VERTIV WHITE PAPER

Adoption of Variable Cooling Systems to Optimize Data Center Infrastructure

Introduction

The adoption of hyperconverged infrastructure and deployment of computing intensive workloads such as Artificial Intelligence (AI), Internet of Things (IoT), and Big Data applications have contributed to the growth of global data center markets. The nature of these loads in modern data centers is now classified as “dynamic.”

Because of these ever-changing environments, the leading heating, ventilation and air-conditioning (HVAC) vendors have started offering certified Energy Star systems with built-in redundant cooling capacity to gain traction in the market. Operational metrics such as power usage effectiveness (PUE), water usage effectiveness (WUE), and carbon usage effectiveness (CUE) are becoming increasingly important when designing mission-critical data center facilities.

Ranging from small- to mega-sized infrastructures, a comprehensive energy efficiency roadmap must support each data center design. To maintain better operational metrics in a proposed energy-efficiency roadmap, optimum design of the cooling solution and component selection must be top considerations.

This white paper provides guidance on thermal management in relationship to variable load profiles in modern data centers. It also describes multiple techniques using variable cooling technologies that enable key operational metrics to be achieved.

Data Center Tier Level

Data center tiers are a standard methodology for ranking data centers in terms of their potential infrastructure performance (uptime). Data center tiers are ranked from 1 to 4 where higher-ranked data centers have more potential uptime than lower-ranked data centers.

Before diving into the approaches for variable cooling, the following table sheds some light on the importance of reliability and availability factors. Any technology upgrade with energy efficiency enhancements should comply with applicable tier requirements.

Tier	System Uptime (%)	Downtime Limit/ Annum Hours	Application
1	99.671	28.8	Construction, branch office, professional services
2	99.741	22.7	Local media, education, CRM
3	99.982	1.58	E-commerce, medical, hospital
4	99.995	0.44	Finance, banking, utility

Dynamic Loads in the Data Center

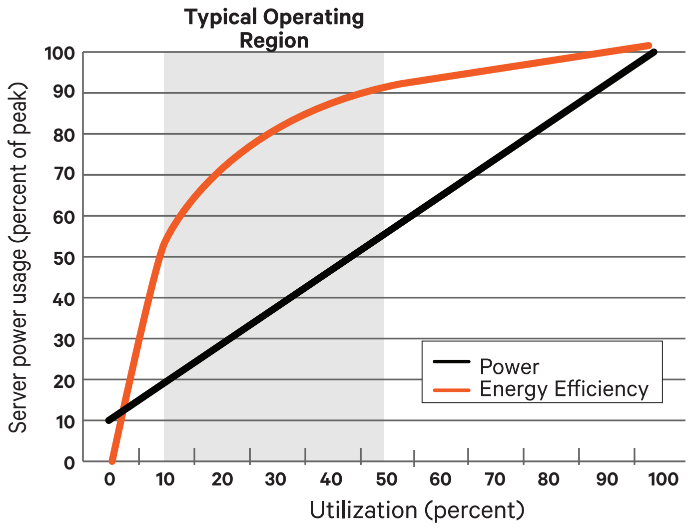
Nearly two decades ago, server power variation was about 20% because, even in an ideal state, the typical server would use about 50% of its full power. Now, due to "effective utilization of server consolidation and visualization techniques," the power consumption has reduced drastically.

In modern processing equipment, new techniques to achieve low power consumption patterns, such as changing the frequency of the clocks, moving virtual loads, and adjusting the magnitude of the voltages applied to the processors to better match the workload in non-idle state, have been deployed. Depending on the server platform, power variation can be found in the 45-106% range — a significant increase in just 20 years.

When the power consumption varies due to load, the heat output also varies. As such, sudden fluctuations in power consumption can cause vulnerable increases in the heat level, creating hot spots.

Hot spots can also occur in a virtualized environment, where servers are more often installed and grouped in ways that create localized high-density areas. Grouping high-density, virtualized servers can lead to cooling issues if air distribution and temperature are not properly considered in the design.

The load profiles of the most modern data centers no longer have fixed loads, so variable cooling is needed to support sudden heat spikes and the corresponding improvements that impact partial power usage effectiveness (pPUE) in the data center.



Source: Hölzle, 2017. Note: In a more energy-proportional server (red line) the power efficiency is more than 80% of peak value for utilizations levels of 30% or more with efficiency remaining above 50% for utilization levels as low as 10%.

Now let's look at how component-level technology enables the thermal management infrastructure to address dynamic load scenarios in modern data centers.

Dynamic Loads Managed by a Variable Cooling Solution

As the server power consumption increases or decreases in proportion to computational loading, the required airflow through the server is impacted. Additionally, to enhance the utilization ratio of the server, virtualization is being commonly deployed, which can result in varying power demands. Precision air-conditioning systems must provide variable cooling capacity and variable airflow to properly match the changing operational requirements of today's technology rooms.

There are four major sections in precision air conditioning. Each has some ratio of variable cooling components. We'll start with the heart of the refrigeration system, the compressor, then close with the evaporator section. Options such as load variation controller location are described in later sections.

Compressor

A compressor acts as the “heart” of a refrigerant-based mechanical cooling system. Its functions include drawing in the cool vaporized refrigerant that carries the heat energy from the evaporator coils, changing it from a low pressure and temperature to a high pressure and temperature, and pushing it around the refrigeration loop for the purpose of heat rejection.

Air-conditioning units with conventional fixed capacity compressors are typically designed for peak load performance and usually have more capacity than daily use requirements. The cooling requirements for the IT infrastructure are quite wide since the density in the data center varies with time.

There are different types of modulation technologies available with a compressor. The following three technology options can help to meet capacity and energy efficiency needs:

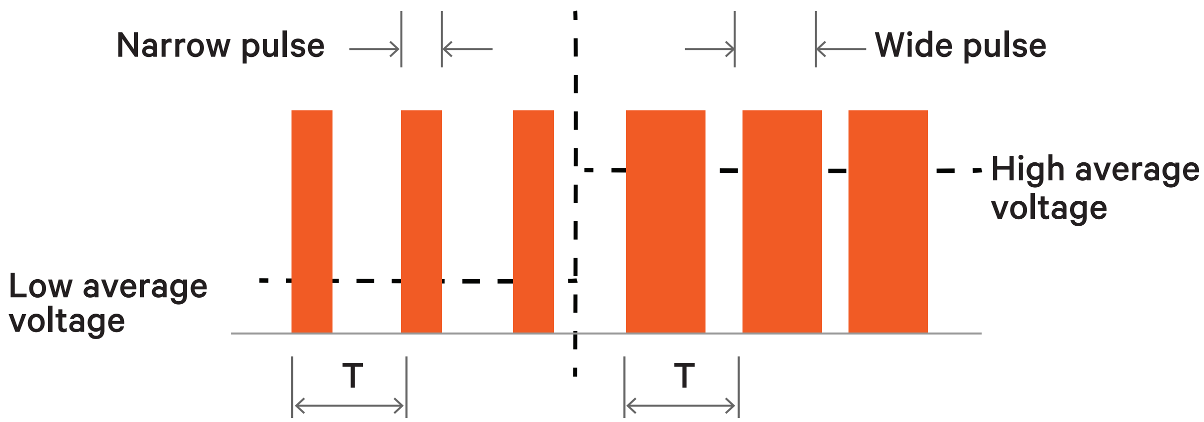
1. Multiple compressors
2. Continuous modulation compressor
3. Variable speed compressor

Multiple Compressors: With multiples, two or more compressors can operate individually or together, delivering several discrete capacity stages as needed while maintaining high Energy Efficiency Ratio (EER). In a standard scenario, these are fixed compressors and the load can be distributed into two or three compressors by uneven ratio (compressor capacity), connected in a series configuration.

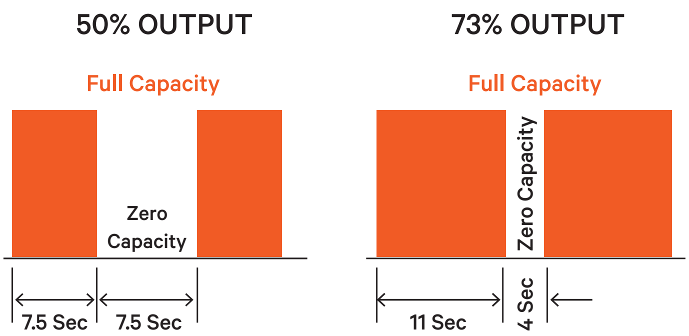
This compressor architecture is beneficial for both partial- and peak-load aplications, providing a versatile compressor combination and offering higher efficiency than a single, fixed compressor, specifically those in partial-load conditions. But this arrangement, at times, can create reliability issues in data centers. Being connected in series configuration, all compressors can be simultaneously affected when the motor burns out, choking an entire circuit. In absence of soft start in series configuration, a jerk load draws more power that leads to lower EER in the long run.

Continuous Modulation: A modulating compressor technique adjusts capacity either in stages or in a continuous manner when compressor loads vary in changing ambient conditions. Continuous variable modulation is found in scroll compressors with digital technology. It is known as “pulse width modulation.”

Pulse Width Modulation Waveform



Loaded and Unloaded States



Source: Understanding Compressor Modulation in Air Conditioning Application

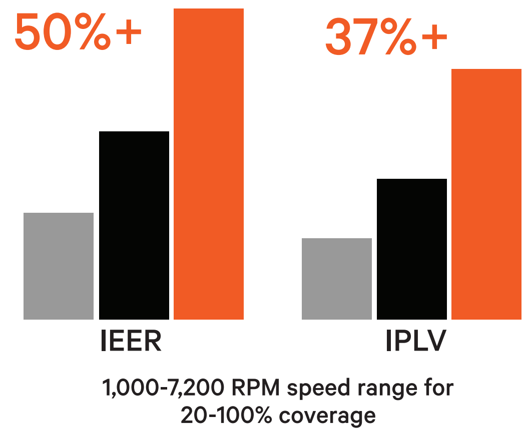
For example, in a 15-second cycle time, if the loaded state time is 7.5 seconds and the unloaded state time is 7.5 seconds, the compressor modulation is 50% (7.5 seconds x 100% + 7.5 seconds x 0%). For the same cycle time, if the loaded state time is 11 seconds and the unloaded state time is 4 seconds, the compressor modulation is 73%. **The capacity is the time averaged summation of the loaded state and the unloaded state.**

This type of technology suits the requirement of data centers, while precise temperature and humidity plays a major role in handling the dynamic load condition. There is negligible power drain due to the continuous operation of the rotor, but unlike multiple compressors, this technology avoids inrush current loss. As a digital compressor system is fully mechanical, there is likely to be minimal issues with output accuracy when handling dynamic load capacities below 30%.

Variable Speed: Variable speed compressors offer the highest partial-load efficiency over any other modulation technology. Variable speed compressors offer breakthrough energy savings by continuously adjusting its output to match loads. The benefits of variable speed technology include:

- Maximum cooling efficiency or Seasonal Energy Efficiency Ratio (SEER)
- 7:1 turndown for better light-load efficiency and dehumidification

Partial Load Comparison



Source: Understanding Compressor Modulation in Air Conditioning Application

The compressor motor speed variance determines the refrigerant flow speed. Therefore, by varying the motor frequency, capacity can be modulated. Output capacity increases and decreases with motor speed. Although this condition can ensure precise temperature and humidity control, oil management hardware and electronics are required to ensure that enough oil is in the compressor during slow motor conditions. This will ensure that excessive amounts of oil are not pushed out of the compressor during fast otor conditions.

The only major challenge with this mechanism is the oil circulation management that can potentially be a barrier during low-load conditions. As the revolutions per minute (RPMs) for the compressor motor reduce during partial-load conditions, the oil returning to the compressor faces issues due to lower pumping speeds.

With an advanced controller and an integrated intelligent algorithm, Vertiv overcomes the above issue by inheriting “variable speed compressor” in both perimeter- and row-based cooling systems to deliver optimum capacity with better operational metrics (EER and pPUE).

Variable Speed Fan (Blower and Condenser)

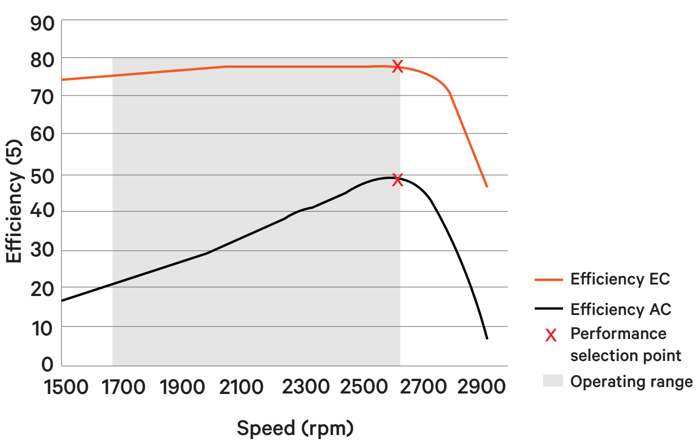
Many data center managers reduce energy usage and control costs by investing in variable speed fan technology. Such improvements can save up to 76% of fan energy consumption.

Today, with numerous options available in the market, variable speed drives (VSDs) — also known as variable frequency drives or VFDs — and electrically commutated (EC) fans are two of the most effective fan improvement technologies available.

EC fans achieve speed control by varying the DC voltage delivered to the fan. Independent testing of EC fan energy consumption versus VFDs found that EC fans mounted inside the cooling unit can deliver an average of 18% savings on the electricity bill. Further savings can be realized by locating EC fans under the floor.

EC fans offer enhanced control and are the most effective solution for reducing cooling system energy consumption. They do so by delivering the same output with less input — just a 10% reduction in air flow saves up to 33% in energy consumption. Apart from energy savings, an EC fan is the perfect tool for supporting dynamic loads in the precision air-conditioning system. Nowadays, the EC fan is a standard part of the evaporator side, but in an air-cooled system, the condenser fan also adopts EC fan technology to support variable loads in the data center, as well address different load patterns due to outside operating temperatures.

Comparison of AC Versus EC Efficiency



Electronic Expansion Valve (EEV)

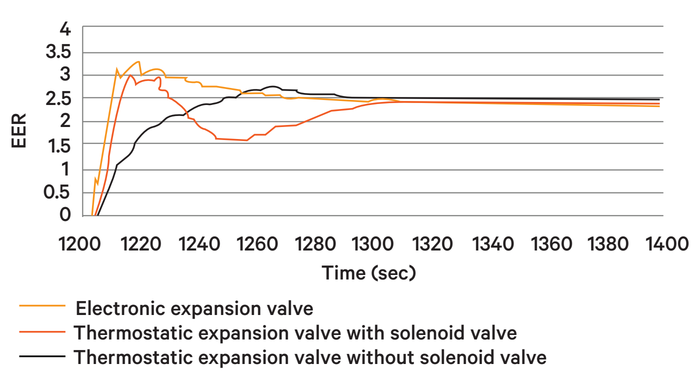
The EEV controls the amount of refrigerant released into the evaporator thereby maintaining the level of superheat. In other words, it controls the difference between the current refrigerant temperature and its saturation temperature at the current pressure value.

While Vertiv uses the variable speed compressor technology, variable refrigerant flow is obviously phenomenal for matching internal load variation in the refrigerant circuit. In this scenario, the EEV is no longer just an energy efficiency tool, saving up to 15% energy as compared to the thermostatic expansion valve (TXV). It is also helpful in delivering optimum capacity. EEV benefits can be summarized as follows:

- Precise control
- Fast and accurate response to load change
- Wider partial-load variation than TXV
- Ability to maintain maximum capacity control even at partial loads
- Injects exactly the right amount of refrigerant

Low superheat, higher evaporating pressure, and better EER are all achieved by constantly sensing the actual superheat value in the evaporator with a pressure transducer (a very sensitive temperature sensor) and transmitting this information to the controller in near real time. Consequently, an EEV can drastically reduce energy losses due to a refrigeration unit's ON/OFF cycles.

Energy Efficiency at Startup



Note: Values measured during testing with the EEV are always higher than the EER values measured using the TXV, with or without a solenoid valve. This higher energy efficiency is ensured by the EEV's capability to optimize the control of refrigerant flow in the evaporator, thus limiting the delivery of liquid into the compressor.

Pressure Independent Control Valve (PICV)

PICV is another component involved in chilled water-based thermal management systems in data centers. It is described as two valves in one: a standard two-way control valve and a balancing valve. PICV achieves optimal results as only the required amount of hot water and chilled water (in gallons per minute) are delivered to the heating and cooling coils.

Even after a system is manually balanced, it is only balanced at the full flow position. Once any valve in the system changes position, it changes the pressure and causes the system to be unbalanced, reducing efficiency.

An automatic flow regulating valve is intended to ensure that each coil has the correct flow at all times and under all load conditions.

PICVs integrate dynamic balancing and control functions into a single product. They respond to pressure changes in order to maintain the desired flow.

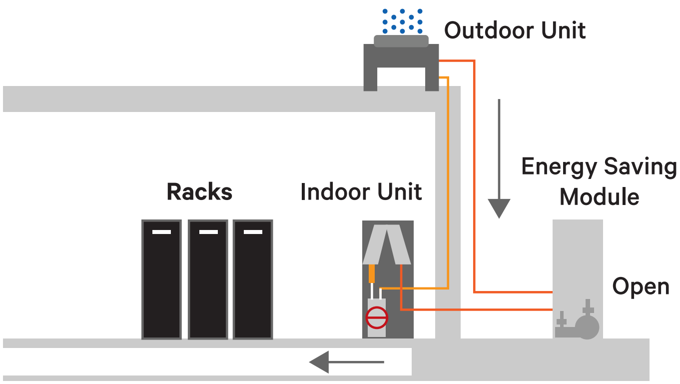
The differential pressure regulator part of the valve incorporates a rubber diaphragm that is moved by pressure differential and a spring. It is exposed to the inlet pressure on one side, and the outlet pressure on the other. As the diaphragm moves, it operates a valve that maintains constant pressure drop across the ball valve, irrespective of changes in system pressure. The ball valve section then modulates to maintain the room setpoint, so that the flow varies with the data center load demand and not with changes in system pressure.

Variable Pumping System

In the modern era, data center operational metrics such as PUE, EER, etc. are very important to maintain world-class standards in data center energy consumption. Economization and free-cooling are such mechanisms by which self-optimization and highly efficient solutions can be offered.

In free-cooling or ECO mode, a pumping system is deployed to circulate refrigerant into the system instead of a compressor. The latest design adopts a variable pumping system (with an inverter-based pump motor) to cope with dynamic loads in IT infrastructure. Refrigerant is circulated through variable pumps during winter or with lower ambient temperatures.

Free-Cooling Operation with Cold Ambient Air

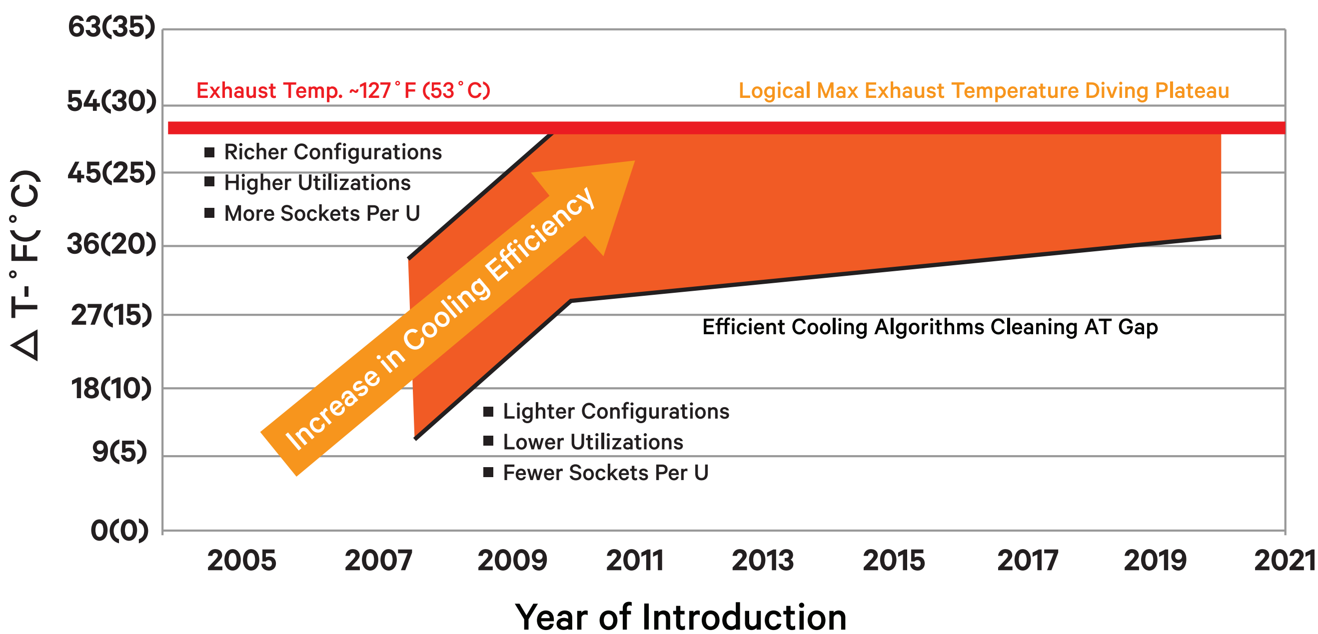


Supply Air Temperature Control

In modern data centers, factors like higher load density and heterogenous load profiles are common. Due to these factors, higher delta T comes into the picture. This is why supply air temperature logic is adopted in temperature control mechanisms, and thus intelligent controllers play a very important role in thermal management systems.

Cooling capacity is a product of air flow and delta T. In variable loading of IT equipment, dynamic airflow and delta T variation across servers are created. In this condition, a constant return air temperature setting is not ideal. An intelligent controller helps with dynamic changes in cooling capacity as well as maintains constant pressure for uniform cooling and power savings.

IT Equipment ΔT Trends at 77°F (25°C)



Source: ASHRAE Presentation, IT Equipment Power & Cooling Trends and Deployment Best Practices Seattle Summer Conference, 2014

Vertiv Recommendation

From the outset, Vertiv has invested both time and resources in upgrading technology and always proposes technological solutions based on market needs. Vertiv offers solutions for all types of critical applications and configurations including perimeter cooling, row cooling, customized air handling unit (AHU), small cabinet cooling, lab cooling, and more, depending on the load pattern and load infrastructure.

Considering variable load profiles in every segment, Vertiv incorporates variable components in its solutions as briefly outlined below:

- 3.5-15 kW: inverter compressor, EC fan, and EEV are standard options
- 15 kW lab cooling direct expansion (DX) system: all related modern components are standard
- 25-120 kW DX system: all variable components are available, few are standard, and the rest can be delivered on request
- Chilled water system: EC fan is standard and PICV is optional
- AHU system: EC fan standard
- ECO mode unit: variable pumping system and variable fans are available

In addition, Vertiv directly or indirectly offers green refrigerant, stage heater, variable humidifier, and other solutions to help in dynamic load situations within critical applications.

Conclusion

Facility managers have increasingly faced non-fixed load patterns, so the criteria for adopting the best cooling strategy is to first have a subsystem that is flexible enough to meet variable demand while at the same time ensuring the best overall energy efficiency. Advanced computing capabilities and the ever-increasing demand for data have only added to variable load conditions, resulting in a sudden fluctuation in power consumption which consequently increases heat production.

In addition, factors such as grouping of servers, server virtualization, and high heat density areas create cooling issues. To overcome these challenges and to comply with the standard PUE, WUE, and CUE metrics, the thermal management solution should be equipped with smart components which not only monitor the data center behavior but also respond to its dynamic changes.

Nowadays, the market is adorned with a wide range of options to serve the purpose of cooling. But to qualify the test case of criticality, it is paramount that the solution must include features such as quick response to dynamic changes, sensible awareness of actual conditions, and sufficient flexibility to respond in real time to variable load handling scenarios.

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