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Efficient Data Centers

Airflow Management of Direct Expansion Computer Room Air Conditioners

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Technical Update, December 2012

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PRODUCT DESCRIPTION

Results and Findings

This technical update provides an overview of airflow management using variable speed drives (VSDs) on direct expansion (DX) computer room air conditioners (CRACs), and particularly how reduced airflow can improve energy efficiency in data centers. VSDs on CRAC units coupled with good airflow management within a data center can have a dramatic impact on energy efficiency. Typically, a lot more cold air is circulated within conventional data centers than is needed to cool equipment related to information and communication technology (ICT). It is not uncommon to supply more than two to three times the minimum airflow required in order to overcome losses from air leakages and short circuiting and to prevent recirculation of hot air in ICT equipment. Reducing airflow is one of the primary and cost-effective means of reducing power demand and energy use in data centers. It reduces not only direct fan energy use but also indirect cooling energy use from reduced fan heat losses. Using VSDs on CRAC unit fans has shown to be a very cost effective measure to achieve reduced airflow.

This report discusses the use of VSDs to reduce airflow in data centers for efficient operation and how it can be used in conjunction with good airflow management for preventing hot spots in data centers. It also discusses how to find opportunities for reduced airflow in existing data centers, how to implement these, and how to estimate energy savings from reduced airflow.

Challenges and Objectives

Many utilities have data center customers who are experiencing increasing energy consumption. The vast majority of the small to mid-sized data centers utilize DX CRAC units, often with multiple units within the data centers. There are over 2.5 million of these data centers in the US representing a large opportunity for them to retrofit their DX CRAC units to save energy and become more energy efficient while still providing the necessary cooling for the ICT equipment. By eliminating waste, the data center owners can unlock some capacity within the existing data center that was lost to inefficiencies.

This report provides utility members with the information needed to understand some of the issues faced by this data center customer segment and help those customers overcome their heating and power limitations.

EPRI Perspective

EPRI's previous work in the areas of power supply, power distribution, and airflow management has had significant impact on the data center industry. The research conducted in the EPRI labs and at demonstration sites has resulted in product specifications and test protocols that have been adopted by agencies such as Intel, the EPA ENERGY STAR program, and the ECOS Consulting 80 PLUS program.

Keywords

Data center
Computer room air conditioning
Variable speed drive
Information and communication technology
Airflow management
Cooling
Energy efficiency

ABSTRACT

The information and communication technology (ICT) industry has grown very rapidly in the past few years, and its growth is expected to continue at a fast pace. Power demand and energy use in data centers that house much of the ICT equipment, and other power conditioning and cooling equipment that support the ICT equipment, have also grown and will continue to grow.

The power demand for cooling equipment in data centers can be reduced with use of variable speed drives on the computer room air conditioning units and proper airflow management. Typically, a lot more cold air is circulated within conventional data centers than is needed to cool the ICT equipment. It is not uncommon to supply more than two to three times the minimum airflow required in order to overcome losses from air leakages, short circuiting and to prevent recirculation of hot air in ICT equipment. Reducing airflow is one of the primary and cost-effective means of reducing power demand and energy use in data centers. It is also non disruptive to the ICT load. It reduces not only direct fan energy use but also indirect cooling energy use from reduced fan heat losses. Lower airflow also requires smaller equipment size for air distribution and cooling, which lowers its first cost in new installation. In existing data centers, it can release cooling capacity that is otherwise tied up to overcome extra heat generated from fans due to inefficient airflow, which allows addition of more ICT equipment in the data center.

This report discusses the use of variable speed drive in direct expansion (DX) computer room air conditioning (CRAC) systems that are common in small to mid-sized data centers and what level of energy savings that can be achieved with this approach. It also discusses how to identify opportunities for energy savings from retrofitting existing DX CRAC units in existing data centers.

CONTENTS

1 **ENERGY USE IN DATA CENTERS 1-1**

2 **ENERGY USE FOR AIRFLOW IN DATA CENTERS 2-1**

3 **HIGH FAN POWER USE IN DATA CENTERS 3-1**

Redundancy 3-1

Actual Data Center ICT Loads versus Design Loads 3-1

Air Leakage and Bypass 3-1

Preventing Hot Spots or Hot Air Re-circulation 3-2

Short Circuiting 3-3

4 **REDUCING AIRFLOW WITH DX AIR CONDITIOING EQUIPMENT AND USE OF VARIABLE SPEED DRIVES 4-1**

Airflow in Cooling Equipment 4-1

Reducing Excess Airflow 4-1

Reducing Airflow in DX CRAC units 4-2

Potential of Condensate Freeze on the Cooling Coil: Not True 4-2

Potential Lower Energy Efficiency at Lower Airflow Rates: Not True 4-5

Potential Mechanical Failure at Low Airflow Rates: Not Likely 4-5

Variable Speed Drives on DX CRAC Unit Fans: Yes! 4-6

Manual or Automatic Control of Variable Speed Drive: Either One Saves Energy 4-6

Containment: Optional 4-6

5 **ENERGY SAVINGS FROM USE OF VSD ON DX CRACS: FIELD EXPERIENCE 5-1**

6 **IDENTIFYING OPPORTUNITIES FOR VSDS ON DX CRAC UNITS 6-1**

Case Study 1 6-4

Case Study 2 6-4

7 **RECOMMENDATIONS FOR DEVLOPING A METHOD FOR AIRFLOW MANAGEMENT TO SAVE ENERGY 7-1**

LIST OF FIGURES

Figure 2-1 Range of Relative Energy/Power Used by Different Subsystems in Data Centers ..2-2
Figure 3-1 Air Leakage and Bypass Around ICT Racks in Data Centers 3-2
Figure 3-2 Hot Air Re-circulation Around ICT Racks in Data Centers 3-3
Figure 3-3 Effects of Air Short Circuiting in Data Centers 3-3
Figure 4-1 Sensible Cooling Energy Efficiency Ratio of a DX CRAC Unit versus Airflow at 100% Cooling Capacity 4-3
Figure 4-2 Sensible Cooling Energy Efficiency Ratio of a DX CRAC Unit versus Airflow at 50% Cooling Capacity 4-4
Figure 4-3 Supply Air Temperatures at Different Airflow Rates in a DX CRAC Unit 4-5
Figure 4-4 Schematic and Picture of Individual Rack Containment Demonstration at Oracle ...4-7
Figure 4-5 Importance of VSD on Cooling Equipment with Containment 4-8
Figure 5-1 Thermal Map Showing Temperature Distribution in a Small Data Center 5-1
Figure 5-2 Energy Use by ICT and DX CRAC Cooling Equipment at Different Fan Speeds 5-3
Figure 5-3 DX CRAC Unit Total Energy Use versus Fan Speed for Each Unit of ICT Power.... 5-3
Figure 5-4 Cooling PUE with DX CRAC Units at Different Fan Speed Settings 5-4
Figure 5-5 Total Cooling (Fans and Compressors) Energy Savings with DX CRAC Units at Different Fan Speeds 5-4
Figure 6-1 Direct Plenum Return to Reduce Hot Spots and Short Cycling 6-1

1
ENERGY USE IN DATA CENTERS

Energy to power data centers that house information and communication equipment (ICT) is growing rapidly. Energy is required for not only powering the ICT equipment but also for cooling equipment that removes heat generated from the ICT equipment as well as power conditioning equipment to provide uninterrupted power supply to the ICT equipment.

Though data centers are often associated with buildings that house large numbers of the ICT equipment, not all data centers are large. These can be as small as a single rack of ICT equipment that is placed in a closet in an office, for example to manage its telephones and emails, to rooms containing a few racks to small data centers and may often be called computer rooms, server rooms, IT rooms or labs, but essentially act as data centers since the heat generated by the ICT equipment must be removed by cooling equipment. There are some 2.5 million such data centers in the US with most of them contained within commercial office buildings.

In the last few years, leading users of ICT equipment have developed some of the very efficient data centers that have greatly reduced the need for power to cool, especially in large enterprise data centers within buildings dedicated for that purpose. Power utilization effectiveness (PUE), defined as a ratio of the total facility energy use divided by the energy use by the ICT equipment, is generally used to define the efficiency of its cooling and power distribution infrastructure. The Uptime Institute reports an average PUE of 1.8 from its 2011 survey of more than 500 data centers. In another study of more than 100 data centers for its ENERGY STAR program in 2009, EPA reported an average PUE of 1.91. A PUE of 1.91 indicates that 0.91 kWh is required to support each kWh used by the ICT equipment. The support power is primarily for cooling infrastructure, but it also includes power losses in electric power distribution infrastructure to provide uninterrupted power to the ICT equipment and other miscellaneous uses of electricity in a facility. Data centers are typically designed to provide continuous and uninterrupted operation of the ICT equipment. Its infrastructure is designed with sufficient redundancy and backup.

The state of the art in cooling large enterprise scale data centers that use about 10 MW or more power has rapidly evolved in the last few years. Coupled with the use of air side economizers as well as advances in the ICT equipment that can operate under a wider range of inlet air temperature and humidity, some enterprise scale data centers have reported PUEs as low as 1.1 or lower.

However, most data centers, large and small, use traditional air conditioning systems that remove heat from the data center space and reject it to the ambient air. The heat is removed from the ICT equipment by cold air, which is provided by traditional air conditioning equipment. Large data centers generally use chilled water systems while smaller and mid size data centers often use DX CRAC units. There are several reasons for small to midsize data centers to use DX cooling systems, primarily because efficient chillers are typically unavailable in small sizes. Generally DX cooling systems dominate in data centers with less than 300 kW of ICT capacity, and compete effectively with chilled water systems to 1000 kW or more. DX systems are modular in nature and can be added incrementally as data center capacity grows. Many owners, concerned about initial costs and uncertain about business needs, start with building small data centers and expand capacity as business grows over time and prefer to use modular systems. Some data

center owners do not like to see water or fluid in data center space and avoid chilled water systems. It also offers speed to market and can be low in the initial cost. DX systems can also be more efficient since there is no intermediate heat exchange fluid such as water between the refrigerant and the air.

There are, however, some limitations and disadvantages as well. It is difficult to leverage cooler outdoor ambient conditions unless the site allows use of an air side economizer. And some water cooled chillers offer higher efficiencies.

A DX system can be air cooled or water cooled for rejecting heat to the ambient air. An air cooled DX system directly rejects heat to the outdoor ambient air. It generally comes in two sections, one indoor for cooling the data center space and the other outdoor for rejecting heat to the ambient air. The indoor section has a fan, typically constant speed, and refrigerant coil. The coil may be circuited to allow connection to one or two compressors to allow some capacity variation in cooling load. The compressors are generally placed within the outdoor condensing unit section. The two sections are connected together with a pair of refrigerant pipes. The distance between the indoor and outdoor sections is generally kept small to reduce losses in the refrigerant pipes and for the system to work efficiently.

A DX system can also be water cooled. In a water cooled system, the indoor unit heat is rejected to an intermediary fluid, which in turn rejects heat through a dry cooler or a cooling tower to outdoors. The unit compressors are placed in the indoor unit where water is circulated to pick up heat and reject it to the outdoors. Water cooled DX units can be placed father away from the outdoor section than the air cooled DX units. Water cooled units may also have some glycol in the loop in cold climates to prevent the circulating water from freezing.

2
ENERGY USE FOR AIRFLOW IN DATA CENTERS

A study of thirteen data centers by Uptime Institute found that the data centers had an average of 2.6 times more cooling capacity than its needs (Uptime Institute White Paper TUI3010; http://uptimeinstitute.com/publications). The excess cooling capacity is coupled with excess airflow. The excess airflow bypasses the ICT equipment and often causes hot spots. The study also found that when bypass airflow were reduced the cabinet inlet air temperatures also dropped and hot spots were eliminated or reduced.

When cooling capacities greatly exceed ICT loads and airflow within the data center space is poorly managed, it will lead to energy waste and hot spots within the space. Consider data centers with DX cooling systems: if cooling capacity is more than what is needed by the ICT equipment, its compressors will shut off, but its fans will continue to move air through it. The supply air becomes a few degrees warmer than the return air as it picks up heat dissipated by the fan motor. Therefore, hot air is delivered to the cold aisle from those DX units whose compressors are turned off due to overcapacity. It is obvious that this hot air will cause hot spots at the inlet of the ICT equipment.

A breakdown of energy consumption by different components of the support infrastructure from a Lawrence Berkeley National Laboratory study of 25 data center sites is plotted in Figure 2-1 (LBNL; http://hightech.lbl.gov/benchmarking-dc.html). Energy use by three major components and subsystems—uninterruptible power supply (UPS), air-distribution equipment, and cooling subsystem—for each kWh unit of the ICT equipment energy use is plotted in the figure. The low, high, and typical values are shown with graded color bars. These data are quite similar to other data reported in the literature and trade press. Some additional data from literature are also used in the plot to show expanded range.

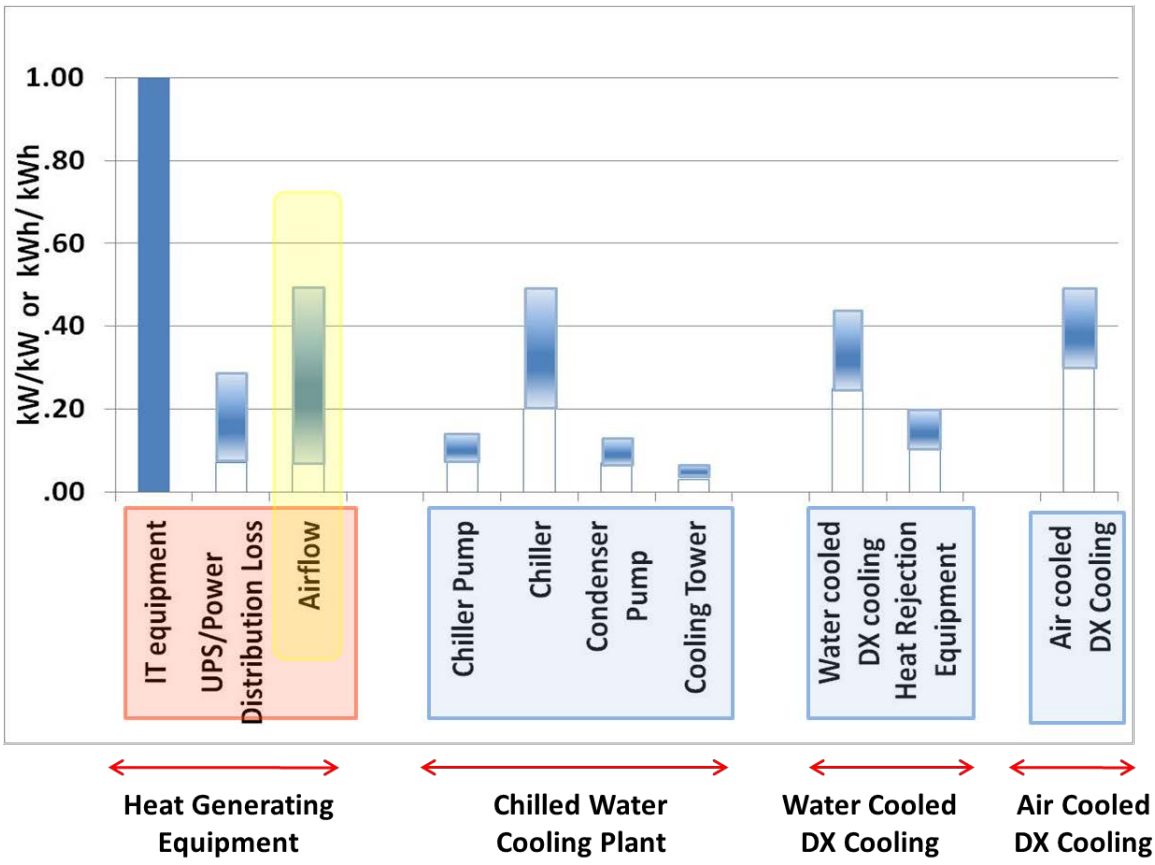


Figure 2-1
Range of Relative Energy/Power Used by Different Subsystems in Data Centers

The figure shows energy use by the ICT equipment as unity. All other energy uses are relative the unity ICT energy use. All energy used by the ICT equipment turns into heat that must be removed by the air-conditioning equipment.

The UPS required for reliability in power distribution accounted for a low of 0.07 to a high of 0.28 kWh/kWh of the IT equipment among different data centers in the study. New UPS configurations such as 'eco' mode of operations and some rotary UPS systems can cut down losses further to just about 0.03 kWh/kWh of the ICT equipment. The efficiency of UPS devices varies with the ICT load; lightly loaded UPS systems are less efficient and waste more energy. The inefficiency of the UPS not only causes direct loss of power, but its inefficiency turns into heat in data centers and requires additional energy for cooling.

The air-distribution fans accounted for a low of 0.07 to a high 0.50 kWh/kWh of the IT equipment. The air-distribution fans are located within the data center space, and any energy use by these fans is eventually converted into heat that must be removed by the air-conditioning equipment. Therefore, the energy use by air-distribution fans is plotted next to the heat-generating equipment such as IT equipment and UPSs. Since the LBNL study, some data centers have reported fan power consumptions of as low as 0.02 kWh/kWh of the ICT equipment, especially in contained systems with closed coupled cooling.

The heat generated by the ICT equipment, UPS system, and the air-distribution fans must be removed by the cooling systems. Energy use for three common types of cooling subsystems is included here. Other variations of cooling systems are possible, such as air-cooled chiller versus water-cooled chiller shown here, as well as air-side economizer, which are not discussed in detail here because the focus of this document is airflow management with DX cooling equipment.

The air-moving fans show the widest range of data, from a low of 0.07 to a high of 0.50 kWh/kWh of the ICT power, or a ratio of ~7 to 1 between the highest to the lowest number. If you consider lower fan power numbers of 0.02 reported since the study, the range between the higher and lower energy use numbers become even wider.

The wide range of power required for airflow clearly shows that addressing it offers one of the most promising opportunities for energy savings in data centers. The direct fan energy savings in data centers also leads to cooling energy savings from reduced fan heat, which lowers the data center cooling requirement. The combined savings provide additional incentive to address fan energy savings.

3
HIGH FAN POWER USE IN DATA CENTERS

The primary reason for use of very high fan power in data centers is perhaps because of perceived reliability. Excess capacity may be perceived to provide more reliability; on the contrary, it wastes energy and may lower reliability by causing hot spots within a data center. Several reasons may contribute to excess airflow and high fan energy use and some are discussed below. Their combined effect is that two to three times more airflow than the minimum required may be taking place. Excess airflow does not do any productive work; it just circulates within the data center, causes hot spots and increases energy use for air movement and adds excess fan heat to the space. Preventing excess airflow would help reduce hot spots and fan energy use.

Redundancy

Cooling and airflow equipment in configuration of N+1 or N+2 (one or two units more than what is required to meet the total load) is generally specified for redundancy in data centers due to reliability requirements and the continuous nature of operation. The redundant equipment is in place to provide sufficient cooling in the event of an unforeseen loss of a unit either due to failure or planned service outage. Where multiple distributed computer room air conditioners (CRACs) or computer room air handlers (CRAHs) are used, it is common to specify one redundant CRAC or CRAH for each five to seven units or provide about 15 to 20% extra capacity. These redundant units typically operate in full service during normal operation and share the space heat loads. Therefore, it is quite common to see 15 to 20% more airflow and fan power than the design load and it adds to the fan energy use.

Actual Data Center ICT Loads versus Design Loads

Most data centers operate at lower-than-design ICT loads. This is a quite common practice; data center operators prefer to keep ICT load below 80% of its capacity, while many data centers operate at even lower loads. It is not uncommon to see data centers actually operating below 50% capacity as data centers owners design larger data centers than what is immediately needed to accommodate future growth. Even at 80% loading, HVAC airflow and fan equipment is 25% oversized, and coupled with redundancy, fan equipment capacity could be 50% more than needed.

Air Leakage and Bypass

In traditional data centers, cold supply air is delivered to heat-generating equipment from under the floor through perforated tiles in front of racks. Power and communications cables are also distributed under the floor through tile cutouts (usually in the back of the racks). The cable cutouts are not sealed, and air leaks through them. These cutouts are often in the hot aisle, so the leaked air does not do productive ICT equipment cooling and simply circulates in the data center, causing extra fan energy use. Air may also leak from openings between adjacent ICT equipment within racks, blank spaces left open to accommodate future ICT equipment within racks, spaces between adjoining racks, or spaces left open to accommodate future racks. A schematic of air leakage around an ICT rack is shown in Figure 3-1. Any air leakage requires additional but unproductive airflow and adds extra fan energy use. Preventing air leakage will reduce airflow

needs and fan energy use. There are several products in the market to help prevent air leakage such as blanking panels that are often used to block such air bypass from partially loaded racks, etc.

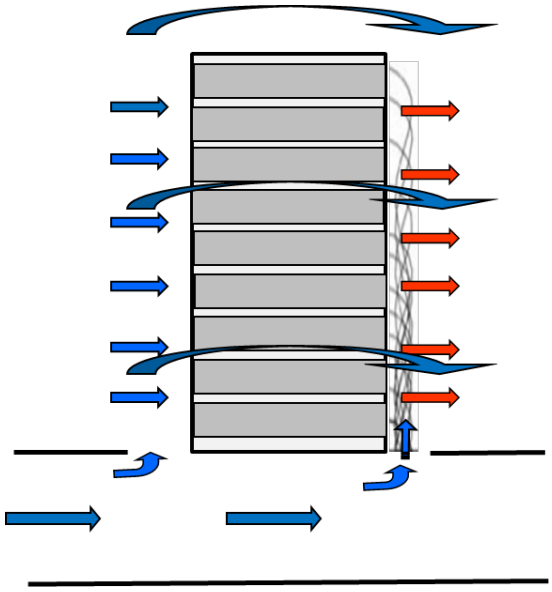


Figure 3-1
Air Leakage and Bypass Around ICT Racks in Data Centers

Preventing Hot Spots or Hot Air Re-circulation

It is a common practice to blow extra cold air in order to reduce hot spots and reduce hot air recirculation in a data center. Hot exhaust air from the IT equipment can re-circulate back to the inlet of the IT equipment, as shown in Figure 3-2**.** The re-circulation generally takes place due to local conditions such as blockage of air discharged from the IT equipment by cables and wires, which causes the hot air to be drawn back at the inlet of the IT equipment. The air may also re-circulate at the end of a row of equipment. The re-circulation is also observed near the top of the IT equipment rack where it is easier for the IT equipment rack to pull hot discharge air adjacent to the equipment than the cold air coming out of a floor outlet.

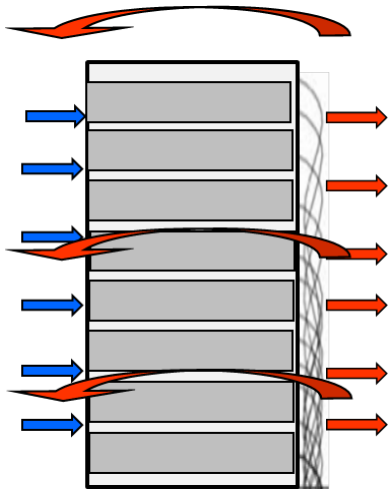


Figure 3-2
Hot Air Re-circulation Around ICT Racks in Data Centers

Short Circuiting

In some cases, CRAC or CRAH units are laid out in such a way that some of the cold supply air simply returns back to the CRAC or CRAH without doing any useful cooling as a result of short cycling of the cold air. This can be reduced with proper locations of air distribution tiles and location of the return air intake. There are some products in the market that duct hot air directly back to the CRAC return air plenum and prevent its mixing with the cold air.

Excess airflow also makes the CRAC unit operate at lower efficiency. Excess air that bypasses the IT equipment mixes with the hot discharge air from the IT equipment before it returns to the CRAC. The mixed return air temperature is lower when it enters the CRAC unit, which lowers the CRAC unit operating efficiency. A schematic of air temperatures with bypass quantity that is twice that of the airflow across the IT equipment is shown in Figure 3-3.

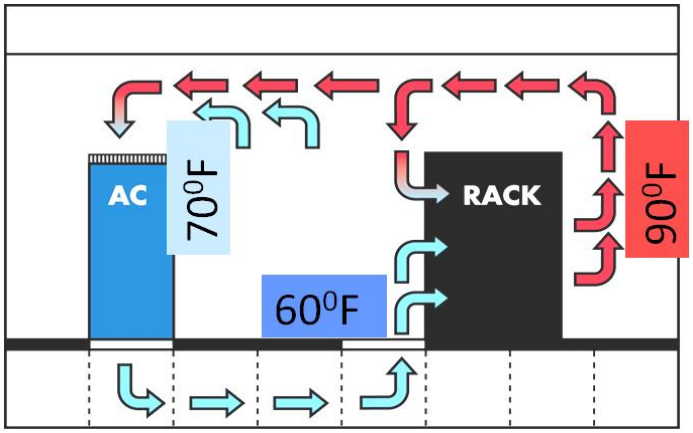


Figure 3-3
Effects of Air Short Circuiting in Data Centers

This is one of the reasons why the thermostat set points, which are located in return air streams and read its temperatures, are kept so low in data centers. In the above figure where 3 times more airflow is circulated than minimum required through the ICT equipment, the return air thermostat

has to be set to a low temperature of 70ºF even when hot air at the outlet of the ICT equipment is 90ºF.

It is clear that airflow in most data centers is much more than minimum required. One way to reduce the airflow is to use variable speed fans that will allow it to match the airflow from the CRAC units to the airflow required by the ICT equipment.

4

REDUCING AIRFLOW WITH DX AIR CONDITIOING EQUIPMENT AND USE OF VARIABLE SPEED DRIVES

Airflow in Cooling Equipment

Direct Expansion (DX) Computer Room Air Conditioning (CRAC) equipment is designed with well matched components that include a compressor, a cooling coil, a fan that moves air over the cooling coil, an air or water cooled condenser and a refrigerant expansion device. All components are selected to work efficiently within a specific operating range and may fail to work if operated much outside that range, though many safety devices are built in the system for it to safely shut down without catastrophic damage when it encounters conditions that are outside of its operating range.

Data center DX CRAC units generally have two compressors, each one with its own independent refrigeration circuit including cooling coil, condenser coil and expansion device. Sometimes cooling coil or condenser are shared in a physical structure, but still have independent refrigeration circuits. The cooling coils can be totally independent pieces of hardware or a single piece of hardware with two totally independent refrigeration circuits. A single piece of hardware with independent but intertwined refrigeration circuits can help in efficiency at part load.

Most of the current air-conditioning equipment used in data centers has been derived from the comfort air-conditioning business. A typical configuration of a DX CRAC unit uses 3- or 4-rows deep finned cooling coils that supply cold air temperatures in mid to upper 50s or low 60s degree Fahrenheit, and delivers airflow in the range of mid 400 to low 600 cubic feet per minute (cfm) per ton of cooling. This translates to about 125 to 175 cfm per kW of cooling capacity at full capacity. It typically cools the air temperature by about 20^{o}F across the cooling coils at full capacity. The cooling capacity of each circuit is fixed. It provides cooling in discreet capacity steps; either its compressor is running and producing cooling or it is shut down and not producing any cooling.

Having two circuits allows for some cooling capacity modulation, though in discreet steps, at part load to match the cooling load. However, the fan speed does not modulate. Therefore, if one compressor is turned off, only 50% cooling is available, though the airflow is still at 100%. The temperature drop across the cooling coil is about half. When both compressors shut off, warm air circulates without cooling.

Reducing Excess Airflow

Reducing excess airflow has proven to improve energy efficiency (*Airflow Management: Energy Efficiency Opportunities in Data Centers*. EPRI, Palo Alto, CA: 2011. 1021973). This not only reduces fan power requirement but could also reduce hot spots and other problems related to excess airflow. Excess airflow results in unproductive use of fan energy. Reducing airflow will provide significant direct fan energy savings as well as indirect cooling energy savings from avoided fan heat losses. In existing data centers, it can release spare cooling capacity that was earlier tied up in inefficient airflow to allow additional ICT equipment in the data center.

Reducing airflow is easier said than done. Airflow management is critical in proper and efficient functioning of a data center. It can be done in a non-disruptive manner to the ICT equipment. It can be accomplished by preventing supply air leakage around cable cut outs and through racks with missing blanking panels, curtailing or eliminating cold air short circuiting back to the CRAC unit and other good housekeeping practices. Hot air containment and preventing it to mix with the cold air that is entering the ICT equipment prevents hot spots and allows the airflow to be further reduced since most of the data centers are over provisioned with excess cooling capacity. The air containment can be based on individual racks (e.g., individual racks with chimneys) or complete aisles (cold aisle or hot aisle).

Once the need for the airflow is reduced, there are two ways to cut down on the airflow:

1. Turning off CRAC units
2. Reducing airflow through CRAC units

Turning CRAC units off is perhaps the least costly approach. One just needs to identify which units to turn off. It can be done by turning one unit off at a time and observing the temperatures with a data center. Care has to be taken that the off unit is 'hot standby mode' so that in case any other operating unit fails, the hot standby unit picks up and provides continuous cooling.

Reducing airflow through DX CRAC units can be done but it requires special attention.

Reducing Airflow in DX CRAC units

Various components and subsystems of a DX refrigerant system are fine tuned to work in unison under all operating conditions and any changes in operating conditions permeate through the system that rebalances its performance under new operating conditions. And if operating conditions drift out of range, the system's safety devices either shut it down or the system breaks down. There are obvious concerns to safe and efficient operation of the system, but many of the concerns are often blown out of proportion. These concerns and scientific response to the same are presented below:

Potential of Condensate Freeze on the Cooling Coil: Not True

When less air flows over cooling coil while the compressor is still operating at full capacity since it has no capacity modulation, the cooling coil temperature drops lower. The lower temperature coil will cool the air further down in temperature. Depending on the inlet air humidity, the lower temperature coil may also condense more moisture on it. The condensate on the coil eventually runs down the drain. If airflow continues to be lowered, the cooling coil temperature fall further, and it is feared that lower temperatures may freeze the condensate on the cooling coil and block airflow.

Since data center spaces do not generate moisture, most DX systems are designed in such a way that they do not unnecessarily dehumidify the air, which requires the cooling coil to operate at as high a temperature as possible, but just cool enough to dehumidify for maintaining acceptable indoor humidity levels in humid climates. Under these design conditions, it has been found that the airflow rates per ton of cooling are quite high than. Even if the airflow rates are reduced down to 60% of the rated airflow, the cooling coil temperature does not reach at low enough levels for the condensate to freeze. But at 60% designed airflow, the fan power is reduced to just about 22% of the rated fan power draw, providing 78% fan savings. Since fans run continuously,

and data centers generally have much more airflow than needed, fan energy savings can provide significant energy efficiency advantages.

In fact, when contacted, the leading DX CRAC unit manufacturers provided ratings that showed safe operations of units down to 60% of the rated capacity in data center applications where return air temperatures are generally high.

The following Figure 4-1 and Figure 4-2 show data from one manufacturer on sensible energy efficiency ratio (SEER) of an air-cooled DX unit at 100% and 50% compressor cooling capacities.

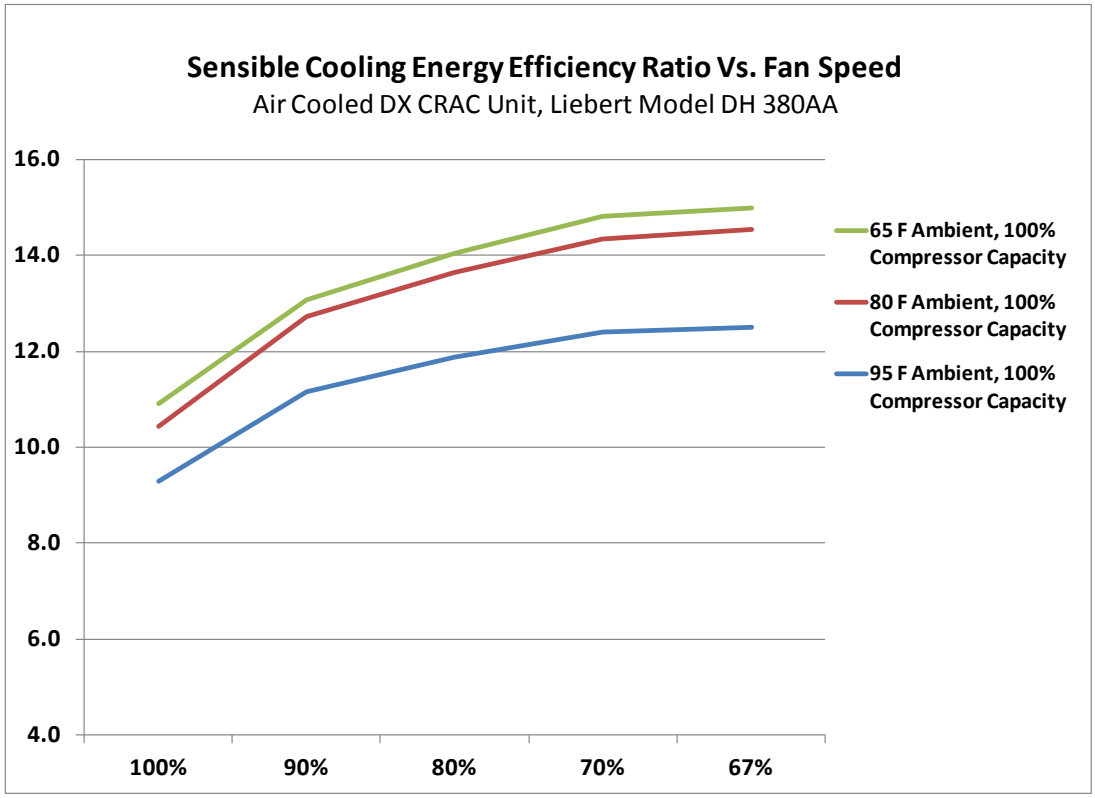


Figure 4-1
Sensible Cooling Energy Efficiency Ratio of a DX CRAC Unit versus Airflow at 100% Cooling Capacity

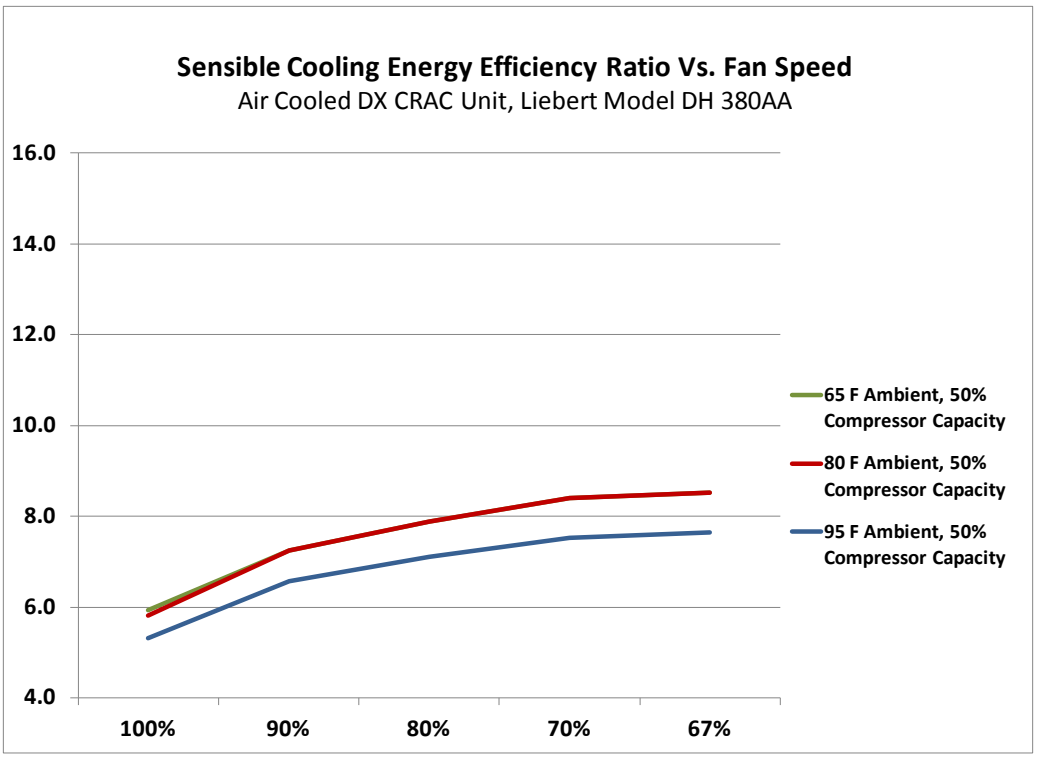


Figure 4-2
Sensible Cooling Energy Efficiency Ratio of a DX CRAC Unit versus Airflow at 50% Cooling Capacity

Observations of Figure 4-1 and Figure 4-2 show that the sensible cooling SEER increases as fan speed is lowered, and the efficiency is much higher at full compressor capacity load than at 50% capacity.

Supply air temperature of a water cooled DX unit from a manufacturer's data at different airflow rates are plotted on a psychrometric chart in Figure 4-3. The data shows that the supply air temperature reduces from 54.9 F at 100% speed to 53 F at 60% fan speed. The supply air temperature is well above conditions where condensate water could freeze on the cooling coil; generally manufacturers are concerned about potential spot condensate freezing when average cooling coil temperatures fall below about 40 F or supply air temperatures fall below about 45 F.

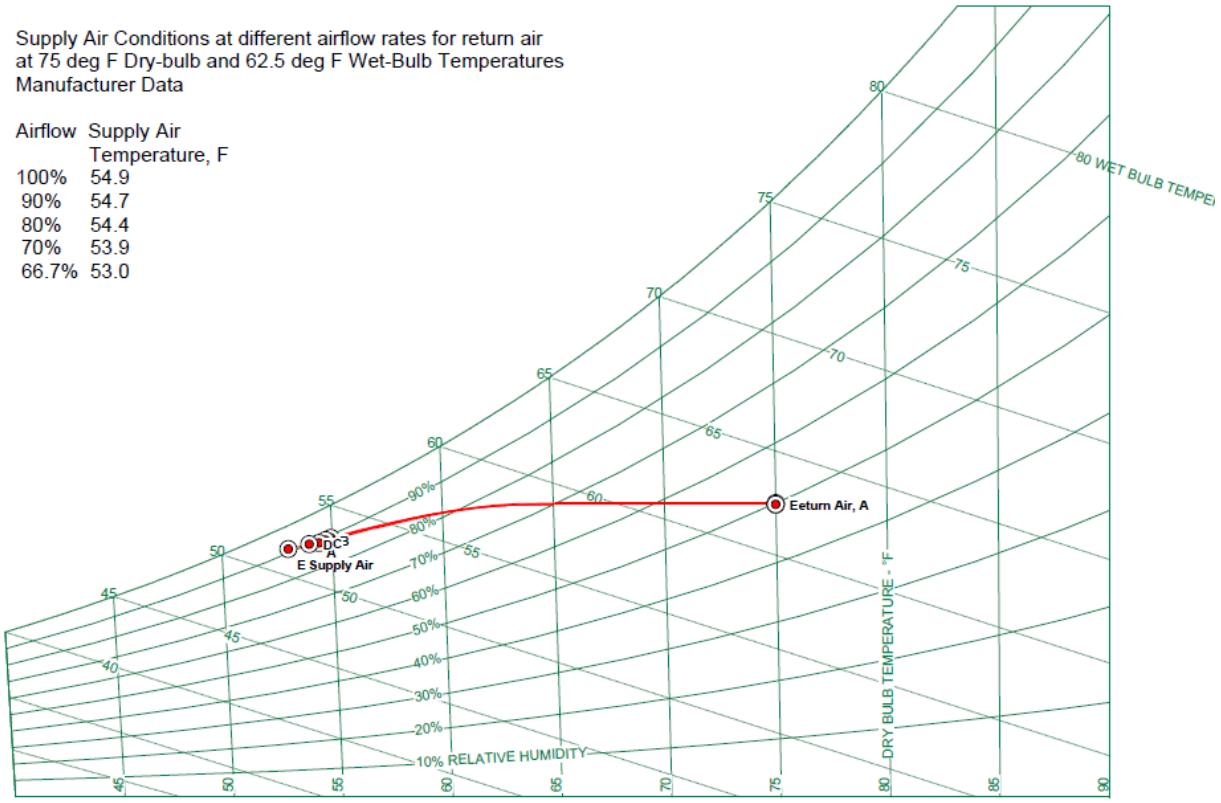


Figure 4-3
Supply Air Temperatures at Different Airflow Rates in a DX CRAC Unit

Potential Lower Energy Efficiency at Lower Airflow Rates: Not True

At lower airflow, the cooling coil temperature is lowered and compressor has to work harder to remove heat, and it could be argued that this will reduce the cooling energy efficiency. It is true that the compressors have to work harder and use more power. However, the reduction in fan power energy more than offsets any increase in compressor power. The data in Figures 4-1 and 4-2 confirm that the unit's SEER increases as fan speed is reduced.

Potential Mechanical Failure at Low Airflow Rates: Not Likely

There is a fear of potential mechanical failure of the DX CRAC units if you run at lower fan speeds and airflow rates. It is likely that some units could run into issues when their filters are dirty and reduce airflow even more, or airflow is blocked with some obstructions, but most DX CRACs have built in safety controls such as minimum airflow cutout, low refrigerant/temperature cutout, etc. that protect the units.

EPRI tested two air cooled DX CRAC units and two water cooled DX CRAC units from two different manufacturers in a California Energy Commission funded project over nearly two years periods in two operating data centers in California with speeds as low as 60% without any issues. Of course, it is always good to exercise precaution and use best practices such as making sure

that filters or other obstructions are not blocking airflow and the data center return air temperatures are not very low.

Variable Speed Drives on DX CRAC Unit Fans: Yes!

Airflow in a DX CRAC unit can be reduced several ways such as blocking air flow, or changing motor pulley size, or varying the fan speed by installing a VSD on the fan motor. Since the ICT load in data center would vary over time, it is preferable to install a VSD so that the fan speed can be easily adjusted as requirements change over time.

Manual or Automatic Control of Variable Speed Drive: Either One Saves Energy

Should you control the VSD manually or use automatic control system. Either one will save you energy. It will depend on user preference. It is possible to manually adjust VSD speed so that hot spots are eliminated or reduced. It may be necessary to adjust the speed periodically as data center ICT loads change or when airflow adjustments are needed.

Automatic controls for VSD can provide comfort in knowing that the data center is being continuously monitored and the system may respond automatically to ICT load changes or failure of any of the DX CRACs. Some vendors offer wireless sensors spread across the data center that monitor ICT equipment inlet temperatures and analyze data and send command the CRAC units' VSD to adjust fan speed optimally. Continual operational optimization may yield some additional energy savings.

Containment: Optional

Is containment needed with the use of VSDs on CRACs? Not necessarily. But if containment is used, VSDs are necessary. Among two sites where EPRI conducted field demonstration with VSDs on DX CRACs, one site did not have any containment while the other had it. Both systems saved energy. The amount of energy savings depend upon how low a fan speed at which the ICT load are satisfied or the minimum acceptable fan speed in DX CRAC units, which is typically 60% or 67% (2/3rd the rated fan speed). In one of the EPRI test sites, the fan speed was gradually reduced until it reached the lower limit of 60% without requiring any containment, so no containment was done. The other site already had flexible strip curtain for hot air containment with over the plenum return air back to the CRAC units.

Containment—cold aisle, hot aisle or rack—requires that the airflow quantity from the CRAC units must match the airflow quantity over the ICT equipment racks. This necessitates the use of variable-speed drives on the CRAC unit fans. Because the airflow in the ICT equipment, especially new ones, can vary over time, and the total load of the ICT equipment can also vary over time, the CRAC units must have the ability to vary the airflow to provide the amount needed by the ICT equipment racks at all times.

The use of variable airflow in conjunction with containment was first demonstrated in a large enterprise data center by Oracle only in 2004 [*High Density Heat Containment*, ASHRAE Journal, p.38, Dec. 2007]. Individual rack containment was used as shown in Figure 4-4. Until this demonstration, the industry was skeptical about using variable airflow in data centers. The usual argument against the use of variable air flow was that the loads in data centers are nearly constant and do not vary much from hour to hour, and variable-speed drives on fans were not economically justified. This argument, however, was debunked in the Oracle demonstration in 2004, where variable-speed drives on CRAC fans were used; the actual payback period was

measured to be less than six months. It is true that data center loads do not vary from hour to hour, but they do vary over time as new IT equipment is added or old equipment is removed. The data centers are generally populated over time, which allowed fans to operate at lower speeds, and contributed to early payback. The data centers are also provisioned with extra cooling capacity for redundancy and future growth. If the airflow can be just reduced by 10% or 20%, direct fan energy savings of 27 to 49% are realized as per fan affinity laws. Additional cooling energy savings, about one-half to one-third of the fan energy savings, are also realized from avoided fan heat. The CRAC units in the Oracle application were chilled water based and did not have the additional issues as are identified with DX CRACs here, but the argument for using the VSDs on CRACs are still valid.

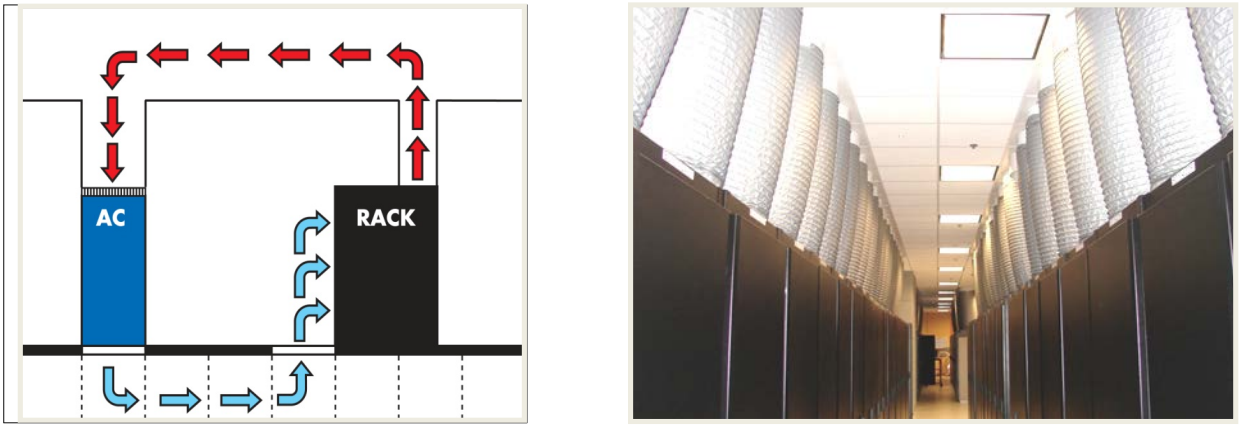


Figure 4-4
Schematic and Picture of Individual Rack Containment Demonstration at Oracle

As containment became popular, some data centers have used it without adding variable-airflow capacity in their CRAC units. There is no path for excess airflow to find its way back to the CRAC units. This causes greater pressure differential between the hot and cold aisle. If the barrier uses strip curtains, the excess airflow will find its way through small openings where strips of curtain overlap as shown in the Figure 4-5. The use of barrier may have reduced the hot spots, but it would not provide energy savings. The energy savings are realized only by slowing down the fan speed.

Care should be taken when installing containment material because of the possibility of blocking the planned operation of the sprinkler system. The authority having jurisdiction, usually the City Fire Marshall or City Building Inspector, must be contacted and approve any containment system.



Figure 4-5
Importance of VSD on Cooling Equipment with Containment

5
ENERGY SAVINGS FROM USE OF VSD ON DX CRACS: FIELD EXPERIENCE

EPRI conducted filed demonstration at two small data centers with VSDs on DX CRACs under a grant from the California Energy Commission. Each site had two CRAC units. One site had air cooled DX CRAC units while the other had water cooled DX CRAC units. Each CRAC unit had two compressors and two refrigeration circuits. The air cooled CRAC unit had an inter-twined cooling coil configuration while the water cooled CRAC unit had independent coil sections. The units were retrofitted with VSDs and operated for more than a year. The VSDs were initially controlled manually and worked fine for several months. Automatic controls were later installed to test its effectiveness as well as to collect additional systems' performance data. The automatic control systems used multiple wireless temperature sensors to monitor inlet air temperatures to the ICT equipment and use this information to send control commands to the VSDs. The automatic control systems also worked fine.

One feature of an automatic control system is that it provides visual thermal map of the data center that is quite helpful in managing ICT equipment locations and airflow in data center. An example of a thermal map of one of the sites is shown in Figure 5-1. The blue, green, yellow and red colors progressively show cold to hot temperatures within the data center space.

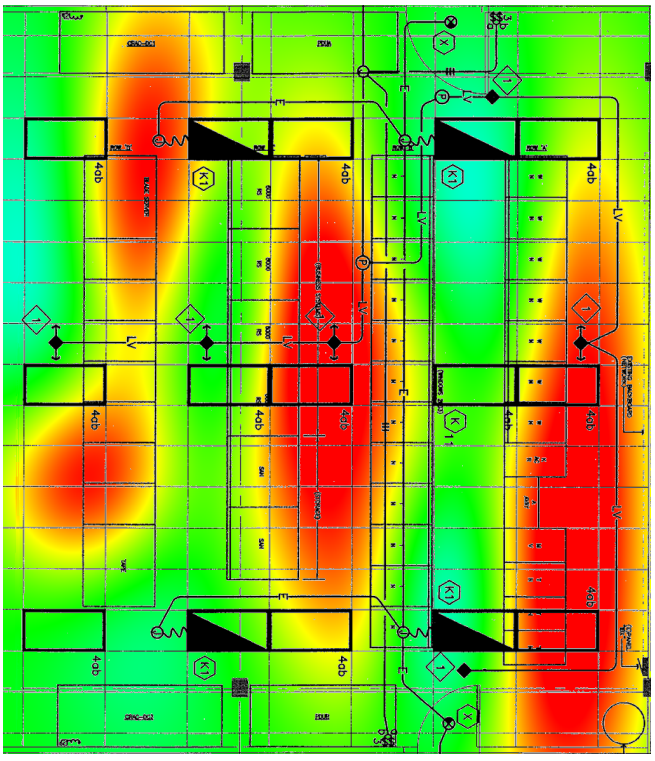


Figure 5-1
Thermal Map Showing Temperature Distribution in a Small Data Center

The power use data by the ICT equipment as well as the cooling equipment (Indoor CRAC fans, compressors and outdoor air cooled condenser fans) were analyzed. The data for one of the sites is presented below for the following conditions:

1. 100% fan speed under manual control
2. 90% fan speed under manual control
3. 80% fan speed under manual control
4. Fan speed controlled by Vigilent Automatic Controls with minimum fan speed set at 70%
5. Fan speed controlled by Vigilent Automatic Controls with minimum fan speed set at 60%

There are two DX CRAC units in this small data center with one provisioned as a redundant unit and each of the two units is sized to serve the total load of the IT equipment. Therefore, it is expected that the units' fans will slow down to the lower fan speed limit of 70% or 60%, and yet be available to ramp up to full speed and provide necessary cooling if the other unit failed.

Periods of data before and after adjustments to the fan speed were selected to compare the cooling energy requirements by the indoor fans, compressor and outdoor condenser fans units. The indoor temperature settings were unchanged, but we did notice return air temperature rise with lower fan speed, possibly due to less mixing with cold air and more air stratification at lower flows. The outdoor weather data over the test periods before and after the speed adjustments were small and data were not corrected for the weather data. The internal IT load varied very slightly—less than 0.4% over the test period.

The energy use by the ICT equipment and the cooling equipment are plotted in Figure 5-2 and Figure 5-3 below. Total cooling energy reduction were very impressive: it ranged from a low of 18.1% at 90% fan speed; 19.7% reduction at 80% fan speed; 26.5% reduction at a minimum fan speed set point of 70%; and a whopping 32.0% at the minimum fan speed setting of 60% in comparison to the cooling energy use at 100%.

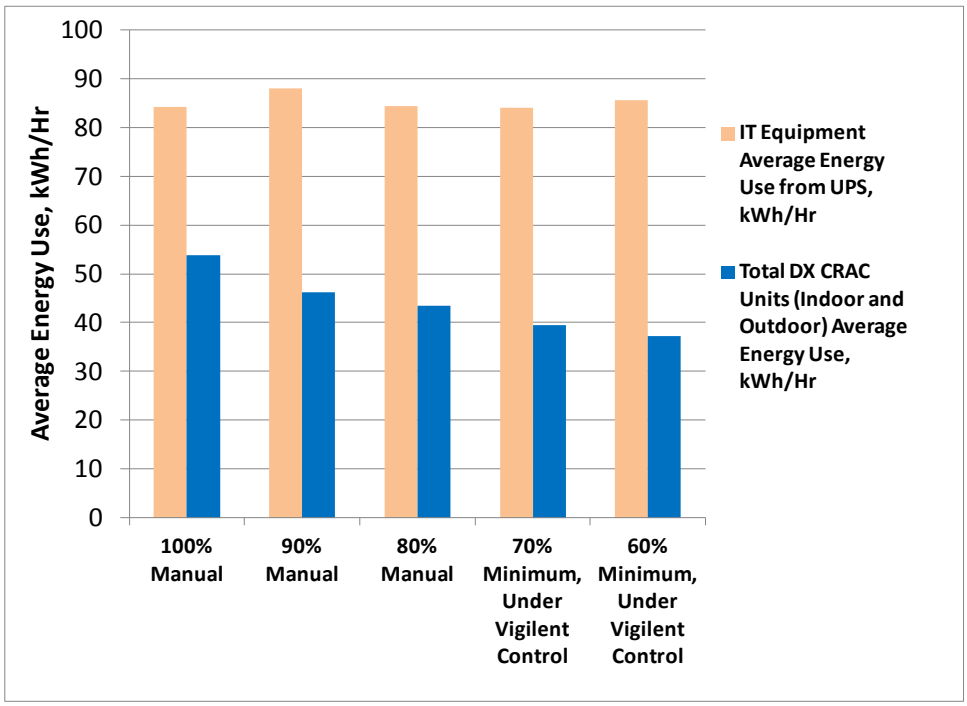


Figure 5-2
Energy Use by ICT and DX CRAC Cooling Equipment at Different Fan Speeds

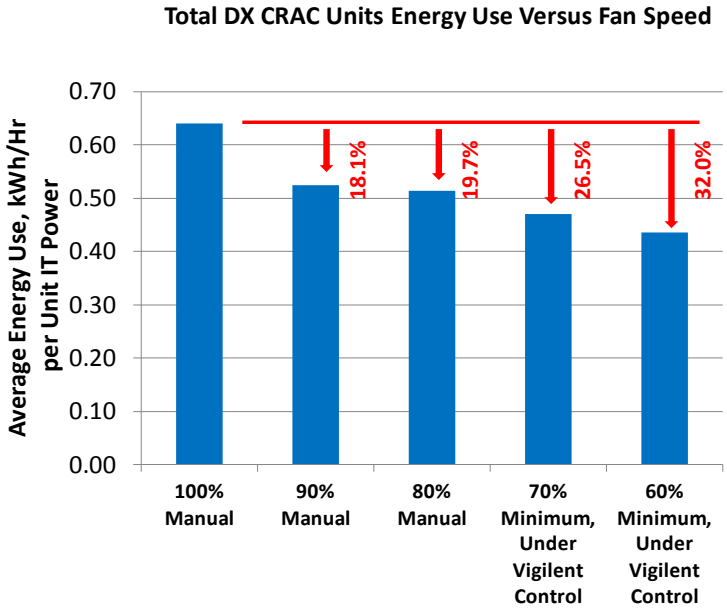


Figure 5-3
DX CRAC Unit Total Energy Use versus Fan Speed for Each Unit of ICT Power

The cooling energy savings as a percentage of the ICT power use, a measure of the absolute reduction in the Power Usage Effectiveness (PUE), was very impressive and ranged from 0.087 at 90% fan speed to 0.194 at the minimum speed of 60% as shown in Figure 5-5 and Figure 5-5.

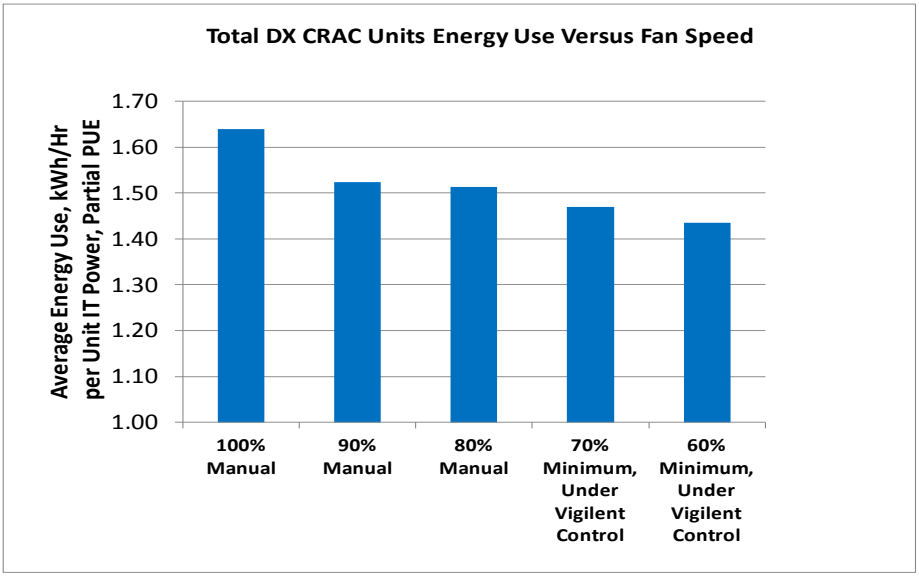


Figure 5-4
Cooling PUE with DX CRAC Units at Different Fan Speed Settings

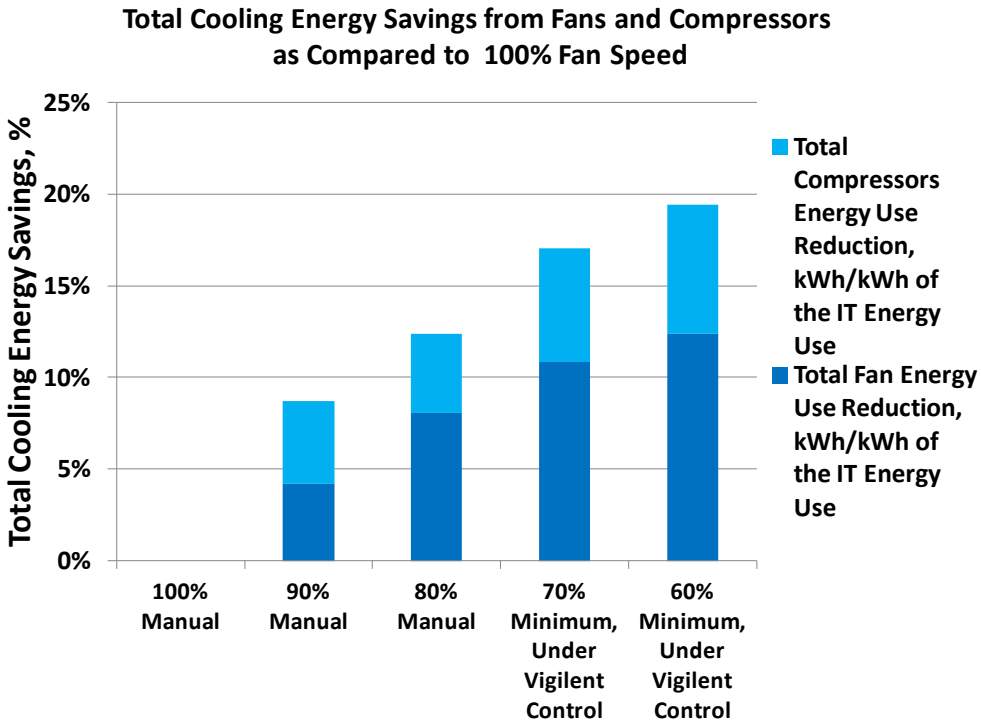


Figure 5-5
Total Cooling (Fans and Compressors) Energy Savings with DX CRAC Units at Different Fan Speeds

6
IDENTIFYING OPPORTUNITIES FOR VSDS ON DX CRAC UNITS

In a new system design, it is cost-effective to install variable-speed fans for airflow management, and it is becoming a common practice, although containment is not as prevalent. However, retrofitting existing data centers with variable-airflow devices and containment can be a challenge. In this section we will discuss how to identify energy-savings opportunities through good airflow management in existing data centers and offer some simple tips on estimating its energy-savings potential.

1. It is not necessary to use containment when variable-speed drive fans are used. VSDs can be used on CRAC and CRAH fans without using containment. The containment only helps in positively isolating hot ICT discharge air from cold supply air. It is often quite expensive to install containment, especially barriers between hot and cold aisles. It may require reconfiguration of fire-suppression systems that can be prohibitively expensive. As long as hot spots can be prevented or limited, there will still be savings from VSDs. One way to limit hot spots would be to use a return duct from a plenum to the CRAC units and direct all return airflow through plenum, as shown in schematic and picture below in Figure 6-1. This will reduce short cycling and reduce hot spots.

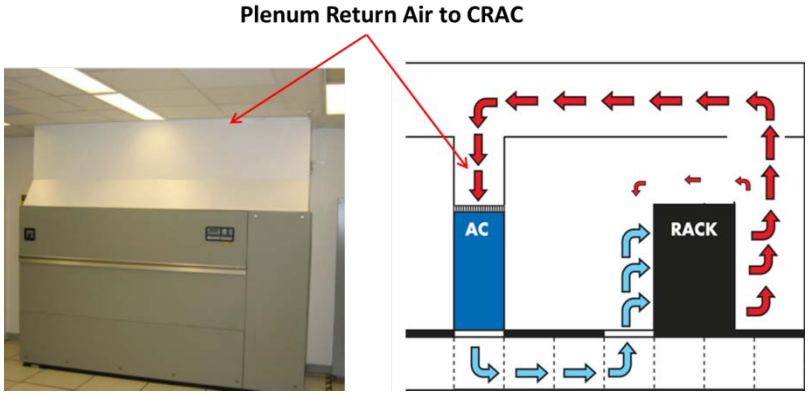


Figure 6-1
Direct Plenum Return to Reduce Hot Spots and Short Cycling

2. Variable-speed drives can be easily installed in CRAC unit fans. In DX CRAC units, limit the lower fan speed set point of 60% or higher. There are few items to take into consideration while considering VSDs for CRACs. The VSDs should be placed within a short distance from the motor to avoid power harmonics. This is generally not a problem if the VSD is located within 10 to 15 feet from the motor, which is common with CRAC units. Moreover, VSDs are generally installed on VSD rated motors, and many of the older CRAH and CRAC units may not have VSD-rated motors. Do you need to replace motors when installing VSDs? Not necessarily. It would be an added expense. Some field experience has shown that it is not always necessary to upgrade the motor, and the expense can be deferred if motor replacement is required later, perhaps after several years. VSDs generate eddy currents and heat in motors; however, because these motors

are located in a cold air stream, potential damage from heat buildup is not an issue. The eddy currents, however, could cause pitting on the motor shaft over time, which may eventually need replacement, perhaps after several years. There will be, however, enough warning signs from the motor shaft grinding, and its service/replacement could be scheduled during maintenance. These eddy currents can be avoided with the use of inexpensive grounding brushes that create a path to drain currents from the motor shaft to the motor body.

3. Can VSDs be installed on CRAC fans? There are some issues with it, but the simple answer is "yes," with some caution. The use of VSDs had been limited to chilled-water CRAH units so far; but the recent study at EPRI and funded by the California Energy Commission has shown that VSDs can be installed on DX CRAC units with some caution. Resistance to the use of variable-speed fans in data centers has mainly been driven by perceived fear that variable-speed operation of data center cooling may adversely affect its reliability. However, EPRI has tested VSDs on two of its data center CRAC units. It has found these units to be working satisfactorily without any problem down to 60% fan speeds while operating under adverse ambient conditions, under which it would have likely shown problems, if any. It may be quite practical to reduce fan speeds down to a safer zone of 70% (instead of 60% testing at EPRI) and still achieve 66% direct fan energy savings. Additional cooling energy savings would be derived from reduced fan heat from avoided fan power. Some manufactures do provide CRAC unit performance ratings on request and do not see red flags down to 60% speed. It is always good to check with your CRAC unit suppliers, but be aware that they may discourage it.

So how do we determine whether a particular data center is a good candidate for VSD installation and airflow management? There are several clues from CRAC and CRAH units' operational data. Start with gathering the following data:

1. What is the ICT load? Generally, these data can be obtained from the UPS or power distribution unit (PDU) for the ICT load. If a UPS is located within the data center space, its heat losses are also to be included along with the ICT load. The ICT load can be measured in kW.
2. What is the CRAC units' total rated cooling capacity? Add cooling capacity and fan power of each of the CRAC units. The CRAC unit nominal capacity may be available in tons or Btu/h of cooling. These numbers can be converted to equivalent kW cooling capacity. A ton of cooling can cool 3.52 kW of IT load. There are 3412 Btu in each kWh, so the Btu/h number needs to be divided by 3412 to obtain its cooling capacity in kW.
3. *Compare the ICT load (kW) against the total cooling capacity (kW). If ICT load is less than 80% of the CRAC unit cooling capacity, it is likely a good candidate. The lower the number, the more the savings opportunity*.
4. Review the temperature of the CRAC unit return air. It is easily available from the CRAC unit display panel.
5. Review the temperature of the CRAC unit supply air. It may also be available from the CRAC unit display panel. If not, insert a temperature sensor near the supply air outlet. Be careful to get an average supply air temperature with DX CRAC units where compressors may be turning on and off.

6. *Calculate temperature difference between return and supply air temperatures. If the temperature difference is less than 15°F, it is likely a good candidate. The lower the temperature difference number, the better the savings opportunity*.
7. Review CRAC units' display panel operating data and look for cooling status. If it has chilled-water coils, it would provide the status of the chilled-water valve open position in percentage. Add and average data from all units.
8. If the CRAC units have compressors, its display panel will show how many compressors are running (such as 0%, 50%, or 100%, if it has two compressors). Add and average compressor run data from all units. Use caution in gathering data because compressors may cycle rapidly, sometime as soon as every 3 minutes. Add the compressors run status data and take an average.
9. *If the average number for CRAH/CRAC cooling status is below 80% (in steps 7 or 8 above), it is likely a good candidate. The lower the number, the larger the savings potential*.
10. Review CRAC units' historical performance data. Most CRAC units have historical data on fan run times as well as on run times of individual compressors. Take two readings over a period of time, say a week or so, and calculate run hours during this period. Calculate average compressor run time from the data. To calculate average run time for compressors, divide the sum of compressor run times with the number of compressors and fan run time. If it is a chilled-water unit, it may show average position of the chilled-water valve.
11. *If the compressors historical run time is less than 80%, or valve average open position is less than 80%, it is likely a good candidate*.
12. Find out CRAC units' total airflow rates and fan power use. Add fan power of all units. Also add airflow of all units.
13. *Divide total fan power by the ICT power. If the number is above 0.10 kW/kW, it is likely a good candidate. The larger the number, the more the savings opportunity*.
14. Estimating fan power energy savings depends on many variables, but if we target fan energy use to be less than 0.06 kW/kW of ICT power, we can estimate annual savings by taking a difference between the current fan power use per unit of the ICT power and a target of 0.06, and multiplying it by the number of hours in a year and the average electricity rates. This target of 0.06 kW/kW of ICT power has been selected based on the lower end of the LBNL airflow range of 0.07 to 0.50 kW/kW and some other data from the industry. The 0.06 kW/kW target should provide substantial energy savings without introducing unnecessary thermal risks within the data center.
15. Besides these quantitative numbers, we also need to review qualitatively whether good airflow management practices are being followed, such as hot and cold aisle arrangement, sealing cable cutout, blanking panels, spaces between racks, and empty rack spaces. Addressing these will help us reduce hot spots, but the energy savings will be derived from reducing airflow, either by shutting down some CRAC units or reducing airflow through the CRAC units.

Here are some quick examples of how energy savings were achieved in practice.

Case Study 1

This site is a small data center located within a large building with traditional hot and cold aisles and no containment. Six 30-ton CRAH units, each with a 7.5-HP fan, are located in perimeter. A 300-kW UPS is located within the data center space with an operating load of 165 kW.

Nominal cooling capacity: 6*30*3.52 = 633 kW
UPS output: 165 kW
ICT load (including UPS eff.): 165/0.88 = 188 kW
ICT load/nominal cooling: 188/633 = 30%
Rated fan power: 6*7.5*0.75 = 33.75 kW
Rated fan power/ICT load: 33.75/165 = 0.205 kW/kW
Potential direct fan energy savings: (0.205-0.06)*165*8760 = 211,030 kWh/annually

ICT load/cooling capacity (30%) is less than 80%, and it is a good candidate for VFD installation. A fan power of 0.205 kW/kW of the ICT power is larger than our target of 0.06 kW/kW of the ICT power, and also suggests it is a good candidate.

The VSDs were installed with the following results:

Fan power before VSD installation: 30.6 kW/165 kW = 0.185 kW/kW
After VSD installation: 6 kW/165 kW = 0.036 kW/kW
Annual direct fan energy savings: (0.185-0.036)*165*8760 = 215,365 kWh
Indirect cooling energy savings: 215,364/3.0 =71,790 kWh
Total direct and indirect fan energy savings: 213,365 + 71,790 = 287,155 kWh/annually

VSDs were installed along with several wireless temperature sensors in front of the IT equipment racks that measured inlet air temperatures, which were processed by a control system that modulated the fan speeds of the CRAH units. The measured fan draw at full speed was about 90% of the rated fan power. More fan energy savings were realized than calculated because the measured fan power after VFD installation was only 0.036 kW/kW of the ICT power instead of the target of 0.06 kW/kW of the ICT power. The energy savings from the indirect cooling were calculated using cooling equipment coefficient of performance of 3.0. The payback period, without considering any incentives, was less than 2 years.

Case Study 2

The data is from the EPRI data center where VSDs on DX CRAC units are being demonstrated. The data center has a combined PDU load of 82 kW. The UPS is located outside of the raised-floor data center. The two 30-ton DX CRAC units have 10-HP motors and 15,000 rated CFM.

Nominal cooling capacity: 2*30*3.52 = 211 kW
PDU load: 82 kW
ICT load: 82 kW
ICT load/nominal cooling: 82/211 = 39%
Rated fan power: 2*10*0.75 = 15 kW
Rated fan power/ICT load: 15/82 = 0.183 kW/kW
Potential direct fan energy savings: (0.183-0.06)*82*8760 = 88,353 kWh/annually

ICT load/Cooling capacity (39%) is below 80%, and it is a good candidate for VSD installation. Fan power of 0.183 kW/kW is larger than our target of 0.06 kW/kW, and also suggests it is a good candidate.

This site is a test site for demonstrating VSD installation on a DX CRAC unit. The VSDs were installed with the following results:

Fan power before VSD installation: 13.7 kW/82 kW = 0.167 kW/kW
Fan power after VSD installation (70% fan speed): 4.6 kW/82 kW = 0.056 kW/kW
Fan power after VSD installation (60% fan speed): 3.1 kW/ 82 kW = 0.038 kW/kW
Annual direct fan energy savings (70% fan): (0.167-0.056)*82*8760 = 79,734 kWh
Indirect cooling energy savings (70% fan): 79,734/3.0 = 26,578 kWh
Total direct and indirect fan energy savings: 79,734 + 26,578 = 106,312 kWh/annually

VSDs were installed, and their speed was put in manual control. The measured fan draw at full speed was about 90% of the rated fan power. Less fan energy savings were realized than calculated because the measured fan power at full speed was less than the rated numbers used in calculations. The fan power after VSD installation was close to the target of 0.056 kW/kW at 70% fan speed. The energy savings from indirect cooling were calculated using cooling equipment coefficient of performance of 3.0.

The system ran successfully for nearly 18 months. The above results are from installation of VSDs and no other changes to the data center floor, such as air containment, blanking panels, and stopping air leakage from tile cutouts. The data center and the DX CRAC units have been working without any problem for the last 18 months. One observation that visitors to this data center often make is “how quiet it is.” Wireless sensors for monitoring temperature distribution within the data center space and using those temperature sensors to modulate fan speed has already been implemented.

The above case studies clearly show that significant energy savings in data centers are possible with reductions in fan power and airflow management, and also show a simple method for estimating energy savings.

7
RECOMMENDATIONS FOR DEVLOPING A METHOD FOR AIRFLOW MANAGEMENT TO SAVE ENERGY

It is well established that airflow management in a data center is critical to its energy-efficient operation. Field experiences show that CRAC units supply far more air than necessary; sometimes more than two to three times what is needed across the IT equipment in typical data centers. The excess airflow increases energy consumption directly from moving the air and indirectly from heat generated by the motors that move the air.

Until very recently, DX CRAC equipment did not use variable-speed fan control. The use of VSDs on fans with or without containment is now gaining acceptance. Some utilities such as PG&E in California provide incentives to operators of data centers to install these devices in new as well as existing data centers. Established manufacturers now offer new products with variable airflow and retrofit kits to convert existing CRAC units to variable airflow. New strategies and controls for modulating the variable airflow are emerging. One vendor offers a package that uses wireless sensors to monitor temperatures at the inlet of the IT equipment and sends a signal to control CRAC fan speed, as demonstrated in the California Franchise Tax Board demonstration (http://hightech.lbl.gov/demo-ftb-wireless.html). Other vendors offer wireless sensors for monitoring a rack's inlet air temperatures in a data center space, which can be used to cycle the fan of a CRAC unit on or off or change its speed manually or modulate it dynamically.

The use of VSDs, however, has been limited to chilled-water CRAC units so far; it should now be extended to DX CRAC units with some caution. Today, a vast majority of smaller data centers use DX CRAC units for cooling for many reasons. Data centers with less than 500 kW of load and a cooling capacity of less than 150 tons predominantly use DX systems. These are also common in larger data centers that have grown or expanded over time. These compressor-based units are modular, standalone, and are added as needed to meet the growing needs of the data center.

Resistance to the use of variable-speed fans in data centers has mainly been driven by the perceived fear that variable-speed operation of data center cooling may adversely affect reliability. The manufacturers who supply equipment to data centers are developing new equipment with compressor capacity modulation where fan speed can be varied. However, a project funded by the California Energy Commission is demonstrating the application of VSDs to existing DX CRAC units at EPRI's own data center. The units have operated for extended periods of time at fan speeds down to 60% under adverse ambient conditions without any problem and are providing energy savings. There is a very large installed base of DX CRAC units that could benefit from the CEC/EPRI research without expensive unit replacements and could fully utilize the existing units' useful remaining life.

EPRI and utilities should consider developing uniform methods and procedures for accurately estimating potential energy savings in different configurations of data centers so that they can better develop their incentive and rebate programs and advise end users on energy efficiency.

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