ETC Group
ENERGY ENGINEERING FOR A SUSTAINABLE FUTURE

June 11, 2015

Banner Desert Medical Center
1400 S. Dobson Road
Mesa, AZ 85202

DELIVERED VIA EMAIL TO: Sean.Greer@bannerhealth.com; shawn.mathiesen@bannerhealth.com;

RE: ClimaCheck chiller testing Banner Desert

Sean,

Thank you for the opportunity to provide energy services for your chiller plant. We are pleased to present the results from our testing using ClimaCheck on Chillers 3, 5, and 6.

We believe that this effort will result in two things:

- These tests have identified 3 issues that will deliver energy savings immediately to Banner.
- These tests have identified that chillers have lots of issues that justify continued monitoring of their performance. Ongoing monitoring of chiller performance provides the means to identify when chiller performance degrades and, at times, identify the culprit.

We look forward to working with you moving forward to finalize a plan to keep your chiller plant operating at peak efficiency.

Sincerely,

Glen Anderson, P.E.
Sr. Engineer, ETC Group
801-278-1927 x103
ganderson@etcgrp.com

cc: bewaite@msn.com

1 Executive Summary

ETC Group conducted chiller testing using a portable ClimaCheck chiller analyzer at Desert Medical center on chillers 3, 5, and 6. Sections 2 and 3 include details for each measure.

- Measures 1, 2, and 4 have been identified through ClimaCheck and have yet to be implemented
- Measure 3 below was identified because Chiller 6 failed. Banner requested JCI to perform these repairs which occurred after our testing.
    - However, ClimaCheck flagged this chiller as having a high kW/ton. Continuous monitoring of this chiller would have identified the kW/ton remaining high even after fixing measure 4 and the savings potential would justify further analysis from a JCI technician.

Table 1 Desert Chiller Energy Savings Summary

Measure #	Measure Description	Electric Savings			Cost	Electric Payback
		kWh/yr	kW/mo*	$/yr	$	Years
1	Chiller 3 Control Board	124,500	39	$9,960	$2,000	0.2
2	Chiller 3 Maintenance	114,900	36	$9,192	$4,720	0.5
3	Chiller 6 Trigger Board	290,200	91	$23,216	$2,000	0.1
4	Chiller 6 Condenser Flow	37,400	12	$2,992	$1,000	0.3
5	Climacheck tests	0	0	$0	$8,150	
Project Totals		567,000	178	$45,360	$17,870	0.4

** Average Monthly kW.*

2 Important Findings

2.1 Chiller 5 is 10% to 15% More Efficient than Chillers 3 and 6

Chiller 5 tested from 10% to 20% more efficient than the other chillers. The issues identified below provide details for these differences.

2.2 Replace the Chiller 3 Control Board

2.2.1 Issues

Chiller 3 needs an upgraded control board. JCI's technician Jeremiah Yanez stated that chiller 3 has an older control board than chillers 5 and 6. This control board doesn't have the processing speed to maintain a constant leaving chilled water supply temperature.

Chiller 3 operated with a cyclic pattern of its inlet vanes opening and closing on a 7 minute cycle. A chiller modulates its inlet vanes as the first response to maintain a constant leaving chilled water supply temperature. With a constant 47°F leaving chilled water supply temperature set point, the chillers delivered water between 46.5°F and 47.5°F. As the VFD speed remained steady, the inlet vanes cycled from full open to around 85% closed.

2.2.2 Next Steps

Replace the control board on Chiller 3 and ensure its control algorithm is tuned to keep the inlet vanes fully open while slowing down the VFD speed.

JCI's technician estimated the new control board would cost $2,000. Labor for this work is covered with Banner's existing service contract with JCI.

2.3 Chiller 3 Refrigerant Level and Evaporator Tube Fouling

Chiller 3 has two maintenance issues:

- Low refrigerant levels
    - High superheat (~ 4°F) and low sub-cool (~5°F) indicate low refrigerant levels in Chiller 3
    - High approach temp (3.2°F) indicates the evaporator tubes have poor heat transfer (either from scaling or oil on tubes)

2.3.1 Next Steps

- Remove the refrigerant from chiller 3. Weigh the total refrigerant removed and refill the chiller with the required amount.
    - Take a sample of the refrigerant and test for the presence of air and oil.
- During annual maintenance, clean the evaporator barrels.

We estimated the chiller is short 400 lbs of refrigerant and refrigerant costs $7/lb. We included another 16 hours of labor for tube cleaning.

2.4 Chiller 6 Trigger Board Replaced

2.4.1 Issues

During testing, we observed that Chiller 6 operated approximately 21% less efficient than chiller 5. Shortly after our testing, Chiller 6 failed on a “VFD single phase failure”. Since this time, Banner personnel had JCI fix the chiller. The trigger board was malfunctioning. This has been replaced and chiller 6 now operates at the same efficiency as chiller 5.

2.4.2 Next Steps

JCI has already replaced the trigger board. We estimated that this cost Banner $2,000.

2.5 Increase Chiller 6 Condenser Water Flow

2.5.1 Issues

Chiller 6 has the highest condenser refrigerant pressure vs the other chillers. This is because it has the warmest leaving condenser water. All of this is the result of Chiller 6 receiving about 14% less condenser water flow than chillers 3 and 5.

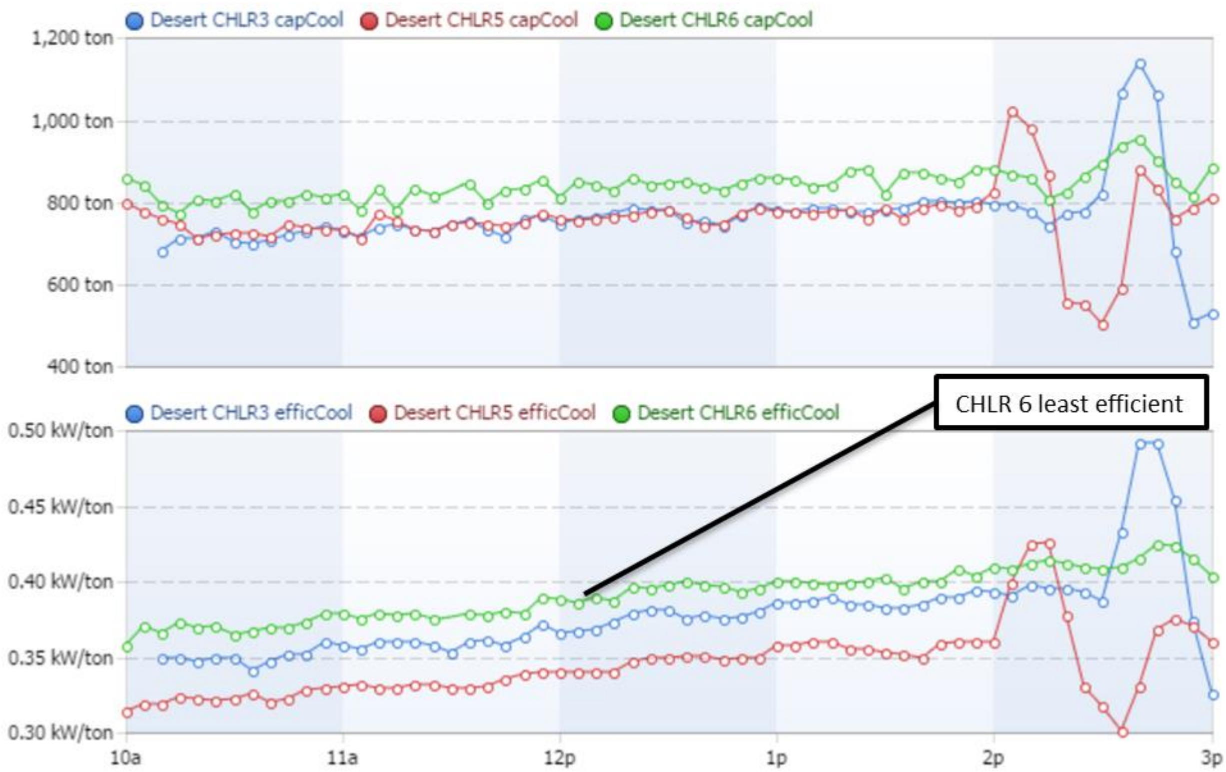
All of these chillers have a modulating valve that controls flow through the condensers to maintain a constant 9°F temperature differential on the water in and out with a minimum flow of 3,100 GPM/chiller. During testing, the actual dT was around 6°F to 7°F which meant the minimum flow measurement was controlling the flow.

2.5.2 Next Steps

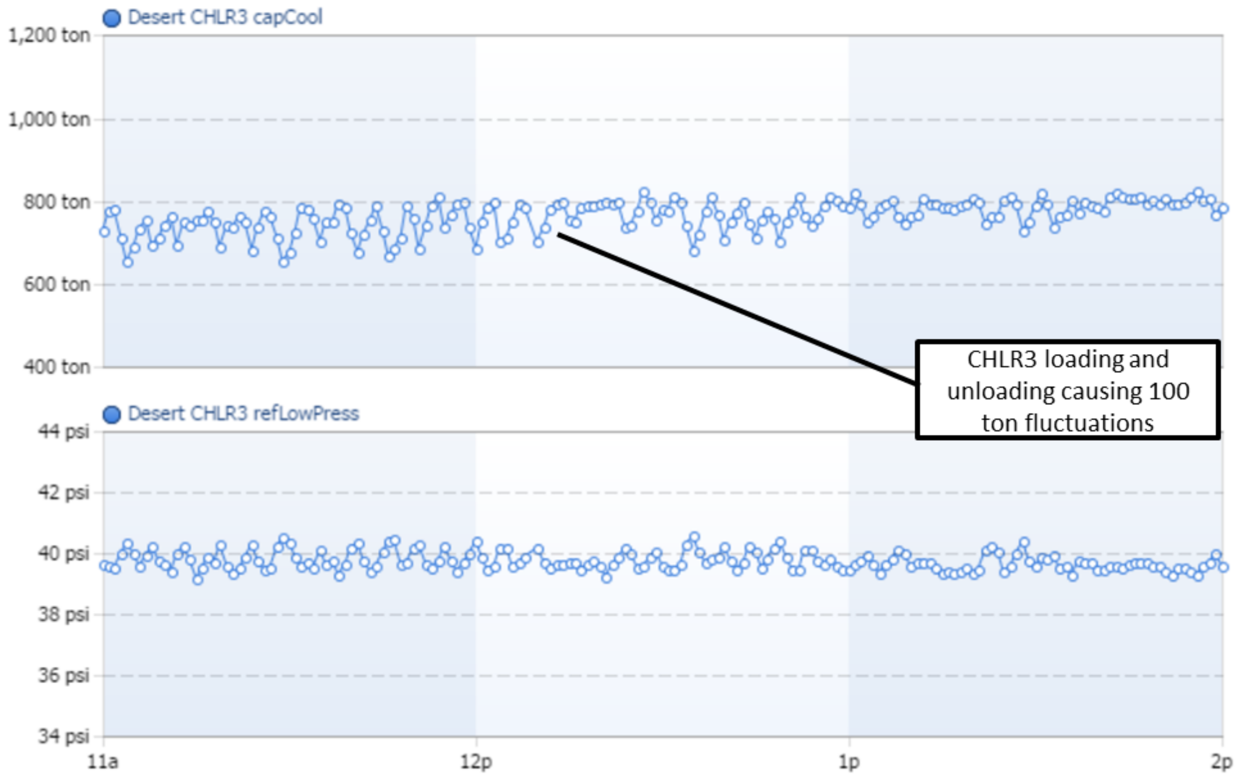
Calibrate Chillers 6 condenser water flow meter. It currently reads about 14% too low. We have estimated that calibration of the flowmeter will cost $1,000.

3 Backup Information

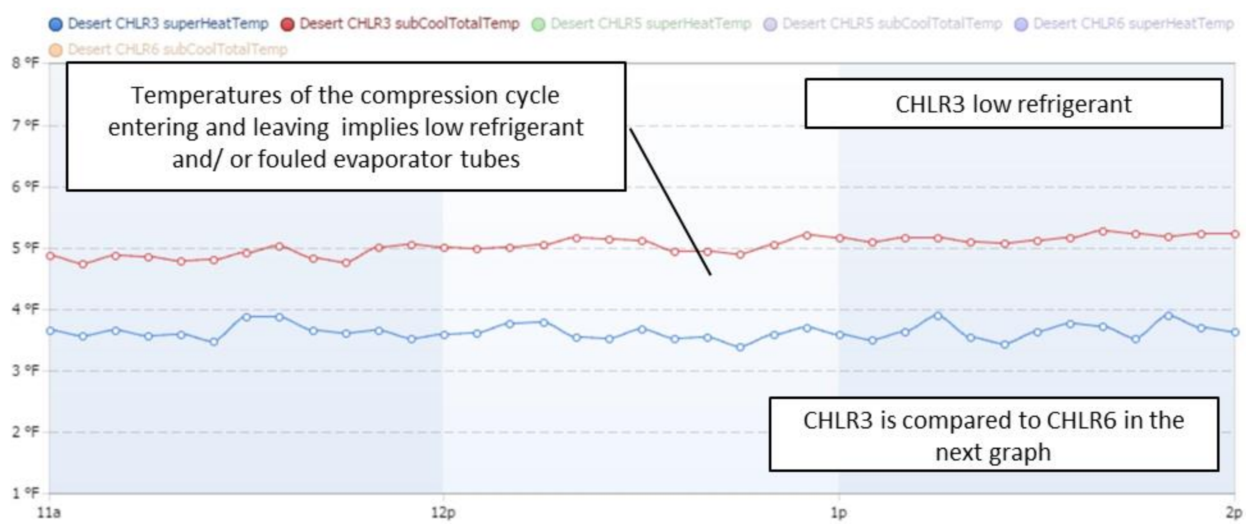
3.1 Chiller 5 is 10% to 15% More Efficient than Chillers 3 and 6



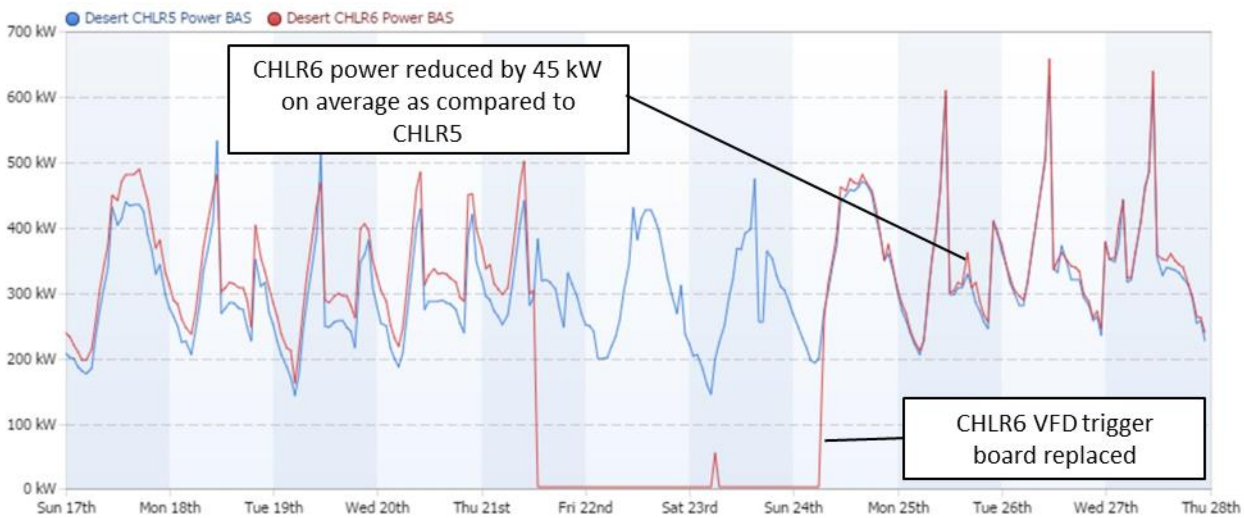
3.2 Replace the Chiller 3 Control Board

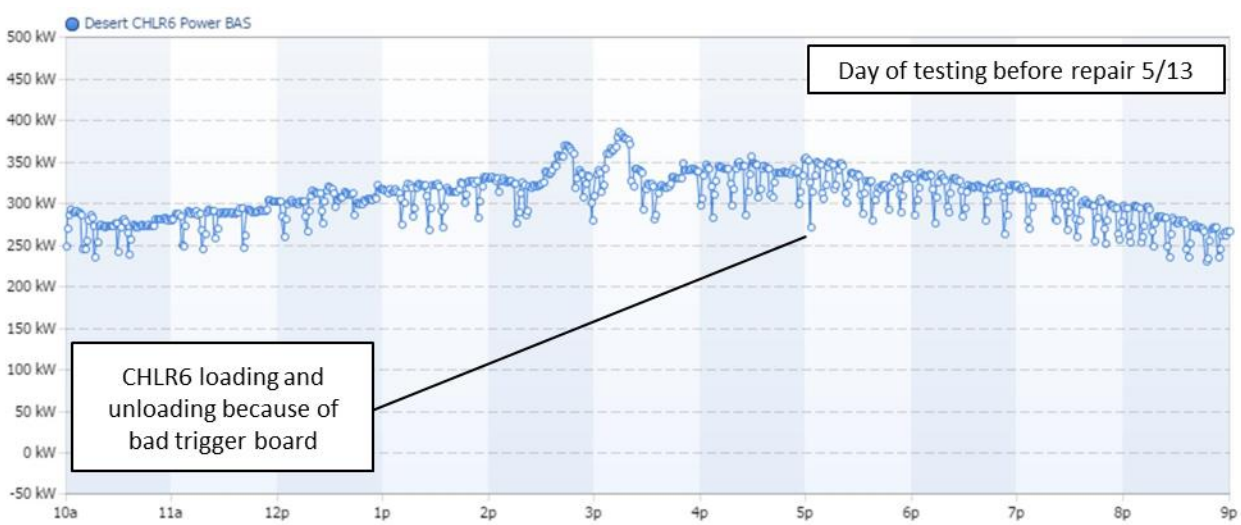


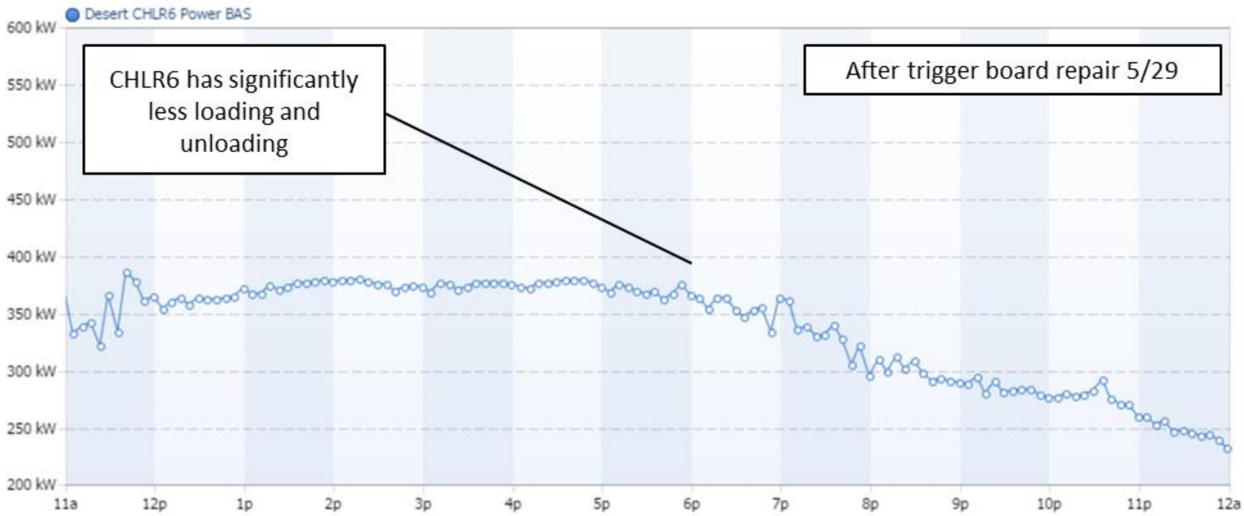
3.3 Chiller 3 Refrigerant Level and Evaporator Tube Fouling



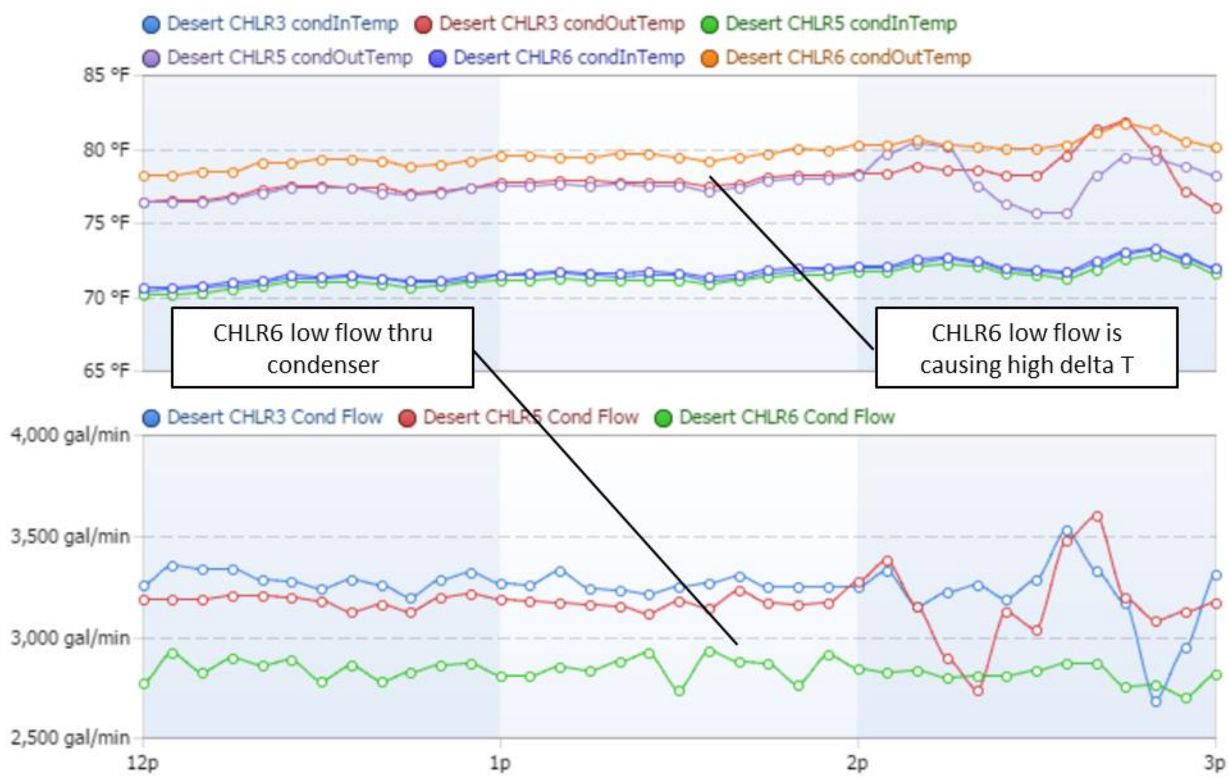
3.4 Chiller 6 Trigger Board Replaced







3.5 Increase Chiller 6 Condenser Water Flow



Banner Medical - Phoenix

York YK Chiller Test Results

June 2015

Tests and report team:

Dan Harris – Teknik Energy

Sean McCaffery – Teknik Energy

Todd Jacques – ETC Group

Technical Director

dharris@teknik-energy.com

Background

In May of 2015 ETC and Teknik Energy coordinated to conduct chiller performance assessment testing at Banner Medical sites located in Phoenix, AZ. All chillers were manufactured by York and were variants on the YK series, refrigerant oil cooled, with ages of between 5 and 11 years. Tests included two sites:

- Desert Medical – 3 chillers – Tested May 13, 2015
- Thunderbird Medical – 3 chillers – Tested May 14,2015

At each site Teknik and ETC set up the ClimaCheck instrumentation and tested performance for approximately 6 hours under normal loading conditions.

Customer	Banner	Banner	Banner	Banner	Banner	Banner
Location	Desert	Desert	Desert	Thunderbird	Thunderbird	Thunderbird
Chiller #	CH-3	CH-5	CH-6	CH-4	CH-5	CH-6
Manufacture	York	York	York	York	York	York
Model year	2004	2009	2009	2005	2008	2008
Model	YKTHTDJ2-DBF	YKQQQ3K2-DBGS	YKQQQ3K2-DBGS	YKHHGDJ1-CYFS	YKLKLKH9-CYFS	YKLKLKH9-CYFS
Serial	SDNM-305670	SNSM-757160	SNSM-757340	SMNM569270	SKSM664020	SKSM664130
Gear Code	AE	AD	AD	FB	RG	RG
Nominal capacity	1374	1374	1374	1000	1000	1000
No of circuits	2	2	2	2	2	2
Refrigerant	R134a	R134a	R134a	R134a	R134a	R134a
VFD	Yes	Yes	Yes	Yes	Yes	Yes
Motor HP	1048	1048	1048	790	790	790

Findings – Desert Location

Certain Key Performance Indicators shown below summarize the findings regarding the operating condition of each of the major components on each chiller. Each chiller is discussed in detail below. In general:

- The compressor efficiency is high for each chiller (Eta 2) and there are no issues with the overall cycle (Eta 1).
- The chillers were operating at a chilled water (secC Evap out) supply temperature of around 47 deg F. Vendor performance data was only available for chiller 3 and was calibrated at a chilled water supply temperature of 42 deg F. The large difference in supply temps makes comparisons to the vendor data not useful.
- Control of loading in the chillers is poor, in particular chiller 3, but also in 5 and 6. In chiller 3 the load fluctuation is regular and pulsing by ~100 tons over a 7 minute interval. In chillers 5 and 6 the load drops out suddenly and snaps back at irregular intervals. The controls for the chillers (assumed to be keeping a fixed chilled water out temperature) are probably tuned in a way that is oversensitive. The control settings should be re-tuned to better "ride out" these fluctuations.
- Chiller 3 is the highest priority for maintenance, mostly in the evaporator:
    - The compressor shows some degradation but it is still a high isentropic efficiency (~63%).
    - The superheat at the compressor inlet is high (~4 deg F) which <u>implies the poor evaporator performance in Chiller 3 is partially due to low refrigerant charge</u>. This is supported by the sub-cool which is also out of the expected range. Proper refrigerant charge will improve performance by 3 – 5%. There may also be some fouling of the evaporator as the chilled water approach in Chiller 3 is slightly high at 3.2 deg F.
    - The Condenser efficiency is very high but is aided by a higher cooling water flow rate and lower loading in terms of % of capacity.
- Chiller 5 is somewhat of a priority and shows slightly low performance in the evaporator. The superheat and subcool are within expectations though in the higher end of the range. The chilled water flow on Chiller 5 is lower with a higher delta t. The performance seems to improve with these conditions so the chilled water flow controls should be checked to see why the variation in the chillers since chilled water supply temp seems to be consistent across the chillers.
- Chiller 6 is the least priority with most metrics high enough to avoid concern.
- With The Desert Chillers delta T across the chilled water and condenser water is a concern. The data is showing large fluctuations in this range. The optimum flow yields a delta of around 6 – 10 degrees on both the evaporator and condenser side. Higher delta T can resulting in unnecessary recirculation and pumping energy. Higher mean temperature in water side, brings up the evaporator midpoint temperature and improves evaporator efficiency. The delta T will depend on design practice.
- In general the flow rates and distribution seem to be a concern. The variation in delta Ts suggests a good opportunity for VSDs on the pumps to maintain the optimal performance.

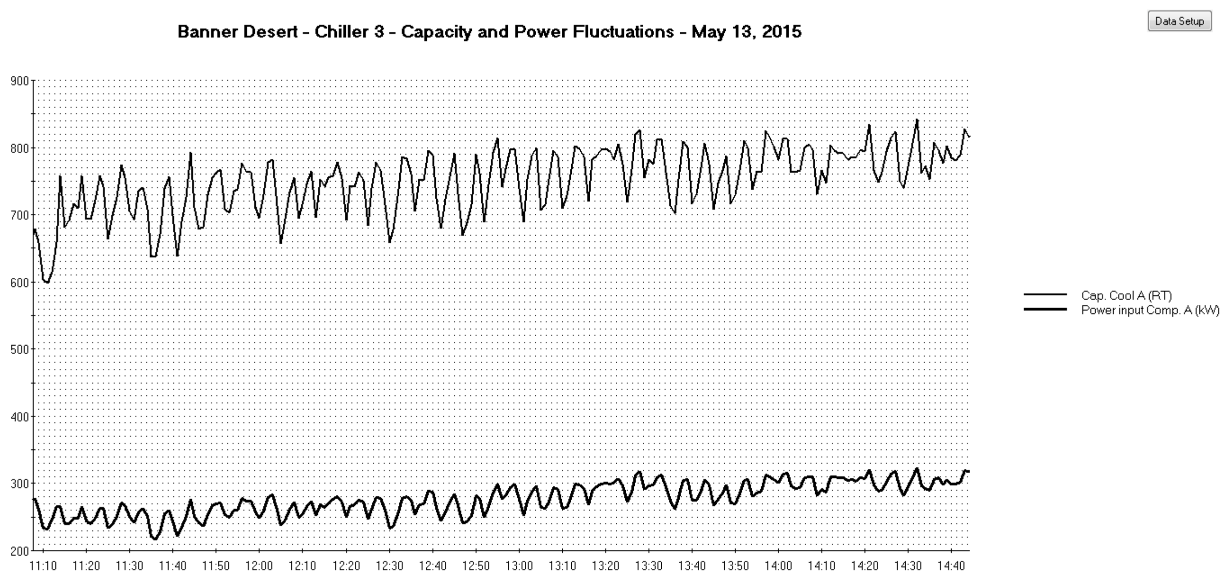
DESERT – All Chillers – York YK Series Chillers – May 13, 2015						
Parameter representative data		**ClimaCheck Measured value**			**Benchmark Good**	**Comments**
SEI - System Efficiency Index cold and sub efficiencies						
Chiller #		3	5	6		
Time of Data		12:28	11:41	12:42		
Reference temperature C		51.8	52.1	51.4		**average of chilled water in and out**
Reference temperature W		72.8	72.9	75.4		**average of cooling water in and out**
Sub efficiencies					**Benchmark Good**	**Comments**
SEI1 Cool	System Efficiency Index	39.7	44.4	41.3	> 40%	
η2	Efficiency Compressor	64.8	71	67.8	> 60%	
η4 evap	Efficiency Evaporator	75.7	78.8	81.9	>85%	
η4 cond	Efficiency Condenser	90	85.4	83.3	>85%	
Electrical power input		278.4	249	340		
Cooling capacity (tons)		765	751	850		
Heating capacity (btu/h)		9996	9680	12000		
kW/ton cool		0.36	0.33	0.40		Note that at lower loadings Chiller 6 seems to have low kW/ton (around 0.32 @ 750 tons) as expected.
Chilled water temp in		55.8	57.4	55.9		Check the chilled water inlet temps across the chillers.
Chilled water temp out		47.8	47.1	46.8	Consistent	
Chilled water delta t		8	9.9	9.1	5.5 < X < 9 F	Higher delta t in Chiller 6 as a result of lower flow.
Evaporation		44.6	45.6	45.1		Chiller 3 approach is at 3.2 deg F.
Super heat		3.9	2.9	1.4	<3.6 for flooded	Chiller 3 is operating at a high super heat. Chiller 5 is approaching the higher end of the desired range.
Cooling water temp in		69.8	71.2	71.4	Should be kept low	
Cooling water temp out		75.4	77.5	79.3		System is operating with too low flow for good efficiency 2 comp/circuit for comp A and 3 for B
Cooling water delta t		5.6	6.3	7.9	7.2 < X < 10.8 F	Lower delta Ts in chiller 3 and 5 as a result of the higher cooling water flow rate. May want to balance and reduce flow to save pump energy.
Condensing		75.9	77.5	81.4	< 3.5 F higher than cooling water out	Approaches seem OK. A little higher in Chiller 6. Perhaps a little fouling in the condenser.
Sub cool		5	6.6	8.8	7 < X > 14 F	Sub cool in Chiller 3 is low, Chiller 5 is a little low.
Chilled Water Flow		146	114	140.2		Low Flow in Chiller 5 from higher delta t
Cooling Water Flow		212	200	178.2		Higher flow in Chiller 3 and 5. Improves condenser efficiency but requires additional pumping power.
Controls cooling water		Check	Check	Check		The flow distribution/valves to the chillers should be examined.
Controls chilled water		Check	Check	Check		More stable but interaction of the chilled water temperature and flow rate controls are not well understood.
Controls in chiller		Check	Check	Check		Loadings are oscillating with large swings particularly in Chiller 3.

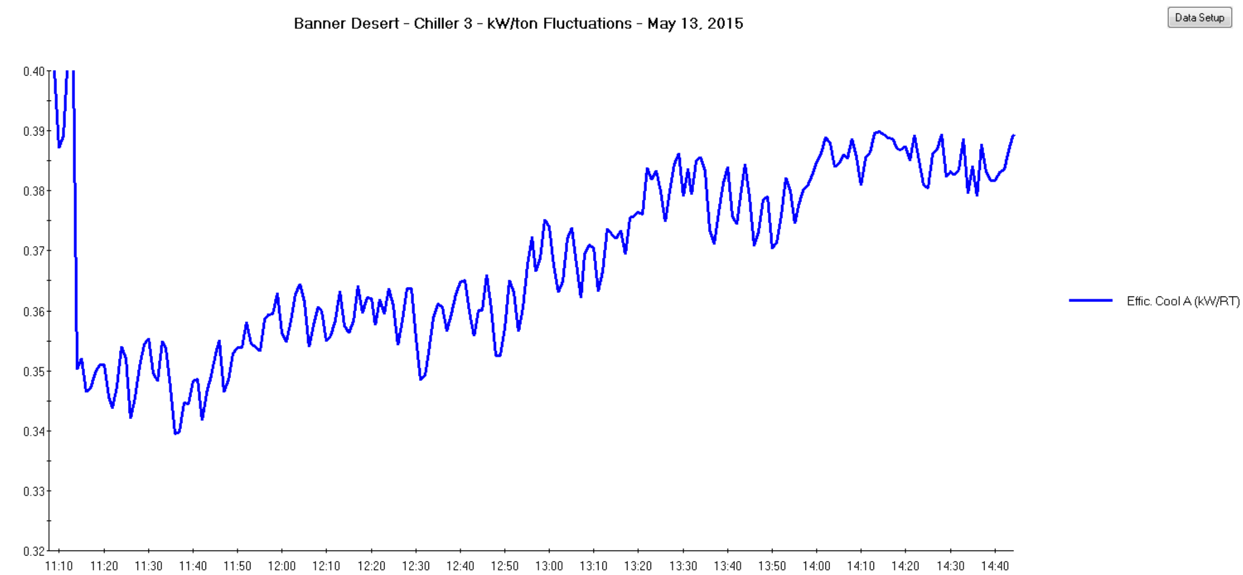
The team collected some representative data from the three chillers at Desert. The graph below shows some of the variation in loading at similar operating points.

Desert Chiller 3

The vendor supplied performance data for Chiller 3 but the calibration testing used a chilled water supply temperature of 42 deg F. The ClimaCheck and BAS data showed a chilled water supply temperature of around 47 – 48. The comparison against vendor data was not possible.

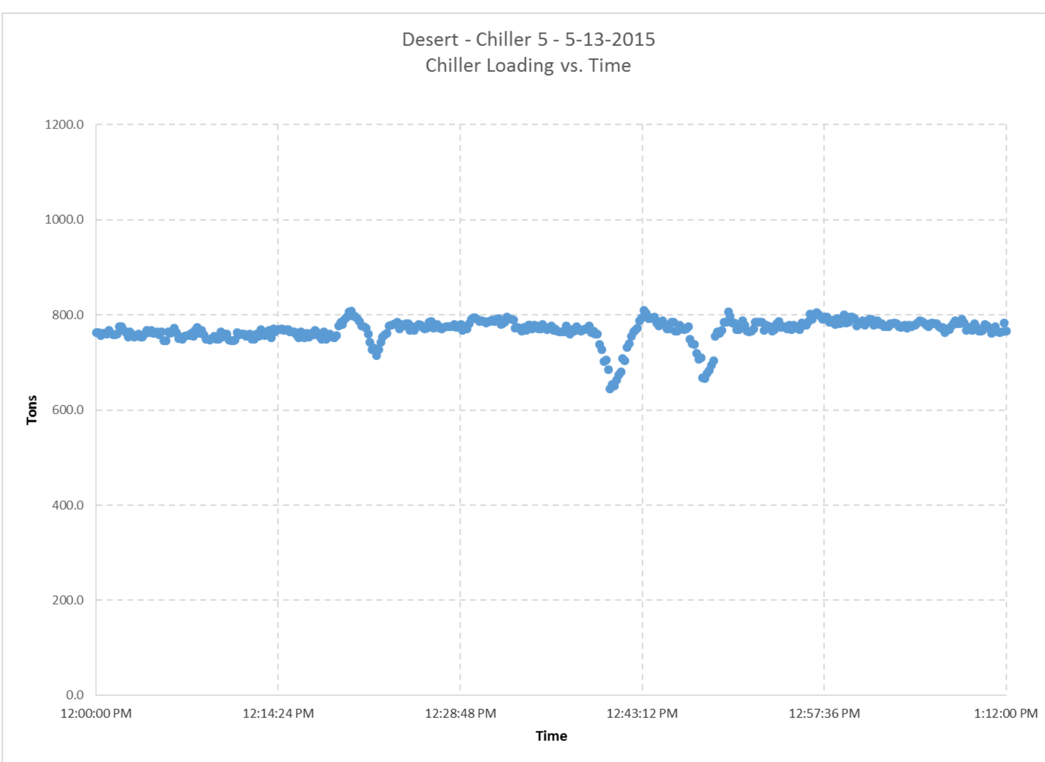
The loading of chiller 3 was highly varying. The controls programming should be examined to find the source of these fluctuations. The magnitude of the fluctuations was approximately 100 tons over a period of about 7 minutes from peak to peak. This had a relatively small impact on efficiency in kW/ton as the period was not long enough for performance to change more than





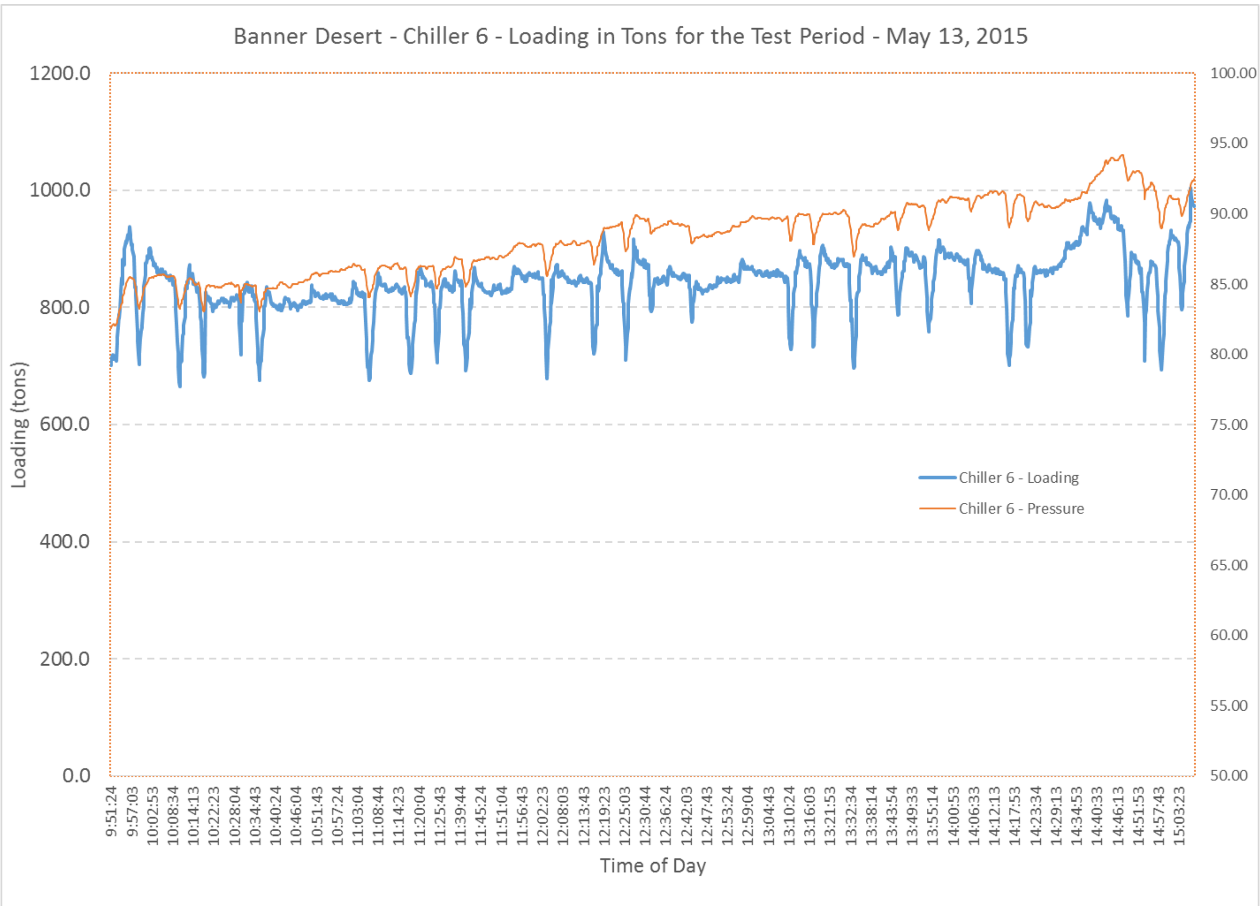
Desert Chiller 5

Chiller 5 and 6 at Desert also experienced fluctuations in loading though rather than a regular fluctuation these were intermittent short duration 'drop outs'. These could be flow related rather than control signal related since the load is otherwise very stable.



Desert Chiller 6

A similar pattern of intermittent fluctuations in load was seen in Chiller 6. Chiller 6 was the best performer of the three chillers and did not seem to have any areas of immediate concern except for the loading drop outs. The overshoot that occurs after the drop out does suggest a control system that is goal seeking and is occasionally fooled by bad data, perhaps in the chilled water temperature algorithm? Then it overshoots to get back on track like a typical PID loop. The effect is seen in the discharge pressure.



Additional Material

Klas Berglof at Climacheck included some additional analysis on several stable points at both sites with flagging of values that were out of bounds. He included relevant additional parameters at each stable point. They are in the attached excel file and are useful for assessing the relationships between flow, temperatures, performance, and overall efficiencies. It's important to note the percent capacity of rated cooling when making comparisons. In general, the sub-efficiencies will improve as loading decreases as the size of the heat exchangers becomes larger relative to the loading but the compressor performance decreases with part load. Using the sub efficiencies in this way becomes an important tool for assessing at what part load to operate the system and translates into better kW/ton without having to normalize the data to try to establish clear points of comparison. The sub-efficiencies capture all the aspects in play that influence performance.

Application	Model	Cool Cap % of rated	SEI SecC System Eff Ref (%)	Eta1 Cool impact of Refr cycle (%)	Eta1b Cool impact of Refr Basic cycle (%	Eta2 Cool impact of Comp (%)	Eta2b Cool impact of Comp liq. cool (%)	Eta4co1 Cool impact of Cond (%)	Eta4ev1 Cool impact of Evap (%)
Chiller (De6)	York YKQQQ3K2-DBGS	68	40.3	93.7	89.4	68.7	99.5	81.5	81.2
Chiller Q (Th5)	York YKHHGDJ1-CYFS	66	37.6	92.0	88.5	66.0	99.4	85.3	76.6
Chiller Q (Th5)	York YKHHGDJ1-CYFS	65	38.3	91.2	87.6	65.3	99.4	86.5	78.0
Chiller Q (Th6)	York YKLKLKH9-CYFS	63	40.1	91.9	88.3	65.6	99.4	86.3	80.4
Chiller Q (Th6)	York YKHHGDJ1-CYFS	63	40.0	91.8	88.3	65.3	99.4	86.4	80.5
Chiller Q (Th5)	York YKHHGDJ1-CYFS	62	36.0	92.7	89.3	65.2	99.5	84.4	75.3
Chiller Q (Th6)	York YKHHGDJ1-CYFS	61	39.2	92.4	88.9	65.9	99.5	85.5	79.0
Chiller (De6)	York YKQQQ3K2-DBGS	59	40.9	93.9	90.2	67.5	99.6	82.9	81.8
Chiller (De3)	York YKTHTDJ2-DBF	57	39.4	92.8	90.6	64.5	99.6	90.7	75.3
Chiller Q (Th4)	York YKHHGDJ1-CYFS	57	42.9	92.0	89.4	65.3	99.5	87.7	83.9
Chiller (De5)	York YKQQQ3K2-DBGS	56	39.1	93.5	90.5	70.2	99.6	85.6	74.0
Chiller Q (Th4)	York YKHHGDJ1-CYFS	54	42.3	92.7	90	65.6	99.5	86.9	82.9
Chiller Q (Th5)	York YKHHGDJ1-CYFS	41	39.5	92.1	89.4	62.6	99.5	88.4	80.4
Chiller Q (Th6)	York YKLKLKH9-CYFS	41	41.5	91.6	89.0	62.5	99.4	89.7	83.0
Chiller Q (Th6)	York YKHHGDJ1-CYFS	41	41.5	91.6	89.0	62.5	99.4	89.7	83.0
Chiller (De3)	York YKTHTDJ2-DBF	35	40.9	93.3	92.0	62.1	99.6	93.9	76.9
Chiller Q (Th6)	York YKHHGDJ1-CYFS	34	38.9	92.4	90.4	58.9	99.5	90.9	80.8
Chiller Q (Th4)	York YKHHGDJ1-CYFS	33	41.3	92.9	91.2	58.4	99.5	90.6	85.8