Measurement & Verification Report for alltemp® Refrigerant: Preliminary Findings

Data Center with Liebert CRAC Units

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1 Executive Summary

alltemp® is a proprietary refrigerant developed and marketed by Sky Green Energy to replace R-22 in air conditioning and refrigeration applications. It is intended to reduce compressor energy use while providing a comparable cooling effect. To demonstrate performance, two CRAC units at a Data Center were monitored for several weeks while one unit was converted from R-22 to alltemp®. The CRAC units evaluated are air-cooled direct expansion models from Liebert (Emerson). The Data Center is a constant load as there is very little system reconfiguration or human intervention.

Data logging of CRAC 4 and CRAC 5 commenced 29 June and after three weeks of operation, CRAC 4 was converted to alltemp® as it was serving a much larger cooling load. When CRAC 4 was evacuated on 19 July, the R-22 removed was measured and compressor circuit #2 had slightly less than the expected amount. Equivalent amounts by weight of alltemp® were added to CRAC 4, which left compressor circuit #2 slightly undercharged. CRAC 4 was operated in this fashion for a week and then the charge was topped off to the correct specifications on 26 July. On 5 August, the 'dehumidification' setting was enabled on both CRAC 4 and CRAC 5. This setting forces additional compressor operation regardless of space temperature. 'Dehumidification' was turned off 11 August and data collected until 5 September.

Initial findings and observations are as follows:

- The initial conversion to alltemp® in the undercharged state left CRAC 4 with a reduced cooling capacity. While energy use of CRAC 4 decreased during this period, the energy use of CRAC 5 increased to compensate.
- Once CRAC 4 was charged correctly, energy use decreased substantially and CRAC 4 was able to hold space temperature with more stability than with R-22. Daily energy use reduction of CRAC 4 was 121 kWh/day, or 22%. This reduction was statistically significant.
- Once CRAC 4 was charged correctly, energy use *of CRAC 5* decreased substantially as well. Daily energy use reduction of CRAC 5 was 65 kWh/day, or 18%. This reduction was statistically significant.
- In aggregate, CRAC 4 and CRAC 5 showed a reduction of 186 kWh/day, or 18% of the baseline energy use.
- Energy cost savings for CRAC 4 alone are $3,530 annually, $5,430 when the additional savings from CRAC 5 are considered[1].

[1] Assuming a marginal cost $0.08/kWh.

2 Project Background

The Data Center operates 24/7 but is unmanned most of the day. The building is a single-story structure with 20' ceilings and concrete walls 12" thick. The Data Center itself has no windows or obvious means of air exchange with the outdoors.

Multiple air-cooled updraft CRAC units provide cooling to the rack system space.
Supply air is distributed to overhead ducts that discharge air to the aisles between the racks. Return air is pulled into the CRAC units at floor level. There is little isolation between CRAC units, which provides cooling redundancy in the event of CRAC unit failure. Standard cooling setpoint is 75 °F. Humidifiers have been disabled; the units have a 'dehumidification' setting that is normally not used.

Two CRAC units were selected for evaluation, with one unit to be converted to alltemp® after several weeks of operation on R-22. The decision on which unit to be converted was made after observing the units for several weeks. The units have the following characteristics:

Designation	**CRAC 4**	**CRAC 5**
Model	UH290AUAAM Deluxe System 3	VH290AUAAEI Deluxe System 3
Type	Updraft	Updraft
Capacity (tons)	22	22
Compressor type & quantity	2 x scroll	2 x scroll
Capacity control	2 circuits, four stages	2 circuits, four stages
Refrigerant	R-22	R-22
Volts / Phase / Amps, Comp 1	460 / 3 / 20	460 / 3 / 20
Volts / Phase / Amps, Comp 2	460 / 3 / 20	460 / 3 / 20
Metering device	TXV	TXV
Special Features	Humidification has been disabled. Dehumidification is via electric reheat but normally not used.	

A data logger from Onset Computer with cellular modem capability was used to measure total CRAC power (true kWh), compressor current, supply and return air temperature and relative humidity, and outdoor air temperature. The Wattnode sensor used to measure total system power uses three current transducers and three voltage probes in order to determine power factor and true power. Measurement accuracy is 0.5% of reading. A single current transducer was installed on each compressor to determine compressor status and approximate energy use. The return (space) air temperature & RH sensor was placed inside the CRAC unit. The supply air temperature sensor was placed at the inlet of the right-hand fan where the supply air is well-mixed. An outdoor temperature sensor was installed underneath the CRAC unit condenser to measure the air as seen by the condenser coils. Data recording intervals were set to one minute.

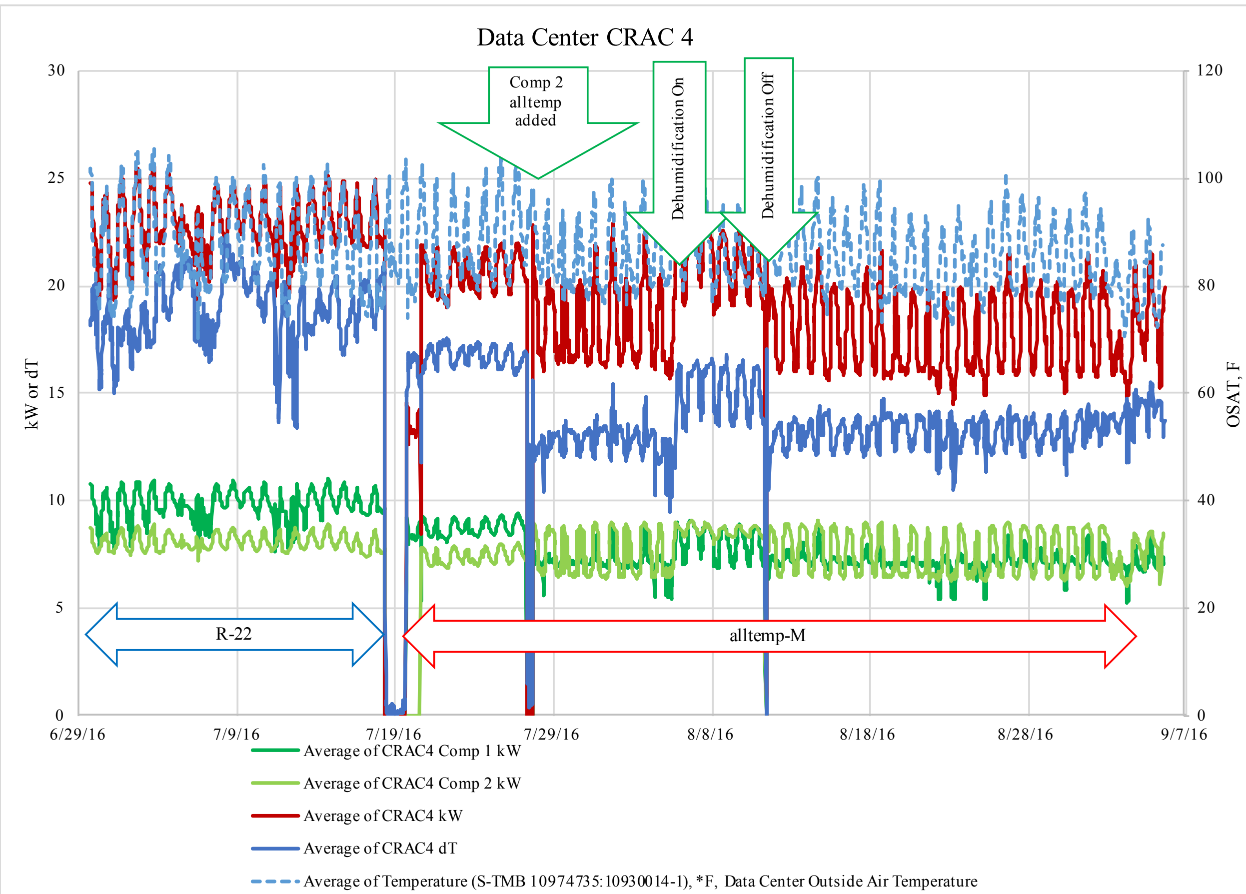
The baseline monitoring period started on 29 June 2016 and continued until 18 July 2016 when CRAC 4 was converted to alltemp®. Due to the volume of the system relative to the vacuum pump size , CRAC 4 was not charged until 19 July. The weight of the R-22 removed indicated that circuit #2 may have been undercharged, so an equivalent amount of alltemp® was added and the unit was restarted. A full charge is 50 pounds of refrigerant.

On July 27, compressor circuit #2 was topped off with alltemp® to the correct mass and pressure. CRAC 4 was then operated normally, but on 5 August 2016, the ‘dehumidification’ setting for both CRAC 4 and CRAC 5 was enabled. The dehumidification forces at least one compressor to operate continuously regardless of cooling set point and space temperature. If the space temperature falls below set point, electric resistance heaters are enabled to raise the supplyair temperature. The ‘dehumidification’ setting was turned off on 11 August. CRAC 4 and 5 have operated normally since then.

3 Initial Observations

Data monitoring started on 29 June with both CRAC 4 and CRAC 5 operating with R-22. Figure 3-1 shows CRAC 4 operation from 29 June through 5 September 2016. The dark red line represents the electrical demand over a 15-minute window. During the baseline period, CRAC 4 demand ranges between 20 and 25 kW. Starting 20 July, total system power decreases to 18 - 22 kW followed by a further decrease after 26 July when compressor circuit #2 was topped off. The green lines represent the current for compressors 1 and 2. On 5 August, the compressor current for both compressors increased - as did total system power – when the 'dehumidification' setting was enabled. This setting was disabled 11 August.

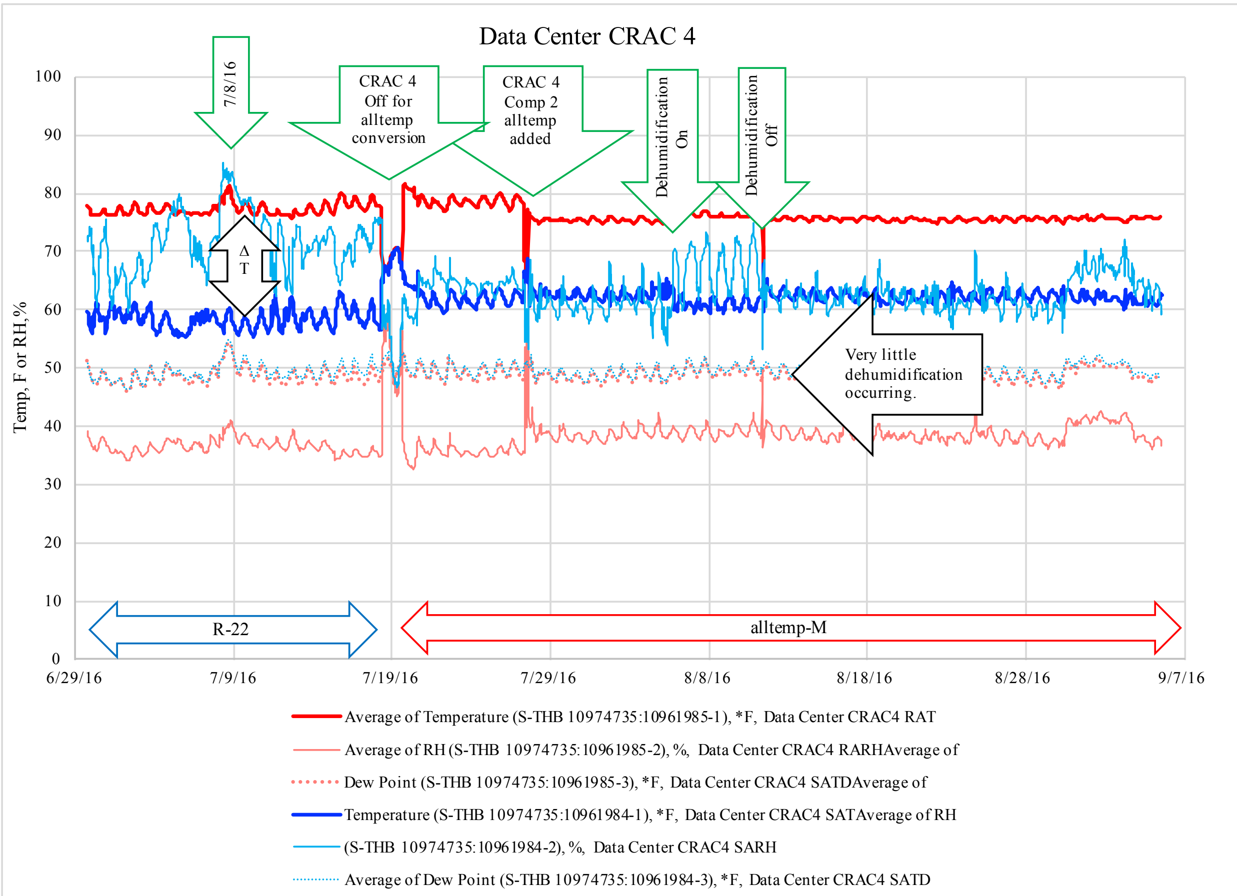
Figure 3-1: CRAC 4 Power and Supply Air ΔT



The temperature difference (ΔT) between the return and supply air load is shown as a heavy blue line. Because the CRAC units operate with constant fan speed and therefore constant flow, ΔT serves as a proxy for cooling load. Cooling load does appear to decrease with alltemp® operation. Despite the apparent reduction in ΔT, CRAC 4 appears to do a better job of maintaining space temperature setpoint than with R-22.

Figure 3-2 shows the return (space) and supply air temperatures in red and blue respectively. After 27 July when compressor #2 was topped off, the variation in space temperature diminished and appeared to be much closer to the target space cooling setpoint of 75 °F.

Figure 3-2: CRAC 4 Supply & Return Temperatures



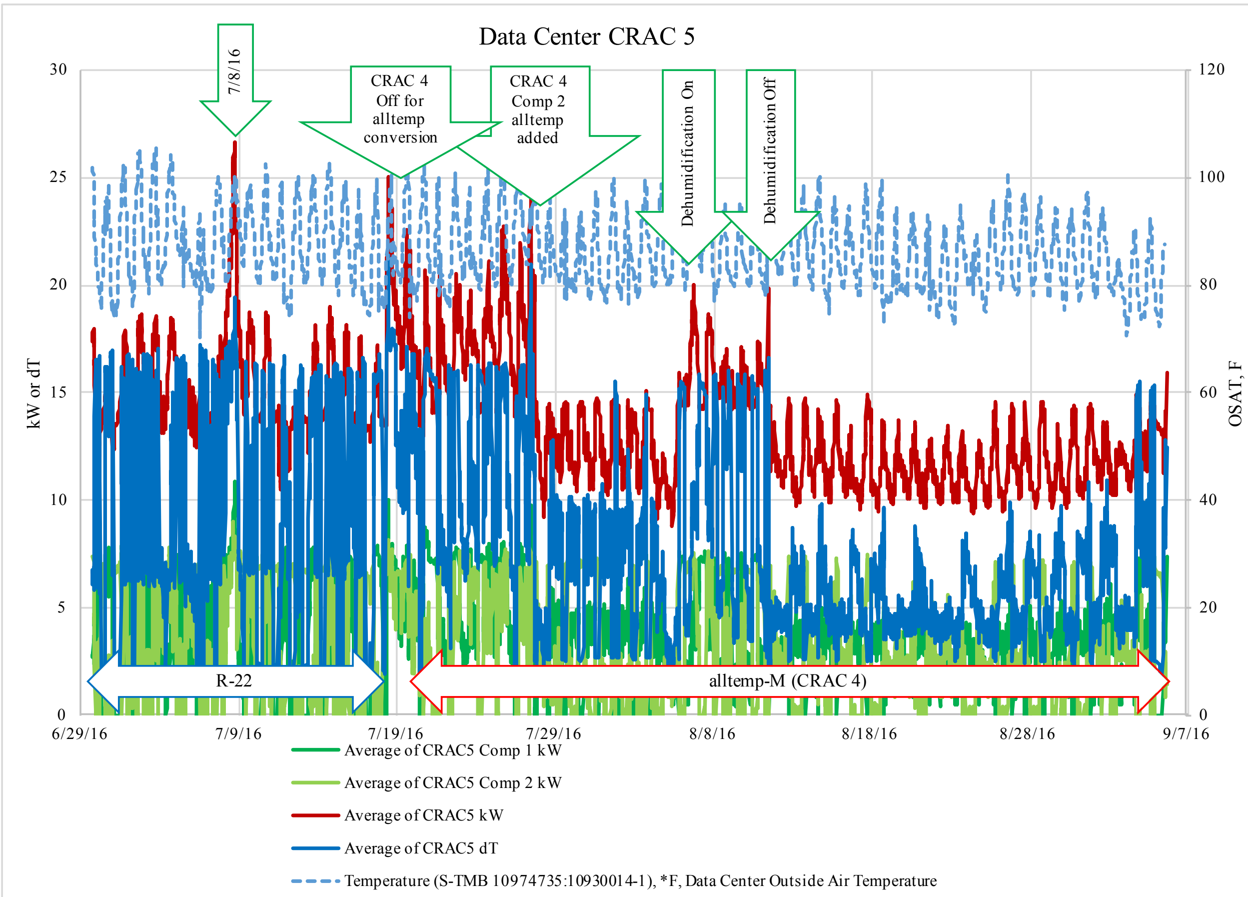
Space relative humidity has been maintained between 35% and 40% with both refrigerants except for a brief period between 30 August and 3 September when it was above 40%. A better indicator of humidity is the dew point temperature[2]. The dew point temperature has remained constant at approximately 49 °F except for a brief period between 30 August and 3 September when it was above 50 °F. That the dew point temperature is nearly identical for both the return (space) and supply temperature indicates that very little dehumidification is occurring. *This includes the period 5 – 11 August when the 'dehumidification' setting was turned on.*

Although CRAC 5 was not converted to alltemp®, changes in power consumption and system loading were observed that appear to be related to changes in CRAC 4. The two units are near one another and serve adjacent areas. There is communication between the two units – if one unit were not functioning at capacity, that cooling load would be seen by the other unit.

[2] The temperature at which moisture will condense out of the air. Unlike relative humidity, the dew point temperature is independent of ambient (dry bulb) temperature.

Figure 3-3 shows a similar graph as CRAC 4. The dark red line indicates total system power. From 29 June to 18 July, CRAC 5 power ranges between 12 and 17 kW except for an unexplained spike to 26 kW on 8 July[3]. After CRAC 4 was converted to alltemp® on 19 July (and compressor circuit 2 was deliberately undercharged), CRAC 5 power and ΔT *increased* to compensate for a reduction in capacity in CRAC 4. However, after 26 July when CRAC 4 compressor circuit #2 was topped off, CRAC 5 power and ΔT *decreased* in response to the changes in CRAC 4. CRAC 5 power ranged between 10 and 15 kW after 26 July except between 5 – 11 August when 'dehumidification' was set to on.

Figure 3-3: CRAC 5 Power and Supply Air ΔT

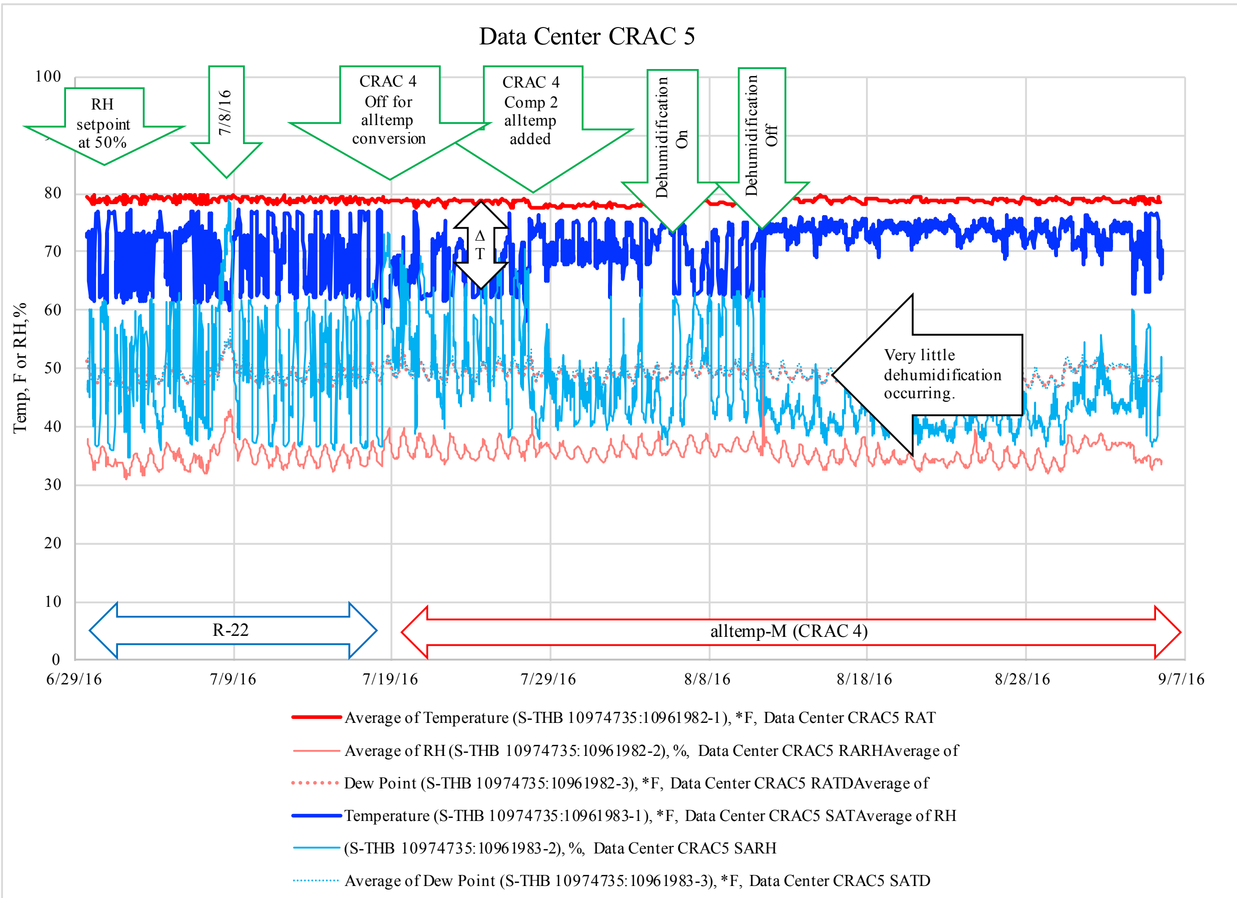


CRAC 5 appears to be able to hold setpoint temperature in a relatively stable manner throughout the monitoring period. The supply air temperature (and therefore ΔT) modulate to meet the load and keep return (space) temperature constant. After 26 July when CRAC 4 compressor circuit #2 was topped off, the supply air temperature increased (and ΔT decreased) significantly, indicating a reduction in cooling load on CRAC 5. Supply air temperature decreased (and ΔT increased) 5 –

[3] Data Center could not provide an explanation as to what may have happened in the data center or with CRAC5 that day. An increase in space temperature is evident in both CRAC4 and CRAC5 data on this day.

11 August when 'dehumdification' was turned on, which forces the compressors to run regardless of temperature setpoint. Humidity levels and dehumidification observations are the same for CRAC 5 as for CRAC 4.

Figure 3-4: CRAC 5 Supply & Return Temperatures



Initial observations of these data sets include the following points:

- CRAC 4 operating R-22 showed some daily variability in space temperature plus some difficulty in maintaining 75 °F space temperature setpoint.

- Replacing R-22 with alltemp® with a matching charge (by weight) in CRAC 4 compressor circuit 2 resulted in a lower energy use but lower capacity. CRAC 5 compensated with a slightly increased energy use during this period.

- Topping off CRAC 4 compressor circuit 2 with alltemp® to the correct charge level further reduced energy consumption of CRAC 4 *as well as decreased the energy use of CRAC 5*. Despite the lower ΔT observed on CRAC 4, return (space) temperature appeared to be more stable and closer to the desired 75 °F space temperature setpoint. The reduction of ΔT and a more stable return air temperature appear to be mutually contradictory for a constant-speed fan system and steady load. But the evidence supports these observations.

- Little dehumidification appears to be occurring as evidenced by the nearly identical values of return and supply air dew point temperature. ASHRAE's *Thermal Guidelines for Data Processing Environments*[4] recommends a maximum dewpoint temperature of 59 °F, or 60% relative humidity for dry bulb temperatures below 75 °F for Class I & II data centers. This data center operates very close to the upper end of the humidity limits, which is not surprising in this locale.

- The dehumidification setting appears to offer little actual dehumidification in practice. In the period 5 – 11 August when the dehumidification setting was enabled on both CRAC 4 and 5, there was no observable change in the dew point temperature despite increased compressor energy use and decreased supply air temperatures. Although not shown, there was no evidence that the reheat coils operated when in dehumidification mode.

[4] *Thermal Guidelines for Data Processing Environments*. Developed by ASHRAE Technical Committee 9.9. (ASHRAE 2008)

4 Energy Savings

The fundamental questions to be addressed by this study are: 1) Did conversion to alltemp® reduce energy use; and, 2) were system performance or space conditions compromised in any way as a result of conversion?

To address the first question, the total daily energy use of CRAC 4 was calculated for both the R-22 and alltemp® cases and compared to the average daily outdoor temperature. Although internal loads are relatively constant, outdoor temperature affects the heat rejection temperature and compressor head pressure, which influences total energy use.

As a secondary consideration, if CRAC 4 using alltemp® were not able to serve the local cooling load, it is expected (and was observed 7/18 – 7/26) that CRAC 5 would handle the balance of the cooling load. For this reason, the daily energy use of CRAC 5 was also calculated as for CRAC 4. The energy use for CRAC 4 and CRAC 5 individually and CRAC 4 plus CRAC 5 were evaluated to test for reduced energy consumption.

As for the second question, space dry bulb and dew point temperature should remain within acceptable limits. This too was evaluated, but only for CRAC 4.

Figure 4-1 shows the total daily energy use for CRAC 4 & 5 plotted as a function of average daily temperature. The baseline period with R-22 shows CRAC 4 in blue has having the highest energy use, between 520 and 560 kWh/day. There is some sensitivity to daily temperature, but the correlation coefficient is only moderate (r^2= 0.6).

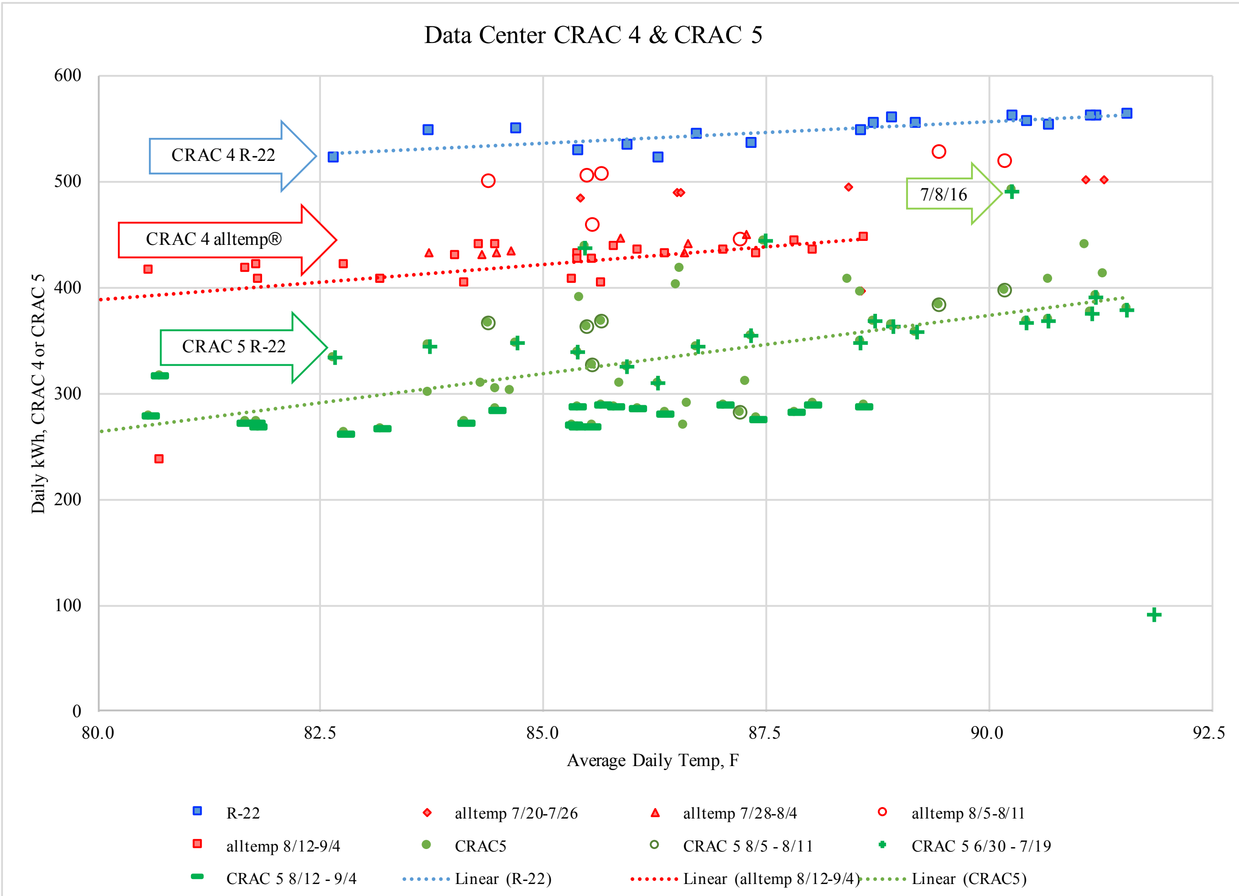
With CRAC 4 converted to alltemp®, observations were segregated into several different periods. The first period (solid red diamonds) was immediately following conversion when compressor circuit #2 was deliberately undercharged. Daily energy use decreased to 480 – 500 kWh/day, but Figure 3-1 and Figure 3-2 suggest cooling capacity decreased and that CRAC 4 had difficulty meeting the desired cooling set point.

The second period covers 7/28 – 8/4/16 (solid red triangles) after compressor circuit #2 was topped off. This shows a markedly reduced daily energy use relative to R-22, 430 – 445 kWh/day. The corresponding period on Figure 3-1 and Figure 3-2 indicate that the space temperature was more consistent and closer to the desired 75 °F space temperature set point. Figure 3-3 indicates that the energy use of CRAC 5 *decreased* as well.

The next period was 5 – 11 August (open red circles) when the ‘dehumidification’ setting was enabled on both units. During this period, CRAC 4 energy use increased to 460 – 525 kWh/day. There was no evidence that the electric resistance dehumidification coils were ever enabled.

The last period was 8/12 – 9/4 (solid red squares) after the ‘dehumidification’ setting was turned off for both units. Daily energy use decreased to 415 – 445 kWh/day and was consistent with the 7/28 – 8/4 observations. These two periods will be aggregated for further analysis and treated as the post-retrofit case.

Figure 4-1: CRAC 4 & 5 Daily Energy Use



For CRAC 5 (solid green circles), overall energy use during CRAC 4's baseline period ranged between 330 and 370 kWh/day with an unexplained peak value of 490 kWh/day on 8 July. Immediately following CRAC 4's conversion to alltemp®, energy use increased to 390 – 440 kWh/day, presumably to handle the extra cooling load not being met by CRAC 4. After CRAC 4 was topped off on 26 July, energy use of CRAC 5 *decreased* to 270 – 310 kWh/day. This decrease was maintained in the period 12 August – 4 September.

In the period 5 – 11 August when the 'dehumidification' setting was enabled on both units, energy use was 280 – 400 kWh/day. The 280 kWh/day value appears to be a low outlier; the average value excluding this point is 366 kWh/day. There was no evidence that the electric resistance dehumidification coils were ever enabled.

To test that the energy use of CRAC 4 and CRAC 5 by themselves and CRAC 4 plus CRAC 5 were different between the R-22 and alltemp® cases, the total daily values were comparedusing a *t* test to check for statistical significance. Normally the observations would be segregated into temperature bins, but the low number of observations and weak relationship with outdoor temperature (over the limited range observed) render that step unnecessary.

Table 4-1 shows the results of the energy use analysis. CRAC 4 operating with R-22 used547 kWh/day while with alltemp® energy use was 426 kWh/day, a reduction of 121 kWh or 22%. The *t* statistic for this reduction was 25, with 2 being the typical accepted value of statistical significance. The corresponding *P* value is well below 0.01 indicating strong statistical significance. The average temperature for the baseline period was 88 °F while for the post-retrofit period it was 85 °F; a decrease of 3 °F. The temperature sensitivity of CRAC 4 operating with R-22 is roughly 3.9 kWh/day-°F, so temperature alone would account for only a reduction of less than 12 kWh/day.

Table 4-1: Energy Savings Results

Baseline (6/30 - 7-7/17 ex 7/8)	**OSAT**	**CRAC 4 (R-22)**	**CRAC 5 (R-22)**	**CRAC 4 + CRAC 5**
Average kWh/Day	88	547	353	900
Standard Deviation	3	14	21	34
Samples	17	17	17	17
alltemp® (7/27 - 9/4 ex 8/5 - 8/11)	**OSAT**	**CRAC 4 (alltemp®)**	**CRAC 5 (R-22)**	**CRAC 4 + CRAC 5**
Average kWh/Day	85	426	288	715
Standard Deviation	2	20	26	26
Samples	33	33	33	33
Daily energy reduction, kWh		**121**	**65**	**186**
Daily energy reduction, %		**22%**	**18%**	**21%**
t statistic	3.6	25.1	9.7	19.9
P value	7.58E-04	1.29E-29	5.86E-13	4.07E-25

Substantial communication between CRAC 4 and CRAC 5 was observed. The units are adjacent and loads not served by one unit influence the other. If CRAC 4 achieved an energy reduction by reducing capacity, it would be expected that CRAC 5 would see an increased load and therefore increased energy use. Instead, CRAC 5 experienced a 65 kWh/day *reduction* in energy use – an 18% decrease. This reduction was also statistically significant. As would be expected, the sum of CRAC 4 and CRAC 5 on a daily basis showed a reduction of 186 kWh/day – 21% – that was statistically significant.

5 Cooling Performance

To ensure that the CRAC units provide necessary cooling, the space temperatures and humidity levels were observed during the different periods. Figure 3-2 shows the average return (space) temperature and supply temperatures as well as the dew point temperatures. That figure shows qualitatively that the space temperature is a few degrees above the set point of 75 °F and that the temperature oscillates slightly when operating with R-22. After conversion to alltemp®, the space temperature is held more closely to set point and with reduced variability.

Table 5-1 shows these results quantitatively using the same date ranges and exclusions as for the energy data. Here, the data used were 15-minute values derived from 1-minute data. The average return air temperature when operating with R-22 was 77.12 °F while it decreased by 1.66 °F to 75.46 °F when operating with alltemp®. Also important was the reduction in standard deviation, from 0.92 to 0.33, an indication of a more stable space temperature in the alltemp® case and one closer to the desired set point. With respect to space humidity levels, the dew point temperature was essentially identical between the R-22 and alltemp® cases; 48.41 °F vs. 48.60 °F. These values were derived from the same sensor, so bias error is irrelevant.

Table 5-1: CRAC 4 Space and Supply Temperatures

Case	Parameter	Return (Space) Temperature	Return (Space) Dew Point Temperature	Supply Air Temperature	Supply Air Dew Point Temperature
R-22	**Average**	**77.12**	**48.41**	**58.41**	**49.06**
	Std Dev	0.92	1.15	1.69	1.26
	Count	1690	1690	1690	1690
alltemp®	**Average**	**75.46**	**48.60**	**62.32**	**49.23**
	Std Dev	0.33	1.08	0.85	1.09
	Count	3277	3277	3277	3277
Difference	**Difference**	**1.66**	**-0.19**	**-3.91**	**-0.18**

What is interesting is the higher supply air temperature with alltemp® than with R-22. Average supply air temperature with R-22 is 58.14 °F while with alltemp® the temperature is 3.91 °F *greater* at 62.32 °F. No explanation is offered for the contradictory observation of reduced cooling capacity from the higher supply temperature while the observed space temperatures indicating the same or higher cooling capacity. If CRAC 4 airflow were to have increased for any reason starting 19 July these results would be understandable.

With respect to supply air humidity levels, the dew point temperature changed little between the R-22 and alltemp® cases. That the supply dew point temperature is higher than the space dew point temperature is likely due to differences in the temperature and humidity sensors. The dew point temperature should always be equal to or lower on the supply side of a cooling coil.