Performance Comparison of Evaporatively-Cooled Condenser versus Air-Cooled Condenser Air Conditioners

Ramin Faramarzi, John Lutton, and Sean Gouw, Southern California Edison

ABSTRACT

This paper presents the findings of a research project conducted in the laboratories of the Southern California Edison (SCE) Technology Test Center (TTC). The objective of this project was to evaluate the performance of an evaporative condenser-type air conditioner (ECAC). The system was tested under several ambient temperature/humidity conditions representative of various climate zones (CZ) representative of SCE service territory. The indoor conditions were maintained in compliance with the Air-Conditioning, Heating and Refrigeration Institute (AHRI) 210/240 test standard. Testing was designed to capture variations in net cooling capacity, total power consumption, energy efficiency ratio (EER), and water consumption across the tested climatic conditions. Test results under the AHRI test conditions reveal this unit operated at an EER of 13.5 Btuh/W.

The performance of the unit was then compared to the performance of air-cooled condenser type Air Conditioner (A/C) systems previously tested in the TTC labs under similar ambient dry-bulb (DB) temperatures. Variations in cooling capacity, total power consumption, and EER were compared. In the most severe hot and dry climate condition of 115° Fahrenheit (F) DB and 74°F wet-bulb (WB), the ECAC had an EER which was 51% higher than that of the air-cooled condenser technology under similar conditions. Due to its high performance in hot and dry climate conditions, the ECAC is being considered for inclusion in SCE's energy efficiency incentive programs.

Background

Air conditioners account for roughly one third of California's peak electric demand. Efficiency of conventional air-cooled air conditioning systems decreases as the ambient DB temperature rises (Faramarzi et al. 2004). Widespread use of energy-efficient A/C technologies may result in a significant statewide peak reduction. However, there are uncertainties associated with performance over a wide range of climates, water consumption, and maintenance that appear to contribute to their smaller market presence.

Objectives

The primary goal of this project was to evaluate the performance of an ECAC across a range of climate zone conditions found in SCE service territory. Additional goals included finding performance degradation of the unit in increasingly harsh climate conditions, general water consumption of the unit in these different climate conditions, comparing normalized performance data to existing results from prior air-cooled roof top packaged unit (RTU) tests conducted at the TTC, and identifying further opportunities for evaluation.

Approach

The series of laboratory tests conducted at the TTC followed the test protocol outlined in the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 37-2005 Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment. The indoor condition was maintained at 80°F/67°F as per AHRI 210/240. The tested ambient conditions follow the ASHRAE's 0.5% mean temperature design conditions for several different climate zones (ASHRAE, Golden Gate/Southern California Chapter 1982), as well as the AHRI condition as shown in Table 1.

Table 1. Ambient Design Conditions

CZ	DB (°F)	WB (°F)	Representative City	Description
AHRI Baseline	95	75	Baseline	AHRI Design Condition
CZ 6	84	67	Los Angeles	South Coast
CZ 7[1]	83	69	San Diego[1]	South Coast
CZ 8	89	69	El Toro	South Coast
CZ 9	94	68	Pasadena	South Coast
CZ 10	100	69	Riverside	South Coast
CZ 13	101	71	Fresno	Central Valley
CZ 14	108	69	China Lake	Desert
CZ 15	111	73	El Centro	Desert
CZ HDAC[2]	115	74	(Similar to) Needles @ 114/72	Desert

[1]CZ 7 is not in SCE service territory.
[2]An additional CZ specified as Hot Dry Air Conditioner (HDAC) was included to identify an extreme hot and dry climate condition that is more severe than CZ 15.

Results from the baseline tests conducted at AHRI ambient design conditions were compared with results from the ECAC manufacturer's tests. Agreement found between these data sets establishes confidence in the results of the independently conducted TTC tests. Each test was conducted under a steady-state operation for a period of at least two hours. All tests were conducted with National Instruments SCXI high-performance signal conditioning and instrumentation data acquisition system. The data acquisition system was programmed to process and average 100 reads from 110 data channels every 20 seconds.

The calculations for capacity, power demand, EER, and water consumption of the unit were determined for all ambient conditions, following the methods specified by ASHRAE Standard 37 -2005 and AHRI 210/240-2003. Performance of the ECAC was normalized and compared to the previous air-cooled RTU tests conducted at the TTC.

ECAC Technology Description

An ECAC residential split system type air conditioner was tested. It was rated at a cooling capacity of 3 tons and used R-410a refrigerant. The ECAC indoor unit was a standard 3-ton 'A' coil evaporator controlled by a thermostatic expansion valve. The outdoor unit was an evaporatively-cooled condensing unit.

Conventional air-cooled condensers are simple refrigerant to air heat exchangers where refrigerant heat is transferred sensibly from the condensing high pressure/temperature refrigerant to a working ambient stream of air. This heat transfer mechanism is dependent on the ambient air stream's DB temperature. In an ECAC, refrigerant heat rejection is primarily driven by the latent heat of vaporization of water into a working ambient air stream. This latent heat transfer is dependent on the WB temperature of the ambient air stream.

Varying design options are seen in ECAC. For example, a field evaluation conducted by the Solar Energy and Energy Conversion Laboratory (Goswami et al. 1993) studied the effects of a retrofit design. In this design, water is distributed across an evaporative media, while an entering ambient air stream flows through the media. As a result, the air stream is directly evaporatively pre-cooled before it is moves across the condenser coil. This lowers the air's DB temperature and increases its capacity to sensibly take in heat rejected by the condensing refrigerant.

Another option, mentioned in a lab evaluation conducted by the Center for Environmental Energy Engineering (CEEE) (Hwang et al. 2001), featured a prototype design where a condenser coil is completely submerged in a pool of water while an ambient air stream is brought across a series of partially submerged rotating disks. The disks keep a wetted film on their surface and as they rotate, they entrain a portion of that film into the ambient air stream. The evaporative cooling effect lowers the temperature of the remaining film and the remaining colder water is reintroduced into the pool of water. Sensible heat transfer occurs due to the temperature difference between the condensing refrigerant, and the surrounding water pool.

In the particular design of the tested unit, a water film is maintained on the condenser coil with a continuous spray, while an ambient air stream is simultaneously drawn across the condenser coil. In this application, two steps of heat transfer take place. In the first step, the temperature difference between the condensing refrigerant and the water film transfers heat from the refrigerant to the water film. In the second step, a combination of temperature and water vapor enthalpy difference between the air water film and the ambient air stream drive water mass transfer from the film to the ambient air stream (ASHRAE 2004).

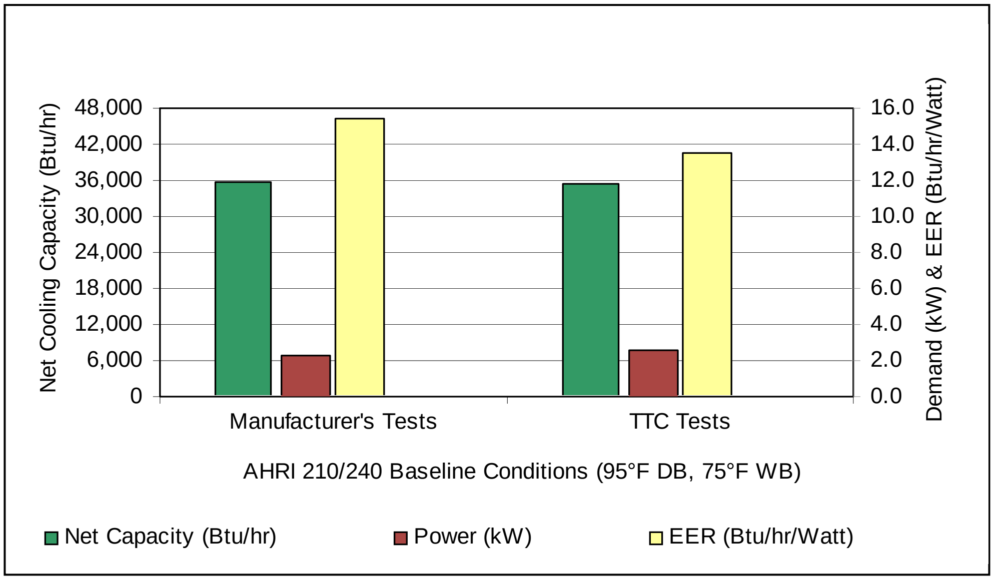
The entrainment of water into the air stream creates cooling effect, which is effectively equivalent to the water's latent heat of vaporization. Therefore, refrigeration heat can be rejected across the condenser coil. Heat transfer at the water film/air stream interface is defined by ASHRAE (ASHRAE 2004) to be primarily influenced by the difference in enthalpy between the water film and incoming ambient air. Incoming ambient air enthalpy and water film enthalpy are approximately directly proportional to the incoming ambient air WB temperature and water film temperature, respectively.

Discussion of Results

ECAC Baseline and Performance Variation Testing

The baseline test reveals a nearly identical cooling capacity to the manufacturer's test data but at a 13% greater power demand, resulting in a 12% reduction in EER compared to the manufacturer's test data as shown in Figure 1. A portion of the difference in power is a result of the use of the ASHRAE indoor blower fan default value of 438 watts for the manufacturer's tests and calculations. The SCE tests used the actual measured values of indoor blower fan wattage in determining the total unit power. This accounts for approximately 3% of the total ECAC power difference, resulting in approximately 2% of the EER difference. Information regarding instrumentation precision for the manufacturer's test setup was not readily available. It is suspected that the remaining discrepancy may be attributed to systematic and random errors associated with instrument precision discrepancy between the manufacturer and the TTC's test setup.

Figure 1. Baseline Test Performance Comparison



As shown in Figure 1, TTC's baseline cooling capacity result seemed in a close agreement with the manufacturer's data. Baseline and additional results from various climate zone conditions are shown in Figure 2 and Figure 3. Climate zones are arranged in order of increasing WB temperature.

Figure 1. ECAC EER Variation

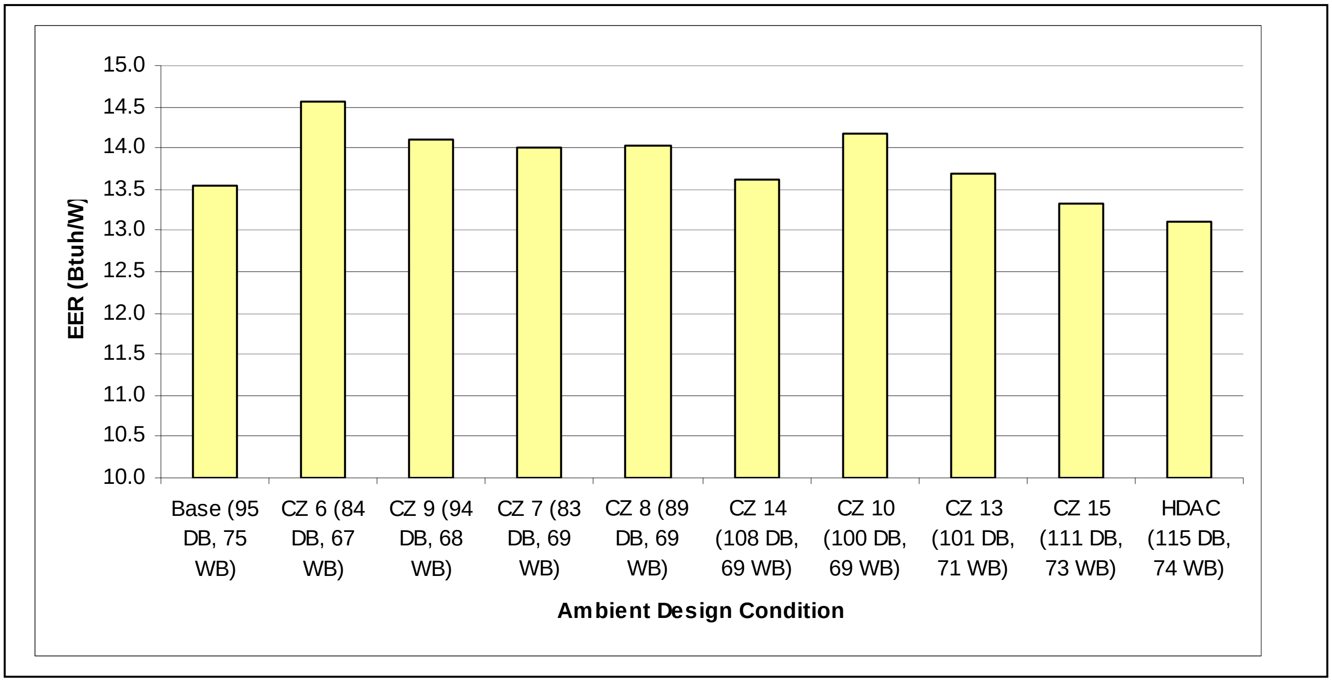
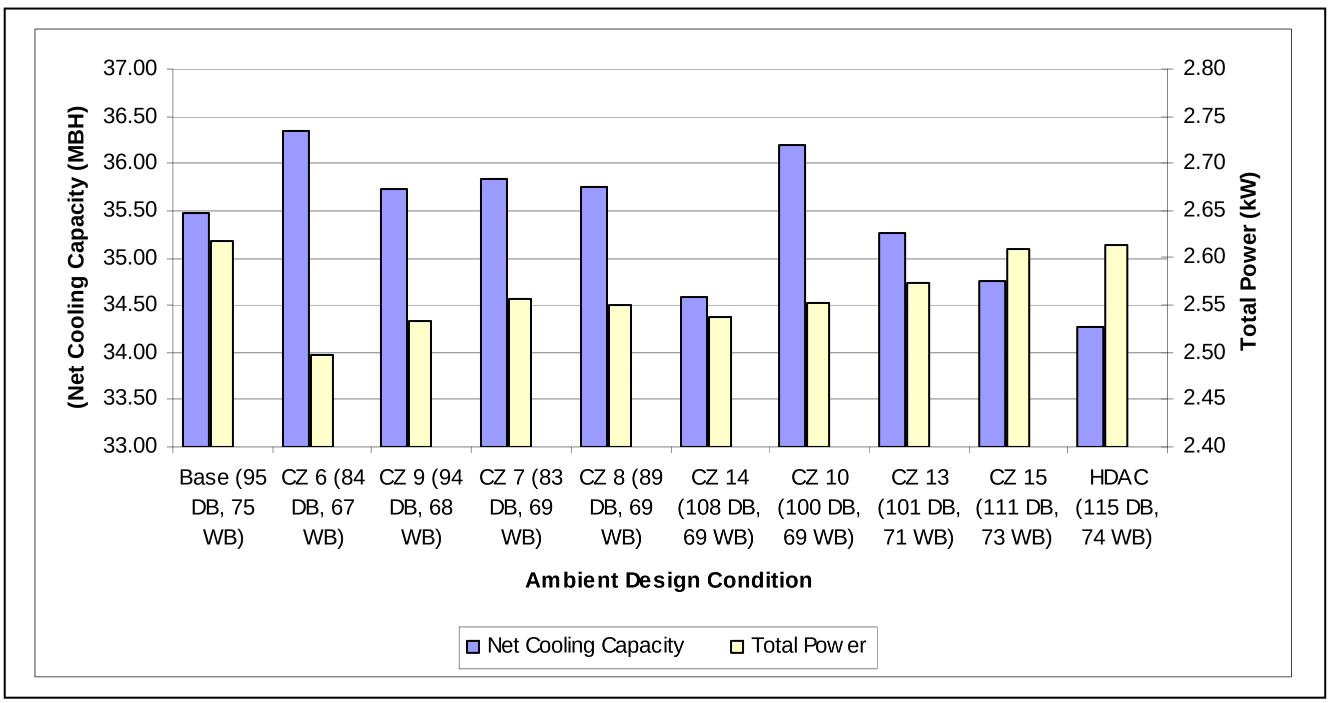


Figure 2. ECAC Cooling Capacity and Total Power Variation



EER was as low as 13.1 Btuh/W at the HDAC condition, and as high as 14.6 Btuh/W in CZ6. Net cooling capacity was as low as 34.3 MBH at the HDAC condition, and as high as 36.3 MBH in CZ6. Total power requirements were as high as 2.6 kW at the HDAC condition and as low as 2.5 kW in CZ 6.

Performance Comparison to Air-Cooled Air Conditioning Systems

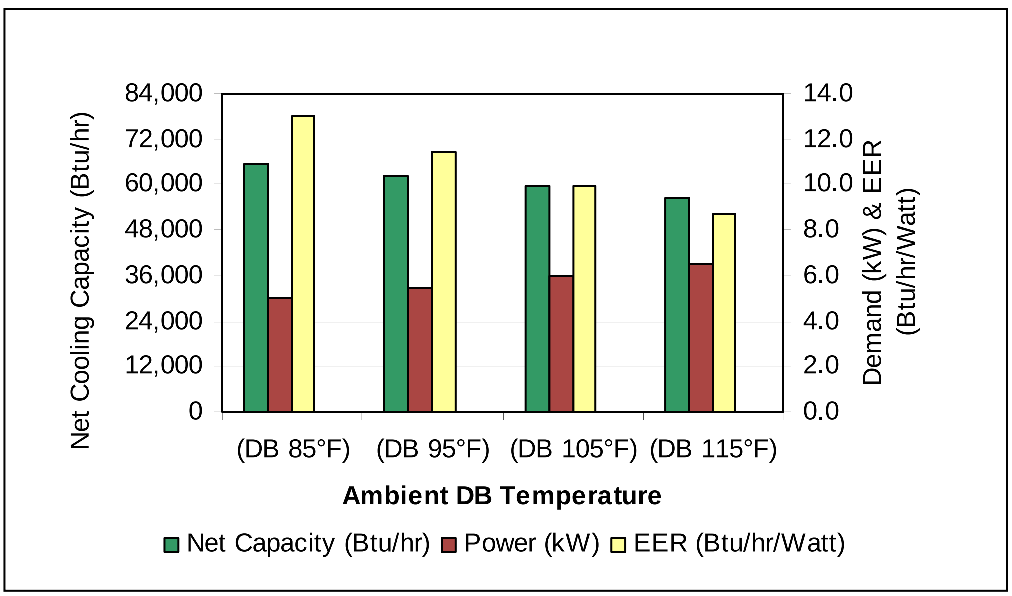
In 2004, steady state tests were conducted at the TTC to evaluate the performance of six 5-Ton air cooled RTUs under varying ambient temperatures (Faramarzi et al. 2004). The 5-ton rooftop package units evaluated included standard and high-efficiency models from three different manufacturers. In order to conduct a general comparison representative of all tested air-cooled units to the ECAC, the results of all six air-cooled units are averaged together and presented in Figure 4 below.

The performance variation of each air cooled unit was evaluated at ambient DB conditions ranging from 85°F to 115°F. This range is similar to the 83°F - 115°F DB temperature range used for the ECAC evaluation. The indoor condition for the air cooled units was also maintained at 80°F/67°F as per AHRI 210/240.

For the purpose of comparison, performance indicators of both systems were normalized based on their nominal tonnages at AHRI's test condition. The performance parameters evaluated included cooling capacity and EER. All evaluated parameters vary more significantly for air-cooled units with increasing DB temperature.

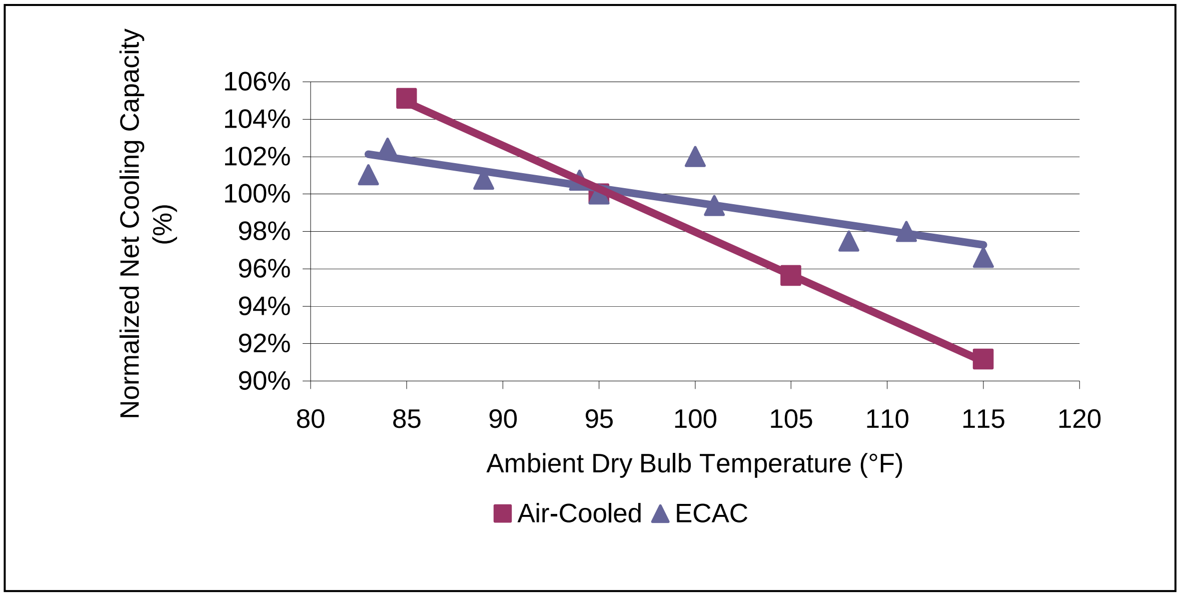
Figure 4 illustrates the air-cooled unit's variation in performance with increasing ambient DB temperature. Net cooling capacity was as low as 56.8 MBH at 115°F, and as high as 65.5 MBH at 85°F. Total power requirements were as high as 6.53 kW at 115°F and as low as 5.01 kW 85°F. EER was as low as 8.70 Btuh/W at 115°F, and as high as 13.1 Btuh/W at 85°F.

Figure 4. Air-Cooled RTU Performance



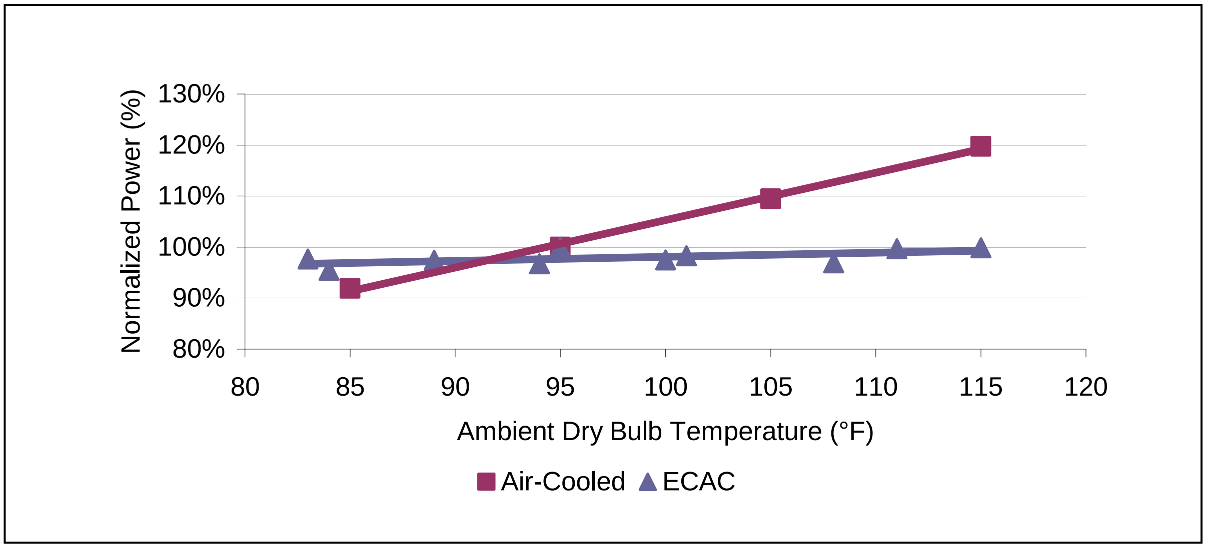
Net cooling capacity. For each technology, net cooling capacity was normalized with respect to their baseline net cooling capacity at 95°F. Figure 5 illustrates the variation in net normalized cooling capacity for both the air-cooled and ECAC units with increasing ambient DB temperature. For air-cooled units, net normalized cooling capacity was as high as 5% over baseline at 85°F and as low as 9% below baseline at 115°F. For ECAC, net normalized cooling capacity was as high as 2% above baseline at 84°F (CZ6), and as low as 3% under baseline at 115°F (HDAC).

Figure 5. Normalized Comparison of Net Cooling Capacity



Total power. For each technology, total power consumption was normalized with respect to their baseline total power consumption at 95°F. Figure 6 illustrates the variation in normalized total power consumption for both the air-cooled and ECAC units with increasing ambient DB temperature. For air-cooled units, normalized total power was as high as 20% over baseline at 115°F and as low as 8% below baseline at 85°F. For ECAC, normalized total power effectively never went above baseline and was as low as 5% below baseline at 84°F (CZ6).

Figure 6. Normalized Comparison of Total Power



Energy efficiency ratio. For each technology, EER was normalized with respect to their baseline EER at 95°F. Figure 7 illustrates the variation in normalized EER for both the air-cooled and ECAC units with increasing ambient DB temperature. For air-cooled units, normalized EER was as high as 14% over baseline at 85°F and as low as 24% below baseline at 115°F. For ECAC, normalized EER was as high as 7% over baseline at 84°F (CZ6) and as low as 3% below baseline at 115°F (HDAC).

Figure 7. Normalized Comparison of EER

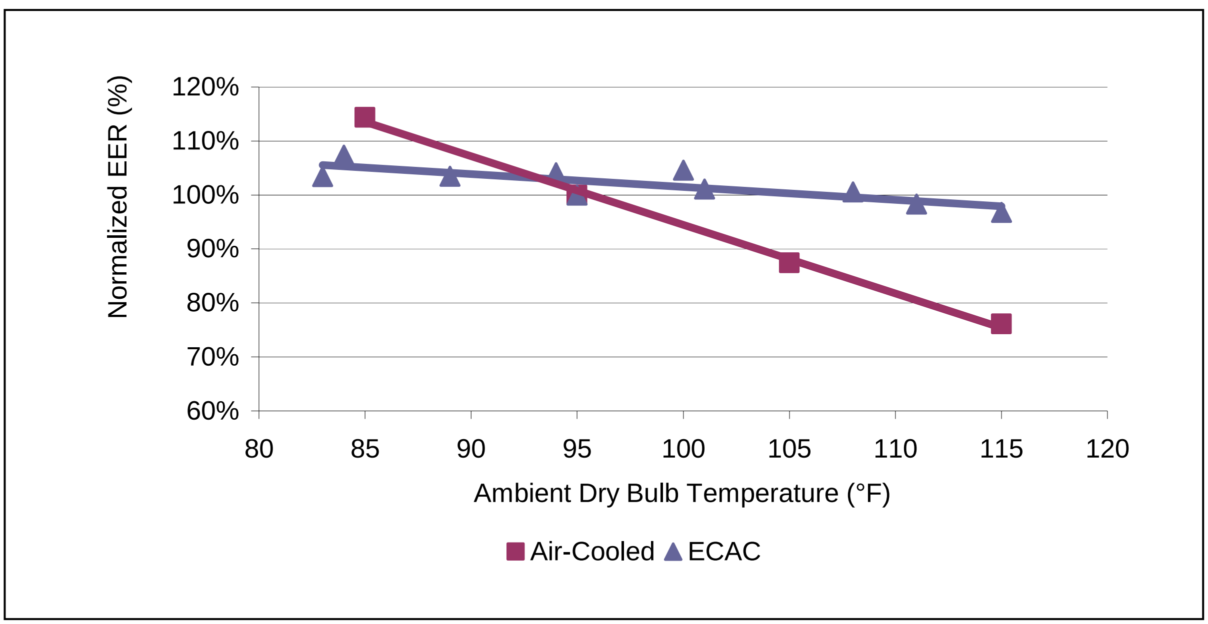
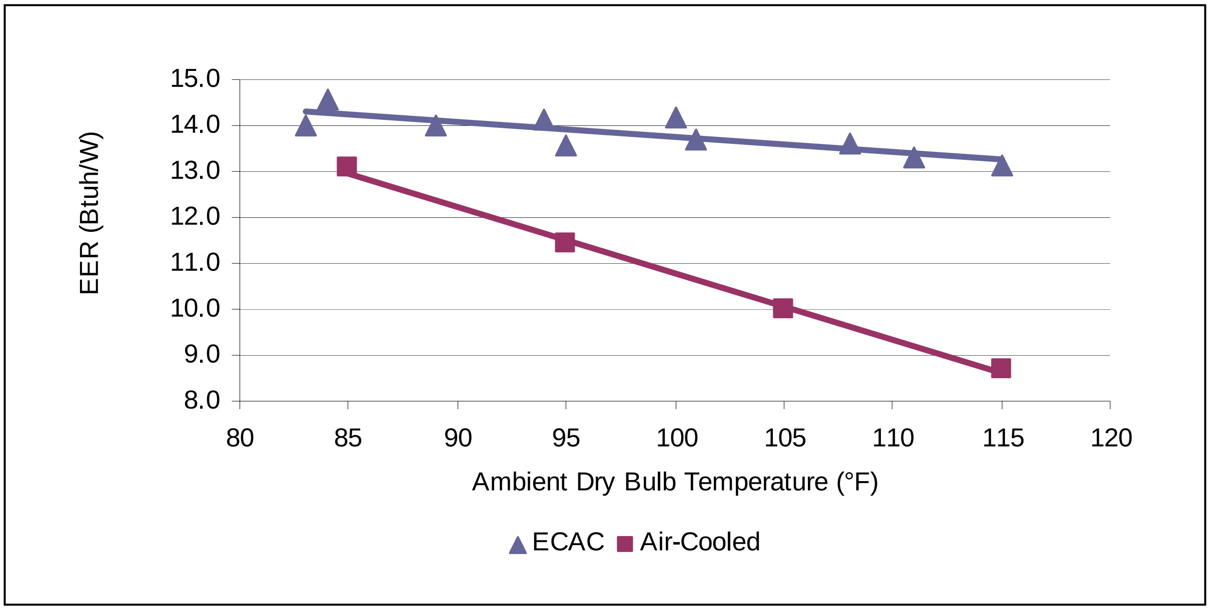


Figure 8 illustrates a direct comparison of EER for air-cooled and ECAC. The ECAC EER is consistently higher than that of the air-cooled unit across the entire range of tested ambient conditions. At low DB temperatures (83°F-85°F) the EER of the ECAC is approximately 9% higher than the air-cooled EER. At 115°F, the EER of the ECAC is approximately 51% higher than the air-cooled EER.

Figure 8. Direct Comparison of EER



Water Consumption

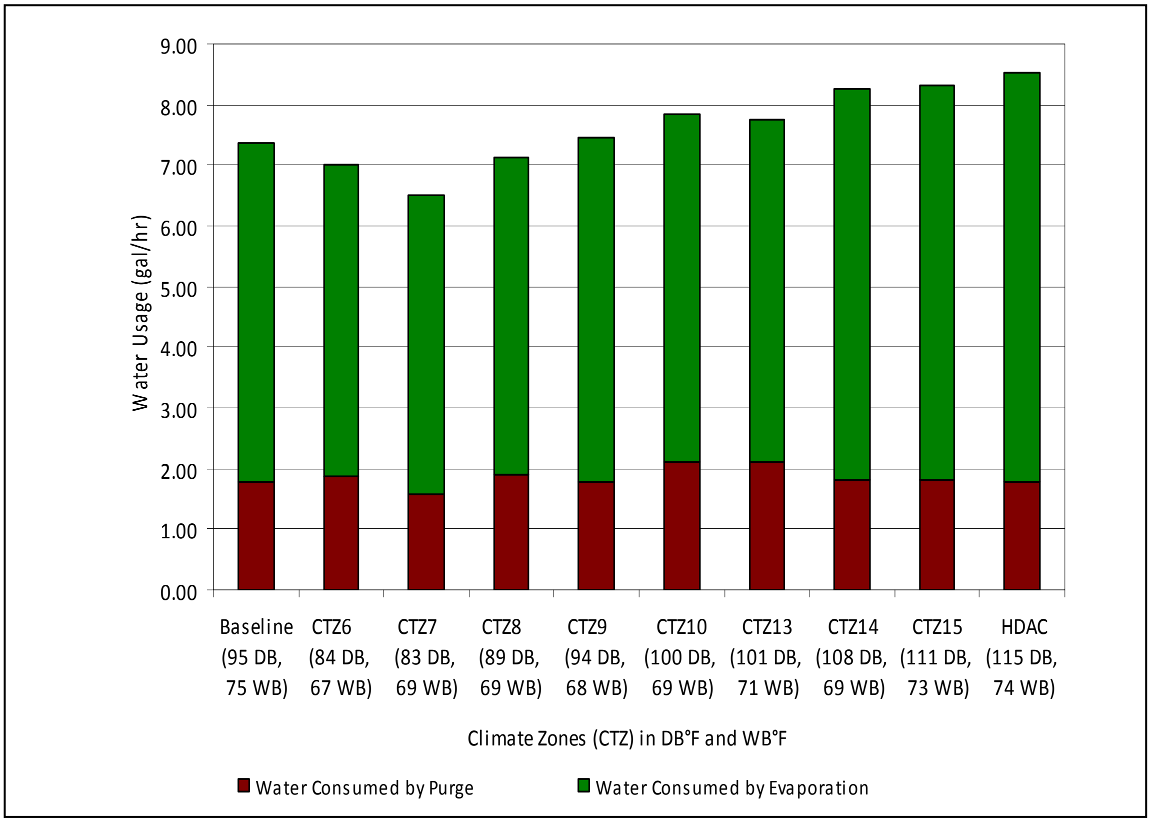
Makeup supply water must be provided to serve the Mecca's needs; purge and evaporation. In order to mitigate effects of water fouling, water must be routinely purged. In order for the ECAC to function properly, sufficient water must be provided for the evaporative effect.

Purge. Supply water to an evaporative cooler inherently contains dissolved minerals. During the evaporation process, only the water component evaporates, leaving an increased concentration of minerals in the sump water as the supply continuously replenishes the evaporated water. Minerals build up as scale and reduce the effectiveness of heat transfer surfaces. Water concentrated with minerals must be cyclically purged. The interval of these cycles may be manually adjusted to accommodate different supply water qualities for a certain installation. For all conducted tests, the purge interval was set to one hour.

The amount of purged water is independent of climate zone variations. It is a function of the purge frequency interval, the purge pump on-time duration, and flow rate. The amount of water purged per interval is relatively constant at approximately 1.8 gallons (gal) per one interval as shown in Figure. Small variations are likely related to variations in purge pump operating parameters such as flow rate or time to establish flow, as in priming the pump.

Evaporation. The remainder and larger component of the water consumption is due to evaporation during the cooling process and is directly related to climate zone conditions. Water consumption of the ECAC due to evaporation increases with hotter/dryer climate zones. The increase is approximately 27% from the lowest usage of 5 gal/hr for the mild condition of CZ 7 to the highest usage of almost 7 gal/hr for the extreme conditions in CZ 14, and CZ 15, as well as the HDAC condition (Figure 9.) Total water usage for evaporation and the hourly purge of water in the sump over all climate zones was in the 6.5 gal/hr to 8.5 gal/hr range during continuous operation. This is equivalent to about 2.1 gal/hr to 2.8 gal/hr per ton of air conditioning capacity for this 3-ton unit.

Figure 9. ECAC Water Consumption



Conclusions

Overall, the test results reveal that the ECAC performed more efficiently than air cooled system in all climate conditions. It experienced minimal performance degradation when subjected to a range of ambient conditions seen in SCE territory. ECAC experiences substantially less performance variation than conventional air-cooled air conditioner systems subjected to the same range of ambient conditions. The performance advantage of the ECAC over conventional air-cooled units is greatest in hot and dry conditions.

General water consumption found under AHRI-Test A conditions of 95°F DB and 75°F WB yielded that the ECAC purged 0.59 gal/hr/ton of water each hour and evaporated 1.86 gal/hr/ton for a total water consumption of 2.45 gal/hr/ton.

Recommendations

To further assess the potential for commercial viability and possible value of an incentive program, the following evaluations should be performed:

- Conduct field testing to verify that laboratory test results can be achieved under actual operating conditions in the field.
- Investigate the potential for improving water usage efficiency. Options may include potential recycling of condensate water for cooling, reduction in sump purge volumes or cycles, and use of purge water for irrigation.
- Investigate potential maintenance, reliability, corrosion, scaling, and other water related operational issues.
- Investigate the impact of effective water treatment solutions.

References

Air-Conditioning & Refrigeration Institute. 2003. **2003 Standard for Unitary Air-Conditioning and Air-Source Heat Pump Equipment – Standard 210/240**. Air-Conditioning and Refrigeration Institute.

American Society of Heating, Refrigeration and Air-Conditioning Engineers. 2004. **2004 ASHRAE Handbook HVAC Systems and Equipment, Inch-Pound Edition.** American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

American Society of Heating, Refrigeration and Air-Conditioning Engineers. 2005. **2005 ASHRAE Handbook Fundamentals, Inch-Pound Edition.** American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. 2005. **ASHRAE Standard 37-2005 Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment**. ASHRAE, Inc.

American Society of Heating, Refrigeration & Air-Conditioning Engineers Golden Gate and Southern California Chapters. May 1982, 1982. **Climatic Data for Region X: Arizona, California, Hawaii, Nevada.** Fifth Edition. ASHRAE Publication SPCDX. American Society of Heating, Refrigeration & Air-Conditioning Engineers.

Faramarzi R., Coburn B., Sarhadian R., Mitchell S., Pierce R., 2004. **Performance Evaluation of Rooftop Air Conditioning Units at High Ambient Temperatures.** American Council for an Energy-Efficient Economy (ACEEE) Paper 202. Southern California Edison, Refrigeration and Thermal Test Center, Design and Engineering Services.

Goswami, D.Y., Mathur G.D., Kulkarni, S.M., 1993. **Experimental Investigation of Performance of a Residential Air Conditioning System with an Evaporatively Cooled Condenser**. Journal of Solar Energy Engineering, Transactions of the ASME.

Hwang, Y., Radermacher R., Kopko W., 2001. **Experimental Evaluation of a Residential-Sized Evaporatively Cooled Condenser**. International Journal of Refrigeration, v 24, n 3, p 238-249.