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Laboratory Evaluation of the OASys™ Hybrid Air Conditioner

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EXECUTIVE SUMMARY

Testing was conducted to evaluate the performance of a prototype OASys™ hybrid air conditioner, which modifies their indirect/direct evaporative cooling unit with an added direct expansion (DX) system for increased range of operation.

A test plan was developed based on the previous testing done on a standard OASys™ air conditioner, with some adjustments to cover operation of the DX system. A test condition matrix was established to evaluate system performance over a range of environmental conditions, which would capture the cooling design conditions for several locations in the PG&E service territory. Other tests were conducted to determine its sensitivity to supply air external resistance.

The results indicate that with the DX system off, the wet-bulb effectiveness and power consumption are about the same as for the standard model, but the supplied airflow is reduced by about 25% on average due to the added resistance of the evaporator coil. Activating the DX system produces 2 to 5°F cooler temperature air, but with an even larger reduction in airflow while more than tripling the power consumption.

Some key test results for this unit are summarized in *Table 1*. (For a more thorough description of the table contents and a comparison with other evaporative cooling systems, refer to Table 4, of which this is a subset.)

Table 1: Average Unit Performance

	Standard OASys™	**Hybrid DX Off**	**Hybrid DX On**
Supply Airflow [1] (cfm)	1,330	**1,088**	**988**
Total Unit Power (W)	584	**534**	**1,804**
Effectiveness [2]	107.6%	**109.4%**	**124.5%**
CA T20 ECER (Btu/Wh)	23.2	**15.6**	**4.6**

[1] Measured supply airflow referenced to the intake density, maximum value at zero inches of water column (IWC) supply resistance (not used for ECER)

[2] Average with 0.30" resistance on supply, and wet-bulb depression above 25°F.

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INTRODUCTION

Background

The OASys™ two-stage indirect/direct evaporative cooling system is designed to provide cooler supply temperatures than are achievable by standard single-stage direct evaporative coolers, while still providing significant power savings relative to a typical direct-expansion (DX) air conditioner. It adds moisture to the supply air because of its direct stage, and there will be outdoor climate conditions under which the unit will not be able to keep an indoor space as comfortable as can be done with DX system. In an attempt to reduce the humidity in the supply air and expand the range of climate conditions during which a comfortable indoor environment can be maintained, a third stage consisting of a small-capacity DX system has been added. This report describes the laboratory evaluation of the resulting product: the OASys™ Hybrid Air Conditioner.

Prior Research

PG&E's Applied Technology Services (ATS) evaluated an early production model of the standard OASys™ product in 2006. A detailed description of the product and testing results were presented in PG&E Emerging Technologies Application Assessment Report #0510 (Reference 7). This new evaluation report is intended to be a supplement to the first, and much of the background text describing the basic process will not be repeated. The main intent of this project is to compare the performance of the two systems.

Objectives

The objective of this project was to assess the performance of this hybrid evaporative cooling unit (ECU), as defined by:

- airflow,
- evaporation (or wet-bulb) effectiveness,
- power demand,
- cooling capacity and efficiency,

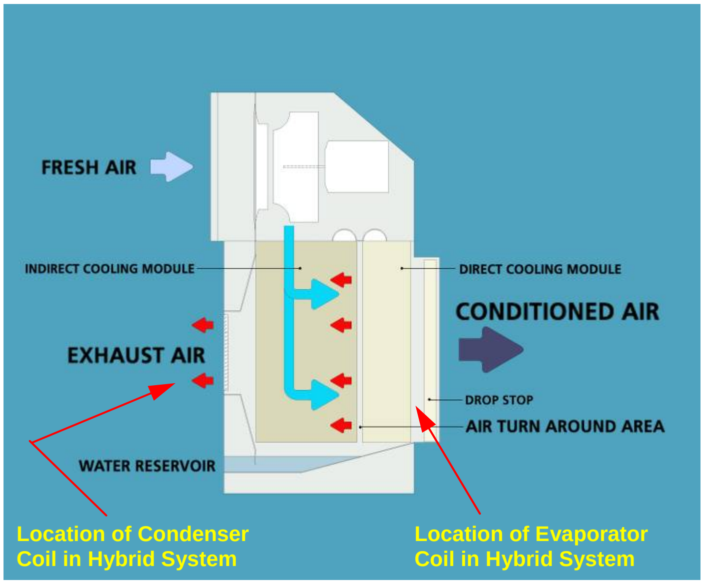
as a function of the variables:

- intake air temperature and humidity,
- external resistance to supply airflow,
- operation of the DX compressor.

System Description

Figure 1 shows two images of the standard OASys™ system (Model CRS1000), provided by Speakman CRS (www.oasysairconditioner.com, www.speakmancompany.com). As shown in the right-hand diagram, outside air is drawn in by a single centrifugal fan, which forces all of the air through the dry side of the indirect evaporative cooler (IEC) module. As the air exits the first stage, it splits in two directions. The supply airflow passes forward through a direct evaporative cooler module on its way to the conditioned space. A smaller exhaust air stream reverses direction to pass through the wetted side of the indirect cooling module, and create the cooling medium for the intake air. The level of water in the reservoir at the bottom of the unit is maintained by a float valve, and a single pump is used to circulate water continuously from the common reservoir to the indirect and direct modules. The reservoir also has a flush pump, which is operated periodically to control the buildup of minerals as water is evaporated, and to drain the system when not in use. The water supply line also has a solenoid valve to shut off the supply when the system needs to be drained.

Figure 1: Standard OASys™ System

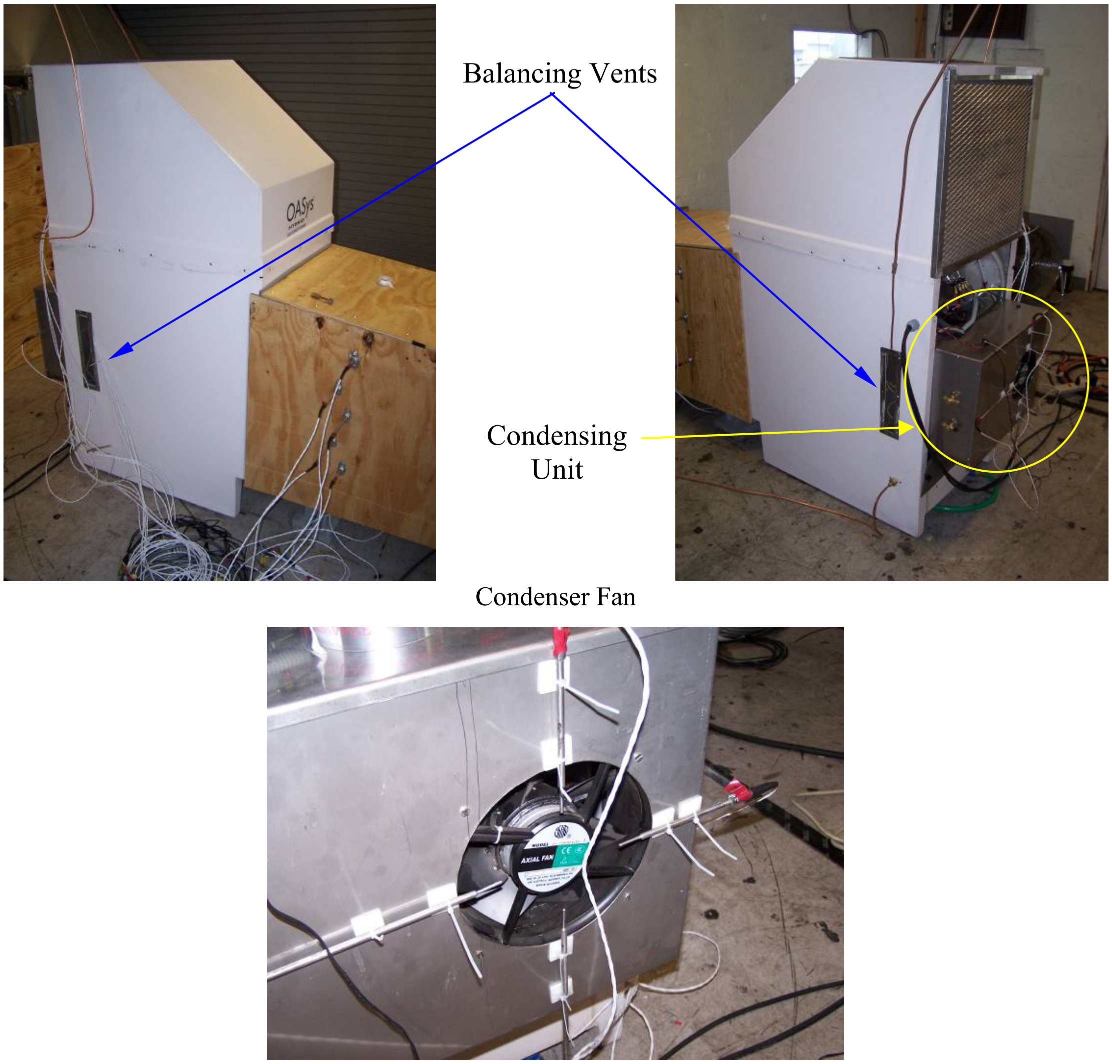


The Hybrid modifies this system with DX components. An evaporator coil is placed downstream of the direct evaporative pad; sandwiched between this pad and another layer of cellulose media meant to be a drift eliminator. (In the diagram in Figure 1, this is between the "direct cooling module" and the "drop stop".) Water that is condensed out by the evaporator coil drains back into the common water reservoir, reducing the makeup water requirements. This condensate is also likely to be cooler than the makeup water, and may enhance the performance of the evaporative stages. The condenser is located in the path of the exhaust air, which should be cooler than the ambient air and should help boost the efficiency of the DX system.

The standard OASys™ has a damper on the exhaust air outlet to aid in balancing the two airstreams after the split. The airflow will take the path of least resistance, so that as backpressure increases on the conditioned air supply (e.g. as the result of closed windows or other inadequate building vents), more air will be diverted to the exhaust. The damper would add resistance to the exhaust stream in order to keep the two streams at the proper proportions. In OASys™ Hybrid, the location for the damper is taken up by the condenser coil. A supplemental fan is included with the condenser coil to ensure adequate airflow, and operates in conjunction with the DX system compressor. Since the condenser coil fan may require more airflow than what is being provided by the exhaust stream, balancing vents were cut into the unit. When the DX system is off, the IEC exhaust air can escape through the vents and bypass the unused condenser. When the DX system is on, the condenser fan can draw additional air from the outside if the IEC exhaust airflow is inadequate. This will also prevent the condenser fan from reducing the static pressure at the indirect exhaust and stealing supply airflow, and thereby reducing the cooling capacity of the system.

The other change from the standard model is the intake blower is now single speed (high only) rather than three speeds (high, medium, and low). This is because the DX system is designed for a fixed airflow rate, and cannot modulate its capacity down to the lower airflows. *Figure 2* contains some photographs of the OASys™ Hybrid in the testing laboratory.

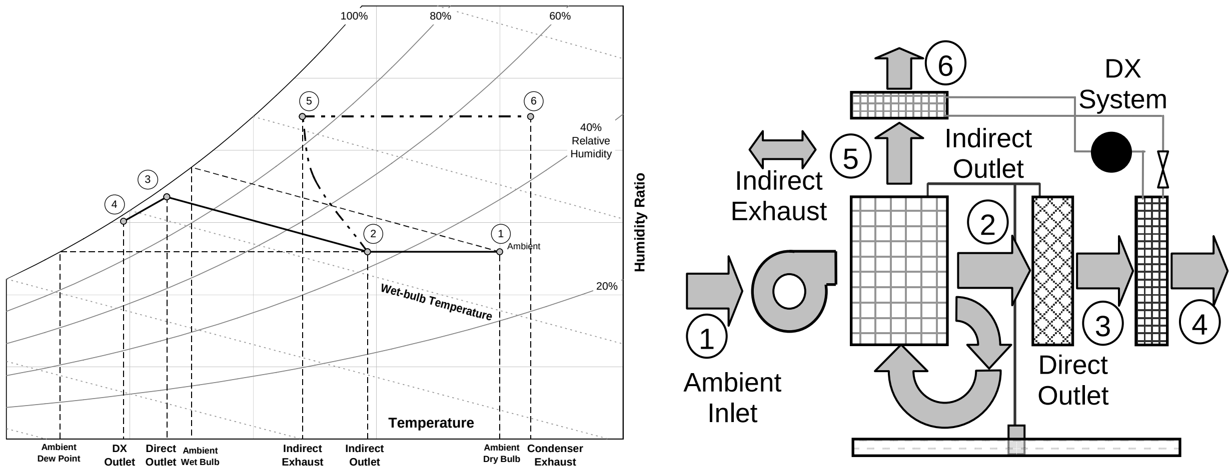
Figure 2: OASys™ Hybrid in Testing Laboratory



Process Description and Performance Characteristics

Figure 3 shows a diagram of the cooling process in the OASys™ Hybrid system on a psychrometric chart. Outside air (1) is drawn in by a blower, and passes through the dry side of the indirect evaporative cooler module (IEC). At this point (2), the airflow splits between supply and exhaust air streams. The supply air passes through the direct evaporative cooling media (2-3) and then through the DX evaporator coil to reach its final temperature and humidity (4). The exhaust air passes through the wetted side of the IEC (2-5), where it may mix with outside air from the balancing vents before passing through the condenser (5-6), rejecting the heat absorbed by the evaporator and generated by the compressor.

Figure 3: OASys™ Hybrid Air Conditioner Process



System Performance Measures

As a hybrid system, performance measures from both evaporative coolers and DX air conditioners can be combined or interpreted in various ways. For consistency, the same performance metrics that were obtained for the standard OASys™ are calculated again. These metrics include:

- Wet-bulb Effectiveness:

$$\text{Effectiveness}\ (\varepsilon) = \left(\frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{wb,in}} \right) \times 100\% \qquad \text{(Equation 1)}$$

where $T_{db_{in}}$ and $T_{wb_{in}}$ are the intake dry and wet-bulb temperatures, respectively, and $T_{db_{out}}$ is the dry-bulb temperature at the air outlet. The effectiveness can also be described as the ratio of the sensible cooling of the intake air to its wet-bulb depression.

Since the IEC is a true sensible cooler (constant humidity ratio or dew-point temperature), both the dry- and wet-bulb temperatures are reduced. The reduced wet-bulb temperature is the limiting temperature for the system, which is why it can achieve a wet-bulb effectiveness better than 100% based on the intake wet-bulb temperature.

- Room Capacity:

$$\textit{Room Capacity (Btu/hr)} \approx 1.08 \times CFM \times (T_{db_{room}} - T_{db_{supply}}) \qquad \text{(Equation 2)}$$

where 1.08 is a units conversion factor combining standard air density and specific heat (0.075 lb/ft³ × 0.24 Btu/lb-°F × 60 min/hr), CFM is the flow rate of air supplied by the unit in cubic feet per minute, $T_{db_{supply}}$ is the discharge dry-bulb temperature of the test unit, and $T_{db_{room}}$ is an assumed indoor space condition in °F. The selected room temperature is **80°F** to be consistent with the ECER metric below. Once the cooling capacity is determined, an energy efficiency ratio (EER) may be determined by dividing it by the total input power in watts.

- Evaporative Cooler Efficiency Ratio (ECER):

$$ECER = 1.08 \times CFM \times (T_{db_{room}} - (T_{db,\,in} - \varepsilon \times (T_{db,\,in} - T_{wb,\,in})) / W \qquad \text{(Equation 3)}$$

The California Title-20 ECER is a slightly modified version of Equation 2 that substitutes in the equation for effectiveness (Equation 1) solved for the supply air temperature. The effectiveness (ε), power (W), and airflow (CFM) are measured with an external static pressure of 0.3 inches of water column (IWC); and in accordance with the ASHRAE test standards, with a minimum entering wet-bulb depression of 25°F. The ECER is then calculated at standard rating temperatures of $Tdb_{, in}$ = 91°F, $T_{wb, in}$ = 69°F, and Tdb_{room} = 80°F. With these inputs, the equation simplifies to:

$$ECER = 11.88 \times (2\varepsilon - 1) \times CFM / W \qquad \text{(Equation 4)}$$

- Intake (or Outside) Air Capacity:

$$IA\ Capacity\ (Btu/hr) \approx 1.08 \times CFM \times (Tdb_{intake} - Tdb_{supply}) \qquad \text{(Equation 5)}$$

This alternative measure of capacity is defined in ASHRAE Standard 143 (Reference 5), which uses the same basic equation, but uses the intake dry-bulb temperature in place of an assumed room temperature. This is because an indirect evaporative cooler could use different air sources for the intake to the indirect cooling section and the intake to the evaporative section (although the OASys™ uses the same outside air source for both). When the intake air is the same as the outside air (as with this system), this equation reduces to:

$$OA\ Capacity\ (Btu/hr) \approx 1.08 \times CFM \times \varepsilon \times WBD \qquad \text{(Equation 6)}$$

where WBD is the outside air wet-bulb depression (difference between the outside dry- and wet-bulb temperatures).

The capacity parameters listed in Equations 2, 5 and 6 are shown as approximations due to the nominal values of density and specific heat that produce the 1.08. For the reported results calculations, the calculations of capacity are made by determining the air mass flow rate and enthalpy from the measurements; except for the ECER values, which use Equation 4 directly.

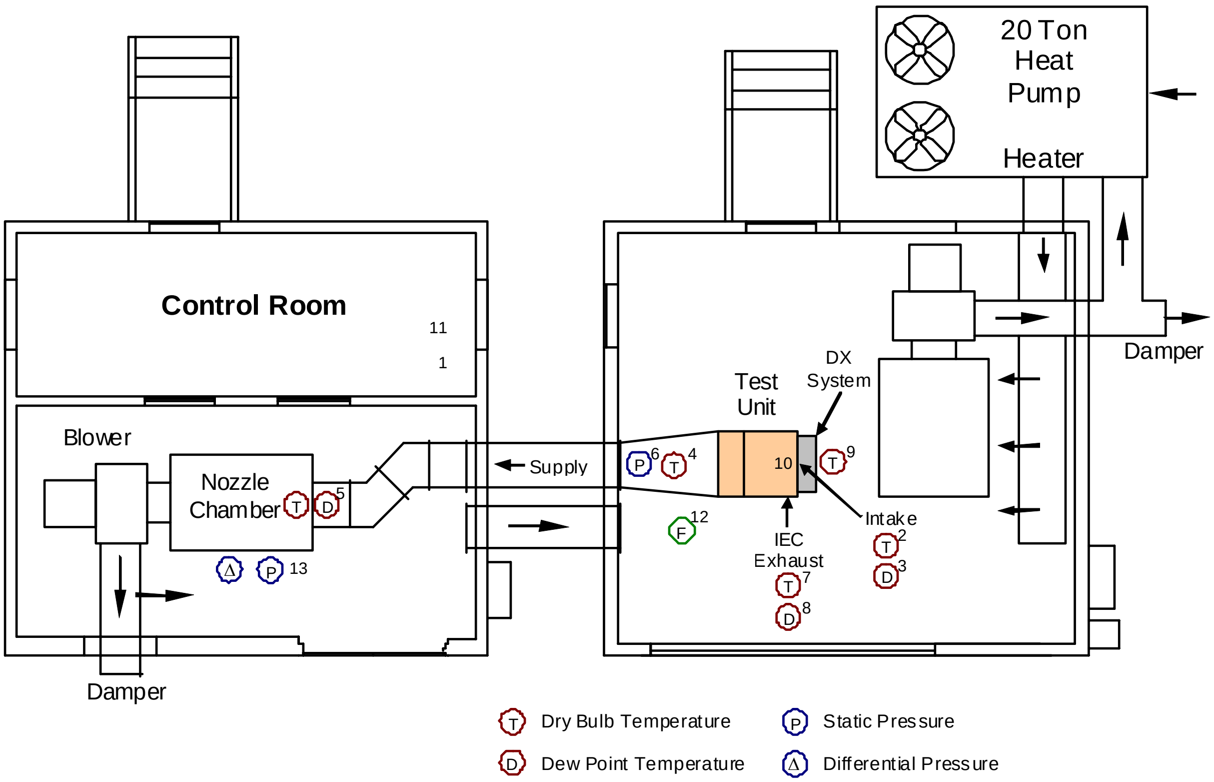
EXPERIMENTAL DESIGN AND PROCEDURE

Test Facility

The test setup was only slightly different from that for the previous evaluation of the standard OASys™. The test unit was placed in a controlled environment room to maintain the intake air conditions, and the supply air outlet was connected to an airflow measurement system located in an adjoining building. The airflow measurement system consists of a sealed chamber with several flow nozzles designed in accordance with ASHRAE specifications. A variable-speed blower on the outlet of the chamber was set to maintain the desired outlet static pressures and compensate for the added resistance of the flow measurement system and ductwork. While the exhaust airflow was measured on the previous unit, the addition of the balancing vents in the Hybrid prevented obtaining an accurate measurement, so none was attempted. While the exhaust discharged back into the room that the intake was drawing from, sufficient outside air was supplied to the room to displace the humidified air and maintain the desired conditions at the intake. Circulation fans were also run in the controlled environment room to keep the air well mixed. A floor plan of the test facility showing the locations of equipment and instrumentation is shown in Figure 4.

To maintain the desired intake conditions to the test unit, temperature control in environmental chamber was achieved using the multiple stages of heat from the two-stage heat pump and variable output resistance heater (72 kW maximum). Testing normally had to be conducted when the outside temperature was less than that of the desired condition. Humidity control was achieved by modulating the fresh air economizer dampers on the heat pump. Dehumidification was inadequate from the heat pump in cooling mode and there was insufficient resistance heat to bring the air back up to temperature, so the low humidity tests had to be performed when the outside humidity ratio (or dew point) was less than the desired condition. For high humidity tests that could not be reached with full recirculation of the room air, an external steam humidifier was activated.

Figure 4: Test Facility and Measurement Locations
(The numbers correspond to the descriptions of the instruments in the next section)



Measurements and Instrumentation

The test set-up followed the guidelines described in the ASHRAE evaporator cooler test standards (References 4 and 5). The following is a listing of the measurements taken and the instruments used for the testing:

1. Barometric pressure, using an electronic barometer.
2. Intake air dry-bulb temperature, using four resistance temperature detectors (RTDs).
3. Intake air dew-point temperature, using a chilled mirror sensor.
4. Supply air dry-bulb temperature, using eight RTDs (located about 12" downstream from unit outlet).
5. Supply air dew-point temperature, using a chilled mirror sensor.
6. Supply static pressure, using a low-range static pressure transmitter.
   Four taps were made in the supply duct at the middle of each duct face. The taps were connected together with a ring of tubing and tees, with an additional tee leading to the transmitter.
7. Exhaust air dry-bulb temperature, using four RTDs strapped cross the indirect media outlet.
8. Exhaust air dew-point temperature, using a chilled mirror sensor and a sampling tube.
9. DX condenser outlet air dry-bulb temperature, using four RTDs.
10. Water basin temperature, using two RTDs.

11. Total power, using a true-RMS power meter. The power to the condensing unit (compressor and condenser fan) was measured separately from the power to the other system components (fan, pump, valves and controls) and summed for the total system power.
12. Make-up water flow rate, using a Coriolis mass flow meter.
13. Supply airflow rate, using a nozzle chamber and measurements of differential and inlet static pressure and inlet temperature.

All of the temperature instruments were calibrated simultaneously against a laboratory standard prior to the tests. The calibration included a low point using an ice bath (32°F), and a high point using a hot block calibrator (~120°F). The raw measurements were adjusted to match the reading from a secondary temperature standard RTD placed in the same bath. The transmitters for the differential and static pressure measurements were calibrated using a water manometer with a micrometer adjustment, accurate to 0.01 inch of water.

Test Conditions
The OASys™ Hybrid was subjected to most of the same conditions that were used previously in the evaluation of the standard unit. The test variables for the Hybrid included intake air temperature and humidity, supply outlet static pressure, and the new variable of the operating status of the DX system. Two variables from the standard system – fan speed and exhaust damper position – no longer apply. The intake air conditions were expanded on from the initial test to include two points at 80°F dry bulb and fairly high humidity. *Table 2* lists the selected test matrix of ten intake air conditions:

Table 2: Test Point Matrix
(Shaded cells have less than the 25°F wet-bulb depression required by ASHRAE test standards)

Dry-bulb	Wet-bulb Temperature		
Temp. °F	65°F	70°F	75°F
80	×	×	
90	×	×	×
100	×	×	×
110		×	×

At least four steady-state tests performance tests were conducted at each of these conditions: at zero and 0.3 IWC outlet static pressure, and with the DX system on and off. Variable resistance tests were conducted at three sets of intake air conditions (91°F_{db}/69°F_{wb} [ECER values], 95°F_{db}/67°F_{wb}, and 100°F_{db}/70°F_{wb}), where the outlet static pressure was varied in 0.1 IWC steps from zero up to about 0.4, both with the DX system on and off.

In a typical residential installation, the system would be normally operated by means of a thermostat in the conditioned space. Since this did not apply in a laboratory setting, the thermostat control was replaced with simple switches to activate the system components manually as needed (intake fan, circulation pump, drain pump, supply water solenoid, and DX system). Measurements were taken every 10 seconds, and the recorded test data were averaged over a stable period (usually 30 minutes) and the averaged results were used to calculate the performance characteristics. The results from all of the tests were tabulated and analyzed graphically by plotting the results as a function of the control parameters.

RESULTS

The following section describes the testing results, along with a discussion of their impact. Most of the referenced graphs are located in the Appendix, along with summary tables of the individual test results. The summary tables list the averaged values of the measurements and calculated performance parameters, and include the standard deviation of several key measurements over the duration of the test period.

Phase 1: Outlet Conditions at a Fixed Outlet Resistance and Variable Intake Conditions

Figure 6 shows two psychrometric charts from the same intake air condition (100°F_{db}/70°F_{wb}) and same external resistance (0.3 IWC) for the two cases with the DX system on and off to show the relative effect of the DX system. The external points that were actually measured are marked by symbols, while the intermediate states that are estimated have none. The intermediate state for the flow-split/turn-around area is estimated as the intersection of the intake dew-point temperature and the direct section outlet wet-bulb temperature. In the second chart when the DX system is on, the direct section outlet condition is estimated based on the effectiveness of the indirect and direct sections as a function of airflow rate, determined from the tests when the DX system was off. For this set of intake conditions, activating the DX system shows a decrease in dry-bulb temperature of 4.5°F, and a decrease in humidity ratio of 0.0019 lb water / lb air (or a dew point temperature decrease of 4.2°F).

The test procedure included obtaining these measurements at a variety of inlet conditions in accordance with the selected test matrix (Table 2). *Figure 7* shows the resulting supply air conditions from all of the tests in this group on two psychrometric charts; again one for each of the cases with the DX system on and off. The tests were conducted at a supply outlet resistance of both 0.3 IWC (to provide data for the ECER calculation) and at zero resistance. (The tests done at zero resistance are indicated by circle symbols, and those at 0.3 IWC resistance are indicated by triangles.) The trends have been simplified slightly to just show the path of the supply air from the intake, and the exhaust air conditions are not shown. The supply air temperatures were all at or below the reference room temperature used for the Title-20 ECER; although in many of the cases (T_{wb} in > 70°F), the outlet humidity was likely too high to be considered comfortable. Under some of the low dry-bulb and high wet-bulb temperature conditions with the DX system on the supply air was actually drier (lower humidity ratio) than the intake air, as all of the moisture added in the direct stage plus some of the intake moisture was condensed out by the evaporator coil.

Table 3 contains three different measures from these tests as a function of the inlet dry and wet-bulb temperatures: the resulting supply and indirect stage exhaust temperatures, and wet-bulb effectiveness. (The points that do not have the 25°F wet-bulb depression required by the ASHRAE Standards are shaded.) The first pair of tables that show the supply air temperatures are the same results as shown graphically in Figure 7. In the last pair, the results with the DX system turned off shows that the unit has an improvement in effectiveness with increasing wet-bulb depression, but the activation of the DX system reverses the pattern due to the decreasing DX system capacity as the condenser intake air temperature rises. (Effectiveness actually has no real meaning when the DX system is activated since the additional cooling comes from the DX process rather than an evaporative process. It is only included for comparison.)

Table 3: Performance Measures at 0.3 IWC Supply Resistance

Supply Temperature (°F) – DX Off

Dry-bulb	Wet-bulb Temperature		
Temp. °F	65°F	70°F	75°F
80	64	69	
90	62	68	74
100	62	67	73
110		66	72

Supply Temperature (°F) – DX On

Dry-bulb	Wet-bulb Temperature		
Temp. °F	65°F	70°F	75°F
80	59	65	
90	58	64	70
100	56	63	69
110		61	67

IEC Exhaust Temperature (°F) – DX Off

Dry-bulb	Wet-bulb Temperature		
Temp. °F	65°F	70°F	75°F
80	69	73	
90	72	75	78
100	74	77	80
110		79	82

IEC Exhaust Temperature (°F) – DX On

Dry-bulb	Wet-bulb Temperature		
Temp. °F	65°F	70°F	75°F
80	68	72	
90	70	74	78
100	71	75	79
110		76	80

Effectiveness (%) – DX Off

Dry-bulb	Wet-bulb Temperature		
Temp. °F	65°F	70°F	75°F
80	106	104	
90	110	108	106
100	110	109	109
110		111	109

Effectiveness (%) – DX On

Dry-bulb	Wet-bulb Temperature		
Temp. °F	65°F	70°F	75°F
80	138	147	
90	128	130	134
100	124	125	124
110		122	122

Phase 2: Fixed Inlet Conditions, Variable Outlet Resistance

For the next set of tests, the intake conditions were maintained constant while the supply outlet resistance was varied. The outlet resistance was varied by changing the speed of the booster fan on the nozzle chamber to maintain the required value. The intake condition selected was 100°F_{db} / 70°F_{wb}, which is close to the Australian rating condition and meets the ASHRAE requirement of a minimum 25°F wet-bulb depression. The other variable was the operation of the DX system. (Additional variable resistance tests were conducted at 91°F_{db} / 69°F_{wb} and 95°F_{db} / 67°F_{wb}, but the results from these tests are not shown in the charts. The results from these tests may be found in the test summary tables in the Appendix.)

The results of these tests are shown as a series of four charts in the Appendix plotted as a function of supply airflow, since this is the recommended reporting method from the ASHRAE Standards. In all of these charts, the measured data points and curve fits are shown for the Hybrid unit with the DX system on and off; and for comparison, the curve fits obtained from the previous testing of the standard OASys™.

Figure 8 shows the trend of supply outlet resistance as a function of supply airflow. This chart is conceptually reversed, since the outlet resistance and the DX system operation are the applied variables and the airflow is the effect. Of key interest in this figure is the change in supplied airflow from the unit as the result of adding the DX coil. The slope of a linear fit of outlet resistance versus supply airflow is about the same for the Hybrid and for the standard when its exhaust damper was open, but it is lower by about 25% (or 230 CFM) on average across the range of testing when the DX system is off. When the DX system is activated, the airflow is reduced by an additional 12%, or 130 CFM. The first effect is the result of the added airflow resistance of the coil when dry; while the second effect is the result of the coil becoming wet as water is condensed out, restricting the airflow further.

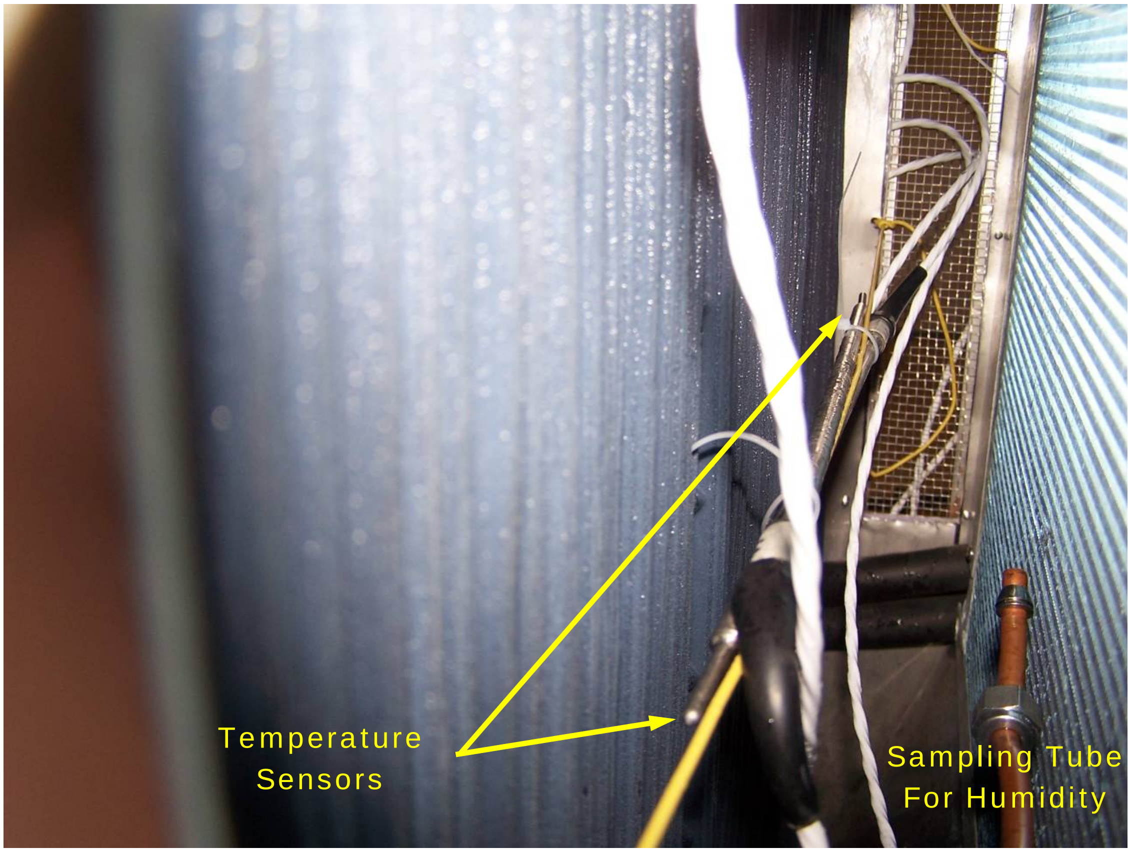
Figure 9 shows the trend of power consumption. The power consumption of the unit with the DX system turned off is slightly less than that for the standard model, and this may be related to a lower overall airflow. As with the standard OASys™, the power consumption is nearly constant as a function of the supply airflow. This is because as the resistance is increased on the supply outlet, more airflow is diverted to the exhaust (following the path of least resistance), and the intake airflow seen by the blower remains relatively constant. However, the evaporator coil in the Hybrid adds an extra resistance that the standard unit does not have, so that the combined resistance on the supply and exhaust is higher. When the DX system is activated, the operation of the compressor and condenser fan basically triples the power consumption. Power also rises with increasing supply airflow (caused by lower supply backpressure) from the combination of more load on the evaporator coil due to the higher airflow, and less evaporatively cooled air coming off the exhaust resulting in higher condensing temperatures.

Figure 10 shows the trend for wet-bulb effectiveness. The wet-bulb effectiveness of the system with the DX system off is of the same magnitude as that for the standard model. Of interest is that it is close to the result for the standard model with the damper closed at high airflows, but moves closer to the result with the damper open at low airflows. Activating the DX system results in an increase of 10 – 20 percentage points in the apparent effectiveness, which increases sharply as the supply airflow is reduced (creating more exhaust airflow for the condenser).

Figure 11 shows the trend of ECER as calculated by Equation 4. The point measured at 0.3 IWC supply resistance is the actual rating point, and these values are emphasized with larger symbols. There appears an easily followed trend along these emphasized rating points starting from the standard unit with its exhaust damper closed and moving towards the Hybrid unit with the DX system off as the result of the reduction in supply airflow.

As more airflow is sent through the wet side of the indirect system towards the exhaust because of increased supply resistance, it increases the likelihood of water carryover. Even with only the 0.3 IW required on the supply for the ECER calculation, enough water was carried over to the DX condenser coil that it would begin to drip out of a weep hole on the bottom of its case. *Figure 5* is a photograph of the space between the IEC outlet and the condenser coil, and the water clinging to the vertical edges of the IEC section is easily seen. Not visible in the photograph are the random droplets being carried across the ~4" gap to the condenser, although the presence of moisture is apparent at the bottom of the coil. With dissolved solids being concentrated in the water pan due to evaporation, the moisture carryover to the coil would likely result in precipitate buildup or encourage biological growth on the coil, creating a permanent resistance to airflow.

Figure 5: IEC Wet Side Outlet – DX Condenser Coil Inlet



Another concern that is not apparent in the results is a lessened effect of the cool exhaust air to the condenser. The efficiency of a DX system is a strong function of the entering condenser air temperature, thus by supplying it with the relatively cool exhaust air from the IEC, the system would perform more efficiently than with the hot outside air. However, the inclusion of the airflow balancing ports between the IEC and the condenser created an opportunity for the relatively cool exhaust air to be mixed with the hot outside air when the condenser fan was running. This was observed in the four temperature measurements on the condenser fan (see Figure 2), where as much as a 20°F difference was seen between the sensors. An example of this is shown in *Figure 12*, where the outlet temperature range between sensors goes from less than 10°F before the start of the DX system to over 20°F after.

Figure 13 shows the water consumption as a function of the intake wet-bulb depression, along with the approximate trend measured for the standard OASys™. The results show nearly a 40% reduction in the water consumption from the standard, although the results are suspect due to a high level of scatter and because an expected relationship is not happening. It was expected that the water consumption would go down when the DX system was operating because the coil would be condensing some of the moisture in the supply air that was added by the direct system and returning it to the water basin for reuse. This effect is not obvious in the results.

Table 4 provides a summary of some key performance measures for comparison with the results from previous OASys™ test.

Table 4: Averaged Results for Airflow and Power

0" water outlet resistance

Test Unit	Standard OASys™ (High speed)		OASys™ Hybrid	
Operating Mode	Damper Closed	Damper Open	DX Off	DX On
Supply Airflow [1] (cfm)	1,457	1,330	1,088	988
Exhaust Airflow [1] (cfm)	189	360	N/A	N/A
Total Unit Power (W)	581	584	531	1,897
Effectiveness	98.7%	104.2%	103.3%	116.5%
Sensible capacity measures with ~100°F_{db}/70°F_{wb} intake air and 0" water outlet resistance				
Room Capacity (tons) [2]	1.19	1.28	1.03	1.20
Room EER (Btu/Wh) [2]	24.9	26.4	23.4	7.5
Outside Air Capacity (tons) [3]	3.70	3.52	2.90	2.89
Outside Air EER (Btu/Wh) [3]	77.3	72.5	65.7	18.1
Water Consumption (GPH)	5	5	3.2	3.4
0.3" water outlet resistance and minimum 25°F wet bulb depression				
Supply Airflow [1] (cfm)	1,135	975	590	456
Exhaust Airflow [1] (cfm)	310	460	N/A	N/A
Total Unit Power (W)	577	575	535	1,747
Effectiveness	102.8%	107.6%	109.4%	124.5%
CA Title-20 ECER (Btu/Wh)	24.7	23.2	15.6	4.6

[1] Supplied airflow referenced to the intake density.
[2] Room Capacity ≈ 1.08 × CFM × (80°F – T_{supply})/12,000
[3] Outside Air Capacity ≈ 1.08 × CFM × (T_{intake} – T_{supply})/12,000

CONCLUSIONS

This study investigated the performance of a prototype of the OASys™ Hybrid, which combines their two-stage evaporative cooler with a DX system for increased operating range. Some of the key findings are summarized below.

1. Supply air temperatures ranged between 62 and 75°F over the range of test conditions with the DX system off, and from 56 to 72°F with the DX system on. This means that it always provided some cooling effect compared to a room reference temperature of 80°F. The temperature reduction from intake to supply ranged from 10 to 45°F with the DX system off, and from 13 to 49°F with the DX system on.
2. The wet-bulb effectiveness of the system with the DX components turned off was about the same as for the standard unit, ranging from 101 to 111% (versus 98 to 112% measured for the standard, which included lower fan speeds). Activating the DX system provided an additional 2 to 5°F of cooling, raising the apparent effectiveness to 113 to 147%. The higher effectiveness numbers were achieved at high supply backpressure and thus lower airflow rates.
3. While the addition of a DX system did provide an additional drop in supply temperature, it came at the cost of a severe reduction in supplied airflow and cooling capacity. With the DX system turned off, the airflow was reduced by an average of 25% from the standard unit due to the presence of the evaporator coil in the flow path. When the DX system was activated, the high humidity air coming off the direct evaporation stage caused considerable moisture to be condensed out on the coil. This condensate blocks passage of air through the coil, and the airflow is reduced by an additional 12%.
4. The power consumption of this system averaged:
    - 530W with the DX system off, and
    - 1,800 W with the DX system on.

    The power consumption with the DX system off is about 9% less than the standard OASys™. The power factor of the fan is also rather low at 0.74, which results in more air heating without the work. In comparison, the power factor of the compressor was 0.94. (The DX system is nominally 1-ton capacity.)
5. The new California Title 20 evaporative cooler efficiency ratio (ECER) is meant for comparing direct evaporative coolers by only looking at their sensible cooling potential. It does not reflect increased comfort from the reduced moisture addition to the supply air, and thus treats this and other systems with indirect components unfairly when compared to direct systems. With the penalty caused by the reduction in airflow and little change in the effectiveness or power consumption, the ECER with the DX system off has been reduced to 15.6 Btu/Wh from the 23.2 for the standard. Activating the DX system increases the apparent effectiveness, but not enough to overcome the combination of an additional reduction in airflow and a very large increase in power. With the DX system on, the ECER is down to 4.6, well below the EER of most standard air conditioners. (As the ECER already misrepresents indirect systems, it actually has no real meaning for a hybrid system.)
6. The airflow required by the condenser coil was more than that provided by the indirect exhaust, and the shortfall was made up by outside air drawn in through the balancing ports. This reduced the benefit gained from condensing on evaporatively cooled air.

Recommendations for Follow-on Activities

This project was to evaluate a prototype of the OASys™ Hybrid air conditioner. The results show that while the system could provide slightly cooler and dryer air than the standard model, the penalty in airflow caused by the evaporator coil and the much greater power consumption when the DX system is turned on do not make this an attractive alternative, at least in its current form. The system design could be refined to address the observed problems in a number of ways:

- The evaporator coil should be designed for high bypass since it is doing about as much latent cooling (moisture condensation) as sensible cooling (temperature reduction). A higher bypass coil (fewer fins per inch) would allow for freer movement of air when on or off.
- The evaporator coil could be moved elsewhere and may provide a larger cooling benefit. Placing it between the indirect and direct stages will reduce the limiting wet-bulb temperature for the direct stage, or the direct stage could be turned off or eliminated altogether. Placing it between the fan and the indirect stage would expose it to the highest system temperatures so that the suction temperature (and pressure) could be raised, improving the DX system efficiency. In addition, it would reduce the limiting wet bulb temperature for both the indirect and direct stages, and would eliminate any flow balancing issues between the supply and the exhaust caused by the coil.
- The balancing vents should be designed with one-way dampers to allow air in only when the condenser fan is operating. By not allowing air to escape when the DX system is off, it will create more backpressure on the exhaust, which may actually help with the flow balancing. Additional direct cooling media could be placed over the vents to cool the supplemental outside air for the condenser, and gain the full benefit of evaporatively pre-cooled condenser air. A “drop stop” should also be installed between the indirect outlet and the condenser coil to prevent moisture carryover.
- As an alternative to an evaporator coil in the air path and restricting its flow, the DX system could be used to chill the water delivered to the evaporative components. Water that has been chilled below the dew point of the air will actually pull moisture out of the air, in the same way that a glass of ice water “sweats”. Some concerns with this option are that the water flow rate may be insufficient to create enough sensible cooling by this method, and there needs to be added safety features to prevent freezing of the water by the DX system.

REFERENCES

1. ANSI/ASHRAE Standard 133-2001, “Method of Testing Direct Evaporative Air Coolers”, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, NE, Atlanta, GA 30329, 2001.
2. ANSI/ASHRAE Standard 143-2000, “Method of Test for Rating Indirect Evaporative Coolers”, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, NE, Atlanta, GA 30329, 2000.
3. Australian Standard AS 2913-2000, “Evaporative Air Conditioning Equipment”, 2000.
4. Davis, R. Pacific Gas and Electric Company PY2003 Emerging Technology Application Assessment Report #0307, “Evaluation of Advanced Evaporative Cooler Technologies”, PG&E/TES Report 491-04.07, February 2004.
5. Davis, R. Pacific Gas and Electric Company PY2004 Emerging Technology Application Assessment Report #0401, “Evaluation of a Thick Media Evaporative Cooler”, PG&E/TES Report 491-04.31, November 2004.
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7. Davis, R. Pacific Gas and Electric Company PY2005 Emerging Technology Application Assessment Report #0510, “Laboratory Evaluation of the OASys™ Indirect/Direct Evaporative Cooling Unit”, PG&E/TES Report 491-06.12, November 2006.

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APPENDIX

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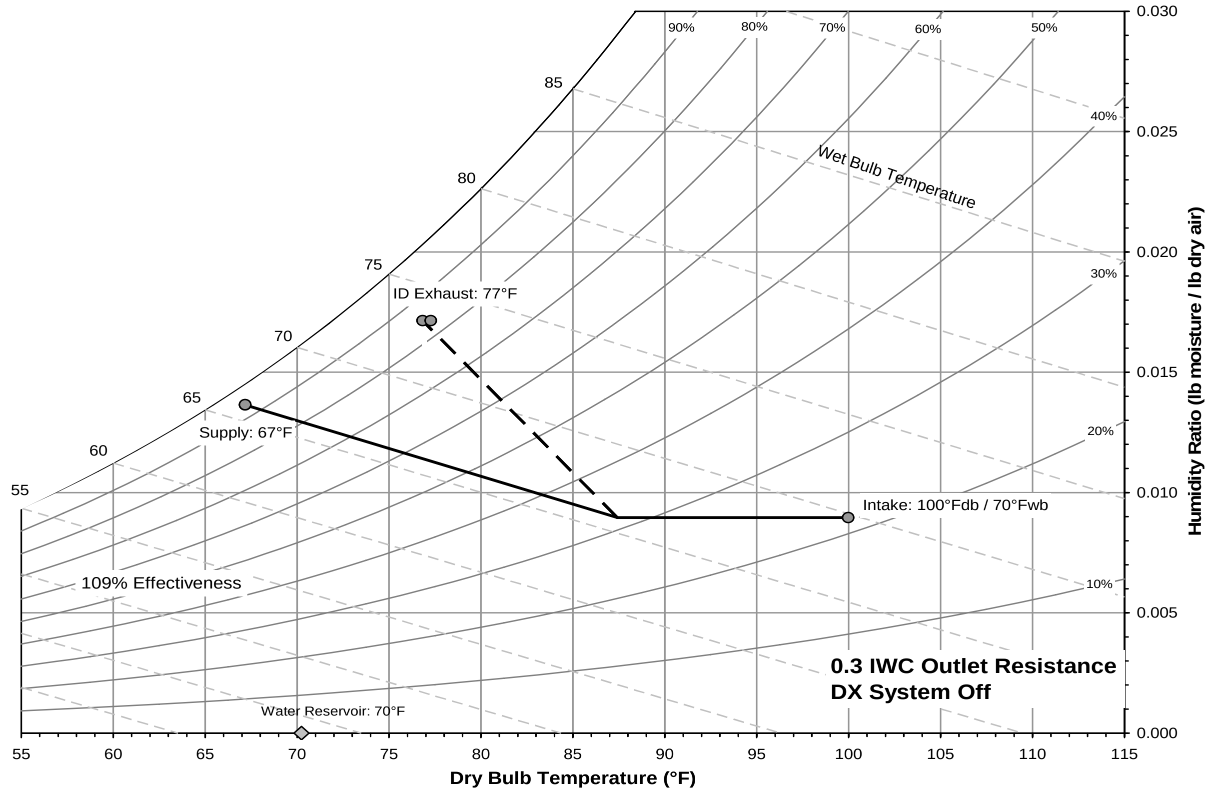
Figure 6: Process Description at one Test Condition



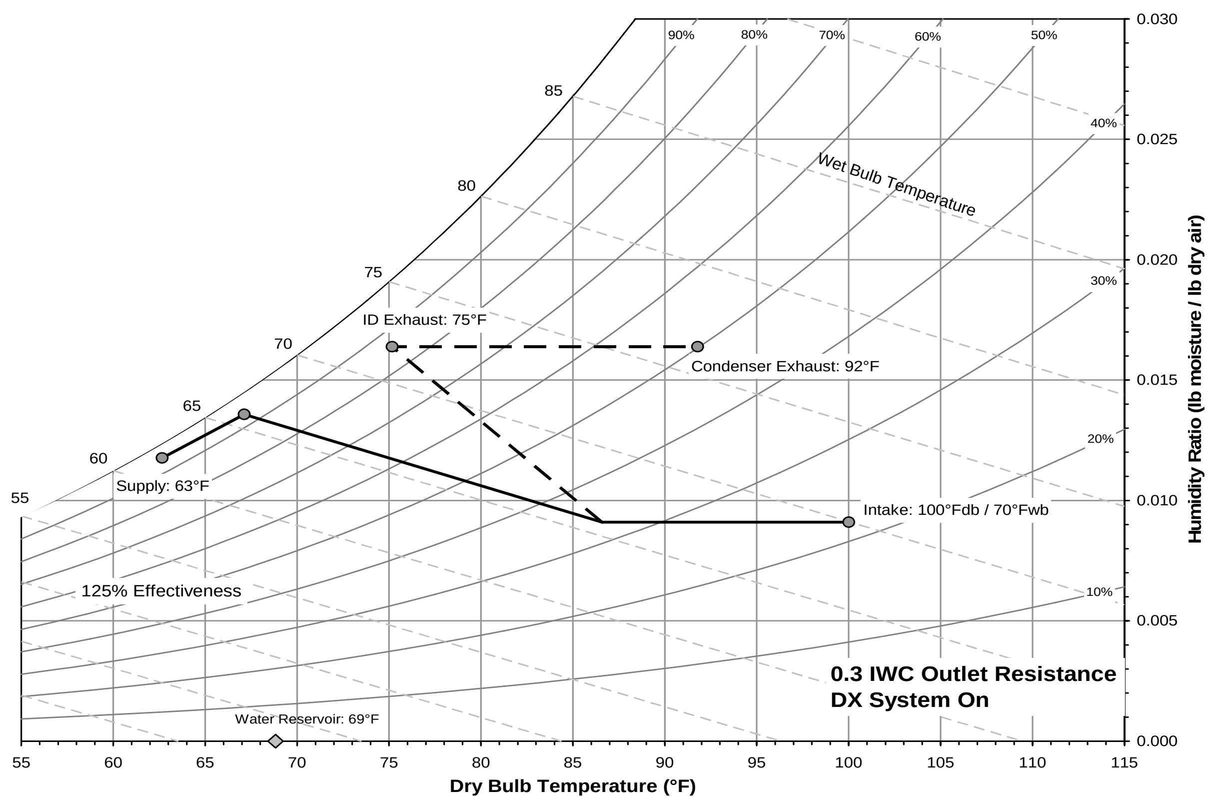
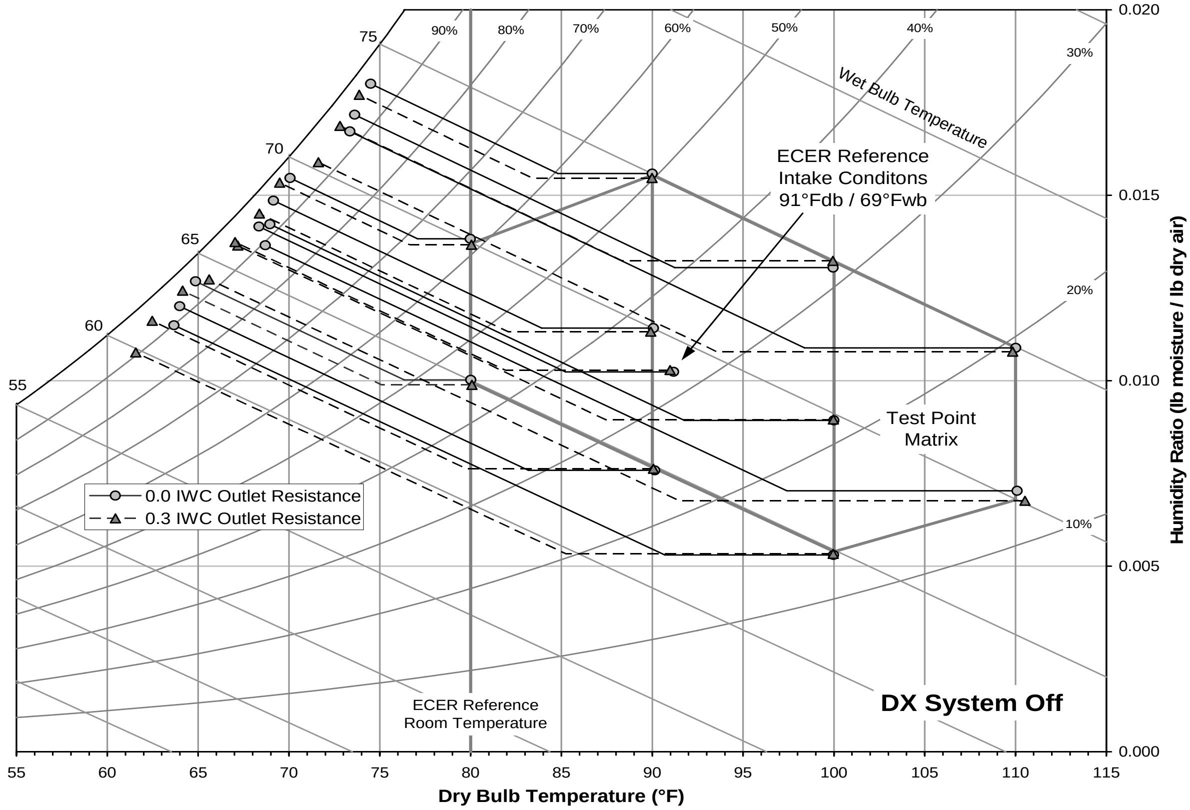


Figure 7: Performance at All Variable Intake Conditions



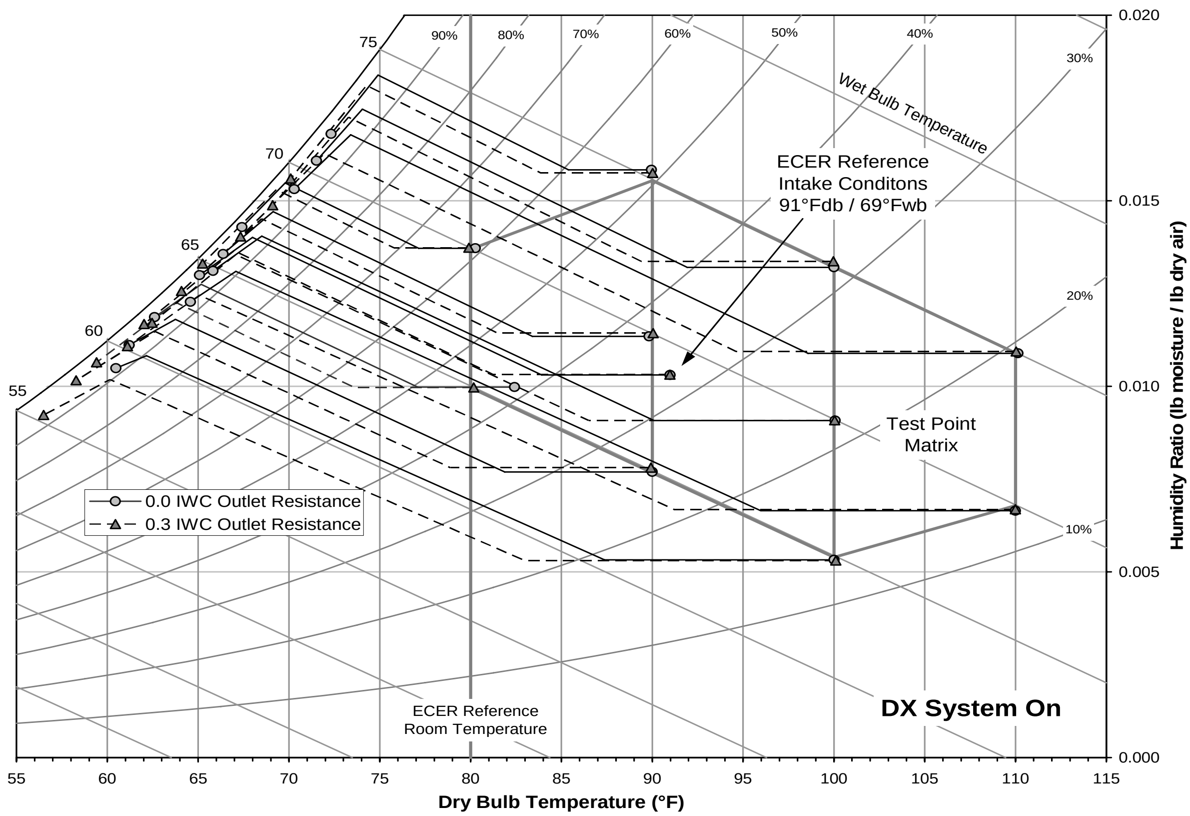


Figure 8: Outlet Resistance versus Supply Airflow

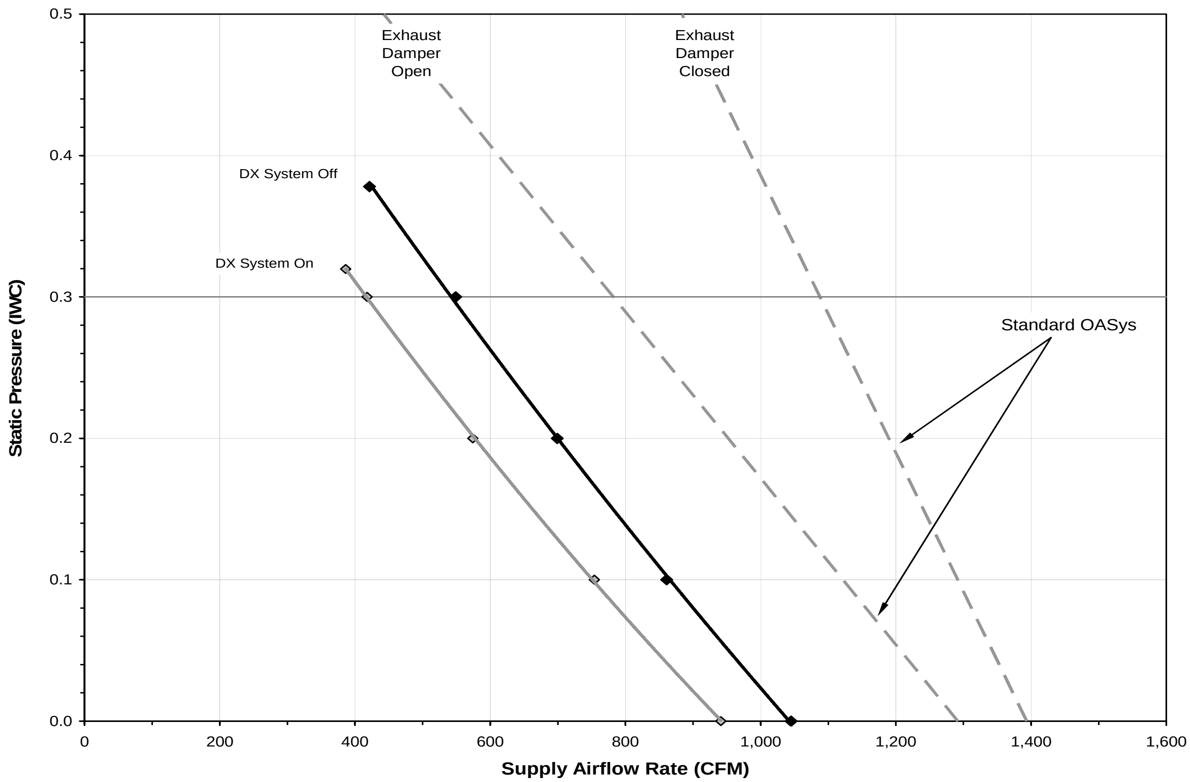


Figure 9: Power Consumption versus Supply Airflow

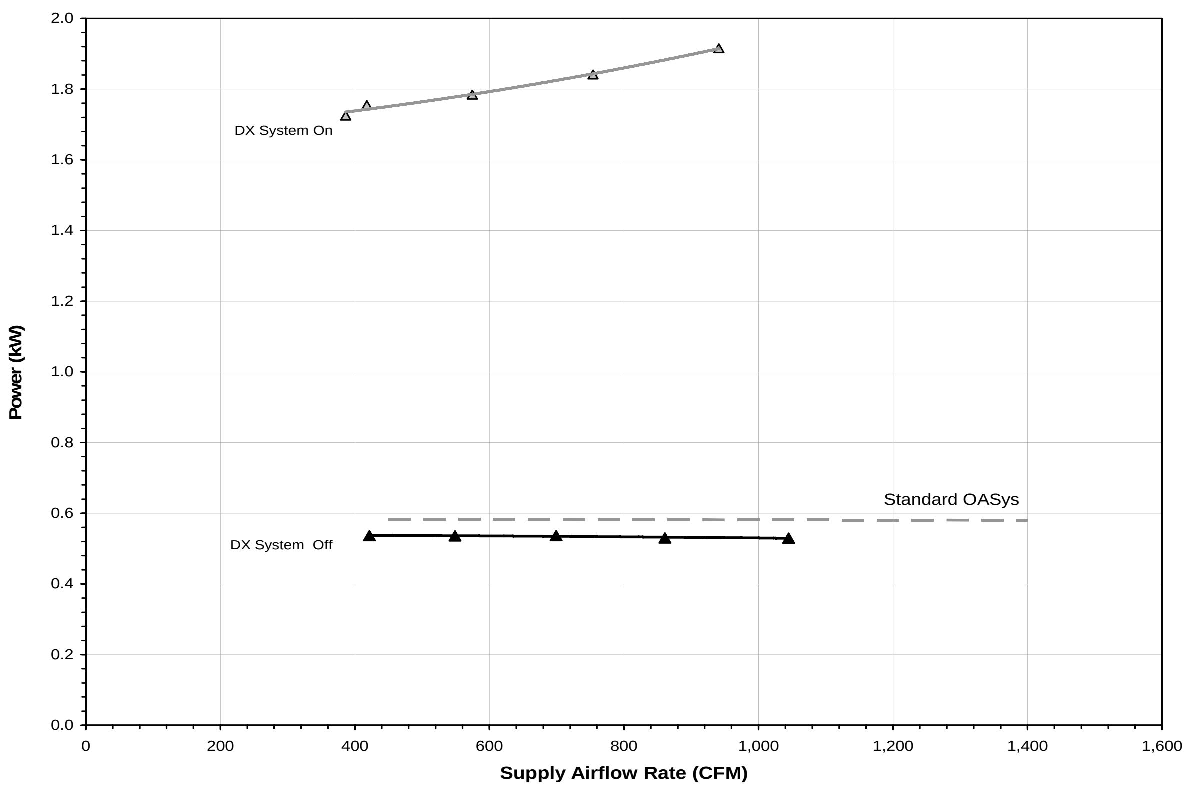


Figure 10: Effectiveness versus Supply Airflow

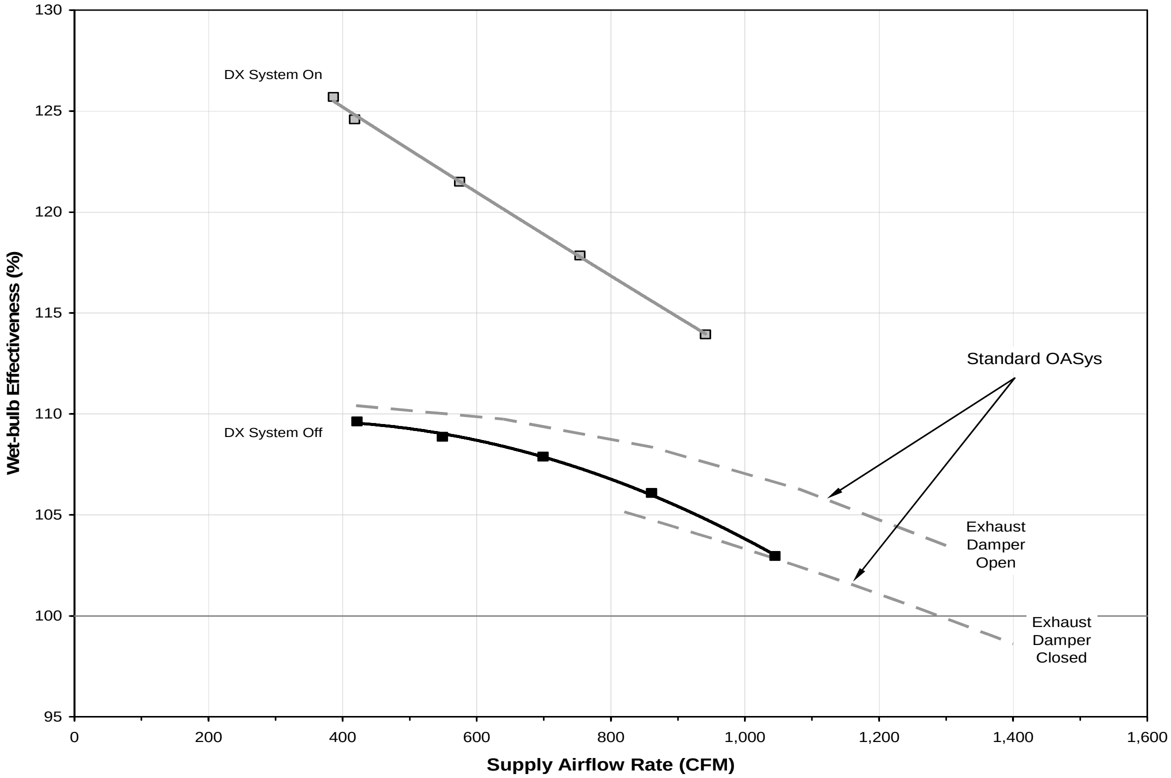


Figure 11: ECER versus Supply Airflow

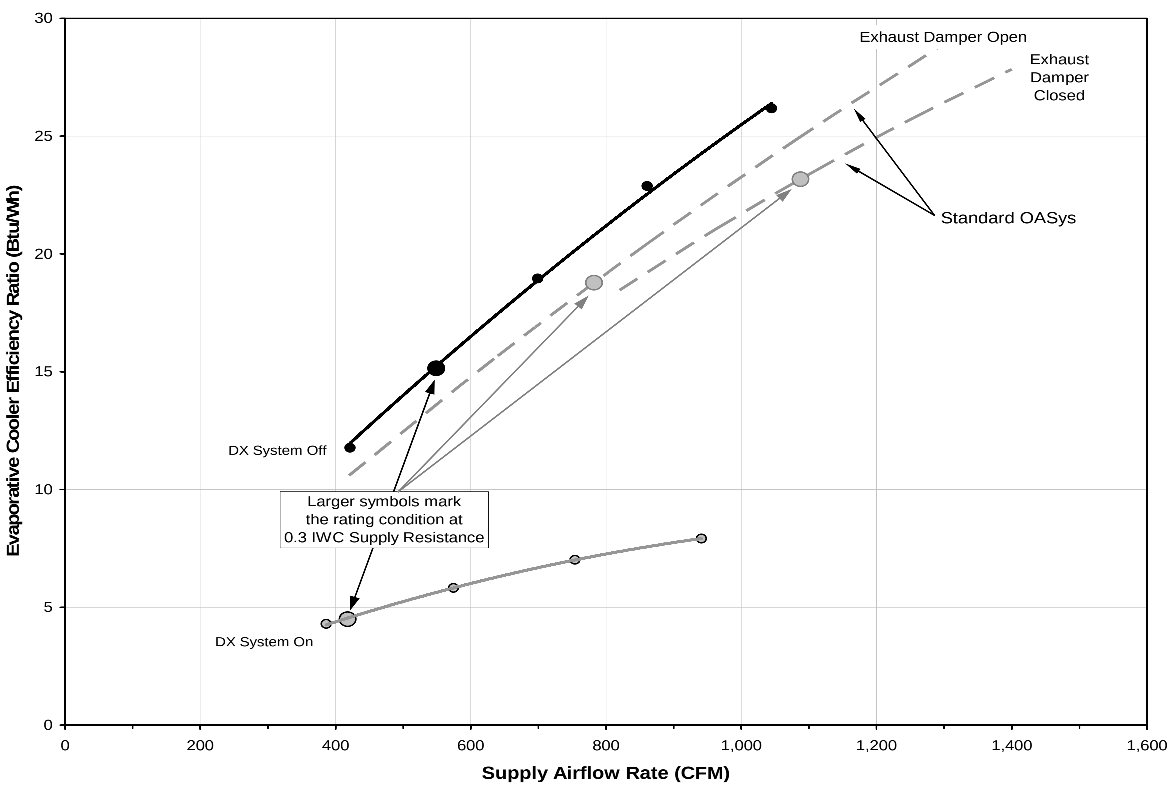


Figure 12: Exhaust Temperatures during Compressor Start

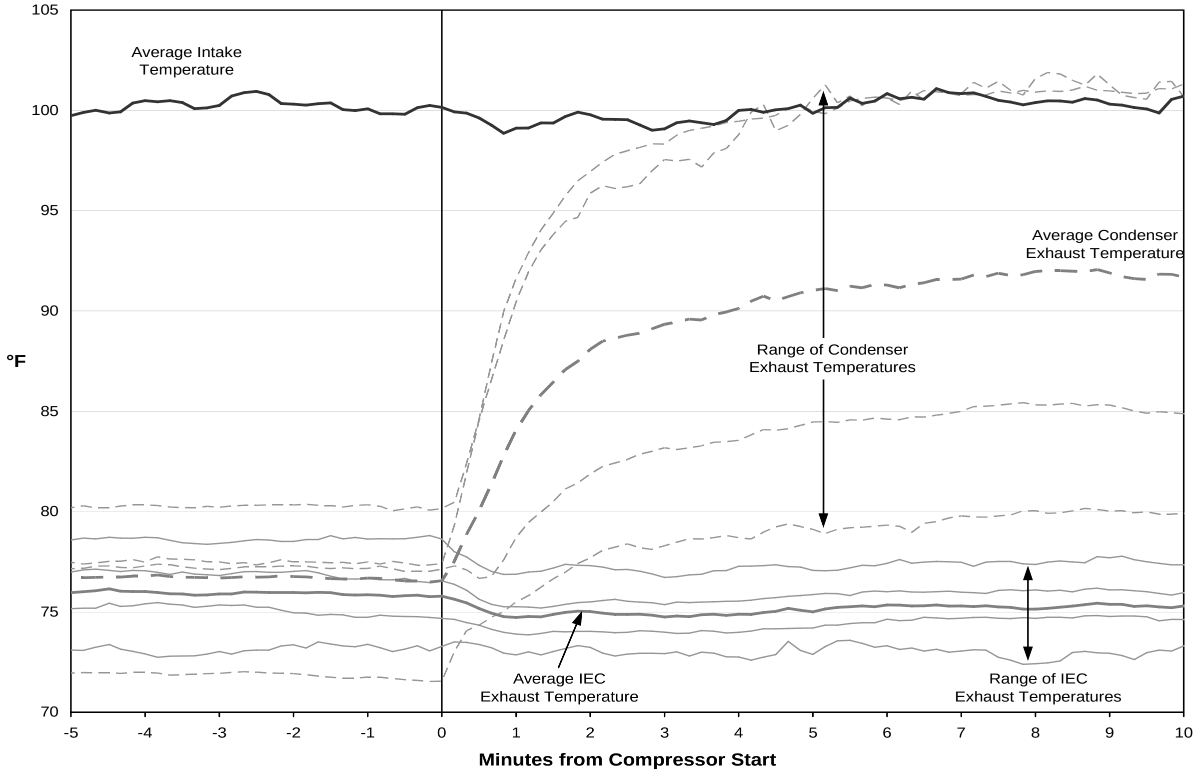


Figure 13: Water Consumption Rate versus Intake Wet-Bulb Depression

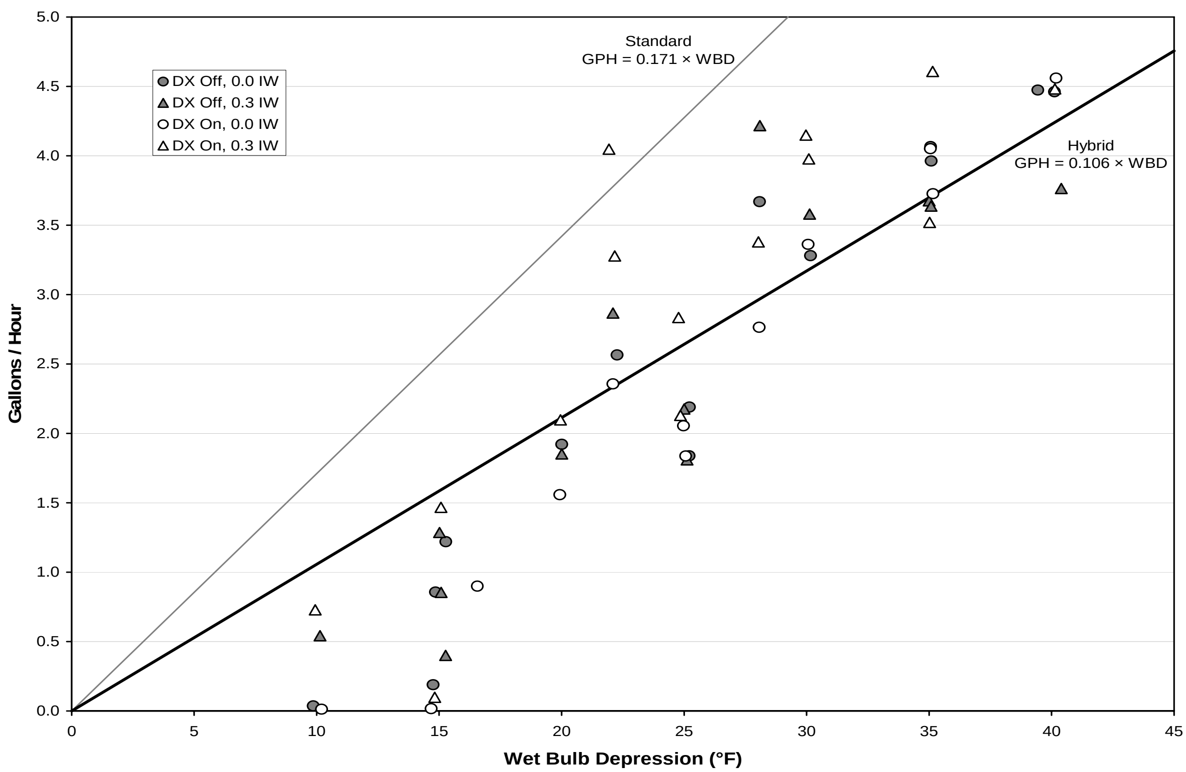


Table 5: OASys™ Test Data

Test Summary Information	DX Off, 0 IW Resistance												
General													
Date (2009)	31-Mar	2-Apr	1-Apr	31-Mar	2-Apr	7-Apr	26-Mar	30-Mar	27-Mar	6-Apr	1-Apr	3-Apr	3-Apr
Start Time	11:39a	11:27a	11:16a	4:55p	4:27p	9:23a	11:14a	1:09p	10:50a	5:41p	3:56p	9:44a	3:02p
Duration (minutes)	30	30	30	20	30	30	30	30	26	30	30	30	30
Samples	181	181	181	121	181	181	181	181	157	181	181	181	181
Barometric Pressure (in. of Hg)	29.64	29.49	29.55	29.52	29.42	29.48	29.58	29.61	29.57	29.46	29.46	29.53	29.46
Inlet Air Properties [Average (Std Dev)]													
Dry Bulb Temperature (°F)	80.0 (0.5)	80.0 (0.4)	90.1 (0.3)	90.1 (0.5)	89.9 (0.7)	90.1 (0.2)	91.2 (0.6)	100.0 (0.3)	100.0 (0.4)	100.0 (0.3)	110.0 (0.6)	110.2 (0.6)	110.0 (0.9)
Dew Point Temperature (°F)	57.0 (1.4)	65.7 (0.9)	49.4 (0.3)	60.4 (0.9)	68.6 (1.5)	69.6 (0.5)	57.5 (0.9)	40.2 (1.2)	53.8 (0.2)	64.1 (0.4)	48.2 (0.2)	46.6 (1.1)	59.1 (0.5)
Wet Bulb Temperature (°F)	65.2 (0.8)	70.1 (0.5)	64.9 (0.1)	70.1 (0.4)	74.7 (0.8)	75.3 (0.3)	68.9 (0.6)	64.9 (0.4)	69.8 (0.2)	74.7 (0.3)	70.5 (0.2)	70.1 (0.4)	74.9 (0.3)
Wet Bulb Depression (°F)	14.9	9.9	25.2	20.0	15.3	14.8	22.3	35.1	30.2	25.2	39.4	40.1	35.1
Relative Humidity (%)	45.3	61.8	24.8	37.2	49.6	51.1	32.3	12.9	21.5	31.2	13.0	12.2	19.4
Supply Air Properties													
Dry Bulb Temperature (°F)	64.9 (0.8)	70.1 (0.6)	64.0 (0.2)	69.1 (0.5)	74.1 (0.9)	74.9 (0.4)	68.4 (0.6)	63.7 (0.4)	69.0 (0.2)	73.6 (0.2)	69.3 (0.1)	68.1 (0.4)	73.4 (0.3)
Dew Point Temperature (°F)	63.5 (0.9)	68.9 (0.7)	61.9 (0.2)	67.8 (0.5)	72.9 (1.0)	73.5 (0.4)	66.5 (0.6)	60.7 (0.4)	66.6 (0.2)	71.9 (0.2)	65.6 (0.1)	65.2 (0.4)	71.1 (0.3)
Wet Bulb Temperature (°F)	63.9 (0.9)	69.3 (0.7)	62.6 (0.2)	68.2 (0.5)	73.3 (1.0)	73.9 (0.4)	67.1 (0.6)	61.8 (0.4)	67.3 (0.2)	72.4 (0.2)	66.8 (0.1)	66.2 (0.4)	71.8 (0.3)
Relative Humidity (%)	95.2	96.2	92.8	95.5	96.1	95.5	93.8	90.1	92.3	94.3	88.1	90.4	92.7
External Resistance (IW)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Interstage Air Temperature (°F) - estimated [1]	76.3	77.1	83.2	83.9	84.8	84.8	85.2	90.7	91.8	91.2	97.5	97.4	98.4
Exhaust Air Properties													
Indirect Out Dry Bulb Temperature (°F)	72.9 (0.5)	75.7 (0.3)	78.6 (0.2)	80.3 (0.2)	81.9 (0.5)	82.7 (0.1)	80.9 (0.5)	83.6 (0.2)	84.9 (0.3)	86.5 (0.3)	92.4 (0.2)	90.2 (0.2)	92.0 (0.3)
Dew Point Temperature (°F)	71.1 (0.7)	73.4 (0.4)	74.7 (1.4)	78.8 (0.2)	79.8 (0.5)	82.7 (0.5)	76.1 (0.6)	78.4 (0.6)	79.1 (0.3)	82.7 (0.2)	86.1 (0.5)	85.1 (0.4)	86.6 (0.3)
Wet Bulb Temperature (°F)	71.6 (0.6)	74.0 (0.3)	75.8 (1.0)	79.1 (0.2)	80.3 (0.5)	82.5 (0.2)	77.4 (0.5)	79.7 (0.4)	80.4 (0.3)	83.5 (0.2)	87.4 (0.4)	86.2 (0.3)	87.7 (0.2)
Relative Humidity (%)	94.1	92.8	87.9	95.2	93.2	100.0	85.5	84.4	82.8	88.3	81.9	85.0	84.6
Condenser Out Dry Bulb Temperature (°F)	73.3	75.9	78.6	81.0	82.4	83.4	80.8	83.5	84.8	87.3	92.7	90.6	93.0
Water Properties													
Basin Temperature (°F)	67.5	71.7	68.4	72.3	76.3	76.2	70.9	69.4	73.1	76.8	74.9	72.7	76.6
Makeup Water Flow (gph)	0.9	0.0	1.8	1.9	1.2	0.2	2.6	4.1	3.3	2.2	4.5	4.5	4.0
Power Consumption													
Voltage (V)	117	117	117	117	117	117	117	118	117	117	118	118	118
Current (A)	6.0	6.0	6.1	6.0	6.0	6.1	6.1	6.1	6.0	6.0	6.1	6.1	6.1
Power (W)	531 (0.7)	527 (0.7)	532 (1.5)	527 (0.7)	527 (0.8)	532 (1.9)	530 (2.5)	536 (2.1)	529 (1.6)	526 (1.2)	532 (1.2)	535 (2.6)	535 (1.4)
Power Factor	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.74	0.75	0.75	0.74	0.74	0.74
Performance													
Dry Bulb Temperature Drop (°F)	15.2	9.9	26.2	20.9	15.8	15.2	22.8	36.3	31.1	26.3	40.7	42.1	36.7
Dew Point Temperature Rise (°F)	6.5	3.2	12.5	7.4	4.4	3.9	9.0	20.6	12.8	7.8	17.4	18.7	12.1
Wet-Bulb Effectiveness (%)	102.0	100.7	103.8	104.6	103.5	102.8	102.5	103.5	103.0	104.4	103.2	104.8	104.5
Supply Airflow Rate (CFM)	1,041	1,039	1,086	1,022	1,027	1,023	1,058	1,038	1,045	995	1,092	1,037	1,021
Room Capacity (tons; 80°F reference)	1.42	0.92	1.57	0.99	0.53	0.46	1.10	1.53	1.03	0.56	1.04	1.10	0.60
Room EER (Btu/Wh, 80°F reference)	32.1	20.9	35.4	22.5	12.1	10.4	25.0	34.3	23.4	12.8	23.5	24.7	13.4
CA T-20 ECER (Btu/Wh) [2]	-	-	-	-	-	-	-	-	-	-	-	-	-
Sensible Cooling of Outside Air (tons)	1.42	0.92	2.56	1.91	1.43	1.37	2.16	3.41	2.90	2.32	3.95	3.90	3.31
Outside Air EER (Btu/Wh)	32.1	20.9	57.8	43.4	32.6	30.9	48.9	76.3	65.7	52.8	88.9	87.5	74.2

[1] Calculated interstage temperature is the intersection of the intake dew point and the supply wet bulb.

[2] ECER can only be derived when the supply resistance is 0.3" and the intake wet-bulb depression is >=25°F

Table 5: OASys™ Test Data (Continued)

Test Summary Information	DX Off - 0.3 IW Resistance											
General												
Date (2009)	31-Mar	2-Apr	1-Apr	31-Mar	2-Apr	7-Apr	26-Mar	30-Mar	27-Mar	6-Apr	3-Apr	3-Apr
Start Time	10:47a	2:13p	12:14p	5:24p	3:35p	10:10a	12:52p	11:42a	1:05p	4:47p	9:07a	3:41p
Duration (minutes)	30	30	30	30	30	30	30	30	30	30	30	30
Samples	181	181	181	181	181	181	181	181	181	181	181	181
Barometric Pressure (in. of Hg)	29.65	29.44	29.53	29.51	29.43	29.49	29.55	29.63	29.55	29.46	29.54	29.45
Inlet Air Properties [Average (Std Dev)]												
Dry Bulb Temperature (°F)	80.1 (0.1)	80.0 (0.3)	90.1 (0.2)	89.9 (0.8)	90.0 (0.3)	90.0 (0.5)	91.0 (0.3)	100.0 (1.0)	100.0 (0.4)	100.0 (0.6)	110.5 (0.9)	109.8 (0.6)
Dew Point Temperature (°F)	56.6 (0.8)	65.4 (0.4)	49.5 (0.2)	60.2 (2.3)	69.1 (0.6)	68.7 (0.2)	57.6 (0.7)	40.3 (1.1)	53.8 (1.0)	64.5 (1.1)	46.4 (0.3)	58.8 (0.9)
Wet Bulb Temperature (°F)	65.0 (0.4)	69.9 (0.3)	65.0 (0.1)	69.9 (1.3)	74.9 (0.4)	74.8 (0.2)	68.9 (0.4)	65.0 (0.4)	69.9 (0.5)	75.0 (0.6)	70.1 (0.3)	74.8 (0.4)
Wet Bulb Depression (°F)	15.1	10.1	25.1	20.0	15.0	15.3	22.1	35.0	30.1	25.0	40.4	35.1
Relative Humidity (%)	44.6	60.9	25.0	37.0	50.4	49.7	32.6	13.0	21.6	31.6	12.0	19.3
Supply Air Properties												
Dry Bulb Temperature (°F)	64.1 (0.4)	69.5 (0.3)	62.5 (0.1)	68.4 (1.3)	74.0 (0.4)	73.7 (0.1)	67.0 (0.4)	61.6 (0.3)	67.2 (0.5)	72.8 (0.6)	65.6 (0.1)	71.6 (0.5)
Dew Point Temperature (°F)	62.9 (0.5)	68.7 (0.4)	60.9 (0.1)	67.1 (1.5)	73.1 (0.5)	72.5 (0.2)	65.6 (0.5)	58.9 (0.4)	65.4 (0.5)	71.4 (0.6)	63.5 (0.2)	69.7 (0.5)
Wet Bulb Temperature (°F)	63.3 (0.4)	68.9 (0.4)	61.5 (0.1)	67.5 (1.4)	73.3 (0.5)	72.8 (0.2)	66.1 (0.4)	59.9 (0.4)	66.0 (0.5)	71.8 (0.6)	64.2 (0.2)	70.3 (0.5)
Relative Humidity (%)	95.8	97.2	94.7	95.8	96.9	96.0	95.3	91.0	94.2	95.3	92.9	93.6
External Resistance (IW)	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**
Interstage Air Temperature (°F) - estimated [1]	75.1	76.7	79.8	82.1	83.9	82.9	81.9	85.3	87.4	88.4	91.5	93.6
Exhaust Air Properties												
Indirect Out Dry Bulb Temperature (°F)	69.3 (0.3)	72.6 (0.3)	71.7 (0.2)	74.9 (1.0)	78.3 (0.3)	78.1 (0.2)	74.4 (0.3)	74.2 (0.4)	76.8 (0.4)	80.1 (0.4)	79.5 (0.3)	82.1 (0.4)
Dew Point Temperature (°F)	66.9 (0.4)	71.1 (0.3)	67.7 (0.2)	73.5 (1.2)	76.3 (0.3)	76.1 (0.2)	70.5 (0.3)	68.3 (0.3)	71.9 (0.4)	76.7 (0.6)	73.0 (0.2)	76.5 (0.4)
Wet Bulb Temperature (°F)	67.6 (0.3)	71.5 (0.3)	68.9 (0.1)	73.8 (1.0)	76.8 (0.3)	76.6 (0.1)	71.7 (0.3)	70.1 (0.3)	73.3 (0.4)	77.5 (0.5)	74.8 (0.2)	77.9 (0.4)
Relative Humidity (%)	91.9	95.1	87.0	95.6	93.6	93.6	87.8	81.9	84.9	89.3	80.7	83.3
Condenser Out Dry Bulb Temperature (°F)	69.9	73.4	72.4	75.7	79.2	79.4	75.1	74.6	77.3	82.1	80.9	83.8
Water Properties												
Basin Temperature (°F)	65.9	70.9	66.1	70.6	75.6	74.5	69.0	65.6	70.2	75.1	69.4	73.8
Makeup Water Flow (gph)	0.9	0.5	1.8	1.9	1.3	0.4	2.9	3.7	3.6	2.2	3.8	3.6
Power Consumption												
Voltage (V)	117	117	118	117	117	117	118	118	118	117	118	118
Current (A)	6.1	6.1	6.1	6.0	6.0	6.1	6.1	6.1	6.1	6.0	6.1	6.1
Power (W)	535 (0.6)	535 (0.8)	535 (3.3)	530 (0.9)	529 (0.9)	534 (1.0)	536 (1.4)	539 (2.4)	536 (1.2)	527 (3.0)	536 (1.4)	533 (1.6)
Power Factor	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.74	0.75	0.76	0.74	0.75
Performance												
Dry Bulb Temperature Drop (°F)	15.9	10.6	27.6	21.5	16.0	16.3	24.0	38.4	32.8	27.1	44.9	38.2
Dew Point Temperature Rise (°F)	6.3	3.3	11.4	7.0	4.0	3.8	8.1	18.6	11.6	6.9	17.1	10.9
Wet-Bulb Effectiveness (%)	105.6	104.0	109.9	107.7	106.2	106.8	108.5	109.7	108.9	108.6	111.2	108.9
Supply Airflow Rate (CFM)	573	583	606	556	573	539	564	544	549	521	557	534
Room Capacity (tons; 80°F reference)	0.82	0.55	0.96	0.58	0.30	0.30	0.66	0.91	0.63	0.33	0.72	0.40
Room EER (Btu/Wh, 80°F reference)	18.4	12.2	21.5	13.1	6.9	6.7	14.7	20.3	14.1	7.5	16.1	8.9
CA T-20 ECER (Btu/Wh) [2]	-	-	16.9	-	-	-	-	15.3	15.1	14.4	16.3	15.0
Sensible Cooling of Outside Air (tons)	0.83	0.55	1.51	1.07	0.81	0.78	1.21	1.90	1.61	1.25	2.25	1.81
Outside Air EER (Btu/Wh)	18.5	12.3	33.9	24.2	18.3	17.4	27.1	42.2	36.1	28.4	50.3	40.7

[1] Calculated interstage temperature is the intersection of the intake dew point and the supply wet bulb.

[2] ECER can only be derived when the supply resistance is 0.3" and the intake wet-bulb depression is >=25°F

Table 5: OASys™ Test Data (Continued)

Test Summary Information	DX Off - Variable Resistance														
General															
Date (2009)	26-Mar	26-Mar	26-Mar	26-Mar	26-Mar	25-Mar	25-Mar	25-Mar	25-Mar	25-Mar	27-Mar	27-Mar	27-Mar	27-Mar	27-Mar
Start Time	11:14a	11:50a	12:06p	12:52p	1:31p	3:13p	3:54p	4:09p	4:21p	4:54p	10:50a	11:27a	11:50a	1:05p	1:40p
Duration (minutes)	30	10	10	30	10	30	10	10	30	10	26	10	30	30	5
Samples	181	61	61	181	61	181	61	61	181	61	157	61	181	181	31
Barometric Pressure (in. of Hg)	29.58	29.57	29.56	29.55	29.54	29.60	29.60	29.60	29.60	29.58	29.57	29.56	29.56	29.55	29.54
Inlet Air Properties [Average (Std Dev)]															
Dry Bulb Temperature (°F)	91.2 (0.6)	90.9 (0.5)	90.9 (0.2)	91.0 (0.3)	90.9 (0.3)	95.1 (0.2)	94.9 (0.7)	95.0 (0.6)	95.1 (0.7)	95.0 (0.8)	100.0 (0.4)	100.0 (0.3)	99.9 (0.4)	100.0 (0.4)	100.2 (0.3)
Dew Point Temperature (°F)	57.5 (0.9)	57.0 (0.3)	57.7 (0.7)	57.6 (0.7)	57.2 (0.3)	50.5 (0.4)	50.5 (0.1)	50.4 (0.5)	50.6 (0.4)	51.0 (0.2)	53.8 (0.2)	53.7 (0.2)	53.8 (0.2)	53.8 (1.0)	54.8 (0.5)
Wet Bulb Temperature (°F)	68.9 (0.6)	68.6 (0.1)	68.9 (0.3)	68.9 (0.4)	68.7 (0.2)	67.0 (0.2)	66.9 (0.2)	66.9 (0.3)	67.0 (0.3)	67.1 (0.2)	69.8 (0.2)	69.8 (0.2)	69.8 (0.2)	69.9 (0.5)	70.3 (0.3)
Wet Bulb Depression (°F)	22.3	22.3	22.0	22.1	22.2	28.1	28.0	28.1	28.1	27.8	30.2	30.2	30.1	30.1	29.9
Relative Humidity (%)	32.3	32.0	32.8	32.6	32.2	22.2	22.3	22.1	22.2	22.6	21.5	21.5	21.6	21.6	22.2
Supply Air Properties															
Dry Bulb Temperature (°F)	68.4 (0.6)	67.5 (0.2)	67.4 (0.4)	67.0 (0.4)	66.7 (0.2)	66.3 (0.2)	65.5 (0.1)	64.9 (0.2)	64.7 (0.3)	64.4 (0.2)	69.0 (0.2)	67.9 (0.1)	67.4 (0.2)	67.2 (0.5)	67.4 (0.2)
Dew Point Temperature (°F)	66.5 (0.6)	65.7 (0.2)	65.8 (0.4)	65.6 (0.5)	65.3 (0.2)	63.6 (0.2)	62.9 (0.2)	62.6 (0.3)	62.5 (0.3)	62.4 (0.2)	66.6 (0.2)	65.9 (0.1)	65.6 (0.1)	65.4 (0.5)	65.8 (0.2)
Wet Bulb Temperature (°F)	67.1 (0.6)	66.3 (0.2)	66.3 (0.4)	66.1 (0.4)	65.7 (0.2)	64.5 (0.2)	63.8 (0.1)	63.4 (0.3)	63.3 (0.3)	63.1 (0.2)	67.3 (0.2)	66.5 (0.1)	66.2 (0.1)	66.0 (0.5)	66.3 (0.2)
Relative Humidity (%)	93.8	94.2	94.8	95.3	95.2	91.0	91.2	92.4	92.9	93.3	92.3	93.0	93.9	94.2	94.5
External Resistance (IW)	**0.00**	**0.10**	**0.20**	**0.30**	**0.39**	**0.00**	**0.10**	**0.20**	**0.30**	**0.40**	**0.00**	**0.10**	**0.20**	**0.30**	**0.38**
Interstage Air Temperature (°F) - estimated [1]	85.2	83.5	82.5	81.9	81.4	87.3	85.2	84.3	83.5	82.6	91.8	89.3	88.1	87.4	87.1
Exhaust Air Properties															
Indirect Out Dry Bulb Temperature (°F)	80.9 (0.5)	78.1 (0.3)	76.0 (0.3)	74.4 (0.3)	73.1 (0.2)	80.1 (0.2)	77.7 (0.3)	75.9 (0.2)	74.2 (0.3)	72.7 (0.2)	84.9 (0.3)	81.4 (0.2)	78.8 (0.2)	76.8 (0.4)	75.9 (0.1)
Dew Point Temperature (°F)	76.1 (0.6)	73.8 (0.2)	72.0 (0.3)	70.5 (0.3)	69.9 (0.2)	74.9 (0.6)	73.5 (0.2)	72.0 (0.2)	69.9 (0.4)	68.7 (0.2)	79.1 (0.3)	76.2 (0.1)	73.5 (0.2)	71.9 (0.4)	71.3 (0.1)
Wet Bulb Temperature (°F)	77.4 (0.5)	74.9 (0.2)	73.1 (0.3)	71.7 (0.3)	70.9 (0.2)	76.3 (0.4)	74.7 (0.2)	73.1 (0.2)	71.2 (0.3)	69.9 (0.2)	80.4 (0.3)	77.5 (0.1)	74.9 (0.1)	73.3 (0.4)	72.6 (0.1)
Relative Humidity (%)	85.5	86.7	87.4	87.8	89.8	84.2	87.0	87.6	86.6	87.3	82.8	84.1	83.9	84.9	85.7
Condenser Out Dry Bulb Temperature (°F)	80.8	78.0	76.2	75.1	74.2	81.6	79.2	76.6	75.3	73.9	84.8	81.3	78.8	77.3	76.7
Water Properties															
Basin Temperature (°F)	70.9	70.1	69.4	69.0	68.1	70.3	69.6	68.4	67.5	66.6	73.1	71.8	70.8	70.2	69.7
Makeup Water Flow (gph)	2.6	1.9	2.7	2.9	3.4	3.7	3.7	3.8	4.2	4.6	3.3	3.6	3.4	3.6	3.9
Power Consumption															
Voltage (V)	117	118	118	118	118	118	118	118	118	118	117	117	118	118	118
Current (A)	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.2	6.0	6.0	6.1	6.1	6.1
Power (W)	530 (2.5)	536 (0.8)	537 (0.6)	536 (1.4)	537 (0.6)	532 (2.2)	535 (0.7)	536 (0.6)	538 (1.8)	540 (0.8)	529 (1.6)	530 (0.6)	536 (1.7)	536 (1.2)	536 (0.7)
Power Factor	0.75	0.74	0.74	0.75	0.75	0.74	0.74	0.74	0.74	0.74	0.75	0.75	0.74	0.75	0.75
Performance															
Dry Bulb Temperature Drop (°F)	22.8	23.5	23.6	24.0	24.2	28.8	29.4	30.1	30.5	30.6	31.1	32.0	32.5	32.8	32.8
Dew Point Temperature Rise (°F)	9.0	8.7	8.1	8.1	8.1	13.0	12.4	12.3	11.9	11.5	12.8	12.2	11.8	11.6	11.0
Wet-Bulb Effectiveness (%)	102.5	105.1	107.1	108.5	109.0	102.6	105.0	107.1	108.5	109.8	103.0	106.1	107.9	108.9	109.6
Supply Airflow Rate (CFM)	1,058	877	713	564	427	1,037	888	735	586	430	1,045	861	699	549	422
Room Capacity (tons; 80°F reference)	1.10	0.99	0.81	0.66	0.51	1.28	1.16	1.00	0.81	0.60	1.03	0.93	0.79	0.63	0.47
Room EER (Btu/Wh, 80°F reference)	25.0	22.1	18.1	14.7	11.4	28.8	25.9	22.3	18.0	13.4	23.4	21.1	17.6	14.1	10.6
CA T-20 ECER (Btu/Wh) [2]	-	-	-	-	-	-	-	-	15.9	-	-	-	-	15.1	-
Sensible Cooling of Outside Air (tons)	2.16	1.84	1.51	1.21	0.93	2.68	2.35	1.99	1.61	1.18	2.90	2.47	2.04	1.61	1.24
Outside Air EER (Btu/Wh)	48.9	41.3	33.6	27.1	20.7	60.4	52.5	44.4	35.8	26.2	65.7	55.9	45.5	36.1	27.7

[1] Calculated interstage temperature is the intersection of the intake dew point and the supply wet bulb.

[2] ECER can only be derived when the supply resistance is 0.3" and the intake wet-bulb depression is >=25°F

Table 5: OASys™ Test Data (Continued)

Test Summary Information	DX On - 0 IW Resistance										
General											
Date (2009)	31-Mar	2-Apr	1-Apr	31-Mar	7-Apr	26-Mar	30-Mar	27-Mar	6-Apr	3-Apr	3-Apr
Start Time	1:02p	12:44p	12:59p	4:24p	11:33a	3:06p	1:47p	3:35p	3:33p	10:21a	2:07p
Duration (minutes)	30	30	30	20	30	30	30	30	30	30	30
Samples	181	181	181	121	181	181	181	181	181	181	181
Barometric Pressure (in. of Hg)	29.61	29.47	29.52	29.52	29.49	29.50	29.61	29.51	29.48	29.52	29.47
Inlet Air Properties [Average (Std Dev)]											
Dry Bulb Temperature (°F)	82.4 (0.2)	80.3 (0.3)	90.0 (0.1)	89.8 (0.4)	90.0 (0.2)	91.0 (0.3)	100.0 (0.9)	100.1 (0.4)	100.0 (0.2)	110.0 (0.8)	110.1 (1.4)
Dew Point Temperature (°F)	56.8 (1.0)	65.5 (0.9)	49.8 (0.2)	60.3 (0.6)	69.6 (0.2)	57.6 (0.8)	40.3 (1.4)	54.2 (0.5)	64.4 (0.3)	45.9 (1.4)	59.1 (0.9)
Wet Bulb Temperature (°F)	65.9 (0.6)	70.1 (0.6)	65.0 (0.1)	69.9 (0.3)	75.3 (0.1)	68.9 (0.5)	65.0 (0.5)	70.0 (0.3)	75.0 (0.2)	69.8 (0.7)	75.0 (0.5)
Wet Bulb Depression (°F)	16.6	10.2	25.0	19.9	14.7	22.1	35.1	30.1	25.1	40.2	35.2
Relative Humidity (%)	41.7	60.8	25.2	37.2	51.3	32.6	12.9	21.8	31.5	12.0	19.4
Supply Air Properties											
Dry Bulb Temperature (°F)	62.6 (0.6)	67.4 (0.6)	61.2 (0.1)	66.4 (0.4)	72.3 (0.1)	65.1 (0.5)	60.5 (0.4)	65.8 (0.3)	71.5 (0.2)	64.6 (0.5)	70.3 (0.4)
Dew Point Temperature (°F)	61.6 (0.6)	66.7 (0.6)	59.7 (0.1)	65.2 (0.4)	71.3 (0.2)	64.0 (0.5)	58.2 (0.4)	64.3 (0.3)	70.0 (0.2)	62.4 (0.6)	68.6 (0.5)
Wet Bulb Temperature (°F)	61.9 (0.6)	66.9 (0.6)	60.2 (0.1)	65.6 (0.4)	71.6 (0.1)	64.4 (0.5)	59.0 (0.4)	64.8 (0.3)	70.5 (0.2)	63.2 (0.6)	69.1 (0.5)
Relative Humidity (%)	96.5	97.4	94.7	96.1	96.5	96.4	92.1	94.8	95.0	92.8	94.4
External Resistance (IW)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Interstage Air Temperature (°F) - estimated [1]	77.1	77.1	81.9	83.4	85.4	83.9	87.4	90.1	91.9	96.0	98.6
Exhaust Air Properties											
Indirect Out Dry Bulb Temperature (°F)	73.1 (0.4)	74.2 (0.4)	76.0 (0.2)	78.1 (0.3)	80.9 (0.1)	77.3 (0.4)	80.0 (0.6)	81.7 (0.4)	84.5 (0.2)	86.8 (0.4)	88.7 (0.4)
Dew Point Temperature (°F)	69.9 (0.4)	72.3 (0.5)	71.5 (0.1)	79.6 (1.1)	78.7 (0.1)	75.3 (0.5)	73.8 (0.4)	77.3 (0.3)	79.7 (0.2)	78.6 (0.4)	82.2 (0.4)
Wet Bulb Temperature (°F)	70.8 (0.4)	72.8 (0.5)	72.7 (0.1)	78.1 (0.3)	79.2 (0.1)	75.8 (0.4)	75.4 (0.4)	78.4 (0.2)	80.9 (0.2)	80.6 (0.4)	83.7 (0.4)
Relative Humidity (%)	89.4	93.9	85.9	100.0	93.1	93.5	81.3	86.5	85.6	76.7	81.3
Condenser Out Dry Bulb Temperature (°F)	92.7	95.3	96.1	98.6	103.0	98.7	100.3	103.2	107.0	108.6	110.9
Water Properties											
Basin Temperature (°F)	68.0	71.3	67.9	71.6	76.0	70.4	67.9	72.4	76.6	71.4	75.2
Makeup Water Flow (gph)	0.9	0.0	2.1	1.6	0.0	2.4	4.1	3.4	1.8	4.6	3.7
Power Consumption											
Voltage (V)	119	119	119	118	119	119	119	118	119	119	119
Current (A)	17.1	17.9	17.5	17.9	19.0	18.2	17.8	18.4	19.2	18.8	19.2
Power (W)	537 (0.7)	540 (0.7)	543 (2.0)	535 (0.7)	540 (0.7)	547 (3.0)	545 (1.8)	542 (2.4)	540 (2.3)	540 (2.1)	541 (2.1)
Power Factor	0.87	0.88	0.87	0.88	0.88	0.87	0.87	0.88	0.88	0.88	0.88
Perfomance											
Dry Bulb Temperature Drop (°F)	19.8	12.9	28.8	23.5	17.6	25.9	39.5	34.3	28.5	45.4	39.8
Dew Point Temperature Rise (°F)	4.8	1.2	9.9	5.0	1.7	6.4	17.9	10.1	5.6	16.5	9.5
Wet-Bulb Effectiveness (%)	119.7	125.9	115.3	117.7	120.1	117.2	112.8	113.9	113.7	113.0	113.3
Supply Airflow Rate (CFM)	948	950	992	929	914	956	945	941	906	943	922
Room Capacity (tons; 80°F reference)	1.49	1.07	1.68	1.13	0.62	1.28	1.68	1.20	0.68	1.31	0.80
Room EER (Btu/Wh, 80°F reference)	10.1	6.9	11.2	7.3	3.7	8.1	10.9	7.5	4.1	8.0	4.7
CA T-20 ECER (Btu/Wh) [2]	-	-	-	-	-	-	-	-	-	-	-
Sensible Cooling of Outside Air (tons)	1.70	1.09	2.58	1.95	1.43	2.22	3.39	2.89	2.29	3.85	3.26
Outside Air EER (Btu/Wh)	11.5	7.0	17.2	12.6	8.6	14.1	22.1	18.1	13.6	23.5	19.5

[1] Calculated interstage temperature is the intersection of the intake dew point and the supply wet bulb.

[2] ECER can only be derived when the supply resistance is 0.3" and the intake wet-bulb depression is >=25°F

Table 5: OASys™ Test Data (Continued)

Test Summary Information	DX On - 0.3 IW Resistance										
General											
Date (2009)	31-Mar	2-Apr	1-Apr	31-Mar	7-Apr	26-Mar	30-Mar	27-Mar	6-Apr	3-Apr	3-Apr
Start Time	2:02p	1:24p	1:48p	3:46p	10:55a	2:13p	2:41p	1:51p	4:11p	11:03a	12:17p
Duration (minutes)	30	30	30	30	30	15	30	30	30	30	30
Samples	181	181	181	181	181	91	181	181	181	181	181
Barometric Pressure (in. of Hg)	29.59	29.46	29.50	29.54	29.49	29.53	29.60	29.54	29.47	29.52	29.49
Inlet Air Properties [Average (Std Dev)]											
Dry Bulb Temperature (°F)	80.2 (0.3)	79.9 (0.4)	89.9 (0.3)	90.1 (0.5)	90.0 (0.2)	91.0 (0.3)	100.1 (0.8)	100.0 (0.5)	100.0 (0.2)	110.0 (1.3)	110.0 (0.7)
Dew Point Temperature (°F)	56.8 (0.5)	65.5 (0.4)	50.1 (0.9)	60.5 (1.1)	69.4 (0.2)	57.5 (0.8)	40.2 (1.3)	54.3 (0.2)	64.8 (0.6)	46.1 (1.7)	59.2 (0.2)
Wet Bulb Temperature (°F)	65.1 (0.3)	70.0 (0.3)	65.2 (0.4)	70.1 (0.6)	75.2 (0.1)	68.9 (0.5)	65.0 (0.4)	70.0 (0.2)	75.1 (0.3)	69.9 (0.9)	75.0 (0.2)
Wet Bulb Depression (°F)	15.1	9.9	24.8	20.0	14.8	22.2	35.1	30.0	24.9	40.1	35.0
Relative Humidity (%)	44.8	61.6	25.7	37.3	50.9	32.5	12.9	21.9	31.9	12.0	19.5
Supply Air Properties											
Dry Bulb Temperature (°F)	59.4 (0.3)	65.2 (0.4)	58.3 (0.5)	64.1 (0.7)	70.1 (0.2)	62.1 (0.5)	56.5 (0.4)	62.7 (0.1)	69.1 (0.3)	61.1 (0.8)	67.3 (0.1)
Dew Point Temperature (°F)	58.6 (0.3)	64.7 (0.4)	57.2 (0.5)	63.1 (0.8)	69.2 (0.2)	61.1 (0.5)	54.7 (0.5)	61.3 (0.2)	67.8 (0.4)	59.6 (0.8)	66.2 (0.1)
Wet Bulb Temperature (°F)	58.9 (0.3)	64.9 (0.4)	57.6 (0.5)	63.5 (0.8)	69.5 (0.2)	61.4 (0.5)	55.4 (0.4)	61.8 (0.1)	68.2 (0.4)	60.2 (0.8)	66.6 (0.1)
Relative Humidity (%)	97.1	98.0	96.3	96.7	96.9	96.6	93.8	95.2	95.7	94.9	96.1
External Resistance (IW)	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**
Interstage Air Temperature (°F) - estimated [1]	73.6	75.8	78.9	81.5	83.9	81.3	83.0	86.6	89.4	91.2	94.6
Exhaust Air Properties											
Indirect Out Dry Bulb Temperature (°F)	68.4 (0.2)	71.9 (0.3)	70.0 (0.3)	73.9 (0.6)	77.5 (0.1)	72.9 (0.4)	71.4 (0.4)	75.2 (0.2)	78.9 (0.3)	76.3 (0.8)	80.0 (0.2)
Dew Point Temperature (°F)	66.7 (0.3)	70.2 (0.3)	66.4 (0.5)	75.0 (1.6)	75.7 (0.1)	76.1 (1.9)	66.2 (0.4)	70.6 (0.2)	75.7 (0.3)	70.3 (0.7)	75.2 (0.2)
Wet Bulb Temperature (°F)	67.2 (0.3)	70.7 (0.3)	67.6 (0.4)	73.8 (0.6)	76.2 (0.1)	72.9 (0.4)	67.8 (0.4)	71.9 (0.1)	76.5 (0.3)	72.1 (0.7)	76.4 (0.2)
Relative Humidity (%)	94.2	94.5	88.3	100.0	94.2	100.0	83.6	85.8	89.9	81.8	85.4
Condenser Out Dry Bulb Temperature (°F)	83.6	88.9	85.8	90.1	96.5	88.8	86.7	91.8	97.5	93.7	99.2
Water Properties											
Basin Temperature (°F)	65.6	70.1	65.5	70.1	74.8	68.0	63.9	68.8	74.8	68.2	72.7
Makeup Water Flow (gph)	1.5	0.7	2.8	2.1	0.1	3.3	4.6	4.2	2.1	4.5	3.5
Power Consumption											
Voltage (V)	119	119	119	119	119	119	119	119	119	119	118
Current (A)	16.0	16.9	16.2	16.9	18.0	16.9	16.1	17.1	17.8	16.9	17.8
Power (W)	540 (0.9)	541 (0.8)	544 (2.2)	541 (0.7)	542 (0.6)	546 (1.8)	547 (2.1)	544 (2.0)	539 (0.9)	541 (1.9)	540 (1.6)
Power Factor	0.86	0.87	0.86	0.86	0.88	0.86	0.85	0.87	0.87	0.87	0.87
Performance											
Dry Bulb Temperature Drop (°F)	20.8	14.7	31.7	26.0	19.9	29.0	43.6	37.4	30.9	48.9	42.7
Dew Point Temperature Rise (°F)	1.8	-0.9	7.1	2.7	-0.3	3.6	14.5	7.0	3.1	13.6	7.0
Wet-Bulb Effectiveness (%)	137.8	147.5	127.8	130.1	134.4	130.6	124.1	124.6	124.1	121.8	121.9
Supply Airflow Rate (CFM)	446	454	483	441	419	430	418	418	414	426	404
Room Capacity (tons; 80°F reference)	0.83	0.60	0.95	0.63	0.37	0.70	0.90	0.65	0.40	0.73	0.46
Room EER (Btu/Wh, 80°F reference)	6.2	4.1	7.0	4.4	2.4	4.8	6.6	4.5	2.6	5.0	3.0
CA T-20 ECER (Btu/Wh) [2]	-	-	5.7	-	-	-	4.9	4.5	4.2	4.6	4.0
Sensible Cooling of Outside Air (tons)	0.84	0.60	1.39	1.03	0.74	1.12	1.67	1.41	1.14	1.88	1.54
Outside Air EER (Btu/Wh)	6.2	4.1	10.1	7.1	4.7	7.8	12.2	9.6	7.4	13.0	10.1

[1] Calculated interstage temperature is the intersection of the intake dew point and the supply wet bulb.

[2] ECER can only be derived when the supply resistance is 0.3" and the intake wet-bulb depression is >=25°F

Table 5: OASys™ Test Data (Continued)

Test Summary Information	DX On - Variable Resistance													
General														
Date (2009)	26-Mar	26-Mar	26-Mar	26-Mar	26-Mar	30-Mar	30-Mar	30-Mar	30-Mar	27-Mar	27-Mar	27-Mar	27-Mar	27-Mar
Start Time	3:06p	2:55p	2:36p	2:13p	1:48p	5:09p	4:46p	4:12p	3:35p	3:35p	3:02p	2:29p	1:51p	4:13p
Duration (minutes)	30	10	10	15	20	20	20	30	30	30	30	20	30	10
Samples	181	61	61	91	121	121	121	181	181	181	181	121	181	61
Barometric Pressure (in. of Hg)	29.50	29.51	29.52	29.53	29.53	29.58	29.58	29.58	29.59	29.51	29.52	29.53	29.54	29.51
Inlet Air Properties [Average (Std Dev)]														
Dry Bulb Temperature (°F)	91.0 (0.3)	91.2 (0.3)	90.8 (0.1)	91.0 (0.3)	90.9 (0.4)	95.0 (0.2)	95.1 (0.3)	95.0 (0.4)	95.0 (0.5)	100.1 (0.4)	99.9 (0.7)	100.0 (0.4)	100.0 (0.5)	100.1 (0.5)
Dew Point Temperature (°F)	57.6 (0.8)	58.3 (0.1)	57.2 (0.2)	57.5 (0.8)	57.8 (0.9)	50.5 (0.5)	50.5 (0.5)	50.6 (0.6)	50.6 (0.5)	54.2 (0.5)	53.7 (1.1)	54.2 (0.7)	54.3 (0.2)	54.1 (0.5)
Wet Bulb Temperature (°F)	68.9 (0.5)	69.3 (0.1)	68.7 (0.1)	68.9 (0.5)	69.0 (0.4)	67.0 (0.2)	67.0 (0.2)	67.0 (0.3)	67.0 (0.3)	70.0 (0.3)	69.8 (0.6)	70.0 (0.4)	70.0 (0.2)	70.0 (0.3)
Wet Bulb Depression (°F)	22.1	21.9	22.2	22.2	21.9	28.1	28.1	28.0	28.0	30.1	30.1	30.0	30.0	30.1
Relative Humidity (%)	32.6	33.3	32.4	32.5	32.9	22.2	22.1	22.3	22.3	21.8	21.6	21.9	21.9	21.8
Supply Air Properties														
Dry Bulb Temperature (°F)	65.1 (0.5)	64.6 (0.1)	62.8 (0.1)	62.1 (0.5)	62.0 (0.5)	62.6 (0.2)	61.5 (0.3)	60.7 (0.3)	59.6 (0.3)	65.8 (0.3)	64.4 (0.6)	63.6 (0.4)	62.7 (0.1)	62.3 (0.2)
Dew Point Temperature (°F)	64.0 (0.5)	63.7 (0.1)	61.9 (0.1)	61.1 (0.5)	61.1 (0.5)	61.1 (0.2)	60.2 (0.3)	59.3 (0.4)	58.2 (0.3)	64.3 (0.3)	63.0 (0.6)	62.1 (0.4)	61.3 (0.2)	61.1 (0.2)
Wet Bulb Temperature (°F)	64.4 (0.5)	64.0 (0.1)	62.2 (0.1)	61.4 (0.5)	61.4 (0.5)	61.6 (0.2)	60.7 (0.3)	59.8 (0.3)	58.7 (0.3)	64.8 (0.3)	63.5 (0.6)	62.6 (0.4)	61.8 (0.1)	61.5 (0.2)
Relative Humidity (%)	96.4	96.7	96.7	96.6	96.9	94.8	95.3	95.3	95.2	94.8	95.3	95.1	95.2	95.8
External Resistance (IW)	**0.00**	**0.10**	**0.20**	**0.30**	**0.33**	**0.00**	**0.10**	**0.20**	**0.30**	**0.00**	**0.10**	**0.20**	**0.30**	**0.32**
Interstage Air Temperature (°F) - estimated [1]	83.9	83.2	81.8	81.3	81.2	85.5	84.2	83.1	82.2	90.1	88.5	87.5	86.6	86.4
Exhaust Air Properties														
Indirect Out Dry Bulb Temperature (°F)	77.3 (0.4)	76.2 (0.1)	73.8 (0.1)	72.9 (0.4)	72.7 (0.4)	78.8 (0.3)	76.2 (0.4)	73.9 (0.3)	72.1 (0.3)	81.7 (0.4)	78.6 (0.5)	76.7 (0.3)	75.2 (0.2)	75.0 (0.2)
Dew Point Temperature (°F)	75.3 (0.5)	77.4 (1.2)	75.6 (2.0)	76.1 (1.9)	71.3 (2.2)	74.3 (0.2)	72.2 (0.2)	70.3 (0.3)	68.1 (0.3)	77.3 (0.3)	74.4 (0.5)	72.3 (0.2)	70.6 (0.2)	70.8 (0.1)
Wet Bulb Temperature (°F)	75.8 (0.4)	76.1 (0.2)	73.8 (0.1)	72.9 (0.4)	71.5 (1.3)	75.5 (0.2)	73.3 (0.2)	71.3 (0.2)	69.3 (0.2)	78.4 (0.2)	75.5 (0.5)	73.5 (0.2)	71.9 (0.1)	72.0 (0.1)
Relative Humidity (%)	93.5	100.0	100.0	100.0	95.2	86.0	87.7	88.8	87.3	86.5	86.9	86.2	85.8	86.6
Condenser Out Dry Bulb Temperature (°F)	98.7	94.5	91.0	88.8	88.1	98.3	93.7	90.7	87.8	103.2	97.4	94.1	91.8	91.3
Water Properties														
Basin Temperature (°F)	70.4	69.9	68.4	68.0	68.0	68.9	67.9	66.9	65.9	72.4	70.9	69.8	68.8	68.9
Makeup Water Flow (gph)	2.4	2.2	2.4	3.3	4.1	2.8	2.5	2.9	3.4	3.4	3.3	3.4	4.2	4.0
Power Consumption														
Voltage (V)	119	119	119	119	119	119	119	119	119	118	119	119	119	119
Current (A)	18.2	17.8	17.2	16.9	16.9	17.6	17.1	16.8	16.4	18.4	17.8	17.3	17.1	16.8
Power (W)	547 (3.0)	546 (2.6)	546 (1.8)	546 (1.8)	545 (2.0)	546 (1.8)	546 (2.0)	545 (1.5)	545 (1.1)	542 (2.4)	547 (1.7)	544 (2.0)	544 (2.0)	543 (2.1)
Power Factor	0.87	0.87	0.86	0.86	0.86	0.87	0.87	0.86	0.86	0.88	0.87	0.87	0.87	0.86
Performance														
Dry Bulb Temperature Drop (°F)	25.9	26.5	28.0	29.0	28.9	32.4	33.5	34.3	35.5	34.3	35.5	36.4	37.4	37.8
Dew Point Temperature Rise (°F)	6.4	5.3	4.6	3.6	3.3	10.6	9.7	8.7	7.6	10.1	9.3	7.9	7.0	6.9
Wet-Bulb Effectiveness (%)	117.2	121.4	126.3	130.6	131.9	115.5	119.3	122.6	126.5	113.9	117.9	121.5	124.6	125.7
Supply Airflow Rate (CFM)	956	765	589	430	391	933	752	584	420	941	754	574	418	386
Room Capacity (tons; 80°F reference)	1.28	1.06	0.91	0.70	0.64	1.47	1.26	1.02	0.78	1.20	1.06	0.85	0.65	0.62
Room EER (Btu/Wh, 80°F reference)	8.1	6.9	6.2	4.8	4.4	9.7	8.6	7.2	5.6	7.5	6.9	5.7	4.5	4.3
CA T-20 ECER (Btu/Wh) [2]	-	-	-	-	-	-	-	-	4.9	-	-	-	4.5	-
Sensible Cooling of Outside Air (tons)	2.22	1.82	1.48	1.12	1.02	2.73	2.28	1.82	1.35	2.89	2.41	1.88	1.41	1.32
Outside Air EER (Btu/Wh)	14.1	11.9	10.1	7.8	7.1	18.0	15.6	12.7	9.7	18.1	15.7	12.7	9.6	9.2

[1] Calculated interstage temperature is the intersection of the intake dew point and the supply wet bulb.

[2] ECER can only be derived when the supply resistance is 0.3" and the intake wet-bulb depression is >=25°F