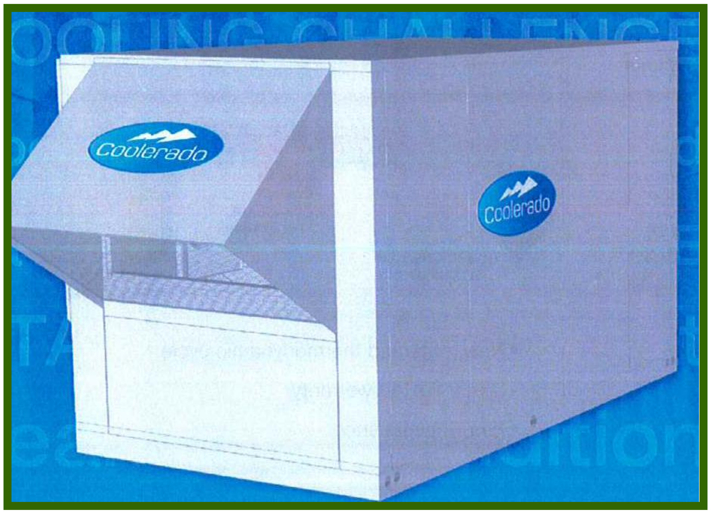
5-Ton Indirect Evaporative HVAC

ET08SCE1160 Report



Prepared by:

Design & Engineering Services
Customer Service Business Unit
Southern California Edison

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ABBREVIATIONS AND ACRONYMS

Btu	British thermal unit
cfm	Cubic feet per minute
CZ	Climate Zone
CT	Current Transformer
DX	Direct Expansion
ET	Emerging Technology
HVAC	Heating, Ventilation, and Air Conditioning
kW	Kilowatt
kWh	Kilowatt Hour
psi	Pounds per square inch
RH	Relative Humidity
RTU	Roof top unit
SCE	Southern California Edison

FIGURES

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EQUATIONS

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EXECUTIVE SUMMARY

This project tests the performance and efficiency of a 5-ton indirect evaporative hybrid roof top air-conditioning unit developed primarily for the small commercial market segment.

Commercial buildings consume more electricity than any other end-use sector in California, and space cooling loads account for 15% of the total electricity consumption. The California Long Term Energy Efficiency Strategic Plan targets a 50% improvement in efficiency in the heating, ventilation, and air conditioning (HVAC) sector for small commercial and residential buildings by 2020, and a 75% improvement by 2030. The plan also identifies the need for more climate appropriate HVAC solutions that are suitable for California's hot and dry climate.

Southern California Edison's (SCEs) Emerging Technologies Program identified the 5-ton indirect evaporative hybrid roof top unit (RTU) by Coolerado Corporation as one possible solution suitable for California's arid climate. This technology works on the principle of Maisotsenko refrigeration cycle, or M-cycle, to perform heat exchange. It uses a two-stage cooling technique to lower the outside air temperature that is ultimately delivered to the conditioned space. In stage one; the outside air is passed through a water media called a heat mass exchanger for preliminary cooling. In stage two, this precooled air is passed through a high efficiency compressor, with R-410A refrigerant system, to cool down the air further. After this stage, the cold air is introduced to the conditioned space.

This field evaluation tests the operation of the hybrid technology described above, and how it saves energy through a two-stage cooling system by using water as a refrigerant. In addition to demand; water consumption, temperature and humidity of conditioned space, supply, return, mixed and outside air of the unit was also monitored. Performance results of the hybrid unit were compared to the performance results of a baseline 5-ton direct expansion package unit .

Results of demand reduction and energy savings and comparison of mechanical performance of the hybrid unit with the baseline unit are shown in Table 1 and Table 2, respectively.

Table 1. Demand Reduction and Energy Savings during Test Period

Parameter	Results
Average Baseline Demand kilowatt (kW)	5.72
Hybrid Unit Demand (kW)	3.23
Average Demand Reduction (kW)	2.49
% Average Peak Demand Reduction	43.47%
Average Daily Energy Consumption kilowatt hours (kWh)- Baseline Unit	42.02
Average Daily Energy Consumption (kWh)- Hybrid Unit	25.49
Energy Savings (kWh)	16.53
% Energy Savings	39.35%

Table 2. Comparison of Mechanical Performance of the Hybrid Unit and Baseline Unit during Test Period

Parameters	Hybrid Unit Performance Results		Baseline Unit Performance Results		Units
	at 103°F Peak Outside Temperature	at 83°F Peak Outside Temperature	at 103°F Peak Outside Temperature	at 83°F Peak Outside Temperature	
Delivered Cooling Capacity (max)	4.79	2.25	6.15	5.13	Tons
Average Outside Air Relative Humidity (RH)	24	53.43	27	63.63	%RH
Supply Temperature	67.48	60.96	63.87	51.99	°F
Average Power	3.09	2.69	5.35	4.87	kW
Energy Efficiency Ratio (EER)	18.6	10.04	13.8	12.64	Btu/h/W
Water Consumption	8.57	8.57	0	0	Gal/day

Cumulative energy savings realized during test period of the hybrid unit were approximately 39%, and average demand reduction was approximately 43%. The unit also performed well on some days with Energy Efficiency Ratio (EER) reaching 18 and cooling capacity close to 5 tons.

However, this technology performed poorly on hot and humid days. On days when outside air relative humidity (RH) was close to or above 50%, EER and capacity of the unit degraded severely. On a day with outside air conditions of 83°F with 53.43% RH, cooling capacity delivered by the unit was as low as 2 tons with an EER of 10. This fluctuation in cooling capacity and inability to meet cooling demand on a hot, humid day makes this technology unreliable in climate zones with humidity levels consistently above 50% RH.

Since this technology uses water to provide precooling in Stage 1 (before the air stream enters the compressor for further cooling in Stage 2), water used in precooling can add to the operating cost of this technology.

Moreover, a conventional HVAC RTU weighs approximately 500 pounds, whereas this hybrid unit weighs approximately 1,500 pounds (operational wet weight). This three-fold increase in weight may require a facility to perform major structural work on the roof to support the weight of the unit. This can increase the installation cost of the unit and adversely affect payback for this technology. High initial cost of $15,595 ($3,119 per ton) for the equipment, and challenges in installation of this technology can become a major barrier to market penetration.

Additional study of the 5-ton indirect evaporative HVAC unit is necessary to understand any additional barriers, beyond those mentioned in this report.

INTRODUCTION

BACKGROUND

A significant amount of energy consumed by heating, ventilation, and air conditioning (HVAC) systems occurs during peak summer days. Air conditioning loads, including small commercial and residential sectors, cause over 30% of California's total peak power demand in the summer.[1] Implementation of air conditioning energy-efficient technologies will help reduce peak demand during summer and overall energy consumption. In addition, this will aid in reducing the utility peak demand requirements and costs.[1,2] The 5-Ton indirect evaporative hybrid roof top unit (RTU) by Coolerado Corporation was developed primarily for the commercial market segment. Commercial buildings consume more electricity than any other end-use sector in California, and space cooling loads account for 15% of the total electricity consumption. The California Long Term Energy Efficiency Strategic Plan targets a 50% improvement in efficiency in the HVAC sector for small commercial and residential buildings by 2020, and a 75% improvement by 2030. The plan also identifies the need for more climate appropriate HVAC solutions that are suitable for California's hot and dry climate.

The indirect evaporative hybrid technology works on the principle of Maisotsenko refrigeration cycle, or M-cycle, to perform heat exchange. It uses a two-stage cooling technique. In stage one; the outside air is passed through a water media called a heat mass exchanger for preliminary cooling. In stage two, this precooled air is passed through a high efficiency compressor, with R-410A refrigerant system, to cool down the air further.

The manufacturer claims peak energy savings of 44% and seasonal savings of 80%. These claims and mechanical performance of this unit will be evaluated during this field evaluation.

Within the Southern California Edison (SCE) service territory, there are approximately 2,750,000 commercial HVAC RTUs. If energy savings claimed by the vendor are realized via this field evaluation, a very high potential to reduce peak demand and increase annual energy savings exists.

ASSESSMENT OBJECTIVES

The primary objectives of this emerging technology (ET) assessment of the hybrid technology are to:

- Evaluate the technologies energy savings in comparison to a conventional direct expansion (DX) air conditioning unit.
- Evaluate demand reduction during the field test period, if any, after installing this technology.
- Evaluate change in monthly water consumption at the test site from this technology.
- Evaluate the performance of this technology in terms of keeping up with cooling demand and delivering air at a desired setpoint.

Since this technology directly impacts the conditioned space, due attention is paid to human comfort during this evaluation.

Steps followed to meet the primary objectives of this evaluation are listed below:

1. Monitoring equipment was installed on the service panel of the existing (baseline), and new (hybrid) unit.
2. Demand, energy consumption, temperature and humidity for supply air, return air, mixed air, conditioned space and outside air were monitored and recorded for the existing and new unit.
3. Recorded data was compared to the manufacturer's specifications to verify the operation of both units.
4. Recorded data from the hybrid unit was compared to the data of the baseline unit to quantify savings and performance of the hybrid unit.
5. Airflow was also recorded to ensure the new unit met indoor air quality requirements.

In conclusion, this project provides the assessment results needed to confirm the electrical energy savings and demand reduction potential of this technology.

TECHNOLOGY DESCRIPTION

BASELINE TECHNOLOGY

The baseline technology for this field evaluation is a conventional 5-ton DX package unit that uses a compressor and a refrigerant to provide cooling in the conditioned space. It is a three-phase 480 Volt (V) unit and uses R-410A as the refrigerant to provide adequate cooling.

MEASURE TECHNOLOGY

The emerging technology tested in this field evaluation was a Coolerado H80, a 5-ton hybrid indirect evaporative air conditioning unit manufactured by Coolerado Corporation, located in Colorado. This air conditioner uses a patented thermodynamic cycle called Maisotsenko cycle, or M-cycle. This hybrid unit uses a two-stage cooling technique to achieve the setpoint temperature. Stage 1 consists of a heat and mass exchanger (HMX) that precools the outside air by circulating water through the heat exchanging media. Stage 2 consists of a compressor that further reduces the temperature of precooled air and delivers air to the conditioned space at optimum temperature. The hybrid unit is also equipped with adjustable dampers for outside air and return air to optimize cooling performance of the unit. The onboard logic unit controls the opening and closing of the dampers and water use to provide adequate cooling to the conditioned space.

An airflow diagram of the two-stage cooling within the Coolerado unit is shown in Figure 1.

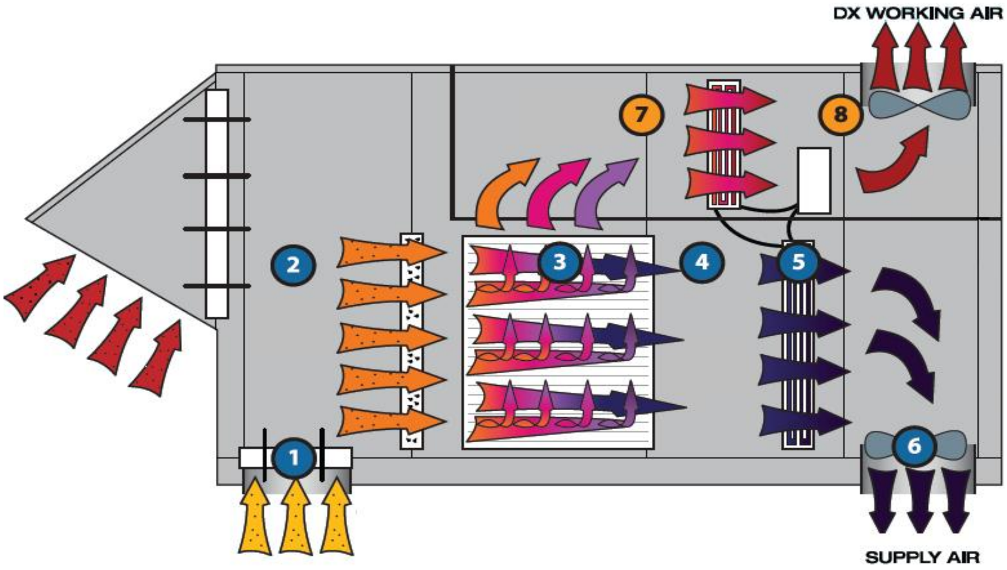

FIGURE 1 AIRFLOW DIAGRAM OF COOLERADO HVAC UNIT

1. Outside air is mixed with return air upon entering the Coolerado unit.
2. Mixed air is passed through an array of filters to provide clean air for cooling.
3. Filtered mixed air is then passed through the HMX, is cooled as it passes through the cooling media without changing the humidity content of the mixed air.
4. Cool mixed air leaves the HMX at a cooler temperature with no change in humidity.
5. Precooled mixed air enters the condenser coils and additional cooling and dehumidification occurs, if required.
6. Cool air enters the conditioned space at a preset supply temperature.
7. Humidified air/working air leaves the HMX. This air, although high in moisture content, is cooler than the outside air and is used to absorb/remove heat from the two-stage refrigerant condenser coils to enhance the cooling capacity of the coils.
8. Hot, humid (DX working) air is released out from the unit after it is used to cool the compressor and working air fan.

EQUIPMENT SPECIFICATION

The hybrid unit tested in this field evaluation is a single-phase 208V unit. Maximum rated demand of this system is 3 kW. The weight of this unit is approximately 1,400 pounds, with an operational weight of the unit at approximately 1,550 pounds (weight with water). This unit consumes water to operate the cooling media in HMX. Water supply to this unit is a regular 3/8” supply line at 35 pounds per square inch (psi).

Physical dimensions of the unit are 97” by 58”, with the average conditioned airflow at 1,800 cubic feet per minute (cfm).

EQUIPMENT COST

The cost of this hybrid unit is $15,595. After shipping, total cost of this unit is $19,595. The installation cost may vary depending on the construction of the roof of a facility. The test site chosen for this evaluation had a typical wood frame roof that is common in most commercial buildings. Total installation cost was approximately $30,000. The installation cost of this unit was higher than the installation cost for a conventional HVAC unit due to its additional weight and type of roof at the test site. Some additional structural work may be required to the roof of a commercial building with construction similar to the test site.

TEST METHODOLOGY

To evaluate the field performance and demonstrate how this hybrid unit reduces energy use and costs; power, temperature and humidity at critical process points were monitored and recorded. Comparison between both units was drawn based on before (baseline unit) and after (hybrid unit) data was recorded at the test site.

BASELINE MONITORING PERIOD

Electrical and mechanical data for the baseline unit was monitored and recorded for a period of 45 days. To obtain electrical parameters such as power, voltage, amperes, and power factor of the unit, a power meter was installed at the electrical panel of the unit.

Mechanical parameters such as temperature and humidity were recorded for outside air, conditioned space, supply air, return air, and mixed air streams. These data points were collected using temperature probes, temperature and humidity combination sensors, and outside air temperature and humidity sensors. The output of these sensors fed into an Automated Logic Control (ALC) board and was collected via an on-site computer.

Typical hours of operation of the baseline unit were between 6:30 a.m. and 2:30 p.m. during weekdays. The baseline unit was manually turned "ON" and "OFF" by the staff.

Baseline testing started after the unit was fully serviced and was almost equivalent to a brand new unit in its performance.

HYBRID UNIT MONITORING PERIOD

The hybrid unit was monitored for a period of 60 days to record electrical and mechanical parameters similar to the baseline-monitoring period.

A power meter was installed to record voltage, amperes, power, and power factor of the unit. Mechanical parameters were recorded using the temperature and humidity sensors for outside air, conditioned space, supply, return, and mixed air streams. In addition, water consumption of the HMX's installed in the unit was recorded via an analog water meter. The water meter was installed at the water supply line to the unit. Airflow measurements were monitored and recorded by an air balance subcontracting company.

The unit was programmed to run from 6:30 a.m. to 2:45 p.m. during weekdays via an onboard programmable Bacnet unit.

Instrumentation installed at the test site was allowed to monitor both units for a few days. Data recorded after initial installation was downloaded and analyzed to ensure proper installation and functioning of the monitoring equipment. If any deviations were detected, the connections were checked to correct any errors in installation or programming of the monitoring equipment. Spot real-time readings of a Fluke® meter (Fluke 43B) were compared with the real-time data of monitoring equipment to ensure accuracy of the installation. After proper installation was verified, data monitoring and acquisition equipment were left at the site to monitor continuously the operation of the units during their respective monitoring periods.

Mechanical data was downloaded, analyzed, and compared to manufacturer specifications. The airflow readings collected for the hybrid unit did not match the manufacturer’s specification. The airflow sensor’s location in the supply duct resulted in erroneous readings and, as a result, the location of the sensor was changed. However, the readings were still erroneous and eventually a professional air balance company was hired to record airflow measurements.

MONITORING EQUIPMENT

ELECTRICAL METERING

The field evaluation used Dranetz PowerXplorer PX5 to monitor power. This device has four independent differential channels for voltage measurements and uses current transformers (CT) to record the amperage readings. Voltage and current readings fed to the PX5 are used to calculate demand and energy consumption at the test site.

The PX5 samples each wave cycle of amperes and volts on each channel 256 times. This means that the voltage and current are sampled continuously. It also administers phase locked loops (PLLs) that automatically adjust the sampling rate according to the line frequency. This allows the PX5 to capture the smallest power variations. The PX5 also has the capability to capture high-speed transient and harmonic measurements. However, analyzing these variables is beyond the scope of this field evaluation. PX5 is equipped with a touch screen programmable device and is capable of monitoring the following circuit types:

- Three-phase delta
- Three-phase wye
- 2 1/2 element
- Split single-phase
- Single-phase
- Generic

The Current Transformers (CTs) used with the PX5 were TR2550A. These CTs are capable of reading currents within the range of 1-100 amperes. Voltage was collected using PX5 compatible voltage leads and clips.

MECHANICAL METERING

Relative humidity (RH) and temperature sensors from Building Automation Products, Inc. (BAPI) were used. For outside air temperature and RH measurements, these sensors come with a specialized weather tight enclosure made of ultra violet resistant, flame retardant polymer. The weatherproof lid of the enclosure comes with a ring that seals completely when it is tightened. The outside air temperature and humidity-sensing unit have etched Teflon lead wires and double encapsulated sensors to create a weather tight package that can withstand high humidity or condensation and can perform accurately in weather conditions such as rain snow or any large temperature swings.

Indoor sensing units were installed in the ducts. These sensors feature medical-grade closed cell foam to seal the probe insertion hole and to absorb vibrations. The duct units are also equipped with etched Teflon lead wires and double encapsulated sensors to create a weather tight package that can withstand high humidity, or condensation, and can perform accurately in weather conditions such as rain, snow, or any large temperature swings.

Monitoring ranges of metering used in the field are listed in Table 3.

TABLE 3. MONITORING EQUIPMENT USED FOR MECHANICAL METERING IN THE FIELD EVALUATION

Sensor Type	Monitoring Range
Thermistor (for duct/outside air/room)	-22°F to 158°F
Humidity Transmitter (for duct/outside air/room)	0% to 100% RH
Enclosure (for ducts and outside air)	Weather proof enclosure- NEMA 3R rated metal enclosure
Enclosure (for room)	Delta style room enclosure
Air Data Multimeter ADM-860C (Electronic Micromanometer)	Differential pressure: 0.05 to 50.00 Temperature: 32 to 158 ºF Air Flow: 25 to 2,500 cfm
Air flow hood	Designed to work with Air Data Multimeter ADM- 860C
Raytek Non-Contact Thermometer	Temperature range: -25°F to 400ºF
Enclosure (for room)	Delta style room enclosure

MONITORING EQUIPMENT SETUP

ELECTRICAL METERING

The power meter at the test site was set up as a three-phase three-wire delta circuit for baseline period since it is a three-phase unit. The electrical metering for the hybrid unit was set up as a single-phase circuit since it is a single-phase unit. Dranetz BMI’s PX5, CT model# TR 2550A and voltage leads were installed on the electrical circuit breaker panel at each test site. Output of the CTs and voltage leads was fed into the PX5 data acquisition equipment. Electrical monitoring and data acquisition setup is shown in Figure 2.

FIGURE 2 ELECTRICAL SETUP AT TEST SITE

MECHANICAL METERING

Temperature and humidity sensors were installed within the ductwork for both units and in the conditioned space. The output of all temperature and humidity sensors was routed into an ALC control unit. This control unit then fed the data to a local computer where data was recorded and further downloaded. Water consumption was recorded using an analog water meter and was read manually at frequent intervals.

Data monitoring setup for the mechanical parameters is shown in Figure 3 .

FIGURE 3 MECHANICAL SETUP AT TEST SITE

Data was sampled every five minutes to achieve higher accuracy. The measurements included sampling for voltage, current, power factor, demand, temperature, relative humidity, and water consumption.

ACCURACY OF THE MONITORING EQUIPMENT

Electrical service at the site was a 208V three-phase delta for the baseline unit and 208Y/120V single- phase for the hybrid unit. To monitor these circuits, a PX5 was used and CTs were sized according to the amperage rating of the respective circuit being monitored. In regards to voltage readings, PX5 has an accuracy of 0.1% of the reading + 0.05% of the full scale up to the 51st harmonic and transients. For current readings, PX5 has an accuracy of a 0.1% reading + accuracy of the CTs. CTs used in this study were TR2550A; these have an accuracy of ± 1% over the full-scale readings. Cumulative accuracy for current readings during this field evaluation totaled to ± 1.1% of the reading. Humidity and combination temperature sensors have an accuracy of 10kilo Ohm (kΩ) at 25°Celsius for the temperature range of the thermistor. Accuracy is ± 2% for the humidity transmitter. Accuracy of the water meter meets or exceeds the accuracy standards of the American Water Works Association (AWWA) standard, C700-95. The air data multi-meter used in airflow measurements has an accuracy of ± 3% of reading ±7cfm from 100 to 2,000 cfm. The accuracy for pressure readings using the same instrument is ± 2% of reading ±0.1 Mercury (Hg) from 14 to 40 inches of pressure in Mercury (in Hg) referenced to the vacuum.

CALIBRATION OF MONITORING EQUIPMENT

All instrumentation used for the mechanical monitoring of this field evaluation was purchased solely for the purpose of this project and were factory calibrated. The CTs used during this project were brand new as well. The calibration data for electrical meters and instruments used for airflow readings is provided in Table 4.

TABLE 4. CALIBRATION OF MONITORING EQUIPMENT

EQUIPMENT	CALIBRATION DATE
PX5 Power Monitor 1	9/28/10
PX5 Power Monitor 2	11/11/10
Air Data Multimeter (used with airflow hood	9/20/10
Non-Contact Thermometer	3/2/11

TEST SITE DESCRIPTION

The test site selected for this field evaluation is located in Irwindale, California. This site is a full service restaurant with dine-in hours from 7:00 a.m. to 2:30 p.m. Typically; the site starts preparation work at approximately 5:00 a.m. in the kitchen. The kitchen has a dedicated swamp cooling system. The dining/ordering area, office space, private conference/party area and restrooms are served by separate HVAC units. All HVAC units serving different areas in the restaurant are fully isolated from each other.

This field evaluation was performed on the dining/ordering area, approximately 1,200 square feet of the restaurant that is served by a 5-ton DX package unit (baseline unit).

The hybrid unit was installed to condition the same area served by the baseline unit. The baseline unit was kept as a backup in the event the hybrid unit failed. The restaurant operated as normal during the monitoring period for both units.

DEMAND REDUCTION AND ENERGY SAVINGS CALCULATION METHODOLOGY

At the conclusion of the testing and monitoring period, data was analyzed. Energy and demand consumption of the hybrid unit was compared to the baseline unit's demand and energy consumption. To draw a fair comparison between both units, matching days were used to calculate demand reduction and energy savings. Days during the test period, with a maximum outside temperature of within ±1°F, and an average outside temperature within ±2°F, during monitoring of each unit, were considered matching days.

Average demand reduction for this field evaluation was calculated using Equation 1 .

EQUATION 1 AVERAGE DEMAND REDUCTION

$$Percent\ Average\ kW\ Reduction = \frac{Baseline_{Average\ kW} - VSD_{Average\ kW}}{Baseline_{Average\ kW}} \times 100$$

The posted hours of operation at the test site are 7:00 a.m. to 2:30 p.m. during weekdays. The hybrid unit was programmed to turn on at 6:30 a.m. and turn off at 2:45 p.m. whereas, the baseline unit was turned on and off manually by the restaurant staff at a similar schedule. However, actual hours of operation during the baseline-monitoring period varied on some days depending on the time when the baseline unit was actually turned on. Hence, the actual hours of operation during the baseline units monitoring period were established from the recorded demand data, since power draw occurred only when the baseline unit was in operation.

Daily average energy consumption was calculated using daily average power demand (kW) and multiplying it with the number of operating hours at each test site. Adjustments were made for any variation in the number of hours of operation during the baseline unit-monitoring period, compared to the hybrid unit monitoring periods to get accurate results.

The energy savings for this field evaluation were calculated using Equation 2 .

EQUATION 2 ANNUAL ENERGY SAVINGS

$$Percent\ Average\ kWh\ Reduction = \frac{Baseline_{Average\ kWh} - VSD_{Average\ kWh}}{Baseline_{Average\ kWh}} \times 100$$

RESULTS

WEEKLY DEMAND ANALYSIS

The test site had a pattern of demand that depicts a typical week at a restaurant. This pattern is shown in Figure 4 .

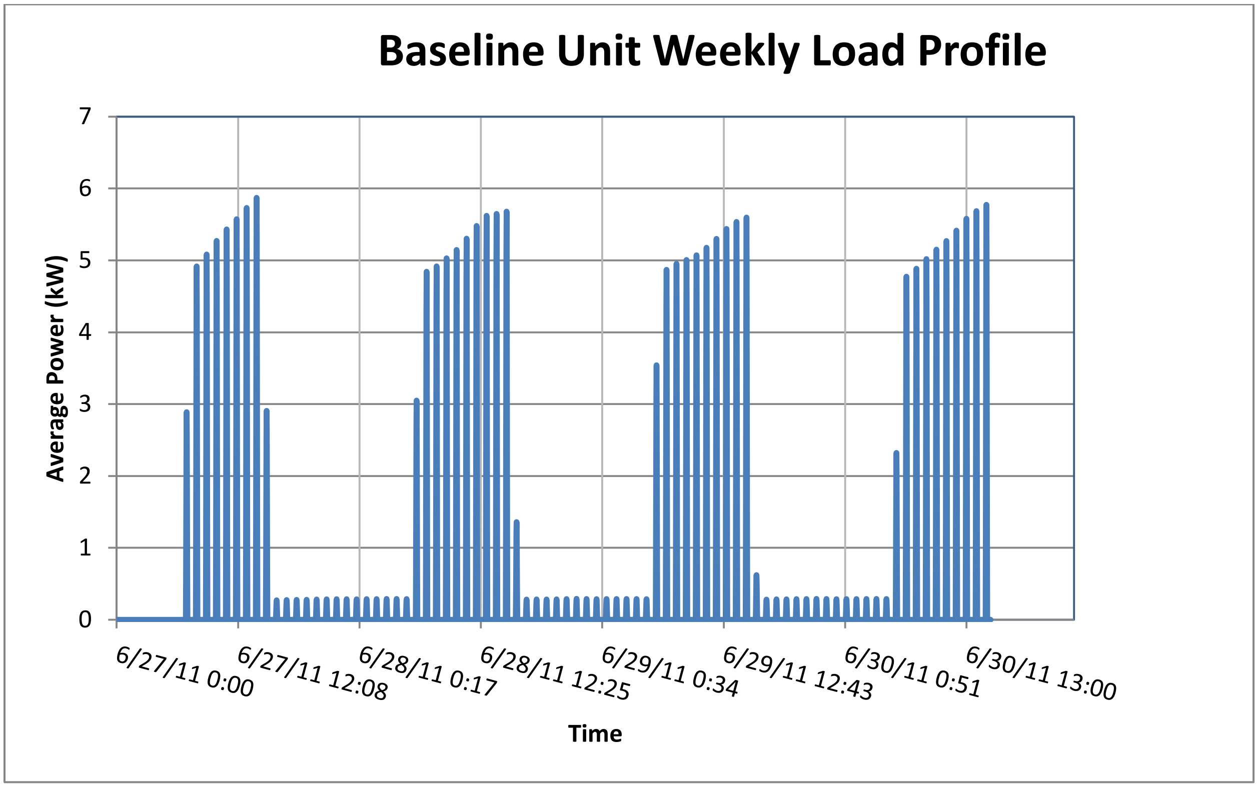

FIGURE 4 AVERAGE WEEKLY LOAD PROFILE AT THE TEST SITE WITH BASELINE UNIT "ON"

Figure 4 is a sample of average weekly profile seen at the test site when the baseline unit was in operation. As illustrated, demand stays within a range of 5-6 kW during the hours of operation and peaks around 2:00 p.m. in the afternoon. A similar pattern was observed during the monitoring of the hybrid unit, and displays in Figure 5 .

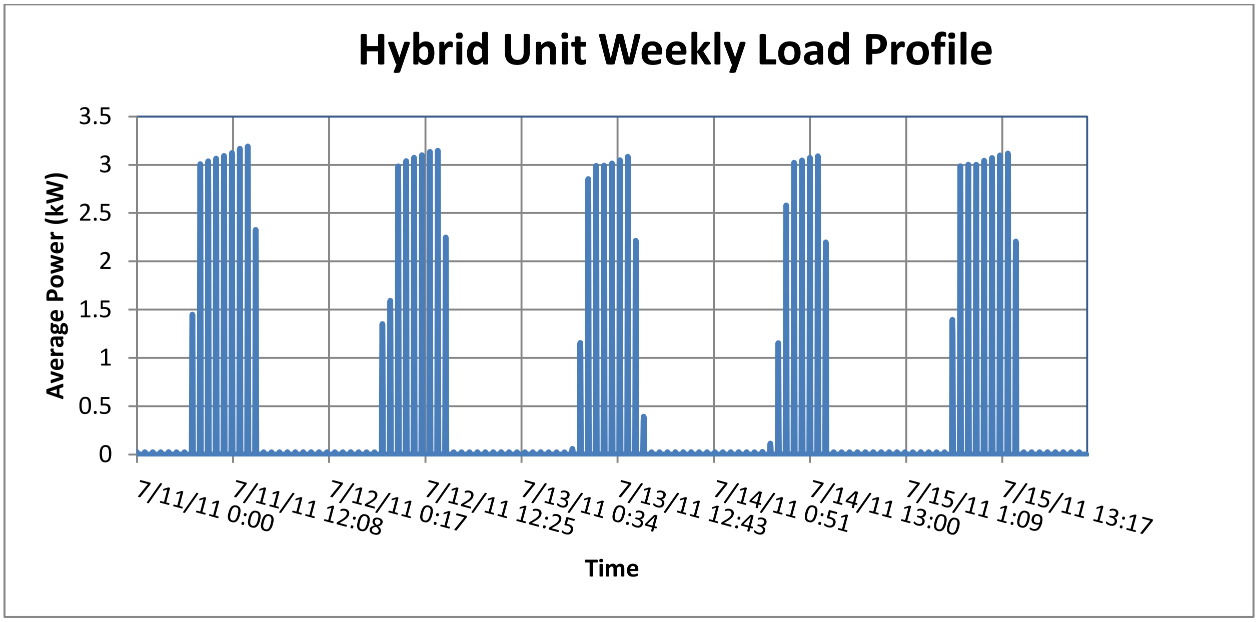

FIGURE 5 AVERAGE WEEKLY PROFILE AT A TEST SITE WITH BASELINE/CONSTANT SPEED SETTINGS

Figure 5 illustrates a typical weekly load profile of the test site while operating the hybrid unit. It represents a constant demand of 3kW, with the peak demand of approximately 3.2kW. It indicates that this technology has the potential to lower demand and save energy over a conventional HVAC unit.

DEMAND REDUCTION

The test site is located in climate zone (CZ) 10 and the peak demand days for this CZ are July 8-10. Since the monitoring period of both units did not fall during the peak demand days for this CZ, days with the peak demand from the matching day’s pool were selected to simulate a peak demand profile for the testing period. In addition, the restaurant was open until 2:30 p.m. during weekdays - a peak demand period between 12:00 p.m. to 2:30 p.m. was assumed to calculate demand savings for this field evaluation. The comparison of peak demand observed during testing and monitoring of the baseline as well as the hybrid unit is shown in Figure 6.

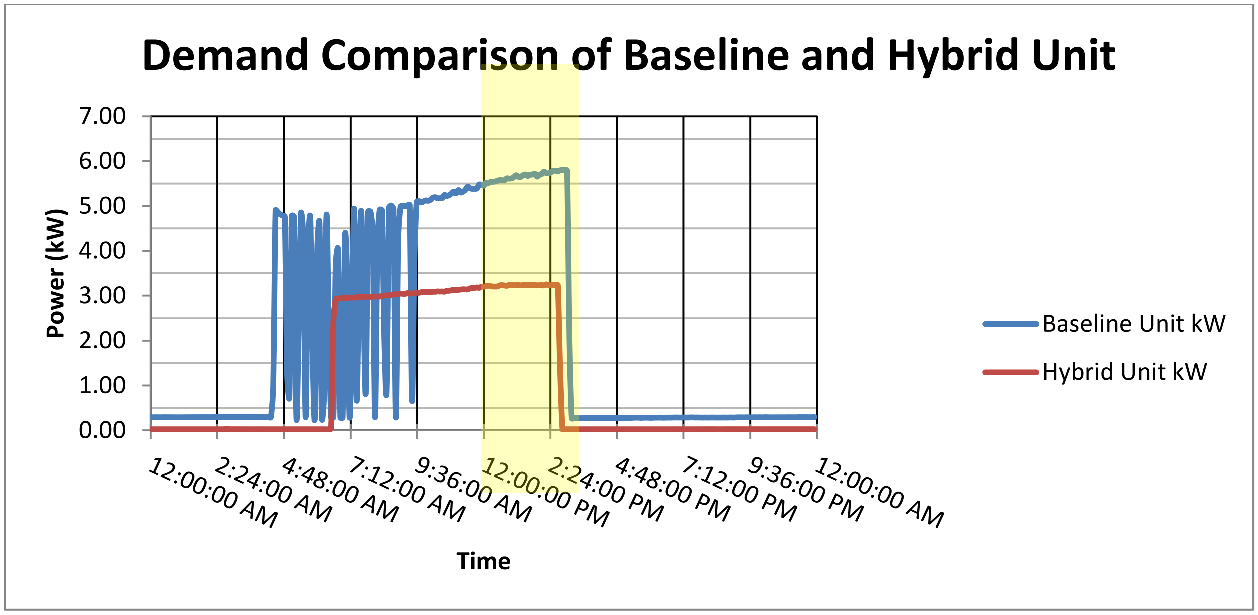

FIGURE 6. DEMAND COMPARISON OF BASELINE AND HYBRID UNIT

An average demand reduction of 43.47% was realized at the test site because of using the hybrid unit. The baseline unit had an average demand of 5.72kW during the hottest days, whereas the hybrid unit consumed 3.23kW. Equation 1 was used to calculate percent demand savings and the results are tabulated in Table 5.

TABLE 5. DEMAND REDUCTION RESULTS

PARAMETER	RESULTS
AVERAGE BASELINE DEMAND	5.72kW
Hybrid Unit Demand	3.23kW
Average Demand Reduction	2.49kW
% Average Peak Demand Reduction	43.47%

ENERGY SAVINGS

The average daily energy consumption at the test site was calculated using the recorded demand data over the daily operational hours. Average energy savings were calculated by comparing the energy consumption of the hybrid unit to the baseline unit. Adjustments were made for the variation in hours of operation during the baseline unit's monitoring period. The baseline unit was manually operated by the restaurant staff and was not turned ON and OFF at the same time every day.

Equation 2 was used to calculate percentage energy savings during the test period. The results of the energy savings calculations for this field evaluation are shown in Table 6.

TABLE 6. ENERGY SAVINGS

PARAMETERS	RESULTS
Average Daily Energy Consumption - Baseline Unit	42.02kWh
Average Daily Energy Consumption - Hybrid Unit	25.49kWh
Energy Savings	16.53kWh
% Energy Savings	39.35%

SCE has approximately 2,750,000 commercial HVAC units in its service territory. If the savings seen at the test site are realized for the entire SCE service territory, then this technology has a potential to induce significant energy savings. Note, these savings are a result of reduction in energy consumption during the monitoring period of this field evaluation. An annual energy savings could not be calculated due to lack of seasonal performance of the baseline as well as the hybrid unit at the test site.

MECHANICAL PERFORMANCE

Mechanical performance of the hybrid unit was also evaluated during this field evaluation. Dry bulb temperature and humidity of: outside, mixed, conditioned space, supply, and return air streams were recorded. From these recordings wet bulb temperature and moisture content for each of these air streams were calculated using the psychometric chart. From this data latent heat, sensible heat and capacity were calculated for both air conditioning units using Equation 3, Equation 4, and Equation 5, respectively.

EQUATION 3. LATENT HEAT EQUATION

$$Q_l = 0.69 \times cfm \times (WA - WB)$$

Where:

Q_l = *Latent Heat, Btu/h*

WA = *Moisture content of mixed air*

WB = *Moisture content of return air*

EQUATION 4. SENSIBLE HEAT EQUATION

$$Qs = 1.08 \times cfm \times (MA_{DB} - SA_{DB})$$

Where:

Q_s = *Sensible Heat, Btu/h*

MA_{DB} = *Dry Bulb temperature of Mixed Air stream (°F)*

SA_{DB} = *Dry Bulb temperature of Supply Air stream (°F)*

EQUATION 5 . CAPACITY EQUATION

$$C = \frac{(Qs + Q_l)}{12{,}000}$$

Where:

C = *Capacity of the unit (tons)*

Q_s = *Sensible Heat, Btu/h*

Q_l = *Latent Heat, Btu/h*

Closely evaluating the supply temperatures of both units revealed that on an average the hybrid unit delivered hotter air to the conditioned space than the baseline unit did. Comparison of supply temperatures of both units is shown in Table 7.

TABLE 7. MECHANICAL PERFORMANCE OF THE HYBRID UNIT DURING TEST PERIOD

	HYBRID UNIT PEAK PERFORMANCE RESULTS		BASELINE UNIT PEAK PERFORMANCE RESULTS		
PARAMETERS	AT 103°F PEAK OUTSIDE TEMPERATURE	AT 83°F PEAK OUTSIDE TEMPERATURE	AT 103°F PEAK OUTSIDE TEMPERATURE	AT 83°F PEAK OUTSIDE TEMPERATURE	UNITS
Delivered Cooling Capacity (max)	4.79	2.25	6.15	5.13	Tons
Average Outside Air Relative Humidity	24	53.43	27	63.63	%RH
Supply Temperature	67.48	60.96	63.87	51.99	°F
Average Power	3.09	2.69	5.35	4.87	kW
Energy Efficiency Ratio (EER)	18.6	10.04	13.8	12.64	Btuh/W
Water Consumption	8.57	8.57	0	0	gal/day

Table 7 shows the comparison of performance of both units on days with highest and lowest outside temperatures observed during the data-monitoring period. Data shown above was taken from the pool when matching peak outside conditions occurred during the monitoring period. The cooling capacity delivered by the hybrid unit on the hottest day, 103°F, and the coldest day, 83°F, is lower than the cooling capacity delivered by the baseline unit. Although there was a demand reduction of over 40% during the operation of the hybrid unit, the reduction in cooling capacity, higher supply temperatures, and loss of human comfort overshadow the benefits of the unit. The Energy Efficiency Ratio (EER), an efficiency metric calculated by taking a ratio of the total cooling capacity (Btu/h) and power draw (W), is another factor worth paying attention to. At an outside temperature of 103°F, the hybrid unit performs well with a high EER of 18.6; however; at a lower outside temperature of 83°F, the same unit performed poorly with a lower EER of 10.04. This reduction in performance can be credited to the higher outside RH ratio that was above 50%.

The hybrid unit was able to deliver colder air and maintain its capacity on days with lower outside air RH, but failed to keep up with the cooling demand on hot and humid days. In addition, the cooling capacity and EER suffered severely during those days.

Carbon dioxide (CO_2) levels were also monitored via spot-checking inside the restaurant. The CO_2 levels were comparative to the outside air levels; typically over 600 parts per million, when the restaurant was completely full during lunch hours (11:00 a.m. to 1:00 p.m.). The restaurant staff preferred more fresh air inside the restaurant provided by the hybrid unit. They felt more comfortable because of more fresh air inside the restaurant during morning hours. However, they felt the cooling delivered by the unit was insufficient during afternoon hours.

CONCLUSIONS AND RECOMMENDATIONS

The evaporative hybrid unit tested in this field evaluation has some advantages over the baseline DX package unit. These advantages include lower energy consumption and power demand, and more fresh air in the conditioned space. Cumulative energy savings realized during testing of the hybrid unit were approximately 39%, and the average demand reduction was approximately 43%. The unit also performed well on some days with EER over 18.

These benefits of this technology are reduced by its poor performance on days with high humidity levels. On days with outside air humidity above 50%, the EER and capacity of the unit degraded severely. During this test period, the capacity delivered by the unit was as low as 2 tons with a corresponding EER of 10. This fluctuation in cooling capacity and inability to meet cooling demand on a hot-humid day makes this technology unreliable.

This technology is a hybrid of an electric HVAC and an indirect evaporative cooler. The indirect evaporative portion of the technology uses water in the heat and mass exchanger to provide precooling before the air stream enters the compressor for further cooling. The water use in heat mass exchangers can add to the operating cost of this technology.

A conventional HVAC RTU weighs approximately 500 pounds whereas this hybrid unit weighs approximately 1,500 pounds (operational wet weight). This three-fold increase in weight may require a facility to perform major structural work on the roof to accommodate the additional unit weight. This can increase the installation cost of the unit and can adversely affect payback for this technology. The high initial equipment cost of $15,595, and challenges in installation of this technology can become a major barrier in market penetration.

These factors can render this technology useful for very limited applications albeit its potential of high energy savings and demand reduction.

REFERENCES

[1] "California Long Term Energy Efficiency Strategic Plan," California Public Utilities Commission. September 2008.

[2] California Commercial End-Use Survey. Itron, March 2006

APPENDIX A – DEMAND REDUCTION AND ENERGY SAVINGS CALCULATION SPREADSHEET

The following calculation spreadsheet, with multiple tabs, is attached to this report and contains:

- Matching Days
    - Compares operating parameters of baseline and hybrid unit by matching days with average outside air temperature within ±2 degrees between the baseline and hybrid unit
- Energy Savings
    - Calculates energy savings during the test period
- Demand Reduction
    - Calculates the demand reduction using average demand of baseline and hybrid units during a peak period of 12-2:30 PM.
- Additional tabs containing raw data, weekly load profile charts, and water readings

Demand and Savings
Calc_5 Ton Hybrid HV