Revealing the Secrets - How to retrofit a DX CRAC Chilled Water System to lower your PUE/OPEX without spending any CAPEX.

It's not news to hear that your typical DX CRAC system is very inefficient, especially when you consider where the cooling industry is today. Now, however, there is an alternative efficient retrofit design and installation process available, one that is very cost effective and achievable without losing redundancy while striving for the much needed gain in efficiency! There are six keys to a successful energy efficient replacement of your Air Cooled DX CRAC system. The design described is a Chilled Fluid System with water side economizing that can reduce facilities PUE from a low of 1.87 to an annual PUE below 1.30.

1. Selecting a Control Platform
2. Designing an Efficient CRAC
3. Designing an Efficient Chiller and Selecting a Fluid Cooler
4. Selecting the Cooling Fluid for your needs
5. Designing a Dewpoint System with parallel air filtration
6. Retrofitting without loosing redundancy

Selecting a Control Platform – For simplicity and scalability of the control system we recommend that a platform be utilized that is not proprietary, one that each component can stand alone and a system that's very flexible. As a basis for this design we recommend using a Rockwell Allen Bradley (type) VFD/PLC Control Platform with a GE Cimplicity SCADA (Data Acquisition*)* Front End to monitor efficiency (in PUE and kW per ton) and adjust the systems parameters.

CRAC Design – Designing a CRAC unit is where the whole process begins and it's the most important part in the process. First there are a few things you must know about your data center as theses parameters generally do not change based on the cooling equipment design.

- External Supply and Return Air Static Losses – The first step to designing a proper CRAC for your system is to understand how much pressure your system requires to move the air where it's needed.
    - Supply Air Pressure ________________________ Note: Take the reading with a monometer 10 feet away from the discharge of the fans.
    - Return Air Pressure Loss ___________________________Note: Return air losses are usually associated with ductwork and air filtration, if you do have ductwork read the negative number right in front of the CRAC unit at the ductwork.

    Note: Even in row units (supposedly efficient) have air side pressure losses that create inefficiencies, usually its within the equipment itself and the air side losses can make these units very inefficient with regards to air flow.

- System Supply Air Temp, Server Inlet Air Temp and Return Air Temp – The theoretical temperature difference between the supply air temperature and the return air temperature is pretty much set in a typical data center. This difference is dictated by the air distribution, server rack arrangement, and amount of containment.
    - Average Supply Air Temp ___________________________ Note: Measure the air temp under the floor or in the ductwork (away from the CRAC units), typically with a CRAC system this temp will vary due to units cycling on and off.
    - Average Return Air Temp ___________________________Note: Measure each CRAC and Note the high and low temperature.

- Average Server Inlet Air Temp ____________________

CRAC Design Conditions - We must start with some basic conditions. For this example we will use a traditional approach. (57˚F Supply Air Temperature, 68-70˚F Return Air Temperature and a 48˚F Dewpoint / 45% Relative Humidity Return Air). The following design approaches must be maintained. These approaches will change with any variance in the baseline temp parameters. The system in this design will maintain a constant discharge air temperature from all CRAC's which will reduce the amount of hot spots in the data center and technically reduce the overall air flow.

- Air Side Pressure Losses – In this design we are limited to the original air side pressure losses plus the CRAC units pressure losses. The goal is to keep them as low as possible.
    - Design the cooling coil losses to be less than .60 and the CRAC units total air side loss to less than .80". Note: these units should have filter racks in them and the fan CFM and HP to draw through them, plan for MERV 13 air filters. Include these air side losses from the filtration in the total. Plan to remove the air filters after construction is complete to reduce the total air side pressure losses. The air filtration will be taken care of by a separate Ultra side stream Air Filtration unit.
    - For an AXIAL fan system (the most efficient) the total air side loss must not be more than 1.0", typically design the fans for less than .06-.09 kW per ton of cooling and drive the fans with a VFD. Note: the larger the fan blade the more efficient it will be. A typical CRAC design will have a 24" to 28" Axial Fan mounts in a very specific fashion.
    - For a Plug Style fan the total air side losses can be higher than 1.0" of total losses, but the fans will suffer a power penalty if the air side losses are too high. Typically design the fans for less than .10-.15 kW per ton of cooling and drive the fans with a VFD. Note: the larger the fan wheel the more efficient it will be. A plug fan works very well with raised floor systems of less than 18".
    - Reduce Air Side Pressure Losses- Evaluate your air side distribution system and adjust the facilities design to reduce the air side losses. Note: Some tricks may include adding ductwork or registers, adding perf tiles or adjusting existing, tiles to reduce the static supply pressures needed. Most importantly once the new system has been installed it must be balanced and continued to be balanced when new loads are applied or removed.
- Chilled Fluid Temperature Difference – Design the CRAC to have a large fluid side temperature difference, a high exist water temp and the supply fluid temp must be a higher temp than the design dewpoint of the facility. The higher exit water temp will lead to more hours of economizing.
    - CRAC Chilled Fluid Inlet Temperature – Design the CRAC to maintain a 50˚F inlet fluid temperature at full load.
    - CRAC Fluid Outlet Temperature – Design to the CRAC to maintain a 2-3˚F Return Air Temperature to Outlet Fluid Temperature Differential (66-68˚F outlet fluid temperature) at full load.
    - Fluid Side Pressure losses – Although not as important as the air side pressure drop keeping the fluid side pressure drop as low as cost effecctiveley possible is a must.
- CRAC Unit Control and Monitoring – There are many ways to control the CRAC design the following are the most efficient way of controlling the indoor units.
    - Temp Control -The most effective way to control the CRAC (in this design) is based on a SAT (Supply Air Temp) Control. Control a modulating inlet fluid feed valve to maintain a 57˚F SAT (Adjustable). This type of control allows for all units to be active all of the time, thus utilizing the surface area of the indoor coil at all times. This also allow for a common supply air temperature, reducing hot spots within the data center.

- Fan Control - The fans can be controlled a few different ways based on the design of the air distribution system.
    - Return Air Temp Fan Control - For efficiency the design controls the fan speed based on RAT (Return Air Temp). Since each air handler will control a differing load based on the arrangement of the CRACs and the loads in the room, this method of control maximizes the efficiency of each unit. The setpoint should be established in accordance to the design of the system. Typically the setpoint with the parameters established in the original specifications will be between 68-72˚F.
    - Static Pressure Fan Control - Control based on supply air static pressure. This way may be necessary based on the air distribution system. With this way of control it is crucial to control with one control point and a redundant sensor. This keeps units from fighting each other.
    - Control Monitoring Points - It's important to track the energy used by the fans and the SAT, RAT, Outlet Fluid Temp of the AHU.

- CRAC unit dimensions – It is important to make the CRACs as big as possible and as tall as possible. To support the components of an efficient CRAC usually the equipment must come in two pieces, a fan section and a coil section. The other requirement would be to ensure that the total unit stands at minimum one foot above the server racks.

CRAC Unit Conclusion – The inside heat exchanger unit (CRAC) is very important when designing an efficient CRAC retrofit. The energy used by the CRAC must be minimized while creating the highest outlet fluid temp possible for more hours of economizing.

- Higher Fluid Return Temperature equal more hours of economizing (up to 7100 hours a year)
- Higher Fluid Temperature Difference equals less gallons pumped, almost half of a typical chilled water system. Half the water flow means half the pump energy.
- Axial Fans typically save about 8kW per 30T typical DX CRAC unit, 8 kW of energy removed also removes about 2.4 Tons of wasted cooling load per CRAC.
- Higher Supply Fluid Temp equals no moisture removal and replacement. On a typical DX CRAC, 18-34% of the energy used by CRAC is in improper humidity removal and replacement.

Chiller and Fluid Cooler Design- A typical chiller in this design must be cooled by water. In this design to minimize the components necessary we recommend going with a single fluid loop design three way valves and a fluid cooler type outside heat exchanger. It is very important to not use secondary plate and frame heat exchangers as they create inefficiencies due to secondary heat exchanges. First we will start with the design parameters of the chiller system and then to the fluid cooler conditions.

- The Chiller – a chillers annual efficiency is based on the conditions it runs during each hour of operation. As a basis of design the CRAC units require an inlet fluid temperature of 50˚F and an outlet fluid temp of 66-68˚F. With these conditions in mind we must design the chiller systems to be efficient at all conditions and loads. Since in this design we are removing heat via the fluid coolers in economizing mode prior to the fluid going through the chillers, these chillers must be able to be efficient with fluid temp conditions changing from 66-68˚F all the way down to an inlet temp of 51˚F. Not many chillers can stay efficient with these conditions and will eat up a majority of the savings from the economizing. There are a few design conditions that must be met to ensure the efficiency at all loads and outside conditions. We refer to this design approach as a *Reduced Compression system.*
    - Evaporator Conditions- Since the largest potential gain in efficiency for the chiller depends directly on the approach of the evaporator (AKA Chiller) we design the approach of the

component at less than a 5˚F approach. If the supply fluid temp is 50˚F than at full load we would like the SST (Saturated Suction Temp / Refrigerant Temp in the Chiller) to be no less than 45˚F at full load.

- Condenser Conditions- The heat rejection component is the second largest area of energy savings potential within the mechanical cooling section. Since we need to use a floating head pressure design to maximize the efficiency we suggest a design of 8-10˚F approach on the water cooled condenser. As an example if the outdoor fluid cooler is supplying 55˚F fluid to the condenser the condensing temperature must be between 63-65˚F.
- Compressor Conditions – The compressor in general in DX systems is the largest energy user in the system using 42% of the energy. In this design use a compressor that can run with a 45˚F SST to a 58˚F SCT (Saturated Condensing Temp). Most chiller companies will not be able to supply an off the shelf chiller than can run efficient under these conditions and one will have to be manufactured specifically for the design. At the following conditions a properly designed chiller compressor should be using no more than .48 kW per ton at fully unloaded conditions and lower when the wetbulb temperature outside decreases.

Wetbulb Temp	Cnd Fluid Temp	Cond Temp	EER	kW per Ton
73°F	78°F	86°F	25.1	0.48
71°F	76°F	84°F	26.2	0.46
69°F	74°F	82°F	27.6	0.43
67°F	72°F	80°F	28.8	0.42
65°F	70°F	78°F	29.9	0.40
63°F	68°F	76°F	31.0	0.39
61°F	66°F	74°F	32.2	0.37
59°F	64°F	72°F	33.4	0.36
57°F	62°F	70°F	34.8	0.35
55°F	60°F	68°F	36.1	0.33
53°F	58°F	66°F	37.6	0.32
51°F	56°F	64°F	39.1	0.31
49°F	54°F	62°F	40.8	0.29
47°F	52°F	60°F	42.5	0.28
45°F	50°F	58°F	44.3	0.27

- Fluid Cooler Design Conditions - Design the economizing fluid cooler section to run 5 Degrees off of the wetbulb temperature. It should also not exceed .11 kW per ton in selection at the conditions of 45˚F WBT, 66-70˚F Fluid Cooler Inlet Temp, 50˚F Fluid Cooler Outlet Temperature. Design at these conditions when dealing with the fluid cooler manufacture. The fluid cooler should be piped with multiple circuits in an N+1 Alignment.
    - Water Treatment –The goal with water treatment is that the energy used for treatment never exceeds .035 kW per ton annually.
        - Filtration – Filtration of the tower is very important, use a centrifugal separators that run on average 1-3 hours a day.
        - Water Use Scale and Corrosion Control – In 20 years we have yet to find the perfect system, we have tried many systems and find that with the cost of energy as the systems primary concern (which rules out a few systems) not many work perfectly. What any company can do is plan to clean and pressure wash the towers monthly. Acid is a good source for PH control but comes with a monthly consumable cost. There are systems such as high PH

control systems with water softeners that seem to work but still require monthly cleaning.
        - Algae Control – We use an ultra violet system that sterilizes the sump water any time the water tower pump is on. Be careful and select a quality UV system manufacture.
- Chiller and Fluid Cooler Control –
    - Chiller Control - The Chillers should be controlled to maintain a 50˚F common Supply Fluid Temperature. All Chillers should operate at all of the time and be arranged in an N+1 arrangement. If a chiller has a failure the other chillers just load up. This way you know the chillers are running. Most chiller systems fail on start-up and when you need the redundant chiller to start, if it fails, the facility temperature will get out of control in a hurry.
    - Fluid Pump Control - The fluid pumps are controlled to maintain a pressure differential (based on field pressure drop results). In this design as the fluid temperature leaving the economizer drops to the point in which the chiller supply temp drops below the desired supply fluid temperature a chiller bypass pump actives and mixes chiller return water with supply water until the fluid temperature returning from the fluid coolers (economizers) drops to 50˚F. All pumps are controlled with VFD's based on pressure differential and function of operation.
    - Economizer Fluid Cooler Control – Since the Outdoor Fluid Coolers do double duty as either a condenser fluid cooler or an economizer cooling the fluid returning from the indoor CRACs or the condensers there is a need for three ways valves, transfer pumps, bypass check valves and VFDs on the fluid cooler fans. As the Wetbulb temperature drops to 59˚F (more than 7100 hours a year) the redundant fluid cooler switches the fluid flow from condenser return water to CRAC return water. The fans, pumps, and staging fluid coolers are controlled to maintain an outlet fluid cooler temp of 5˚F off of the wetbulb temperature.
        - Use Typical Safety Controls on Chillers
            - Low, High and Oil Pressure Control
        - Monitor and Trend Compressor Parameters
            - Energy Usage
            - Suction Pressure
            - Discharge Pressure
            - Suction Line Temp
            - Discharge Temp
        - Monitor and Trend temp in and out and GPM of each fluid cooler
        - Monitor and Trend Energy used by fans and pumps

Chiller and Fluid Cooler Conclusion – A properly designed *chiller system* should average between .57 and .40 kW per ton, the heat rejection system of this design should run between .07 and .10 kW per ton at full load, while providing at a minimum of 7100 hours of economizing (reducing the total load and energy from the chiller systems) under the current room conditions. If the room conditions can increase the hours and percentage of economizing will increase.

Selecting the Cooling Fluid - The fluid used is design preference based on the facilities needs. A typical systems would use water as the heat transfer fluid, but other fluids are available that demonstrate high dialectic strength and great heat transfer properties such as 3M Novec 649, although these fluids come with quite an upfront cost. If a leak in the coolant system is a great concern for your facility then we recommend going with the 3M fluid. Most data centers have made the decision to accept water within the data center in the last few years so typically we see water as the main heat transfer fluid.

Designing a Dewpoint Control System with Parallel Air Filtration – The most optimal way to control infiltration moisture is to do it with a separate system. Since the new primary cooling system does not remove moisture as part of its operation (unlike the DX CRAC system), the secondary moisture control system will regulate the infiltration load. With this type of control a dewpoint control of 48˚F (+- 1˚F) is not only possible and a must with this system, but very economical to do. There are two differing scenarios to evaluate when it comes to humidity control. A building that uses outside air to pressurize the facility (while providing fresh air) and one that does not. Obviously the outside air unit (OAU) requires the greater amount of energy and it's what we'll concentrate on in this design. If you do not utilize outside air for fresh air then just analyze the building envelopes infiltration of moisture for the design.

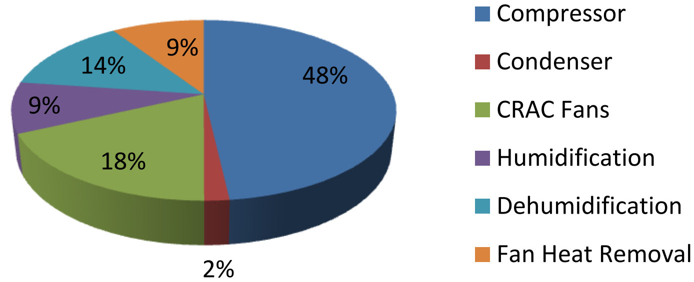
- Outside Air Unit Moisture Control - In the United States most moisture loads from outside air will not exceed .5lbs of water per 1000 CFM. Outside air moisture control can be a very large energy load depending on the facilities geographical location. Any time we design this type of system we us two units to perform these requirements. We use a 100% outside air unit for dehumidification and an inside air unit for moisture addition.
    - Outside Air Dehumidification Unit- Any typical cooling system can be designed to remove moisture. When we design the systems dehumidification systems we use two forms of cooling, we also recommend the use a heat pipe cooling system. We use the "heat pipe" designed AHU to remove the sensible loads and a primary cooling system to remove the latent load. Since the volume of outside air is low with this design the energy and consumable cost are minimal.
        - Filtration – The outside air unit requires the greatest amount of filtration, we recommend going with MERV 13prefilters, bag filters and a layer of carbon filtration.
        - Control – We control the humidity using dewpoint sensors within the facility as the dewpoint goes above the 48˚F Setpoint we stage on the de-humidification system. The air coming into the facility will be below the room conditions thus drying out the room and lowering the dewpoint. We typically use a VFD on the cooling compressor to control the level of dehumidification.
    - Filtration Humidification Unit– There are two type of humidification we design with. One being Adiabatic and the other being Ultra Sonic. Both have shown a very low potential for failure and low energy cost.
        - Filtration – Since the primary filtration system for this building will be this unit, this unit should be an ultra filtration unit. We like to use Hepa level filtration with ultra violet purification in this unit and design the unit to turn the air 2-4 times per hour. We typically design the filtration unit at 1000 CFM per 7,500-15,000 Cubic Feet
        - Control – We control the humidity using dewpoint sensors within the facility as the dewpoint goes below the 48˚F Setpoint we stage on the humidification system. The warmer air coming from the facilities ceiling will be capable of absorbing the moisture added to the air steam. In this design turn off the filtration system during peak energy cost hours during the summer and only bring on the system when the Dewpoint drops to below a lower emergency setpoint.

Retrofitting Without Losing Redundancy – The retrofit process is easier than people think. The only special requirement is land use. For a cost effective retrofit the chiller systems and fluid coolers must be able to be installed cost effectively. We typically look for an outside area in which we can add a mechanical area on the ground floor or the roof top if the building structure allows for the additional weight.

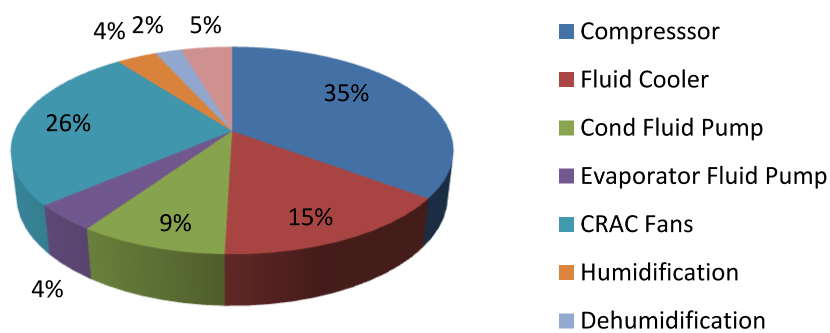
- Construct a Mechanical Area
- Install the Pre Manufactured Built-up Chiller, Pumps, Valves and Fluid Cooler Section
    - Perform Electrical Work
    - Add a backup water tank for fluid coolers
    - Run communication cables to each components location
    - Install Front End System Server
    - Tie in UPS energy monitoring system to front end systems
- Pipe double main design (Double Main refers to a circular loop with two routes of supply and return) to air cooled CRAC penetrations (2N Redundant Loop)
    - Leave isolation valves for CRAC units
    - Size each side of loop for 75% of total flow rates
- Complete install and startup of Chiller System, Fluid Cooler Section, Valves, Pumps and Controls
- Begin CRAC unit replacements
    - Pump down and remove indoor CRAC unit (add 20 ton porta cool units for redundancy, if needed)
        - Reclaim Refrigerant
        - Tie Off Electrical (all electrical can be reused for new units)
            - Replace breakers to smaller breakers for new units
    - Install new highly efficient Chilled Fluid CRAC (one at a time)
        - Tie units in with ProPress type compression connectors
        - Vent Air from New CRAC
        - Install power and controls to the new unit
        - Start up CRAC unit
        - Validate Control and Monitoring

Retrofit without CAPEX – Data Center retrofit projects are prime candidates for energy efficiency finance. There are a handful of Efficiency Finance companies that want to invest in project like these DX CRAC retrofits. Typically a customer would pay 80% of their guaranteed savings to the Efficiency Finance Company, while rolling in their service maintenance and monitoring as part of the process. Data Center owners are in an enviable position with the technology that is available for measurement and verification; no owner should ever get cheated. Require a guarantee and make your vendor prove their savings, kW of server vs. kW of cooling can't be agued and an hourly review on the annual comparison is the only way of ensuring the energy savings. Start with your pre-validation, a data center uses energy based on a very consistent model, UPS energy use from IT and Infrastructure energy. Infrastructure energy typically is consumed by Cooling (90%), and Utilities (9%), UPS Power Conversion, Battery Losses, Lighting and (1%) infiltration. Although the percentages may vary slightly (due to density), cooling accounts for the majority of energy use within the infrastructure. A simple evaluation of the UPS energy use charts vs. the energy used by the facility (utility bill) in total can tell much of the cooling efficiency story. Once the facility has been retrofit, use a GE Cimplicity type SCADA system to monitor the energy use of all of the components and evaluate the LOAD (IT UPS Load in Tons of Cooling) vs. the Cooling kW use. This gives us a facilities kW per ton. This is a very accurate way of evaluating the energy saved by the cooling system. Please keep in mind, in most cases this cooling design free's up energy that can then be used for additional IT load "Higher Densities" (Sales to a Collocation Facility), even though the total energy use may increase over time, with increased densities, the total savings also increases and the facilities utilization of space and cost effectiveness increases as well. The following are guidelines to show the difference between the energy used by each component and the kW per ton for each.

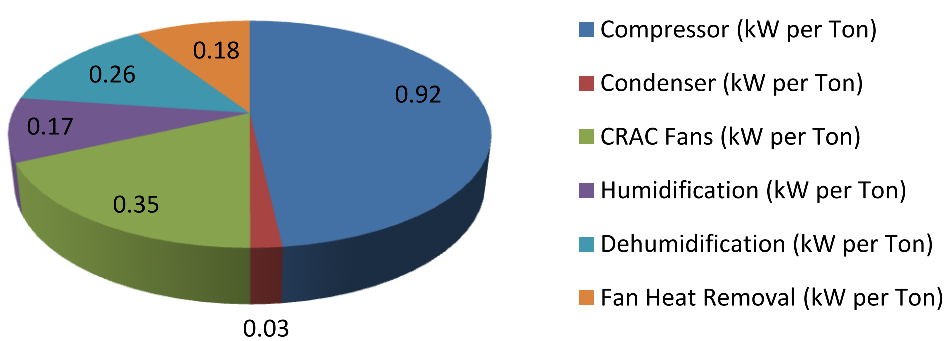
PUE 1.87 Data Center Energy Use Per Component



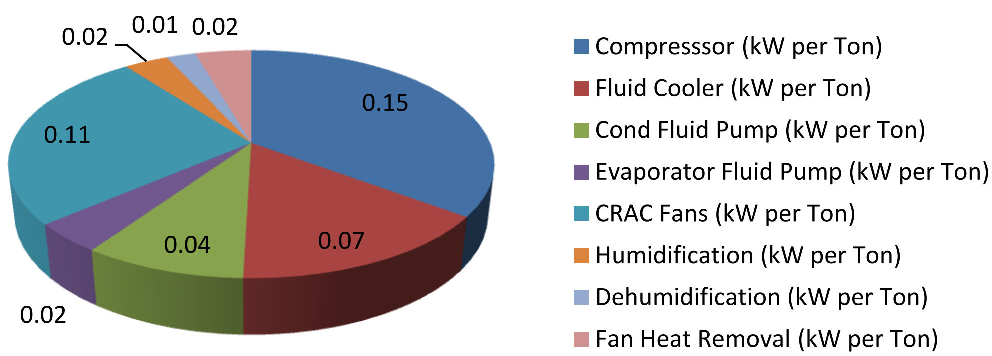
PUE 1.3 Data Center Energy Use per Component



kW per Ton Per Component with CRAC DX Unit Annually



Annualized (with economizing) kW per Ton per Component WSE Design



Piping Design