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Data Center Master List of Energy Efficiency Measures

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FEMP

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Disclaimer

Acknowledgments

The Center of Expertise For Energy Efficiency in Data Centers, a joint initiative of the U.S. Department of Energy and Lawrence Berkeley National Laboratory, and Kim Traber of Traber Engineers prepared this resource for the U.S. Department of Energy/Federal Energy Management Program.

Purpose and How to use this Document

The Master List is a living document of best-practice recommendations (measures) to increase energy efficiency in data centers. Designed for data center owners, operators, and qualified assessors, this document provides actionable guidance to both prioritize and implement energy saving measures in data centers. The Master List can be used as a stand-alone reference document for in-house improvements or to inform an energy assessment report being prepared for an external organization. More specifically, individuals can copy and paste relevant measures into an action plan or into the recommendations section of an energy assessment report.

A glossary is presented at the end of this document.

The Master List is divided into seven major categories:

Some of the major categories are further divided into sub-categories. All of the categories contain measures, arranged hierarchically in order of increasing detail. The table of contents illustrates the organizational scheme.

The Master List is maintained by the Center of Expertise for Energy Efficiency in Data Centers (CoE), which is hosted by the Lawrence Berkeley National Laboratory and sponsored by the U.S. Department of Energy. CoE offers the following tools that align with the Master List or directly draw upon it to provide tailored recommendations:

- Data Center Profiler (DC Pro), a web-based "early stage" scoping tool that estimates Power Usage Effectiveness (PUE): datacenters.lbl.gov/dcpro
- The Data Center Air Management Tool, an Excel-based tool that estimates energy and cost savings from implementing recommended Measures for effective air management: https://datacenters.lbl.gov/tools/5-data-center-air-management-tool-featured
- Energy Assessment Report Template, a Word document that can easily be filled in with site data to report data center energy efficiency assessment findings: https://datacenters.lbl.gov/tools/7-energy-assessment-report-template-featured

Please send suggested improvements to the Data Center Master List of Energy Efficiency Measures to CoE@lbl.gov.

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Category 1: Data Center Energy Efficiency Management

Data center energy efficiency management has several components. Start the management process when first contemplating new construction or major retrofits. Be sure you have a means of directly measuring key energy performance parameters. Design your data center controls to have the capability to adjust setpoints that affect energy efficiency. Finally, implement a program of regular maintenance and upgrades.

EEM 1-1: Plan and Design for Data Center Energy Efficiency

The highest levels of data center energy efficiency are achieved by establishing a framework for management and execution before construction begins.

EEM 1-1.1: Assign an Energy Manager

If your facility does not already have an Energy Manager, consider assigning one. Efforts to improve energy efficiency often falter when there is no clearly identified "champion" to lead and coordinate.

EEM 1-1.2: Create a Project Integration Team

A major step towards more energy-efficient operation is to create a team. The team sets targets for data center energy efficiency in accordance with federal, state, and local mandates, and company aspirations. The team should include both Facilities and IT personnel to resolve potential communication gaps between these two groups. The process can include:

1. Set a goal to improve data center energy efficiency and reduce energy use.

2. Resolve potential communication gaps between IT and Facilities organizations. Gaps usually exist when there are organizational issues, cultural differences, especially between employees and outsourced management.

3. Make sure the goals of operational activities and services (e.g., the implementation of energy efficiency measures such as installation and commissioning of new systems) are well defined and discussed with all parties.

EEM 1-1.3: Use Life Cycle Cost to Make Decisions

Project decisions are often made on the basis of first cost only (the cost of purchasing and installing components and systems). A more optimal fiscal strategy is to consider the life cycle cost of a proposed measure, and compare it to the "do nothing" case. Such strategy considers not only first cost but also operating and maintenance cost over the measure's lifetime, including disposal cost. The total life-cycle cost is also known as the total cost of ownership or TCO. Data centers have high power demand in terms of Watts per square foot, which means the energy cost of operating a data center over time can exceed the first cost. An energy-efficient data center, examined from the standpoint of life cycle cost, can justify the purchase of more efficient equipment if it is more costly.

Note that closing an inefficient data center and moving to either a more-efficient one internal to the organization, or moving to a commercial co-location facility or the cloud, can sometimes be the best economic choice.

EEM 1-1.4: Engage Upper Management with a Compelling Life-Cycle Cost Case

Some energy efficiency measures have little or no first cost to implement, but many others do. Even if a proposed measure has a rapid payback, management may choose not to fund it based on the cost of implementation. A clearly presented analysis of the return on investment of the proposed measure will help management compare it to alternate investment opportunities.

EEM 1-1.5: Train/Raise Awareness of Data Center Stakeholders in the Latest Energy Management Best Practices and Tools

Designers

The best data center energy efficiencies are achieved when the efficiency is considered and included in the design of the data center layout and support systems (electric distribution, cooling, lighting) from the beginning. Energy-efficient design & practices are sometimes counter-intuitive, or differ from past solutions.

The following are just a few examples of many resources available:

Organizations That Focus on Data Centers

- US Department of Energy (US DOE), Federal Energy Management Program (FEMP), and the Lawrence Berkeley National Laboratory (LBNL). These organizations co-host the Center of Expertise for Energy Efficiency in Data Centers: https://datacenters.lbl.gov/. This site includes the Data Center Energy Efficiency Toolkit, of which this Master List of EEMs is a part.

- The Uptime Institute. https://uptimeinstitute.com/
- Green Grid. https://www.thegreengrid.org/

Industry Standards and Guidelines

- The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) publishes the “Thermal Guidelines for Data Processing Environments”: https://www.ashrae.org/technical-resources/bookstore/datacom-series

Best Practices Guides

- The Federal Energy Management Program (FEMP) publishes “Best Practices Guide for Energy-Efficient Data Center Design”: https://www.energy.gov/sites/prod/files/2013/10/f3/eedatacenterbestpractices.pdf

Operators

Training for IT and facilities operators are important to ensure efficient operation persists.

EEM 1-1.6: Create an Energy Management Plan

Maintaining long-term energy-efficient operation of your facility is best accomplished by creating and executing an Energy Management Plan. This plan will identify who the responsible parties are and what the energy management goals are. It will address how to collect measurements of system performance, how the data are managed and interpreted, and the process of identifying, funding, and implementing energy efficiency measures.

EEM 1-1.7: Establish Continual Improvement Goals

Establish continual improvement goals (e.g., 15% reduction in energy use by the following year). The International Organization for Standardization (ISO) offers Standard 50001: https://www.iso.org/iso-50001-energy-management.html.

EEM 1-1.8: Look for the Simple Energy Saving Measures First

A first-pass assessment of the power-consuming systems will often reveal simple energy-saving measures that can be performed with relatively little effort and expense.

EEM 1-2: Monitor Data Center Energy Efficiency

It is often said, "You can't manage what you don't measure." The common "big picture" metric is PUE (Power Usage Effectiveness). This measurement indicates how much energy the support systems use in comparison to the IT equipment itself. The less energy the support systems use for a given IT load, the more efficiently the facility operates. Continuously monitoring this ratio is the best way to keep track of the performance of the data center's power and cooling infrastructure as a whole.

The following sub-measures focus on different approaches to measuring data center efficiency. Measures that deal with *controlling* energy efficient operation are addressed under EEM 1-3: Control Data Center Efficiency.

EEM 1-2.1: Use Metrics to Measure Efficiency

Data center efficiency can't be effectively managed without measured data. There are many different efficiency metrics that can be applied to data center support systems – Power Usage Effectiveness (PUE), Cooling System Efficiency, Electric Distribution Efficiency, and more. It is important to become familiar with different metrics to determine which ones are most appropriate for a given data center. Then determine what measurement devices and system(s) are needed to collect the data and calculate the metrics.

EEM 1-2.2: Implement an Energy Measurement and Calibration Program

Identify the key parameters of your systems that indicate how well they are performing. Determine which of these parameters are already being monitored and what your recording capabilities are. Add instrumentation to capture the parameters that are currently not monitored. Finally, implement a program to regularly calibrate your sensors to ensure that you always collect accurate readings.

EEM 1-2.3: Install Monitoring Equipment to Measure System Efficiency and Performance

Many data centers have only a few main electric meters. These may report the total energy use of the facility accurately, but they cannot indicate how the energy use is distributed among the IT equipment and support systems. Installing sub-meters at key locations provides a powerful tool for measuring the energy performance of individual systems. Providing these sub-meters with recording capability allows you to monitor system performance over time, providing evidence of degradations and improvements.

If you do not have permanent instruments installed to measure key performance parameters, you can install temporary instruments to obtain the same information for selected periods. Electric power meters, chilled water flow meters, and temperature sensors can be quickly deployed and will quantify system performance. Permanent meters are preferred so as to enable continuous tracking of performance over the life of the facility.

EEM 1-2.4: Install an Energy Use Monitoring and Reporting System

Data centers consume a lot of energy – not only the IT equipment itself but all of the support systems as well. Even small gains in energy efficiency tend to achieve large energy savings. Knowing where energy is being used in the data center, and how efficiently, is key to capturing the savings. If an energy monitoring system is not in place yet, consider installing one.

A more comprehensive option is to install a Data Center Infrastructure Management (DCIM) system. In addition to helping monitor, manage, and control energy efficiency, a DCIM system can support inventory, design, procurement, and managing IT/infrastructure capacity and redundancy.

EEM 1-2.5: Use Visualization Tools

Tables of instrument readings often require a trained eye to interpret. Putting the data in visual form – charts, graphs, maps – are usually the best way to quickly assess how systems are performing and where the trouble spots are.

A data center monitoring system can include a real-time dashboard. This is analogous to a car's dashboard – it provides an overview of real time data of key variables in an easy-to-interpret format. From an energy efficiency perspective, having real time readout of key efficiency metrics is a great way to focus and sustain attention on the issue. For suggested metrics, see EEM 1-2.1: Use Metrics to Measure Efficiency.

EEM 1-2.6: Recommission Energy Monitoring Systems

Energy monitoring systems rely on sensors and meters to provide raw data. Inaccurate data can lead to false conclusions and wasted effort. Schedule periodic recommissioning of the monitoring system, including calibration of sensors and meters.

EEM 1-2.7: Perform an Energy Audit

The first step towards more energy-efficient operation is to quantify how efficiently your facility is currently operating. An audit will reveal how the total energy use of the facility is distributed among the IT equipment and its support systems -- power distribution, cooling, humidity control, etc. Comparing your results against public benchmark data may indicate the where the best opportunities for cost-effective improvements are.

The DCEE Toolkit's Energy Assessment Process Manual provides guidance:
https://datacenters.lbl.gov/resources/assessment-resources-energy-training-assessment-process-manual

EEM 1-2.8: Benchmark Performance

Benchmarking energy performance usually entails the comparison of a data center's energy use data and energy efficiency metrics to other data centers. In the DC EE Toolkit, the following tools include benchmarks from other, anonymized data centers:

- Data Center Energy Efficiency Assessment Workbook v2.0
- Data Center Electrical Power Chain Tool v2.1

Performance can also be benchmarked against a data center's own data and metrics over time and against internal improvement goals (e.g., 15% reduction in energy use by the following year).

EEM 1-2.9: Review Full System Operation and Efficiency Regularly

Data center support system efficiency can degrade over time. Establish a policy of periodic review of all support system performance. At a minimum, monitor the data center's overall PUE.

EEM 1-3: Control Data Center Efficiency

Efficient data center operation typically involves active, coordinated control of the following support system variables:

Electric Distribution System

- Staging of UPS modules to maintain high module load factor (and therefore efficiency)

Cooling the Data Center Space

- Air temperature and humidity.
- Air flow rate (variable-speed fans or staging fans).
- Air-side economizers.

Central Cooling Plant

- Water temperature.
- Water flow rate (variable speed pumps).
- Staging of cooling plant equipment.
- Water-side economizers.

Lighting

- Controls to provide lighting only when & where necessary.

This measure focuses on implementing the capability to effectively control these variables. For specific control schemes, refer to the respective system categories later in this document.

EEM 1-4: Improve Data Center Energy Efficiency through Maintenance and Upgrades

After efficient data center operation is established, ongoing maintenance activities will ensure it persists and improves. These activities include training of staff as well as physical maintenance of equipment.

EEM 1-4.1: Upgrade All Cooling Supply Fan, Pump, and Cooling Tower Fan Motors to Higher Efficiency

AC Motors

Premium efficiency AC motors are generally a few percent more efficient than their baseline counterparts. The efficiency gains are modest, but the incremental first cost tends to be low as well, especially when replacing existing motors that have reached the end of their service life. Specifying a premium efficiency motor is usually cost effective for applications with long or continuous runtimes. Be sure to specify inverter-duty motors if they will be used with VFDs.

Electrically Commutated Motors (ECMs)

ECMs greater than 10 horsepower (hp) are generally not available, but where applicable, they offer even greater efficiency than AC motors. They have the added benefit of intrinsic variable speed control.

EEM 1-4.2: Conduct Regular Preventive Maintenance

Data center support systems are more likely to operate efficiently when they are kept in tune. It is often the case that a support system is meeting its nominal requirements, there are no alarm conditions, but the system is using more energy that it was designed to. Preventive maintenance will bring these situations to light and correct them before a lot of energy waste occurs.

EEM 1-4.3: Raise Awareness and Develop Understanding Among Data Center Staff about the Financial and Environment Impact of Energy Savings

Data center staff typically has a list of priorities. Maintaining continuous up-time is usually first followed by providing capacity for future growth. Energy efficiency is usually third or fourth, at best. Implementing and preserving energy efficient operation is helped by coaching staff on how energy efficiency can increase data center capacity, save money, and support the company's overall environmental goals.

EEM 1-4.4: Retrocommission/Recommission Data Center Support Systems

Commissioning is performed when bringing a new data center on line, to ensure it conforms with the design intent. It ensures that all the support systems are performing as intended and have adequate capacity. Since data centers have dynamic environments that can change significantly over just a few years, commissioning is also sometimes performed later in the data center life cycle (often called retrocommissioning or recommissioning). This is often done in conjunction with an energy assessment.

Some example resources:

- Case study from the Center of Expertise site: https://datacenters.lbl.gov/resources/retro-commissioning-increases-data-center-efficiency-low-cost
- "Defining the Four Phases of Data Center Retro-Commissioning" 2018. Engineered Systems Magazine: https://www.esmagazine.com/articles/99147-defining-the-four-phases-of-data-center-retro-commissioning

EEM 1-4.5: Implement a Continuous Commissioning Plan

Continuous commissioning calls for "continuous" checking of system health, capacity, and efficiency. This alerts facility operators of negative trends, giving them time to adapt and maintain high operating efficiency.

Category 2: IT Power Distribution Chain

The IT power distribution chain is the series of components that brings electric power from the electric utility's service feed all the way to the IT equipment. This chain usually consists of step-down transformers, an uninterruptible power supply (UPS), and power distribution units (PDUs). The chain also usually includes backup generators to keep the facility running during an extended outage.

All of the power chain components can be examined from the standpoint of energy efficiency.

EEM 2-1: Plan and Design for an Energy Efficient Power Distribution Chain

An efficient power chain will include:

- Components that are "right-sized" (not over-sized or under-sized) for the expected loads.
- Modular systems that can be expanded as load grows. This keeps individual modules at high load factors, where they tend to be most efficient.
- A minimum of voltage conversion steps.
- Backup power only for IT systems that need it.

EEM 2-1.1: Right-Size the Datacenter Power Equipment

Electric power distribution system components that perform voltage conversions (transformers, rectifiers, UPS systems, PDUs) tend to operate less efficiently at low load factors. To ensure efficient operation, size the components appropriately for the load. Most electrical equipment has a sweet spot of efficiency in the 75% range, but it is important to get the actual curve from the manufacturer.

EEM 2-1.2: Use 480V UPS Instead of 208V UPS

A higher voltage equates to a lower current, all else held equal. Less current implies less heat generation in the UPS, which means less energy loss.

EEM 2-1.3: Use 240V Instead of 208V Supply to IT Equipment

A higher voltage equates to a lower current, all else held equal. Less current implies less heat generation in the circuit, which means less energy loss. There are also IT power supplies available that directly take 277-volt input, which is the phase-to-neutral voltage of a 480-volt, three-phase system. Where used, these supplies eliminate the need for the PDU-level transformer and its associated losses.

EEM 2-1.4: Include a UPS Only Where Necessary

To minimize UPS energy loss, provide only critical IT equipment with UPS backup, and size the UPS accordingly.

EEM 2-1.5: Install a Modular UPS

The efficiency of double-conversion UPS systems falls off rapidly at low load factors. It is not uncommon to find a data center served by two UPS systems running in parallel, sharing the total electric load so that one UPS can carry the entire load if one fails, with a 20% safety factor. Each unit will then be running at about a 40% load factor, at a noticeably reduced efficiency.

If N+1 redundancy is required, running three or more smaller UPS systems in parallel improves the situation. For example, three equally sized systems can be run at 53% load, four systems can be run at 60% load, etc. UPS systems often have more than the necessary number of active modules, even for 2N redundancy. Deactivating unneeded modules can save significant energy.

EEM 2-2: Monitor the Performance of the Power Distribution Chain

The entire electric distribution system should be regularly maintained and monitored for performance. Doing so will minimize the energy losses associated with the system.

EEM 2-2.1: Perform an Infra-Red Test

Infra-red scans of power conversion equipment will reveal hot spots. Overly warm equipment may have loose connections or may be undersized for the load it is serving and is operating inefficiently. Tighten connections, reduce the load or upsize the equipment as appropriate.

EEM 2-2.2: Install Power Analyzer Meters at Critical Components

Efficient performance of the electric distribution system cannot be consistently maintained without having a means of monitoring what it is doing. Make sure you have the ability to see input power, output power, power factor, and total harmonic distortion at each major power conversion step in the chain.

EEM 2-3: Maintain High Power Quality

High power quality means less loss in the power distribution system. High quality is achieved by balancing voltage and loads between phases, and maintaining a high PF / low THD.

EEM 2-3.1: Maintain Balanced Loads Between Phases

Unbalanced electric loads in 3-phase systems cause higher current flows between the legs of the transformer, resulting in waste heat and less efficient transformer operation. Redistribute the loads to improve the balance. If the transformer is in an air-conditioned space, the reduced waste heat will also reduce the load on the cooling system.

Generally, the distribution to the UPS is automatically balanced because all flow is three-phase up to that point. At the UPS output and below, voltage balance is achieved by equally distributing the IT loads among the phases (typically phases A-B, B-C, and C-A).

EEM 2-3.2: Maintain Total Harmonic Distortion at Main Feeder Panel at 5% or Less

This measure is simply stating EEM 2-3.3: Maintain Power Factor at Main Feeder Panel at 0.90 or Higher in another way, as THD and Power Factor (PF) are mathematically related. If the facility is subject to PF tariffs from the electric utility provider, maintaining a low THD / high PF ensures the facility operates efficiently and avoids high tariffs.

Generally, if the IT power supplies have a high power factor, then power factor and THD will be excellent on the downstream side of the UPS. UPS input power factor correction takes care of the THD and/or power factor on the 480-volt side. In the chiller plant, harmonic filters (typically “line reactors”) on the VFD inputs of the chillers are generally recommended.

EEM 2-3.3: Maintain Power Factor at Main Feeder Panel at 0.90 or Higher

If the facility is subject to Power Factor (PF) tariffs from the electric utility, maintaining a high power factor ensures the facility operates efficiently and avoids high tariffs. See also EEM 2-3.2: Maintain Total Harmonic Distortion at Main Feeder Panel at 5% or Less.

EEM 2-3.4: Retrofit IT Equipment to Maintain High Power Factor and Low Total Harmonic Distortion

Low power factor (PF) and high total harmonic distortion (THD) cause the power distribution system to operate inefficiently. Correcting the power factor and THD at the UPS input and the IT power supply saves energy.

EEM 2-4: Implement Energy Efficient UPS Systems

A standard double-conversion UPS transforms the power passing through it, twice. First, a rectifier converts incoming AC power to DC in order to keep a battery bank charged. The power flows through the battery bank, and then an inverter transforms the DC power back to AC. Each of these steps has some loss associated with it. An efficient UPS system will minimize these losses.

EEM 2-4.1: Replace the UPS with a More Efficient Unit

UPS technology continues to evolve. If the existing UPS is scheduled for replacement, be sure to specify a high-efficiency UPS. If the existing UPS more than 10 years old, it may be cost-effective to replace it even if it is still serviceable.

EEM 2-4.2: Shut Down UPS Modules when Redundancy Level is High Enough

In some facilities, the array of UPS modules and/or PDUs has more than enough capacity to serve the load. It may be possible to shut down some modules and still retain the required level of redundancy. This will allow the remaining units to operate at a higher load factor, which usually translates to higher efficiency.

EEM 2-4.3: Use UPS Without Input Filters

Total Harmonic Distortion (THD) levels on the input side of a standard double-conversion UPS that is not equipped with an additional input filter, are typically in the range of 12-13%. Adding an input filter can drop the THD to 5% or less, but at an efficiency cost. Input filters can also cause negative interaction issues with backup generators. If the data center electric distribution system can operate adequately without UPS input filters, consider omitting them. Consult with the UPS manufacturer for THD and efficiency effect of the filters in question.

EEM 2-4.4: Eliminate or Bypass UPS Systems

If a UPS is not strictly needed, consider eliminating it or bypassing it. Most UPS systems offer a bypass mode.

This measure applies especially to UPS systems connected in series, such as a main UPS serving a rack-mounted non-switching UPS. If the main UPS works as designed, the rack UPS will never experience a loss of input power. Yet the rack UPS will continuously lose energy.

UPS systems are usually located in an air-conditioned space, and the waste heat they generate creates an additional load on the cooling system. EEM 5-4.5 is a middle ground between manual bypass and full UPS operation.

EEM 2-4.5: Implement a Switching UPS

Many double-conversion UPS systems offer a switching, or "eco-mode" feature. Rather than converting all the incoming AC power to DC and passing it through the battery bank, the batteries are fed just enough to keep them charged. The majority of the incoming AC power passes through the UPS without conversion, to serve the IT equipment. This avoids the losses inherent in the conversion. If a power outage is detected, the UPS switches to the battery bank and output inverter in a few milliseconds. The loss of power to the IT equipment is so short that it continues to run unaffected.

EEM 2-4.6: Change UPS DC Capacitors

The DC capacitors in typical UPS systems tend to lose effectiveness over time. This can result in the inverter failing to operate under load, and increased ripple current in the batteries. Not only does this result in less efficient operation, it becomes a safety issue as well. The DC capacitors usually have the same design lifetime as the batteries; approximately 5 years. The capacitors should be checked regularly.

EEM 2-4.7: Ensure Non-Critical Loads are Not Connected to the UPS

A review of the IT equipment served by a UPS system may reveal some equipment that does not need backup power. Placing this equipment on a non-UPS circuit will reduce the load on the UPS and will tend to reduce the absolute UPS energy loss. However, as you continue to remove load from a UPS, it will operate less efficiently; at some point the inefficiency will negate the absolute savings. This can be avoided by consolidating the critical loads on UPS modules that are appropriately sized for the load.

EEM 2-5: Implement Energy Efficient Transformers

The efficiency of a transformer is inherent in it manufacture. The efficiency varies with the load placed on it, and how that load is balanced if there are multiple phases. The efficiency increases with load up to typically 75%, then drops a bit as the load increases.

EEM 2-5.1: Right-Size the Transformers

To minimize transformer loss, make sure the transformers are sized such that they will spend most of their life operating near their optimal loading.

EEM 2-5.2: Use High Efficiency MV and LV Transformers

Medium Voltage (MV) and Low Voltage (LV) transformers are available in a range of efficiencies, and are often optimized for a specific load point. Specify high efficiency transformers when any existing units are scheduled for replacement. If inspection reveals that any existing transformers are operating with particularly poor efficiency, analyze the cost-effectiveness of replacing them with high efficiency, appropriately-sized units immediately.

EEM 2-5.3: Reduce the Number of Transformers Upstream and Downstream of the UPS

Energy is always lost at each active transformer. Minimizing the number of transformers in a power distribution system will help minimize energy loss.

EEM 2-5.4: Consolidate Transformer Loads

If you have transformers in parallel with low load factors, consolidate the loads and shut down unused transformers.

EEM 2-5.5: Locate Transformers Outside the Datacenter

If an active transformer is located in an air-conditioned space, the waste heat it generates becomes an additional load on the cooling system. Moving the heat source to the outdoors reduces the energy demand of the cooling system.

EEM 2-6: Implement Energy Efficient Backup Generators

Engine-powered backup generators run only during testing and utility outages, so their operating efficiency is not of great concern. However, the engine blocks of backup generators are kept warm with electric resistance heat to help promote rapid, reliable starting and the ability to quickly pick up the electric load. This EEM focuses on efficient heating methods for the engine blocks.

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EEM 2-6.1: Apply Thermostat Control to Generator Block Heaters

Generator engine block heaters are often very simple devices that provide continuous heat without any thermostat control. Adding a thermostat will help minimize the electric use of the heater. In other cases there is a thermostat, but it is set much higher than necessary—sometimes high enough that the engine's cooling water thermostat opens, creating a natural convection flow of coolant through the engine's radiator, wasting even more energy. Typically, lower temperature settings combined with a longer delay in the transfer switch before switching the load to the generator will not compromise reliable starting, will save significant energy, and allow the engine to better warm up after it starts. Consult with the generator manufacturer to determine the lowest safe temperature settings.

EEM 2-6.2: Use Chilled Water Return to Warm Generator Blocks

If your facility has a chilled water (CHW) plant, consider routing some of the return CHW to the generators and using it for block heating before returning it to the chillers. This is particularly applicable to plants with relatively high chilled water temperature. This has the additional benefit of pre-cooling the return CHW, which reduces the load on the chiller plant.

EEM 2-7: Implement Renewable Energy Sources

Data center efficiency is typically expressed in terms of "site" energy usage, i.e., the energy consumption as measured at the data center's main energy meters. A broader view of efficiency considers "source" energy. This energy represents the total amount of input energy that is required to operate the building. In other words, source energy traces the heat and electricity requirements of the building back to the fuel input, thereby accounting for any losses and enabling a complete thermodynamic assessment. Generation loss at the utility power plant, plus transmission loss between the power plant and the site, can be quite significant.

Installing renewable energy production systems on-site (photovoltaic, wind, or other) can provide a means of increasing source-energy efficiency and/or reducing carbon, Sox, NOx, and particulate emissions. Renewable energy is often intermittent (available only when sun or wind are present), so it is typically used as on offset to utility power. Data centers typically demand so much electric power that installing a battery bank to allow completely "off-grid" operation is not practical.

Another option is to purchase renewable energy from the utility or a third party. This provides the same benefits without the need to install on-site renewable energy production equipment.

Category 3: IT Equipment

"Information Technology Equipment" refers to everything performing computation and communication – computers/servers, data storage devices, network switches and routers. We subdivide this major category as follows:

Category 3.1: All IT Equipment Types

The following measures apply to all types of IT equipment.

EEM 3.1-1: Plan and Design for IT Energy Efficiency

There are several IT energy efficiency issues to consider when planning a new data center, or upgrading an existing one.

- Confirm that your estimates of IT power demand are realistic.
- Set a target for computing efficiency.
- IT technology evolves rapidly. Keep an eye on the cost-effectiveness of replacing current IT equipment, even if it is still serviceable.

EEM 3.1-1.1: Obtain Realistic Estimates of IT Equipment Actual Power Use

Inexperienced data center designers sometimes use the IT equipment nameplate power supply rating to (over)size data center support systems. The nameplate rating contains electrical safety information. IT equipment essentially never draws its nameplate power; it is often far less. This is especially true of power supplies in double-fed equipment, which under normal operation will never get to 50% rated load, and often much less. Oversized support systems tend to run inefficiently. Knowing the true power draw (and subsequent heat release) characteristics of the IT equipment allows the designer to specify right-sized support systems.

EEM 3.1-1.2: Specify Computing Performance Metrics for New IT Equipment

Future procurements of IT equipment can benefit from use of appropriate performance metrics coupling computational performance with energy performance. Such metrics will allow comparison of overall computing efficiency and will take into account such issues as processor efficiency, hardware/software compatibility, memory efficiency, etc.

The ENERGY STAR program (supported by the US DOE and the US EPA) provides some guidance: https://www.energystar.gov/products/data_center_equipment

EEM 3.1-1.3: Evaluate the Potential Savings from Upgrading to Newer IT Equipment

IT technology evolves rapidly, and improvements in energy performance are often provided in newer equipment. A cost-benefit analysis will reveal when it makes economic sense to replace existing equipment. During refresh, procure more-efficient IT equipment (e.g., ENERGY STAR-qualified). In the financial analysis, do not neglect the energy cost savings that will be realized in the data center support systems (electric distribution, cooling) as well as the IT equipment itself.

EEM 3.1-1.4: Evaluate Alternative Financing Methods to Enable Faster Technology Refresh

The computing efficiency of IT equipment increases from one generation to the next. One energy efficiency strategy is to simply refresh the IT equipment in the data center (see EEM 3.1-1.3: Evaluate the Potential Savings from Upgrading to Newer IT Equipment). If your standard financing method does not support a timely refresh, consider alternatives. Examine purchase vs. lease, and alternate providers of equipment. For federal agencies, Energy Service Performance Contracts (ESPCs) and Utility Energy Service Contracts (UESCs) may be viable options.

EEM 3.1-1.5: Use Vendor Programs to Dispose of Old Servers

Older servers tend to be less energy efficient than new ones. The intent of this measure is to physically remove old servers from the facility, reducing the temptation to continue using them. Vendor "take-back" offers the additional advantage of having the equipment recycled in an environmentally responsible manner. For example, see http://www.electronicstakeback.com/how-to-recycle-electronics/manufacturer-takeback-programs/

EEM 3.1-2: Monitor IT Energy Efficiency

Server- and system-based tools are available for monitoring IT equipment efficiency. The Center of Expertise also offers a spreadsheet-based IT Equipment Tool that allows both a current IT efficiency analysis with recommendations for improvements and "what-if" analyses to gauge the impacts of implementing different strategies.

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EEM 3.1-2.1: Monitor Utilization of Servers, Storage, and Networks

IT systems are often under-utilized. Servers may run at a fraction of their processing capability, data storage may be oversized and infrequently accessed, and network traffic may be well below maximum transfer rates. This results in poor energy performance. Monitoring utilization rates will allow data center staff to optimize performance as the data center mission evolves.

EEM 3.1-2.2: Install IT Management Systems and Applications

IT management systems show the status and computational load of IT equipment, but they can also provide evidence of support system performance via server temperatures, power draw, and fan speed. These indicators can help the data center operator tune the support systems for improved performance. An IT management system can be part of a DCIM package.

EEM 3.1-3: Improve IT Energy Efficiency

This measure applies to IT equipment of all types, including servers, data storage devices, and networking equipment. Efficiency measures focus on internal powers supplies, voltage to the racks, and equipment utilization rates.

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EEM 3.1-3.1: Eliminate Redundant Power Supplies

Some pieces of IT equipment are equipped with dual power supplies. The power supplies run in parallel at low load factor, which is inefficient. If this is not absolutely necessary, consider disconnecting one of the power supplies.

EEM 3.1-3.2: Specify More Efficient Power Supplies in IT Equipment

This measure addresses the final step in the chain of power conversions that occurs between the main power feed to the data center and the end-point of the IT equipment. It can be an effective strategy for reducing load in existing servers that have hot-swappable power supply capability, but most servers are not so equipped. This measure is usually most effective for new equipment. A customer has more clout to specify efficient power supplies when placing a large order with a supplier.

For a list of efficient power supplies, see www.80plus.org.

EEM 3.1-3.3: Supply DC Voltage to the IT Racks

In a typical data center, AC power is delivered to the uninterruptible power supply (UPS). It is converted to DC and fed to the battery bank. The power is taken from the batteries and converted back to AC, then distributed to the power distribution units (PDUs) on the data center floor. There may be a voltage step-down at the PDUs before the AC power arrives at the racks. The IT equipment accepts the AC power and converts it to DC to run its internal circuitry. Each of these conversions is less than 100% efficient, so some energy is lost in each step. A more energy-efficient arrangement is to maintain the power as DC all the way from the UPS to the IT equipment.

A standard delivery voltage for this type of arrangement is 380V DC. However, several different DC voltage levels are typically needed by the IT equipment's internal components, all of them less than 380V.

Resources

- LBNL report "DC Power for Improved Data Center Efficiency": https://datacenters.lbl.gov/sites/default/files/DC%20Power%20Demo_2008.pdf
- A trade press article: https://www.datacenterknowledge.com/archives/2015/06/25/380v-dc-power-shaping-future-data-center-energy-efficiency
- The industry association Emerge Alliance: https://datacenters.lbl.gov/sites/default/files/380VdcArchitecturesfortheModernDataCenter.pdf
- At least one manufacturer offers power supplies for IT equipment that accept the 380V DC standard directly: http://www.directpowertech.com/docs/HP%20Common%20Slot%20Power%20Supply.pdf

EEM 3.1-3.4: Turn Off Unused Equipment

This measure expands EEM 3.2-2.1: Perform an Audit to Ensure all Operational Servers are Still in Active Use to all equipment. UPS units, PDUs, switches, storage arrays, etc. should be turned off if not in use.

EEM 3.1-3.5: Virtualize

Virtualization refers to the creation of "virtual" computing platforms that outnumber physical devices such as servers or data storage components. For example, a single, physical data storage unit may appear as multiple storage units to the rest of the network. This allows the physical unit to work at greater capacity, reducing the quantity of physical units needed. The total data storage resource can then operate more efficiently.

For server virtualization in particular, see EEM 3.2-2.2: Implement Server Virtualization.

Category 3.2: Servers, Air or Liquid Cooled

Most servers in operation today rely completely on the air passing through them to remove the heat they generate. Some servers, however, call for water or some other liquid to come into contact with it. The designs vary – some have a liquid-to-air heat exchange plate attached to the shell of the server; others have such a heat exchanger attached to the hottest internal components. These heat exchanger designs typically still rely on some air flow for complete cooling. Alternatively, some designs call for the server to be completely submerged in a liquid bath. Such "immersion" cooling removes the need for air entirely.

The measures in this category apply to all servers regardless of how they are cooled.

EEM 3.2-1: Specify Servers That Promote Energy Efficiency

This measure addresses new servers. Server design can promote efficiency in two main ways. The first is direct: How much power does the server need to perform a given set of computations? The second asks: How much power does the cooling system draw in order to keep the server satisfied?

EEM 3.2-1.1: Specify Servers With Energy Efficient Processors

Processing power per unit of energy consumed has steadily climbed over the last 70s years, with computations per Watt increasing on average 90 times each decade. Specify servers with a high computations/Watt ratio.

EEM 3.2-1.2: Specify Servers That Work Well With Energy Efficient Cooling Systems

Servers that tolerate higher temperatures allow for a more efficient cooling system.

EEM 3.2-1.2.1: Specify IT Equipment that can Accept a High Cooling Temperature

The colder the temperature a cooling system produces the less energy efficient it will be, all else held equal. Therefore, servers that tolerate a higher intake cooling temperature (with a resultant higher exhaust temperature) allow for a more efficient cooling system. For example, IT equipment that can meet ASHRAE A2 or A3 allowable temperatures enables many more hours of operation of air-side or water-side economizers.

EEM 3.2-1.2.2: Specify Liquid-Cooled Servers

Water (and other cooling liquids) have a much higher heat capacity than air, meaning that a given rate of heat transfer can be accomplished with a much smaller volumetric flow rate of water. This in turn allows for a more efficient heat removal process, as the required water pumping power is much less than the required fan power, all else being equal. Liquid-cooled servers reduce (and in the case of full immersion cooling, completely eliminate) the need for fans to supply cooling air to the servers.

EEM 3.2-2: Maintain Energy Efficient Server Operation

This measure addresses maintaining and improving the efficiency of existing servers.

EEM 3.2-2.1: Perform an Audit to Ensure all Operational Servers are Still in Active Use

In a large data center that has been in operation for a while, it is common to have servers that are drawing power but no longer have any assigned tasks. Performing an audit will identify which servers are candidates for shutting down.

EEM 3.2-2.2: Implement Server Virtualization

Virtualization techniques can consolidate computing operations on fewer servers, permitting shutting down or eliminating some servers and increasing computation-per-Watt efficiency.

EEM 3.2-2.3: Enable Power Management Features on Servers

Most servers have power management features that allow them to "throttle back" on energy use when the computing load is light. ENERGY STAR servers are shipped from the manufacturer with these features enabled. IT managers often disable these features when the servers are installed, for a variety of reasons. Confirm that the power management schemes are unlikely to impair compute operations before re-enabling them.

Category 3.3: Servers, Air Cooled

This category is for measures that address air-cooled servers, specifically. Systems that supply the cooling air to the air-cooled servers are addressed in Category 6.1: Air-Based Cooling.

EEM 3.3-1: Specify Servers that can Tolerate High Air Intake Temperature & Humidity

The colder the temperature a cooling system produces the less energy efficient it will be, all else held equal. Therefore, servers that tolerate a high intake cooling air temperature and a wide range of intake air humidity (beyond ASHRAE recommended) allow for a more efficient cooling system.

EEM 3.3-2: Eliminate Server Fans

If an air-based cooling system is fully enclosed (such that 100% of the cooling supply air flows directly through the servers) it may be possible to remove the servers' internal fans and rely entirely on the cooling system to keep the servers satisfied. This eliminates the power draw of the internal server fans.

Category 3.4: Servers, Liquid Cooled

This category is for measures that address liquid-cooled servers, specifically. Systems that supply the cooling liquid to the liquid-cooled servers are addressed in Category 6.2: Liquid-Based Cooling.

EEM 3.4-1: Specify Servers that can Tolerate High Intake Water Temperature and Low Flow Rate

The greater the cooling water temperature a liquid-cooled server can accept, the more efficient the cooling system can be. If the cooling system includes a water-cooled chiller plant, the number of hours per year that waterside economizing is viable increases with the cooling supply temperature. If this temperature is high enough, it may be possible to use cooling tower water alone to cool the data center all year, and eliminate the chillers entirely.

The lower the flow rate of cooling water needed by the server, the less energy the pumping system will use.

Category 3.5: Data Storage Devices

The measures in this category focus on data storage devices.

EEM 3.5-1: Consolidate to Network-Attached Storage and Diskless Servers

Servers typically have on-board mechanical disk drives. These drives are responsible for a significant percentage of the server's total energy use, but they often have a low utilization rate. Converting to solid-state memory at the servers, or consolidating to a network-attached (NAS or SAN) data storage device may be a path to an effective energy performance improvement.

EEM 3.5-2: Assess Data Storage Usage

It is not uncommon to have more storage allocated to processing tasks than is needed, and to have the storage accessed infrequently. This can result in poor energy performance, as storage devices draw energy whether they are in active use or not. Investigating data storage utilization patterns can reveal opportunities, such as moving less performance-sensitive data to higher capacity, more efficient media.

Data storage devices use energy. If user data is spread across multiple devices but can be consolidated on fewer, the emptied device can be turned off or repurposed.

EEM 3.5-3: Reduce the Capacity Requirements of Data Storage Systems

Your data storage utilization patterns may allow for storage virtualization. In other words, selected processes can be assigned storage limits that, when summed, exceed the actual total provided storage capacity. If the needs of the individual processes for active storage are non-coincident, the actual storage limit will rarely or never be exceeded.

EEM 3.5-4: Automate Data Retention and Deletion Policies

As data accumulates and grows, a standard response is to add more data storage devices. Compared to the labor cost of manual cleanup, storage is inexpensive. But more storage devices equates to more energy use. Consider an automated solution for implementing data archiving and deletion policies.

Category 3.6: Other IT Equipment

The measures in this category focus on IT equipment other than servers and data storage devices.

EEM 3.6-1: Networking Equipment

Most IT rack equipment is designed to have cooling air flow from front to rear. Being consistent in this arrangement allows the racks to form hot and cold aisles.

Some manufacturers, particularly of network switches, continue to sell equipment that does not follow this convention. This works against establishing an efficient air-based cooling system.

Specify networking equipment that has the power and communication cables entering on the air-discharge side of the equipment so that the air flow will be from the cold aisle to the hot aisle when installed in normal racks of servers.

Category 4: Lighting

The requirements for lighting in data centers differ from most other facilities. Data centers:

- Run continuously and may be occupied at any time of day or week.
- Are typically are not daylit.
- Are sparsely/intermittently occupied.
- Do not have to be uniformly illuminated when occupied. Task lighting is an effective approach.

EEM 4-1: Implement Energy Efficient Lighting

An energy efficient lighting system delivers the right spectrum of light, only as much as needed, where and when it is needed, with a minimum of energy use. This is accomplished with a combination of effective lighting design, lighting controls, and high efficacy light fixtures.

Improving lighting energy efficiency also reduces the heat load in the data center, saving cooling system energy.

Standards

- The Telecommunications Industry Association (TIA) publishes Standard TIA-942, Telecommunications Infrastructure Standard for Data Centers. It includes a section on data center lighting. https://tiaonline.org/

- ASHRAE publishes Standard 90-1, Energy Standard for Buildings Except Low-Rise Residential Buildings. This includes a lighting efficiency standard. https://www.ashrae.org/

- Building Energy Efficiency Standards – Title 24 applies in California. https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards

EEM 4-1.1: Implement Effective Lighting

Effective lighting provides the amount of light needed, where it is needed.

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EEM 4-1.1.1: Illuminate Work Areas Only

One lighting solution for data centers is to provide task lights for use on the IT equipment racks, with little or no ceiling lights. Staff can illuminate the rack while they are working on it, and turn the task light off when done.

EEM 4-1.1.2: Coordinate Light Fixture Placement with IT Equipment Placement

The IT equipment in most data centers is arranged in parallel rows, forming aisles. Placing ceiling light fixtures directly above the aisles will provide an effective lighting solution.

EEM 4-1.2: Implement Lighting Controls

Data centers run continuously, but are seldom occupied. Controls that turn off lights when they are not needed are a key to an efficient lighting system. Timeclocks will save lighting energy, but sensors that detect human occupancy are better suited for data centers.

A bi-level lighting system that alternates between low illumination when unoccupied and full illumination when occupied will save lighting energy, but not as much as turning the lights off completely when unoccupied.

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EEM 4-1.2.1: Install Occupancy Sensors to Control Lights

Many data centers are unoccupied for long periods. Controlling the data center lights with occupancy sensors directly saves lighting energy.

EEM 4-1.2.2: Implement Manually Controlled Zone Lighting Control

One method of lighting control is to provide a manual switch or a count-down timer. A timer is preferable for energy savings, as manual switches are often left on after the occupants leave. If the data center is large, creating multiple, independently controlled lighting zones increases energy efficiency.

EEM 4-1.2.3: Control Lighting with a Timeclock

Data center lights can be operated on a pre-defined schedule with a stand-alone clock, or via the building management system (BMS). This is a less effective solution, though, as the lights may be on when the data center is unoccupied, or the lights may have to be turned on if the data center is accessed after hours.

EEM 4-1.2.4: Install Peak Shaving Devices on Lighting Systems

If the electric power utility serving the data center offers a power demand response program, installing controls to reduce lighting levels is one strategy for reducing electric demand when requested. The main benefit of complying with a demand response program is electric cost savings (particularly if the facility is on a time-of-use rate schedule), but it saves energy too, increasing data center efficiency.

EEM 4-1.3: Install LED Light Fixtures

New lighting technologies such as LEDs can save a significant percentage of the energy use of existing, older lighting systems. If the data center is equipped with fluorescent lighting, replace it with LED lighting.

Table 1: Lighting Technology from Lowest to Highest Efficacy

Incandescent
Compact fluorescent, Fluorescent T12
Fluorescent T8
Fluorescent T5
LED

Category 5: Air Management

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EEM 5-1: Plan and Design for Effective Air Management

Effective management of the air flow in the data center space maximizes the opportunities for efficiency throughout the cooling system.

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EEM 5-1.1: Follow ASHRAE Thermal Guidelines

At minimum, follow ASHRAE guidelines for data center temperature ranges.

Specifying a low IT equipment intake temperature causes the cooling system to run less efficiently and limits the utilization of economizers. Target the maximum recommended intake temperature from guidelines issued by ASHRAE (80.6F) and NEBS (80F) depending on the type of electronic equipment in the data or telecom center. If the air distribution system can be modified to deliver air more effectively to the equipment, it may be possible to raise the average intake temperature. This in turn will allow the cooling supply air temperature to be raised, which typically results in more efficient cooling system operation.

The guidelines are illustrated in a psychometric chart that defines combined temperature and humidity regimes that are recommended or allowable for IT equipment in Classes A1 through A4. Recommended operating regimes represent industry consensus on temperature and humidity ranges within which equipment of the specified class will operate reliably for its design life. Allowable regions define the wider ranges at which equipment may be operated reliably for limited periods of time.

EEM 5-1.2: Increase the Supply Air Temperature

A low supply temperature makes the chiller system less efficient and limits the utilization of economizers. Enclosed architectures (isolated hot or cold aisles, etc.) allow the highest supply temperatures (near the upper end of the recommended intake temperature range) since mixing of hot and cold air is minimized. In contrast, the hottest intake temperature often dictates the supply temperature in open architectures.

Data centers with enclosed architectures are typically uncomfortable for humans. The cold aisles may be too cool for comfort, and the hot aisles too warm. Raising the supply air temperature setpoint will make the hot aisles even warmer, and even the cold aisles may become uncomfortably warm. Train staff to recognize that these conditions are selected by design, to promote energy efficiency. One simple method for increasing comfort in the hot aisles of a raised floor facility, is to bring a perforated tile to *temporarily* place next to the IT equipment while it is serviced.

Other considerations:

- Verify that temperature alarms can be reset to accommodate the higher temperatures.
- Power supply cables for the IT equipment are typically on the exhaust side of the equipment. Verify that the cables are rated for the increased temperature.

EEM 5-1.3: Convert the Data Center CRAC/ACU/CRAH/AHU Air Temperature Control to Rack Inlet Air Temperature Control

IT equipment manufacturers design their products to operate reliably within a given range of intake temperature and humidity. The temperature and humidity limits imposed on the cooling system that serves the data center are intended to match or exceed the IT equipment specifications. However, the temperature and humidity sensors are often integral to the cooling equipment and are not located at the IT equipment intakes. The condition of the air supplied by the cooling system is often significantly different by the time it reaches the IT equipment intakes. It is usually not practical to provide sensors at the intake of every piece of IT equipment, but a few representative locations can be selected. Adjusting the cooling system sensor location in order to provide the air condition that is needed at the IT equipment intake often results in more efficient operation.

CRAC/CRAH air temperature and humidity setpoint sensors are typically located in the return air opening of the unit. To apply ASHRAE guidelines, sensors are needed to measure the IT equipment intake air condition. If the CRAC/CRAH supply air temperature and humidity do not change rapidly, then moving the sensors to the supply air opening is a good start, as the supply air condition is better correlated to the IT equipment intake condition than the return air. CRAH supply air temperature and humidity tend to not change rapidly, but this is typically not true of CRACs. As the CRAC compressor cycles on and off, the supply air condition tends to oscillate.

EEM 5-1.4: Use Supplemental Cooling

The heat generated by IT equipment is often not uniform across a data center space. The cooling air supplied to the space must be sufficient (in both temperature and flow rate) to satisfy the hot spots. This in turn causes over-cooling of the rest of the space, leading to inefficient cooling system operation.

Equipment areas with high heat densities and/or significantly higher heat densities than the average density (>4 times the average density) may be prime candidates for supplemental cooling. This can take several forms:

- In-row cooling units, overhead cooling units, and rear door heat exchangers: See EEM 6.1-1.1: Bring the Source of Cooling Closer to the IT Equipment.
- Liquid-cooled IT equipment. See Category 6.2: Liquid-Based Cooling.

EEM 5-1.5: Ensure an Adequate Ratio of System Flow to Rack Flow

At the data center level, the total supply airflow ideally will closely match the total IT equipment airflow. The Return Temperature Index (RTI) is a measure of the level of net bypass air or net recirculation air in the equipment room. Both effects are detrimental to the thermal and energy performance of the data center. The target is 100% whereas >100% implies net recirculation air and <100% implies net bypass air. (Note that it is common to have some recirculation in data centers with net bypass.) Methods for adjusting system air flow include:

Reduce the Resistance to Air Flow
If the air flow path currently contains obstructions (cabling, floor tiles with small perforations, cosmetic grills, overly aggressive air filters), clearing them will allow the CRAC/ACU/CRAH/AHUs to flow more air. See EEM 5-3.3: Minimize Obstructions in the Air Flow Path.

If there is currently too much system air flow, then imposing flow restrictions will reduce the flow. This is not advised as it will cause the fans to work harder than necessary and will decrease cooling system efficiency.

Adjust Variable Speed Fans

If the CRAC/ACU/CRAH/AHUs are equipped with variable speed fans, the speed can be turned down to reduce air flow. If the fans are not currently running at full speed, they can be turned up to increase air flow. See EEM 6.1-2.3.4: Install CRAC/ACU/CRAH/AHU Fan Speed Control Capability.

Replace Fan Belt Sheaves
If the CRAC/ACU/CRAH/AHUs are not equipped with variable speed fans, but have a belt-and-sheave drive, it may be possible to change the sheave sizes to increase or decrease the air flow. If increasing the flow, consult with the manufacturer to ensure the fans are not being over-driven for their given motor size.

Turn CRAC/ACU/CRAH/AHUs On/Off
If a lower airflow is desired and the preceding methods are not applicable, then it may be possible to turn off selected CRAC/ACU/CRAH/AHUs. This is not a precise way of controlling the air volume, but it can still yield acceptable results. Some experimentation may be required to determine which units can be shut off without compromising adequate cooling of the IT equipment. Since a unit that it turned off will allow air to flow backwards through it, increasing bypass air flow, units should be equipped with dampers that can be closed when they are off, minimizing this air flow.

EEM 5-2: Monitor the Effectiveness of Air-Based Cooling

An efficient cooling system must also be effective; i.e., it must capably deliver as much cooling as is required, to the locations that need it. To ensure effectiveness, monitor the temperature distribution of the cooling supply and return air.

EEM 5-2.1: Measure the Return Temperature Index (RTI) and Rack Cooling Index (RCI)

A low air temperature rise across the data center and/or IT equipment intake temperatures outside the recommended range suggest air management problems. A low return temperature is due to bypass air and an elevated IT inlet temperature is due to recirculation air. Estimating the Return Temperature Index (RTI) and the Rack Cooling Index (RCI) will indicate if corrective, energy-saving measures are called for. The DCEE Toolkit contains two tools for measuring RTI and RCI:

- Air Management Estimator. https://datacenters.lbl.gov/resources/data-center-air-management-estimator
- Air Management Tool. https://datacenters.lbl.gov/resources/data-center-air-management-tool-v118

Data center conditions can change over time, so periodic re-assessment is recommended. If the data center is equipped with a monitoring system and a sufficient number of air temperature sensors, it may be possible to set up dashboard that provides continuously updated RTI and RCI.

EEM 5-2.2: Recalibrate the Temperature and Humidity Sensors

This measure refers to the sensors that measure the cooling air condition. Temperature sensors generally have good accuracy when they are properly calibrated (+/- a fraction of a degree), but they tend to drift out of adjustment over time. In contrast, even the best humidity sensors are intrinsically not very precise (+/- 5% Relative Humidity or RH is typically the best accuracy that can be achieved at reasonable cost). Humidity sensors also drift out of calibration. To ensure good cooling system performance, all temperature and humidity sensors used by the control system should be treated as maintenance items and calibrated at least once a year. Twice a year is better to begin with. After a regular calibration program has been in effect for a while, you can gauge how rapidly your sensors drift and how frequent the calibrations should be. Calibrations can be performed in-house with the proper equipment, or by a third-party service.

EEM 5-3: Implement Effective Air-Based Cooling

The most effective air-based cooling system supplies all cooling air directly to the equipment that needs cooling, and then returns it directly to the cooling coil, without allowing any mixing between the hot and cold air streams. In practice, air-based cooling systems may fall short of this ideal.

The following sub-measures focus on methods for:

- Physically directing air flow in a data center.
- Minimizing leaks in a given physical configuration.
- Minimizing obstructions to air flow in a given physical configuration.

EEM 5-3.1: Implement Effective Physical Configurations for Air-Based Cooling

Physical barriers prevent mixing of hot and cold air. For a given cooling load, this allows for:

- A reduction in airflow, which saves fan energy.
- An increase in the supply air temperature, which can improve refrigerant compressorefficiency.
- An increase in the return air temperature, which presents an opportunity for more hours of air-side or water-side economizing.

The following sub-measures describe different physical configurations, starting with basic principles and proceeding to more advanced solutions.

EEM 5-3.1.1: Use IT Equipment with Front to Rear Cooling Airflow

The Equipment-Cooling (EC) class describes where the entry and exit points for the cooling air are located on the equipment envelope. An optimal class moves air from the cold front aisle to the rear hot aisle, conserving the alternating hot and cold aisles. Non-optimal gear should be isolated, re-oriented, or adapted rather than dictating the cooling requirements for the entire data center.

EEM 5-3.1.2: Configure Equipment Racks in Straight Rows

Since straight equipment lineups are generally a prerequisite to alternating hot and cold aisles, it should have a very high priority. Straight lineups also allow structured cable management.

EEM 5-3.1.3: Maintain Unbroken Rows

Broken rows should be filled with empty racks with blanking panels from top to bottom. Managing unbroken equipment rows is especially important in hot and cold aisle environments. Any opening between the aisles will degrade the separation of hot and cold air.

EEM 5-3.1.4: Implement Alternating Hot and Cold Aisles

This is generally the first step towards separating hot and cold air, which is key to good air management. Cold air is supplied to the cold aisles, the IT equipment moves the air from the its front to its rear, and the hot exhaust air is returned to the air handler from the hot aisles. A variant of this has the IT equipment exhaust directed out the top of the rack instead of the rear, but the principle is the same.

Adding a raised floor and/or a ceiling plenum increases the effectiveness of the hot/cold aisle arrangement.

Hot & cold aisles may not be suitable for data centers with non-optimal gear (not moving air from front to rear/top).

EEM 5-3.1.5: Place Supply Air Devices in Cold Aisles Only

Perforated floor tiles or over-head supply diffusers should only be placed in the cold aisles to match the "consumption" of air by the electronic equipment. Too little or too much supply air results in poor overall thermal and/or energy conditions. Note: the hot aisles are supposed to be hot and supplies should not be placed in those areas.

EEM 5-3.1.6: Take Return Air from Hot Aisles

The thermal efficiency of the data center increases when the return temperature is maximized. The closer the return is located to the heat source, the better. If a return plenum is used, the grilles should be placed directly above the hot aisles. If over-head supply diffusers are used with wall returns, the diffusers should be lowered to allow hot air to pass horizontally along the ceiling without mixing with the supply air

EEM 5-3.1.7: Implement a Tile/Diffuser Location Program

A program should be in place to maintain the alternating hot and cold aisle configuration of perforated tiles or over-head supply diffusers. There is no reason to place tiles or diffusers in the hot aisles.

EEM 5-3.1.8: Line up CRAC/CRAHs with Aisles

For data centers with an underfloor supply plenum and free air return, the CRAC/CRAH units should be placed to promote an even pressure distribution in the floor plenum. Although it may seem counter-intuitive, centering them on the hot aisles rather than on the cold aisles results in better cooling performance because the warm return air has a more direct path back to the unit.

If the data center does not have a raised floor, the CRAC/CRAHs deliver supply air horizontally and unducted, and the return air is ducted, then the CRAC/CRAHs should be centered on the cold aisles.

For data centers with both a supply plenum and ducted return air, the CRAC/CRAH placement in relation to the aisles is not as important.

EEM 5-3.1.9: Provide Adequate Clear Ceiling

Remove the dropped ceiling if not used for air distribution and the clear ceiling is less than 12 feet. Tall open ceilings promote thermal stratification, and the placement of the return grilles is not critical. The stratification ensures that the hot exhaust air is not mixed with the cooler ambient air but is rather returned directly to the air handler. Such ceilings have an unmatched simplicity compared to return plenums. Take care that cold air is not oversupplied and encroaching on the ceiling space, creating bypass.

EEM 5-3.1.10: Place Air Returns at High Elevation

The importance of this measure is a second-order effect in most environments. Nevertheless, CRAC/CRAH units can benefit from ducted vertical extensions that help capture the return air closer to the ceiling rather than at the top of the unit. If a ceiling return plenum exists, provide a continuous duct from the plenum to the CRAC/CRAH return air inlet.

EEM 5-3.1.11: Use Appropriate Overhead Diffusers

The generally high-pressure drops across the end devices (diffusers) and low-pressure losses in the distribution system (ductwork) promote high air stability. Stability means that the system can be balanced successfully and that external disturbances have limited impact on that balance. In addition, the diffusers should have characteristics promoting penetration of the supply air into the cold aisles. Diffusers for human-occupied spaces are designed to have the supply air hug the ceiling, to avoid the discomfort of downdrafts. This type of diffuser is usually not appropriate in the data center context.

EEM 5-3.1.12: Ensure Adequate Match between Heat Load and Effective Plenum Height

This EEM refers to both ceiling and floor plenums. The effective height (flow area) of a plenum depends on its actual physical height, and any obstructions to air flow that are present in the plenum. This effective height dictates how much cooling can be achieved, all else held equal.

When designing a plenum maximize its physical height, within constraints. A shallow plenum may result in high pressure losses, poor pressure distribution, and high fan energy costs.

Ceiling plenum height can be increased if the clear ceiling allows. A ceiling return plenum often means a lower clear ceiling but allows placing the return grilles directly above the hot aisles. Such a plenum needs to be maintained similar to a raised floor.

Many downflow CRAC/CRAHs have supply fans that blow air directly downwards. A shallow floor plenum will interfere with this flow, cause the fan to operate inefficiently, and may work against a uniform pressure distribution in the plenum. Turning vanes mounted directly under the CRAC/CRAH can alleviate this situation, but still contribute to poor air flow efficiency. A taller floor plenum is preferred, if possible. Another option is to specify CRAC/CRAHs with vertical-axis plug fans, which blow air horizontally. See EEM 6.1-2.3.1: Install Efficient Fans in CRAC/ACU/CRAH/AHUs.

Remove cables and other obstructions that are not in use. Congested plenums often require an overall elevated static pressure to deliver the required airflow. Providing the increased static pressure requires additional fan energy.

EEM 5-3.1.13: Provide Adequate Plenum Pressure

A high static pressure often means high plenum leakage and bypass air. A moderate static pressure (0.05 inches of water) allows relatively high perforated tile or diffuser airflow rates but caps the plenum leakage. If a standard 25% perforated tile cannot deliver enough airflow to cool the equipment at the target pressure, rather than increasing the pressure consider using a tile with a larger open area. Similarly with overhead supply diffusers.

EEM 5-3.1.14: Use Existing Dropped Ceiling as Return Plenum

The thermal effectiveness of the data center increases when the return air temperature is maximized, and a return plenum allows the return grilles to be placed directly above the hot aisles. If no dropped ceiling exists, however, installing one is generally not warranted. If fire sprinklers exist in the dropped ceiling, verify their temperature ratings before proceeding.

EEM 5-3.1.15: Balance the Air Distribution System

Branched Ducted Supply

Branched, ducted, constant-flow air supply systems are typically equipped with manually adjustable balancing dampers. The dampers are adjusted to provide the desired air flow through each branch. Verify that at least one damper is fully open. If all branches are partially closed, the fan is being forced to work harder than it needs to. Reduce the fan speed until at least one branch can be fully opened.

Raised Floor Supply Plenum

Raised floor systems are balanced by adjusting the floor tiles – quantity, location, and size of perforations. This is often more an art rather than science, especially since the pressure difference across the floor tiles is relatively small. The aim is to provide the correct amount of air flow to all of the IT equipment. In many data centers, tile adjustment is a continuous activity to follow IT equipment "churn".

EEM 5-3.1.16: Enclose the Aisles

Arranging IT equipment racks in alternating hot and cold aisles is a basic first step in air management. To provide greater effectiveness, the hot aisles or the cold aisles can be contained.

There are different approaches to aisle containment:

- Doors at each the end of the aisle, top of aisle remains open. The doors can be rigid, or they can be flexible strip curtains. Leaving the top of the aisle open allows some bypass/recirculation, but it does not interfere with the fire sprinkler system.
- Aisles are completely closed at each end and at the top. This provides excellent separation of hot and cold air, but fire code may require sprinklers to be installed inside the enclosed aisle.

Some IT rack designs have the return air exiting the top. If this air stream is kept physically separate (by ducts/plenums) all the way back to the CRAC/ACU/CRAH/AHU, then alternating hot and cold aisles are no longer needed. Every aisle can be a cold aisle.

For other solutions that do not rely on hot and cold aisles, see EEM 6.1-1.1: Bring the Source of Cooling Closer to the IT Equipment.

EEM 5-3.2: Eliminate Air Leaks

In the context of a data center air-based cooling system, a "leak" is any point in the supply air path that allows supply air to escape before it reaches the IT equipment. This escaped air can bypass the IT equipment and return to the cooling coil without performing any useful cooling. Leaks can occur in many places, typically at joints or transitions between the materials that define the supply air path.

EEM 5-3.2.1: Seal Raised Floor Leaks

A large fraction of the air from the CRAC/ACU/CRAH/AHUs may pass through leaks in the raised floor. The leaks are often hidden under the equipment racks and not visible during a casual walk-through audit. Such leakage often causes bypass air that does not contribute to cooling the IT equipment. There are a number of commercial products that can be used to seal the raised floor.

If the supply plenum is overhead rather than underfloor, the same principles apply.

EEM 5-3.2.2: Implement a Floor Tightness Program

Raised-floor leakage can be a significant part of the total airflow delivered by the air handler, especially in less dense and lightly populated environments. A well-maintained raised floor results in less air leakage, a higher plenum pressure, and higher flow rates through the perforated floor tiles.

EEM 5-3.2.3: Maintain Tight Racks and Rows

Blanking panels should be used to seal openings under and between equipment racks, between IT equipment in partially filled racks, or completely empty racks. Managing blanking panels is especially important in hot and cold aisle environments. Blanking panels come in various heights and widths to fit almost any application, and they come in snap-on or screw-in types.

EEM 5-3.2.4: Implement a Rack and Row Tightness Program

Any opening between the cold aisle and the hot aisle will degrade the separation of hot and cold air. A program should be in place to minimize leakage by maintaining blanking panels and unbroken rows.

EEM 5-3.2.5: Seal Ducts or Casings to Reduce Leakage

Although raised-floor systems generally leak significantly more than ducted systems, duct systems should be sealed and maintained to avoid unnecessary large airflow rates and energy costs.

EEM 5-3.3: Minimize Obstructions in the Air Flow Path

Obstructions in the air flow path cause fans to use more energy to deliver a given amount of cooling air. The nature of the obstructions can vary depending on the flow path design.

EEM 5-3.3.1: Remove Abandoned Cable and Other Obstructions

Under-floor and over-head obstructions often interfere with the distribution of cooling air. Such interferences can significantly reduce the air handlers' airflow as well as negatively affect the air distribution. The cooling capacity of a raised floor depends on its effective height, which can be increased by removing obstructions that are not in use.

EEM 5-3.3.2: Implement a Cable Mining Program

Cable congestion in raised-floor plenums can sharply reduce the total airflow as well as degrade the airflow distribution through the perforated floor tiles. Both effects promote the development of thermal hot spots.

EEM 5-3.3.3: Remove Cosmetic Doors from IT Equipment Racks

Such doors often impede the cooling airflow and may promote recirculation within the enclosed cabinet further increasing the equipment intake temperature. Truly cosmetic doors should not be used. If rack doors are necessary for security reasons, provide them with openings to permit adequate cooling airflow. For example, solid doors can be replaced with perforated doors.

EEM 5-3.3.4: In-Rack Cable Management

To obtain adequate cooling of servers and other rack IT equipment, an unobstructed air flow path through the equipment is required. Organize communication and power cables in the racks to stay clear of the air flow path.

EEM 5-3.3.5: Implement an Air Balancing Program

At the data center level, the total supply airflow should closely match the total IT equipment airflow. The Return Temperature Index (RTI) is a measure of net bypass air or net recirculation air. Both are detrimental to the performance of the data center. The target is 100% whereas >100% implies recirculation air and <100% implies bypass air. On a row or rack level, air balancing is also important to avoid local bypass air or recirculation air.

EEM 5-3.3.6: Eliminate Pre-Filters

AHUs and ACUs designed for general use are often equipped with air pre-filters in addition to a standard filter bank. Pre-filters serve to trap larger particles in dirtier environments. They also impose an additional resistance to air flow, resulting in a higher fan power demand.

CRACs & CRAHs are 100% recirculating and data centers are relatively clean environments, so they typically do not have pre-filters.

If you are using AHUs or ACUs to cool the data center, examine the need for pre-filters. If they can be removed, it will save fan energy.

EEM 5-3.3.7: Change Filters to Appropriate MERV Rating

MERV stands for Minimum Efficiency Reporting Value. It is a rating system for air filters. The higher the number the more effective the filter is at trapping particles, but increased effectiveness comes at the cost of higher resistance to air flow. Use the minimum MERV rating that is appropriate for your airside equipment.

EEM 5-3.3.8: Replace Dirty CRAC/ACU/CRAH/AHU Filters

Maintain a frequent filter changeout schedule. Filter pressure drop increases significantly before the filters are visibly dirty. Air filters are relatively inexpensive; their cost can be weighed against the energy use of the fans, which run continuously in a data center.

EEM 5-3.3.9: Fix System Effects in Air Distribution System

The narrow definition of "system effect" refers to negative impacts on fan power demand due to a sub-optimal transition between the fan housing and the duct system it is connected to. We use the term "system effect" here in a broader sense, including fan power impacts due to poor air transitions anywhere in data center's air circulation path. There are two main areas of concern:

- Down-flow CRAC/CRAHs, particulary if you have a shallow raised floor plenum. The air must make a sharp turn to the horizontal immediately after exiting the unit. This can be alleviated by installing a turning vane below the unit, to smoothly bend the air stream.
- Any sharp turns in an air duct system. The most efficient duct designs have smooth, large-radius turns.

EEM 5-4.4: Implement Efficient Humidity Control

Servers are fairly tolerant of changes in humidity, but some IT equipment – like magnetic tape and paper printers – that require a relatively narrow humidity range. For more on this subject, see "Humidity Control in Data Centers", at https://datacenters.lbl.gov/sites/default/files/Humidity%20Control%20in%20Data%20Centers.03242017_0.pdf

If air is too humid, the standard way of dehumidifying is to over-cool the air passing through the cooling coils. This condenses moisture out of the air. This is energy-intensive in two ways – it requires colder temperatures to produce the condensation, and then re-heat is often employed to bring the over-cooled air back to setpoint.

If air is too dry, the standard way of humidifying is to create water vapor (steam) by heating water, and then inject the vapor into the cooling air stream. These heat-based humidifiers are energy-demanding.

To implement efficient humidity control, consider the following sub-measures.

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EEM 5-4.4.1: Eliminate Humidity Control

If the local climate is not extreme and the IT equipment has a wide range of acceptable humidity, it may be possible to eliminate humidity control entirely. See EEM 5-1.1: Follow ASHRAE Thermal Guidelines.

EEM 5-4.4.2: Move Humidity Sensitive Equipment to a Separate Space

Paper printers or magnetic media (disks and especially tape) often drive humidity control requirements. Moving these technologies to their own humidity-controlled space can be a significant energy-saving opportunity.

EEM 5-4.4.3: Eliminate Dehumidification Control or Increase the Dehumidification Setpoint

Most modern IT equipment is designed to operate reliably when the upper limit of intake air humidity is 59 F dew point and 60% RH ASHRAE Recommended) and for limited periods, 63 F dewpoint and 80% RH (ASHRAE Allowable A1). However, 55% RH is a typical upper limit in many existing data centers. Maintaining this relatively low upper limit comes at an energy cost, as the cooling system must work harder to condense moisture out of the data center air. Raising the limit can save energy, particularly if the cooling system has an airside economizer. In most climates it is possible to maintain an acceptable upper limit without ever needed to actively dehumidify due to the inadvertent dehumidification provided in the process of cooling the air. In this case, consider disabling or removing the dehumidification controls entirely.

EEM 5-4.4.4: Eliminate Humidification Control or Decrease the Humidification Setpoint

Most modern IT equipment is designed to operate reliably when the lower limit of intake air humidity is 15.8 F dew point (about 8% RH (ASHRAE Recommended). However, 40% RH is a typical lower limit in many existing data centers. Maintaining this relatively high lower limit comes at an energy cost, as humidifiers must produce water vapor to add to the data center. Reducing the limit can save energy, particularly if the cooling system has an airside economizer. In some climates it is possible to maintain an acceptablelower limit without ever needed to actively humidify. In this case, consider disabling or removing the humidification controls entirely. This has the added benefit of removing the need to service the humidifiers, a high-maintenance item.

EEM 5-4.4.5: Add Personnel and Cable Grounding to Allow Lower IT Equipment Intake Humidity

The lower humidity limit in data centers is often set relatively high (40% RH at the IT equipment intake is common) to guard against damage to the equipment due to electrostatic discharge (ESD). Maintaining this level of humidity is energy intensive if the humidifiers use electricity to make steam, which is most common. Energy can be saved if the allowed lower humidity limit can be lowered, particularly if the cooling system has an airside economizer. ESD can be kept in check by conductive flooring materials, good cable grounding methods, and providing grounded wrist straps for technicians to use while working on equipment.

Category 6: Cooling the Data Center Space

IT equipment generates heat. Data center spaces are designed to remove this heat and send it to the outdoor environment. This major category presents measures that focus on the efficiency of the mechanical equipment that is cooling the data center space.

Most data centers cooling systems use only air for the final stage of extracting heat out of the IT equipment racks.

Some cooling systems bring cooling water close to the racks, but the water stops short of the IT equipment itself – the last step of cooling is still performed by air.

Both of these schemes are addressed under Category 6.1: Air-Based Cooling.

A few data center cooling systems bring cooling water into contact with the IT equipment itself. Measures for this type of data center are addressed under Category 6.2: Liquid-Based Cooling.

Category 6.1: Air-Based Cooling

Measures in this category address cooling systems that use air to remove the heat from IT equipment.

EEM 6.1-1: Plan and Design for Energy-Efficient Air-Based Cooling

There are many factors to consider when designing an efficient air-based cooling system for a data center. Chief among these is establishing what range of cooling air temperature and humidity is appropriate for the IT equipment. All other design considerations stem from this.

Efficient air-based cooling systems for data centers are characterized by:

- A relatively high cooling air temperature.
- Cooling supply air completely separated from cooling return air.
- A short, low pressure drop air circulation path.
- Moving only as much air as needed.
- Taking advantage of economizing opportunities.

EEM 6.1-1.1: Bring the Source of Cooling Closer to the IT Equipment

For this EEM, "the source of cooling" refers to the cold refrigerant or chilled water supplied by the cooling system. In most data center cooling systems this source cools air via a cooling coil, and the air in turn cools the IT equipment. Cooling with air is less energy efficient than cooling with liquid, so decreasing the distance between the cooling coil and the IT equipment provides efficiency gains.

There are a variety of products that accomplish this. They can be deployed as supplemental cooling for hot zones in the data center, or they can be installed throughout. Two examples:

Rear Door Heat Exchanger (RDHx)
This is a chilled water cooling coil designed to mount on the rear (exhaust side) of an IT equipment rack. The IT equipment internal fans propel the warm air through the coil. When used as supplemental cooling, the aim of the RDHx is to reduce the temperature of the exhaust air of the high-density rack to align with the exhaust temperature of the less-dense racks.

In-Row Cooling Unit
This is a CRAC or CRAH with a form factor that matches the IT equipment racks. It is placed in the row and serves the racks immediately adjacent.

These technologies are still considered "air-based" cooling, as the final step of extracting heat from the IT equipment relies entirely on air. For solutions that bring liquid into contact with the IT equipment itself, see Category 6.2: Liquid-Based Cooling.

EEM 6.1-1.2: Implement Airside Economizing

Airside economizing refers to the scheme of drawing outdoor air directly into the data center for cooling purposes. There are two basic methods:

Non-Integrated
The economizer does not open until the outdoor air temperature drops to the supply air temperature setpoint. It then opens fully, outdoor air is drawn in to the data center, and it is exhausted from the data center after one pass. At this point the refrigerant compressors in the cooling system can shut off, as the cooling load is carried entirely by the outdoor air. Only the fans need to run. If the outdoor air temperature continues to drop, the economizer begins to close. The outdoor air is mixed with some of the exhaust air to maintain the supply air at the desired setpoint temperature.

Integrated
This is similar to the non-integrated scheme, but instead the economizer opens fully when the outdoor air temperature drops below the *return* air temperature. The refrigerant compressors still need to run, but their load is reduced. If the outdoor air temperature continues to drop until it reaches the supply air temperature setpoint, then the economizer behaves as in the non-integrated case. The integrated scheme saves more energy, as the economizer is able to operate for more hours of the year.

The effectiveness of airside economizing depends on the local climate and the Allowable and Recommended temperature ranges in the data center. Even with relatively narrow ranges, airside economizing can often provide large annual savings.

If the data center space is humidity controlled, the humidity of the outdoor air must also be considered when assessing the viability of airside economizing. For more on this subject, see "Humidity Control in Data Centers", at
https://datacenters.lbl.gov/sites/default/files/Humidity%20Control%20in%20Data%20Centers.03242017_0.pdf

Off-the-shelf ACUs and AHUs can often be ordered with an economizer option direct from the manufacturer.

Airside economizing in combination with CRAC/CRAHs is possible, but the economizer must be designed and installed as a separate piece of equipment.

If adding an economizer to an existing facility, note that you will need the ability to move a relatively large volume of air simultaneously into and out of the building. Design for low-pressure drop intake and exhaust paths to minimize fan energy.

EEM 6.1-1.3: Implement a 100% Outside Air System

Integrated airside economizing uses outside air to cool the data center only when the outside air temperature is less than the return air temperature from the data center. Otherwise, it is more efficient to recirculate the data center air and cool the return air stream.

If the supply and return air temperatures are raised, in some climates it becomes more efficient to simply use 100% outside air all the time for cooling. The number of hours in the year when the outside air temperature exceeds the Recommended maximum supply air temperature diminishes as the latter is increased. Likewise, the number of hours that the Allowable maximum temperature is exceeded diminishes. This makes occasional excursions above the Recommended maximum, but less than or equal to the Allowable maximum, less frequent.

Another strategy for successfully implementing continuous 100% outside air is to use direct evaporative cooling during the hours of highest outside air temperature. This is a much more efficient method of cooling than refrigerant-based equipment. The NASA Ames supercomputing facility is a working example: https://www.nas.nasa.gov/hecc/resources/electra.html

EEM 6.1-1.4: Provide Computer Room with its Own Cooling System

Many small computer rooms and IT closets embedded in larger buildings rely on the "house" cooling system. This forces constant operation of the building's cooling system in order to keep the computer room from overheating. Providing the computer room with its own dedicated cooling unit allows the house system to run on a normal occupancy schedule. The efficiency of the computer room cooling system can be maximized by setting temperature ranges appropriate for IT equipment; see EEM 5-1.1: Follow ASHRAE Thermal Guidelines.

EEM 6.1-2: Implement Energy Efficient CRAC/ACU/CRAH/AHUs

The most commonly used data center cooling units are similar, but have some differences:

Table 2: CRAC, ACU, CRAH, AHU

	CRAC	ACU	CRAH	AHU
Fan System	Yes	Yes	Yes	Yes
Cooling Coil	DX	DX	CHW	CHW
Humidifier	Optional	No	Optional	Optional
On-board Refrigerant Compressor	Yes	Yes	No	No
Controls	On-board	On-Board	On-board	Remote
Efficiency Metric	COP/SCOP	COP/EER/SEER	W/cfm	W/cfm

The measures in the following table apply to CRACS, ACUs, CRAHs, and AHUs.

For measures that apply specifically to CRACs and ACUs, see EEM 6.1-3: Implement Energy Efficient CRAC/ACUs.

For measures that apply specifically to CRAHs and AHUs, see EEM 6.1-4: Implement Energy Efficient CRAH/AHUs.

EEM 6.1-2.1: Specify CRAC/ACU/CRAH/AHUs with High Rated Energy Efficiency

CRACs and ACUs are direct-expansion (DX) units. Their efficiency is expressed as the ratio of total electric input power to the rate of heat transferred. There are different metrics for DX unit efficiency – COP, SCOP, EER, SEER, kW/ton – but they are all based on this ratio.

CRAHs and AHUs use chilled water from a separate plant. The efficiency of these units is usually expressed as the ratio of input power to rate of air flow, at full fan speed and a specific external static pressure. CRAH manufacturers provide heat transfer capacity ratings for their products, but do not always provide an efficiency rating.

CRAH/AHUs may contain other components that require electric power, such as humidifiers and re-heaters. This demand is not reflected in the efficiency rating. Consider omitting the humidity control components if they are not needed.

In all cases, specify units with the highest efficiency that is cost-effective for your project.

EEM 6.1-2.2: Replace Existing CRAC/ACU/CRAH/AHUs with More Efficient Units

If a CRAC/ACU/CRAH/AHU needs to be replaced with a new unit of the same form factor, specify the most efficient unit that is cost-effective. If a unit is old but still functioning, examine its efficiency. It may make economic sense to replace it with a high efficiency unit anyway.

In addition to specifying units with higher efficiency, specify variable speed drives (VFDs or EC Motors) on the fans. See EEM 6.1-2.3.4: Install CRAC/ACU/CRAH/AHU Fan Speed Control Capability.

If it is time to replace all the cooling units, consider a more efficient system design. See EEM 6.1-1.1: Bring the Source of Cooling Closer to the IT Equipment, and Category 6.2: Liquid-Based Cooling.

EEM 6.1-2.3: Implement Energy Efficient Fan Systems for CRAC/ACU/CRAH/AHUs

A fan system consists of the fan itself, a drive mechanism that connects the fan to the motor, the motor, and optionally, a VSD to control the motor speed. All of these components can be examined for energy efficiency.

The efficiency of a fan system is the ratio of the total electric power input to the volumetric air flow rate produced.

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EEM 6.1-2.3.1: Install Efficient Fans in CRAC/ACU/CRAH/AHUs

Centrifugal fans are standard in these types of cooling units.

CRAC/CRAHs: Most manufacturers offer options, including plug fans. Plug fans are more efficient at pressurizing plenums, as they do not have the air friction losses associated with the casing on standard centrifugal fans. By discharging horizontally into the plenum, they also avoid the often poor system effect of the down-blast fan discharge against the bottom of the under-floor space.

Manufacturers of high-efficiency ACUs usually include a high efficiency fan in their product to contribute to the overall high efficiency rating.

AHUs are usually ordered by specifying their individual components. Look for high-efficiency fan offerings.

EEM 6.1-2.3.2: Install Efficient Fan Motors in CRAC/ACU/CRAH/AHUs

The most common fan motor is the AC induction type, but EC motors are gaining in popularity.

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EEM 6.1-2.3.2.1: Change CRAC/ACU/CRAH/AHU Fan Motors to Premium Efficiency

For AC induction motors, specify Premium Efficiency. If they will be used with a VFD, make sure they are also rated for inverter duty.

EEM 6.1-2.3.2.2: Install EC Fan Motors in CRAC/ACU/CRAH/AHUs

EC motors have built-in speed control, and offer even better efficiency than AC induction motors. EC motors are limited to about 10 hp capacity. They are commonly supplied with direct-drive plug fans (see EEM 6.1-2.3.3: Install Efficient Fan Drives in CRAC/ACU/CRAH/AHUs.)

EEM 6.1-2.3.3: Install Efficient Fan Drives in CRAC/ACU/CRAH/AHUs

Direct-drive (attaching the fan directly to the motor shaft) is the most energy efficient. Belt drives incur a few percent loss Wear particles from the belt end up in the supply air, as the belts are downstream of the filter, so direct-drive fans provide the benefit of cleaner air.

EEM 6.1-2.3.4: Install CRAC/ACU/CRAH/AHU Fan Speed Control Capability

Providing fans with variable speed capability expands energy efficiency opportunities in two ways:

- Air flow in the data center can be balanced by fully opening any balancing dampers and then manually adjusting fan speed, rather than having full-speed fans fighting against partially-closed balancing dampers.
- Fan speed can be placed under automatic control, to respond to changes in the cooling load. See EEM 6.1-2.5: Maximize CRAC/ACU/CRAH/AHU Energy Efficiency via Networked Controls.

Variable speed control for AC motors is usually achieved by means of a variable frequency drive (VFD).

EC motors have speed control capability built in.

EEM 6.1-2.4: Change the Type of Humidifier

Most humidifiers are heat based, i.e., they supply steam to the air stream by boiling water. Electricity or natural gas are common fuel sources. The heat of the steam becomes an added load on the cooling system. An evaporative humidifier uses much less energy. Instead of boiling water, it introduces a very fine mist of water droplets to the air stream. When set up properly the droplets quickly evaporate, leaving no moisture on nearby surfaces. This has an added cooling benefit, as the droplets absorb heat from the air as they evaporate. A wetted media can also be used. These devices are also known as direct evaporative coolers or adiabatic coolers.

EEM 6.1-2.5: Maximize CRAC/ACU/CRAH/AHU Energy Efficiency via Networked Controls

CRACs, ACUs, and CRAHs are typically self-contained, with an autonomous on-board control system. (AHUs tend to be part of a networked system.) Running multiple independently-controlled units can lead to energy inefficiency, or leave efficiency opportunities unaddressed. Controlling all units with a network takes advantage of these opportunities, and allows customized control sequences that would not be possible with the stand-alone controllers.

EEM 6.1-2.5.1: Control Multiple CRAC/ACU/CRAH/AHUs with a Common Set of Sensors

CRAC/ACU/CRAH/AHUs are typically equipped with their own air temperature and humidity sensors. The sensors may not be calibrated to begin with, or they may drift out of adjustment over time. In a data center with many CRAC/ACU/CRAH/AHU units it is not unusual to find some units humidifying while others are simultaneously dehumidifying. There may also be significant differences in supply air temperatures. Both of these situations waste energy. Controlling multiple CRAC/ACU/CRAH/AHU units from a common set of sensors avoids this.

EEM 6.1-2.5.2: Minimize Data Center Fan Energy Use

The amount of heat removed from the data center space is proportional to the total air flow rate through the space times the temperature rise of the air. A given cooling load can be handled by a large air flow and a relatively small temperature rise, or a smaller air flow and a greater temperature rise. The latter scenario tends to be more efficient, as it minimizes fan power demand, enables DX or chilled water systems to operate at higher temperatures, and maximizes the potential for compressor-free cooling.

In any event, the aim is to match the cooling system air flow to the IT equipment air flow; see EEM 5-1.5: Ensure an Adequate Ratio of System Flow to Rack Flow.

If a CRAC/ACU/CRAH/AHU has a variable speed fan, a common method of automatic fan speed control is to have the unit's on-board controller maintain a constant air pressure at a specific place in the data center (commonly the supply air plenum). Each unit works to maintain its own independent air pressure setpoint.

This method is more efficient than running all the fans continuously at full speed (no speed control), but the air pressure setpoints remain constant regardless of how much heat the IT equipment is producing at any given time.

If the CRAC/ACU/CRAH/AHUs have variable speed fans and are networked, it opens the possibility of controlling all the supply fans in parallel to minimize the amount of air delivered in response to the heat load.

Note that unless the air flow to and from the IT equipment is completely contained, a reduction in air flow may starve the IT equipment that is not close to the supply outlets (e.g., the perforated tiles in a raised floor system).

EEM 6.1-2.6: Maintain CRAC/ACU/CRAH/AHU Energy Efficiency

Regular maintenance of cooling units helps ensure they continue to operate efficiently.

Table 3: Cooling Unit Maintenance

Maintenance Item	CRAC/ACU	CRAH/AHU
Fan belts (if any)	✓	✓
Air filters	✓	✓
Sensor calibration	✓	✓
Airside economizer (if any)	✓	✓
Chilled water valve actuator		✓
Refrigerant charge	✓	
Condenser coil	✓	

EEM 6.1-2.6.1: Retrocommission the Airside Economizers

While airside economizers can offer large energy savings (particularly in milder climates), they need regular service to operate properly. Outside air temperature sensors that control when the economizer opens and closes must be kept calibrated. The actuators and linkages that control the economizer louvers must be kept lubricated and in adjustment. The entire economizer system should be tested at least once a year to ensure it operates as intended.

EEM 6.1-3: Implement Energy Efficient CRAC/ACUs

Unlike CRAHs and AHUs, CRACs and ACUs contain on-board refrigerant compressors. Energy efficiency measures specific to CRAC/ACUs focus on this difference.

EEM 6.1-3.1: Specify CRAC/ACUs with High-Rated Efficiency

There are several different metrics that describe the efficiency of DX cooling units: COP, EER, SEER, SCOP. SCOP (Sensible Coefficient Of Performance), is the best to use for data centers because the cooling load for recirculated air is mostly sensible (results in a change of air temperature), not latent (dehumidification at a constant temperature). SCOP is the ratio of the net sensible cooling capacity divided by the electrical power input.

For a listing of CRAC efficiencies, see: https://www.regulations.doe.gov/certification-data/CCMS-4-Air_Conditioners_and_Heat_Pumps_-_Computer_Room_Air_Conditioners.html#q=Product_Group_s%3A%22Air%20Conditioners%20and%20Heat%20Pumps%20-%20Computer%20Room%20Air%20Conditioners%22

This site reports rated CRAC efficiencies as SCOP. Note that these efficiencies apply at a standard operating condition, which may be different than the actual operating conditions in your data center.

ACUs are designed for commercial applications (office buildings, etc.). ACUs can successfully cool a data center as easily as CRACs. ACUs are available in a range of efficiencies. The higher the SCOP, EER or SEER value for a given unit, the less overall energy it uses for a given cooling load profile.

High DX unit efficiency can be achieved in several ways:

1. High efficiency components (such as the compressor motor and fan motors), and coils with large surface areas for better heat transfer.
2. Multi-stage compressors. Two or more smaller compressors are staged as needed to more closely match the load on the cooling system.
3. Variable-speed compressors. These allow even closer load matching than units with multi-stage compressors.
4. Refrigerant economizer. This can take several forms, but the principle is to allow the compressor to shut off when outdoor air temperature is low enough. A small pump circulates the refrigerant and the refrigent condenses in the condenser without needing to be pressurized first.

EEM 6.1-3.2: Implement Energy Efficient Heat Rejection for CRAC/ACUs

CRAC/ACUs use a refrigerant loop to extract heat from the supply air stream and send it to the refrigerant condenser. In turn, the heat is rejected from the condenser to the environment.

- One common method of heat rejection employs water-cooled condensers connected to an outdoor “dry cooler” via a water loop. This can be a convenient physical arrangement, but is generally the least efficient. It incurs the energy cost of the water loop pumps, there are two heat exchange steps, and the final stage of heat rejection is an (inefficient) air-cooled coil.
- Another common method runs refrigerant lines from the compressor to an outdoor air-cooled refrigerant condensing coil. This is a more energy efficient scenario, but it typically involves running refrigerant lines from each indoor cooling its paired outdoor condenser.

- An even more energy efficient method is to use water-cooled condensers and connect the water loop to a cooling tower. There is still a water pumping cost, but the cooling tower can reject heat much more efficiently than an air-cooled coil.

EEM 6.1-4: Implement Energy Efficient CRAH/AHUs

CRAHs and AHUs receive chilled water from an external source. Measures specific to these units focus on their air-delivery efficiency. See also EEM 6.1-1.2: Implement Airside Economizing.

EEM 6.1-4.1: Specify CRAH/AHUs with High Rated Efficiency

CRAHs and AHUs are not stand-alone devices; they are served chilled water from other components of the overall cooling system. As such, their efficiency is described by the ratio of their fan power input to the rate of air they deliver, at a specified value of external static pressure.

High efficiency CRAH/AHUs are characterized by:

- Low internal pressure drop due to a low-resistance cooling coil and air filters, and a smooth air flow path.
- A high efficiency fan system – the fan itself, the fan drive, the motor, and the VSD (if any).

EEM 6.1-5: Recover Waste Heat for Heating Uses in Other Spaces

Data centers typically reject all of their heat to the environment. The heat is relatively low grade (low temperature) in the context of many industrial processes, but it may still be an attractive resource for purposes such as heating human-occupied space.

In buildings that contain a data center and office space, the air distribution system can be arranged to take warm return air from the data center and supply it to the office space for heating purposes. Heat transfer can be accomplished by an air-to-air heat exchanger, run-around coils, heat-pipe heat exchangers, or heat pumps.

Category 6.2: Liquid-Based Cooling

Direct liquid cooling brings the cooling liquid into direct thermal contact with the hottest components inside the IT equipment, either by means of a heat exchanger mounted on the surface of the component, or completely immersing the equipment in a thermally conductive – but not electrically conductive – bath. This provides a great advantage in terms of efficiency, as the heat capacity of the cooling liquid is much greater than the heat capacity of air. Much less energy is required to circulate the fluid to remove the heat.

EEM 6.2-1: Provide Liquid-Based Heat Removal (Liquid to the Chip)

Most data center cooling systems use either refrigerant or chilled water to provide cooling. Cold air is produced at the cooling coil, and it this cold air that ultimately enters and cools the IT equipment. In general, the closer the cooling coil is to the IT equipment, the more thermally effective and efficient the cooling system can be.

The term "liquid cooling," as used here, refers to bringing the cooling liquid all the way to the hot surfaces inside the IT equipment, eliminating the transition to cold air altogether. This can provide the most thermally effective and efficient cooling possible. There are several different liquid cooling solutions in the marketplace. The type of cooling system required to support these solutions varies.

EEM 6.2-2: Implement Immersion Cooling

Immersion cooling has the IT equipment completely submerged in a liquid. Depending on the specific technology, the liquid may or may not experience a phase change as part of the heat transfer process.

Category 7: Central Cooling Plant

"Cooling Plant" refers to a system that produces cooling water. Cooling plant designs vary.

Category 7.1: Entire Cooling Plant, Any Type

The following measures apply to cooling plants of all types.

EEM 7.1-1: Plan and Design for an Energy Efficient Cooling Plant

The performance of a cooling plant is typically measured in kW/ton, where:

kW = the total electric power demand of the plant
ton = the cooling rate provided by the plant

A lower kW/ton value indicates a more efficient plant.

There are many ways to design an efficient plant. For more on the subject, see the "Chilled Water Plant Design Guide" at https://www.taylor-engineering.com/wp-content/uploads/2020/04/EDR_DesignGuidelines_CoolToolsChilledWater.pdf

EEM 7.1-1.1: Right-Size the Cooling Plant

Provisioning a data center with oversized refrigerant compressors results in the compressors running at low load factors, where they tend to be less efficient. The compressors should collectively be sized to handle the peak expected load, plus a reasonable safety margin. A modular plant is a good choice from an efficiency perspective; it allows compressors to be brought on line as the data center is built out.

EEM 7.1-1.2: Use a Centralized Cooling System Instead of Individual DX Systems

Progress has been made in recent years on the efficiency of DX cooling systems, but they still fall short of the efficiency that can be achieved by a central chiller plant, especially a water-cooled one.

EEM 7.1-1.3: Design a Chiller-Free Cooling Plant

Modern servers are tolerant of high cooling temperatures. In climates that are not extremely hot or humid, it is possible to cool a data center year-round with only cooling towers, eliminating the energy-intensive chillers from the cooling plant design.

If the chillers can not be entirely eliminated, it may still be possible to cool the data center for most of the year without them, bringing them on line only during peak hot weather. Air-cooled chillers may be the most cost-effective solution in this scenario. They are less expensive to install, and even though they are less efficient their runtime will be low.

EEM 7.1-2: Replace the DX Cooling System with a Chilled Water Cooling System

Chilled water (CHW) based cooling systems consist of one or more chillers that supply CHW to CRAH/AHUs. This type of system is usually more energy efficient than one based on DX cooling units

(CRAC/ACUs). Both CHW and DX based systems use a vapor compression cycle for cooling, but because the CHW system is centralized, it uses larger, more efficient equipment.

The efficiency of a CHW system depends largely on the type of chiller used. In general order of increasing efficiency, the chiller types are:

- Air-cooled.
- Water-cooled, with corresponding cooling towers.
- Evaporatively cooled. This technology has the heat rejection advantage of the water-cooled type, but the condensing water loop is less energy-demanding.

A CHW based cooling system can result in significant energy savings compared to an existing DX based system. If the existing DX system is being expanded, there are several options:

1. Install a chiller plant large enough to meet present and future cooling needs, specify CRAH/AHUs to serve the new loads and also replace all existing CRAC/ACUs with CRAH/AHUs. This option provides the largest energy savings but incurs largest first cost.

2. Repeat Option 1, but instead of replacing all CRAC/ACUs immediately, replace them as they reach the end of their service life.

3. Size the chiller plant to meet only the new cooling load, and specify CRAH/AHUs to serve these new loads. The existing CRAC/ACU system remains in operation.

EEM 7.1-3: Monitor Cooling Plant Efficiency

The actual operating efficiency of a cooling plant cannot be determined without measuring the cooling load it is serving and the power draw of the cooling plant components. Setting up temporary measuring devices will provide a snapshot of the efficiency at one point in time. For more robust plant efficiency management, permanent monitoring devices should be installed.

The simplest approach is to treat the plant as a "black box". Assuming an all-electric chilled water plant, install the minimum number of electric meters needed to isolate the total power draw of the plant (chillers, pumps, cooling towers and any other peripherals). On the cooling side, install the minimum number of chilled water temperature sensors and flow meters to capture the total cooling load. The whole-plant efficiency (in kW/ton) is simply the ratio of the power draw (kW) to the cooling load (tons).

Extending the distribution of measurement devices to the level of individual chillers, pumps, and cooling tower fans provides additional resolution on efficiency. Many chillers have this capability built into their on-board controls. Multi-channel power meters that can monitor all the loads in a chiller plant's motor-control center offer relatively low per-channel cost.

EEM 7.1-4: Optimize Cooling Plant Controls

There are many ways to optimize the control of chilled water plants. Many of the strategies involve automatic resets – of condenser water temperature, condenser water flow rate, cooling tower fan speed, chilled water supply temperature, and chilled water pumping pressure.

Resources

- “Chilled Water Plant Design Guide”. https://www.taylor-engineering.com/wp-content/uploads/2020/04/EDR_DesignGuidelines_CoolToolsChilledWater.pdf

- “Control Optimization System for Chiller Plants”. https://www.gsa.gov/cdnstatic/GPG_Findings_028-Control_Optimization_System.pdf

- “Optimization of Variable Speed Chiller Plants: Frank M. Johnson Jr. Federal Building and U.S. Courthouse, Montgomery, Alabama”. https://www.gsa.gov/cdnstatic/Control_Optimization_System_for_Chiller_Plants.pdf

Category 7.2: Chilled Water Plant

The measures in this category address plants that use electric chillers to produce cold water. A chilled water plant consists of the chillers, a chilled water distribution system, and means of rejecting heat to the environment. If your plant uses cooling towers for the latter, refer to Category 7.3: Cooling Tower Plant.

EEM 7.2-1: Implement Efficient Chillers (All Types)

Heat naturally flows from areas of higher temperature to areas of lower temperature. Chillers work against this natural tendency, by moving heat “uphill” against a temperature gradient. The temperature difference the chiller creates is referred to as the “lift”. The power a chiller requires is a function of the lift and the rate of heat being transferred.

Chillers are often the greatest energy-using components in a chilled water cooling system. Small improvements in chiller efficiency provide relatively large energy savings.

Chiller efficiency is defined as the ratio of its power input to the rate of heat it removes (its load). Efficiency is a map rather than a single value. Efficiency is a function of:

- Load. For a constant-speed chiller, the highest efficiency will usually be seen at the chiller’s full load capacity. For variable-speed chillers, the highest efficiency is usually in the range of 60-80% of full load.

- Evaporator temperature. This is the cold end of the chiller, where the chilled water is produced. Higher evaporator temperatures increase efficiency.

- Condenser temperature. This is the warm end of the chiller, where the heat is rejected. Lower condenser temperatures will increase efficiency.

Manufacturers usually cite a single (highest) efficiency value for their chiller. This efficiency corresponds to a specific operating condition of load, CHW supply temperature, and CW temperature. In operation, chillers may or may not see this nominal condition. In the US, the standard rating conditions are 44F CHW supply temperature, 54F CHW return temperature, 85F CW supply temperature, and 94.3F CW return temperature. See "AHRI Standard 550/590, Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle". http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_550-590_I-P_2015_with_Errata.pdf

Chillers do not always have to operate at the manufacturer's nominal CHW and CW temperatures. Most chillers can be pushed to more efficient operation by increasing the CHW temperature setpoint and/or decreasing the CW temperature setpoint. Chiller manufacturers can provide performance data at CHW temperatures more suitable for data centers; CW temperatures consistent with local weather, and at the range of loads anticipated for the particular application.

The heat transferred by the chillers is ultimately shed to the environment. Chillers are characterized by their heat rejection method, listed here in decreasing order of typical efficiency: evaporative-cooled, water-cooled, air-cooled.

[1] These are different chiller choices. Normally a plant will include only one type.

EEM 7.2-1.1: Evaluate Chillers for Replacement

Recent advances in chiller technology, especially variable-speed compressors, offer more efficient operation. For these reasons, it is often worthwhile to examine the cost-effectiveness of replacing existing chillers if they are more than 5 years old or are in poor condition.

EEM 7.2-1.2: Specify High-Efficiency Chillers

Given a particular chiller design, a manufacturer can tune its efficiency profile to match expected operating conditions. If the more efficient model costs more, the cost differential can be compared to the expected energy cost savings of the unit over its operating lifetime.

EEM 7.2-1.2.1: Select Chiller for Optimum Operating Efficiency

Chillers are selected with a peak load and a safety factor in mind. The chiller plant has to be able to handle the highest expected load with an adequate safety margin. The annual average cooling load, however, is typically considerably less than the peak load.

A chiller's efficiency varies with the cooling load it is asked to serve, the specified CHW supply temperature, and the condensing temperature. The achievable condensing temperature will vary with the weather. The shape of the efficiency curve will vary depending on chiller technology type and, to some degree, on what the buyer requests from the manufacturer. Electric chillers tend to be highest single electric power demand in the entire suite of data center support systems.

Taking these factors into account, an efficiency-oriented designer will match the expected cooling load profile with the chiller efficiency curve to obtain the most efficient annual average operation.

EEM 7.2-1.3: Implement Variable-Speed Chillers

Chillers that can automatically vary the speed of their compressors in response to conditions will operate more efficiently. This is true even if the CHW load is constant, as variations in the outdoor air temperature and humidity will change the total load on the chiller.

EEM 7.2-1.3.1: Specify Variable-Speed Chillers

During the design stage of a new cooling system, the predicted energy use of a constant-speed chiller and a variable-speed chiller can be compared. The energy cost savings of the variable-speed chiller can be weighed against the initial cost premium of the chiller.

EEM 7.2-1.3.2: Retrofit Constant-Speed Chiller with Variable Speed Drive (VSD)

A variable-speed chiller typically offers better performance at partial loading than a constant-speed chiller of the same type and capacity, all other factors held equal. Variable speed control of a chiller is complex, so this retrofit is typically performed only by a qualified manufacturer's representative. Not all chillers can be retrofitted. Whether or not this is a cost-effective measure depends to a large extent on the capacity of the chiller and the load profile it serves.

EEM 7.2-1.4: Implement Efficient Water-Cooled Chillers

Water-cooled chillers use a water loop to carry heat away from the chiller's condenser. This loop is usually served by a cooling tower plant; see Category 7.3: Cooling Tower Plant.

Depending on the local climate, significant energy savings can be achieved by implementing a water-side economizer.

Efficiency gains can also be realized by focusing on the operation of the condenser water loop.

EEM 7.2-1.4.1: Add Integrated Waterside Economizer to CHW Plant

This measure is applicable to a water-cooled chilled water plant; i.e., a plant that includes cooling towers. During periods of low wet bulb temperature (often at night), the cooling towers can produce water temperatures low enough to precool the chilled water returning from the facility, effectively removing a portion of the load from the energy-intensive chillers. During the lowest wet bulb periods, the towers may be able to cool the chilled water return to the chilled water supply temperature setpoint, allowing the chillers to be shut off entirely. The air handlers see the same chilled water supply temperature at all times, allowing them to maintain the required temperature and humidity requirements. Waterside economizing also offers an additional level of redundancy by providing a non-compressor cooling solution for portions of the year; even in hot periods, a water-side economizer can often provide IT inlet temperatures in the ASHRAE Allowable range, even when it can't provide temperatures in the Recommended range, allowing continued IT operation when there is a chiller failure.

EEM 7.2-1.4.2: Implement an Efficient Condenser Water Loop for Water-Cooled Chillers

A condenser water loop is a hydronic loop that connects a chiller's water-cooled condenser to a cooling tower plant. For measures that apply to hydronic loops in general, see Category 7.4: Pumps and Hydronic Distribution.

For a condenser loop, the first priority is to maintain the CW setpoint at the condenser. During some weather conditions this will require the condenser loop to operate at full flow capacity; at other times, less flow will suffice. Implementing a variable flow loop can save energy. In some cases, the condenser water flow is greater than needed even for peak conditions; reducing the flow will save energy.

EEM 7.2-1.4.2.1: Recalibrate the Condenser Water Supply Temperature Sensors

A water-cooled chiller's efficiency is directly affected by the temperature of the condenser water (CW) entering the condenser. A higher CW supply temperature typically results in lower chiller efficiency, all other factors held equal. An out-of-calibration CW supply temperature sensor can cause the cooling towers to produce a warmer than desired CW temperature and in turn cause the chiller plant to work unnecessarily hard.

EEM 7.2-1.4.2.2: Use VFD to Adjust Condenser Water Flow Rate

Condenser water pumps are typically constant-speed, one per chiller, and turned on and off in tandem with their associated chiller. This arrangement provides a constant condenser water flow rate through each chiller's condenser. Condenser water pumps are typically selected to be slightly over sized, and the desired flow rates are achieved by restricting the flow of each pump with a balancing valve. This wastes energy, as the pumps continuously work against the obstruction of the balancing valves. A more efficient method of controlling the condenser water flow rate is to install a VFD on the condenser water pump motor, completely open or remove the balancing valve, and manually adjust the VFD speed to provide the desired flow rate.

EEM 7.2-1.4.2.4: Implement Variable Condenser Water Flow

The standard operating procedure for water-cooled chillers is to have a constant condenser water (CW) flow and a constant temperature of water entering the condenser, also referred to as the cold condenser water temperature (CCWT). Reducing the CW flow will save CW pump energy, all else held equal. However, reducing the CW flow increases the chiller's condensing temperature, causing it to run less efficiently. If low CCWTs can be produced by the cooling tower then the chiller's condensing temperature can be reduced again, restoring efficient chiller operation and retaining the benefit of reduced CW pump energy. This must be compared against the increased cooling tower fan energy needed to produce the lower CCWT's to determine if there are net energy savings.

Note: The standard operating procedure for water-cooled chillers is to have a CW flow and a CCWT. Reducing the CW flow will save CW pump energy, all else held equal.

First determine if a reduced CW flow is viable. It usually is, for the following reasons:

1. ASHRAE recommends a minimum condenser water flow velocity of 3.3 fps to maintain turbulent velocity and prevent formation of deposits in the condenser. This value is well below the 6 to 8 fps found in most modern chiller designs.

2. The condenser water velocity is only a small factor in the overall heat transfer. The main factor controlling refrigerant condensation is the condenser surface area; i.e., the number and size of the condenser tubes.

3. Tests by major chiller manufacturers demonstrate that many chillers can operate at low CW flow velocities and high CW delta-T's without effecting the stable operation of the chiller.

EEM 7.2-1.4.2.5: Reduce the Condenser Water Flow Rate

The standard operating procedure for water-cooled chillers is to have a constant condenser water (CW) flow and a constant temperature of water entering the condenser, also referred to as cold condenser water temperature (CCWT). Reducing the CW flow will save CW pump energy, all else held equal.

Additional information: First, determine if a reduced CW flow is viable. It usually is, for the following reasons:

1. ASHRAE recommends a minimum condenser water flow velocity of 3.3 fps to maintain turbulent velocity and prevent formation of deposits in the condenser. This value is well below the 6 to 8 fps found in most modern chiller designs.

2. The condenser water velocity is only a small factor in the overall heat transfer. The main factor controlling refrigerant condensation is the condenser surface area; i.e., the number and size of the condenser tubes.

3. Tests by major chiller manufacturers demonstrate that many chillers can operate at low CW flow velocities and high CW delta-T's without effecting the stable operation of the chiller.

Will reducing the CW flow help optimize the efficiency of the entire chilled water plant? The plant is a series of linked loops. Reducing the energy requirement of one loop may merely shift the energy demand to another loop, for zero or even negative net savings. The proper approach is to optimize all the loops together in order to achieve the best plant efficiency. Reducing CW flow will save CW pump energy, but it tends to increase chiller lift, which in turn decreases chiller efficiency. The chiller is typically the greatest energy-using component in the plant. If the CW flow rate and/or CW dP are too high, the CW pump energy will be disproportionately large. Decreasing the CW flow rate will provide CW pump savings that may or may not outweigh the increased chiller energy use. You will want to keep the cold condenser water (CCWT) as low as possible in order to keep the chiller lift low, in order to maintain high chiller efficiency. Maximizing the CW flow provides the lowest CCWT, everything else held equal.

1. Start with the maximum CW flow.
2. Lower the CCWT setpoint until the chiller lift is as low as permitted.

Up to this point, CW flow has not been reduced. If there are a significant number of hours per year that a colder CCWT can be achieved, then the CCWT setpoint can be lowered further and the CW flow can be manually reduced to maintain the minimum lift. Note:

1. Reducing the CW flow tends to improve cooling tower performance.
2. Do not reduce the CW flow below the minimum flow needed by the cooling towers.
3. Reducing the CCWT setpoint will increase the CT fan energy, which will reduce and perhaps even eliminate the CW pump savings.

EEM 7.2-1.4.3: Decrease the Condenser Water Temperature Setpoint

Electric chillers tend to offer better performance as the cold condenser water temperature (CCWT) is reduced. Typically, chiller efficiency improves by about 1.5% for every 1F the CCWT is reduced, all other factors held equal.

Reducing the CCWT reduces the temperature difference between the chilled water return (the heat source) and the CCW (the heat sink). The lower temperature 'lift' required from the chiller compressor results in more efficient chiller operation.

The cooling tower fans will draw more power to produce the colder CCWT, but this is typically more than offset by the chiller power reduction, resulting in net savings. All chiller manufacturers provide a lower acceptable limit on CCWT for their products. This lower limit varies between chiller makes and models. Selecting chillers that can accept lower CCWTs helps maximize the savings attainable with this measure.

EEM 7.2-1.5: Implement Efficient Evaporatively Cooled Chillers

Evaporatively cooled chillers are similar to water-cooled chillers, but rather than using a refrigerant-to-water heat exchanger to reject heat to a condensing water loop, their hot gaseous refrigerant is condensed by evaporating water flowing over the condenser tubes.. This reduces the number of heat exchange steps from two to one, and ties the condensing temperature to the ambient wet-bulb temperature. The condenser, water, sump and pump, etc., are usually all integral to the chiller, though remote evaporative condensers are also used.

Whereas a water-cooled chiller requires a cooling tower, condenser water pump, and field-erected piping, an evaporatively cooled chiller generally comes as a complete package from the factory. Evaporatively cooled chillers offer a relatively low cost, low maintenance chiller with a compact footprint.

EEM 7.2-2.3: Raise the Chilled Water Supply Temperature Setpoint

Increasing the chilled water supply temperature setpoint increases chiller efficiency, all else held equal. If the setpoint can be raised without adversely affecting cooling performance in the data center space, doing so will yield immediate gains. If there is room for improved air management in the data center, addressing air management first will likely provide more room for raising the CHW supply temperature setpoint. See Category 5: Air Management.

Selection of the chilled-water supply temperature (CHWST) setpoint has wide-ranging implications.

1. It affects the operating efficiency of the chiller. As a rule of thumb, chiller efficiency improves by 1% for every 2 deg F the evaporator leaving water temperature is raised, all other factors held equal. This holds only to a point; if the chiller lift is reduced too much, it will no longer operate. The room for adjustment varies among chiller make/models, and depends largely on the chiller loading.

2. It can affect the efficiency of the CHW distribution system.. If raising the CHW supply setpoint is not accompanied by a corresponding raising of the supply *air* temperature setpoint, an elevated CHWST may result in a smaller CHW delta-T, and therefore a greater chilled water flow rate to handle a given load. This means increased pumping energy for a given hydronic system pressure drop.

3. A lower CHWST causes greater air dehumidification at the cooling coil via condensation. The dehumidification may be a desired feature of the design, or it may occur unnecessarily, by default. In either case, this latent cooling represents a load on the chiller, and therefore an energy expense.

Note: A typical CHWST setpoint for facilities with normal space humidity control requirements is about 45F. This setpoint is typical even in facilities that have relaxed or even no humidity requirements, due to the persistence of design "rules of thumb". The upper end of the ASHRAE Recommended humidity range is 59°F dew point, thus any chilled water temperature below this will result in inadvertent dehumidification.

EEM 7.2-2.4: Use Dry Coolers to Treat Chilled Water Return

For air-cooled chiller plants in colder climates, adding dry coolers to the return chilled water line can be an effective way to achieve efficient cooling. Dry coolers are relatively inexpensive, and do not have the maintenance issues associated with open (wet) cooling towers. If the plant is already water-cooled, adding dry coolers does not have much benefit. Cooling tower maintenance is already incurred, and waterside economizing offers a substantial energy efficiency opportunity. See EEM 7.2-1.4.1: Add Integrated Waterside Economizer to CHW Plant.

Dry coolers have a relatively large approach temperature, so they achieve the greatest cooling benefit in cold climates. During the coldest weather, the dry cooler may be able to handle the entire cooling load, fully relieving the chiller of duty. Otherwise the dry cooler serves to lessen the load on the chiller.

EEM 7.2-3: Implement a Thermal Energy Storage (TES) System

Adding thermal storage to a chilled water plant allows the chillers to be partially decoupled, or "time-shifted", from the cooling load.

There are several storage technologies available, e.g., ice, eutectic salts, paraffin, and chilled water. All of these offer the following advantages:

1. The chillers can be turned off during peak electric demand periods, saving significantly on electric cost. This requires that the chiller plant has a maximum cooling capacity that significantly exceeds the average cooling load, so that the cooling plant can simultaneously keep the data center cool and store enough "coolth" during non-peak hours to allow coasting through the peak hours.
2. During chiller runtime the cooling load can be adjusted (by controlling the rate of TES recharge) to have the chiller plant operate at peak efficiency.
3. The chillers will spend a greater percentage of their runtime during night hours, when ambient temperatures are cooler and the cooling plant can reject heat more efficiently.
4. A thermal storage system offers another level of redundancy to the cooling plant.

For a given storage capacity, tanks containing phase-change materials (ice, eutectic salt, paraffin) are smaller than a chilled water tank. However, the chillers generally must be able to produce colder temperatures (below the freezing point of water in the case of ice storage). The existing chillers may not be capable of this, in which case new chillers would be required. Chillers that produce sub-freezing temperatures are generally less efficient than the standard chilled water variety. It is common for phase-change storage systems to use more annual energy than an equivalent, non-storage chilled water plant, but they still have the advantage of allowing peak demand charges to be avoided. A chilled water storage system can offer significant annual energy reduction over an equivalent, non-storage chilled water plant, but usually requires a very large tank. Siting the tank can pose a challenge. Often the tank is placed underground, for example under a parking lot.

A bonus of thermal energy storage is that the chilled water pumps can distribute cooling from the thermal storage quickly after the generator starts during a utility power outage, whereas the chillers typically have re-start delays that can adversely affect the data center temperatures.

Category 7.3: Cooling Tower Plant

The measures in this category apply to cooling towers. Cooling towers are typically used for cooling condenser water from chillers or DX systems, but they can – in some circumstances – be the sole source of cooling for a data center, at least for much of the year.

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EEM 7.3-1: Implement an Effective Cooling Tower Plant

An effective cooling tower can reject a comparatively high amount of heat for a given outdoor wetbulb temperature. This is usually accomplished by maximizing the surface area available for water evaporation.

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EEM 7.3-1.1: Increase Cooling Tower Capacity

The cooling tower plant is typically sized to handle the peak design load at the 99% wetbulb condition. Oversizing the cooling tower plant allows it to reject heat to the environment more efficiently at all load and wetbulb conditions, with less fan energy. It will also be able to produce lower CW temperatures, which is an important consideration in several other waterside measures.

EEM 7.3-1.2: Specify a Low Approach Temperature Cooling Tower

Every single-stage cooling tower can produce a water temperature that approaches, but is never lower than, the ambient wetbulb temperature. The difference between these two temperatures is called the "approach" temperature. During operation, the approach temperature will vary as a result of several factors – the tower water flow rate, the temperature of the water entering the tower, the ambient wetbulb temperature, the cooling tower fan speed, etc. To allow comparisons between different tower models, manufacturers report the approach temperature at a single, specific operating condition. This nominal condition may not be the same from one manufacturer to the next, so exercise care when making comparisons. A tower with a smaller approach temperature is more efficient and enjoys the same advantages of an oversized tower. A low approach temperature tower is often created merely by oversizing the tower but can also be created by a different design without increasing the physical dimensions of the unit. A lower approach temperature can improve chiller efficiency. For example, see EEM 7.2-1.4.3: Decrease the Condenser Water Temperature Setpoint.

EEM 7.3-1.3: Convert Cooling Towers from Series Staging to Parallel Staging

By operating as many cooling towers as possible at all times, the amount of water to be cooled is distributed across a greater number of towers. This decreases the amount of heat rejection required by each tower, which in turn reduces the required fan speed. This translates directly to energy savings. Care must be taken that no tower is starved for water flow.

EEM 7.3-2: Implement a Water-Efficient Cooling Tower Plant

Cooling towers transfer heat to the environment by evaporating water. The water lost by evaporation is replaced by a source of make-up water. When the water evaporates, minerals and other constituents are left behind. The concentration of these items in the water remaining in the cooling tower increases. At some point the concentration becomes high enough that the water needs to be drained from the tower and disposed of. This "blow-down" water is replaced by fresh water from the make-up source.

The amount of water consumed by the tower can be minimized by not blowing down tower water prematurely.

If the temperature of the water entering the cooling tower is high with respect to the ambient dry-bulb temperature, a greater proportion of heat will be rejected by convection, and less by evaporation, in turn saving water. This is an argument in favor of higher temperature regimes for compressor-free cooling systems.

Locating a cooling tower plant in a dry climate allows it to operate both energy- and water-efficiently, but water use also tends to be restricted/expensive in dry climates.

Electric chillers operate more efficiently with a *lower* condenser temperature. Raising the CW temperature setpoint may conserve water, but it the chiller will have to work harder. One strategy is do away with the chillers entirely; see EEM 7.1-1.3: Design a Chiller-Free Cooling Plant.

EEM 7.3-3: Implement an Energy-Efficient Cooling Tower Plant

Cooling towers are typically rated as water flow rate (gpm) divided by fan motor nameplate output power (hp), at a standard operating condition of 95 F entering water, 85 F leaving water, and an ambient air wetbulb temperature of 75 F. See ASHRAE 90.1 or CA Title 24.

The actual wetbulb temperature will of course vary significantly over the course of the year, and by location. This in turn affects what leaving tower water temperature is achievable. The entering water temperature will vary based on leaving water temperature and cooling system load. Finally, the fan motor may or may not run at full power, depending on the other conditions. All this is to say that the cooling tower rating alone will not reveal how efficiently the tower will operate over the course of the year at a given site.

Cooling towers normally include a fan to move air through the tower.

For open cooling towers serving a water-cooled chiller plant, the water flow through the towers is propelled by the condenser water pumps. See EEM 7.2-1.4.2: Implement an Efficient Condenser Water Loop for Water-Cooled Chillers.

Closed cooling towers have their own dedicated pump to circulate the evaporation water, which is kept out of direct contact with the condenser water.

EEM 7.3-3.1: Select High Efficiency Cooling Towers

The basic design of a cooling tower significantly affects its efficiency. Draw-through (induced draft) towers are about twice as energy efficient as blow-through (forced draft) towers. The former tend to use more aerodynamically efficient propeller fans, and the latter tend to use less efficient centrifugal fans.

A cooling tower's "approach" temperature is the difference between the leaving tower water temperature and the ambient air wetbulb temperature. The smaller the approach a tower can achieve for given set of conditions, the more effectively it is rejecting heat. Towers achieve low approach temperatures by maximizing the amount of air that flows across their wetted surface area.

Specifying high-efficiency fan motors increases overall tower efficiency.

EEM 7.3-3.2: Implement Energy Efficient Fan Systems for Cooling Towers

A cooling tower fan system consists of the fan itself, a drive mechanism that connects the fan to the motor, the motor, and usually a VSD to control the motor speed. All of these components can be examined for energy efficiency.

The efficiency of a fan system is the ratio of the total electric power input to the volumetric air flow rate produced.

EEM 7.3-3.2.1: Install Efficient Fans in Cooling Towers

Most cooling towers need to produce a relatively large air flow rate, against a low resistance. Propeller-type fans are the most efficient in this application. Some propeller fans have stamped sheet metal or plastic blades that are less efficient. The most efficient propeller fan blades will have a carefully-design aerodynamic cross-section.

EEM 7.3-3.2.2: Install Efficient Fan Motors in Cooling Towers

Cooling tower fan motors are usually the AC induction type, but EC motors can be found on smaller towers.

EEM 7.3-3.2.2.1: Install Premium Efficiency Fan Motors in Cooling Towers

For AC induction motors, specify Premium Efficiency. If they will be used with a VFD, make sure they are also rated for inverter duty.

EEM 7.3-3.2.2.2: Install EC Fan Motors in Cooling Towers

EC motors have built-in speed control, and offer even better efficiency than AC induction motors. EC motors are limited to about 10 hp capacity.

EEM 7.3-3.2.3: Install Efficient Fan Drives in Cooling Towers

Direct-drive (attaching the fan directly to the motor shaft) is the most energy efficient. Belt drives and gearboxes suffer a few percent loss, even in ideal conditions, and require additional maintenance.

EEM 7.3-3.2.4: Add VSDs to Cooling Tower Fans

Cooling towers are often equipped with a single-speed or a two-speed fan motor. The motor cycles on and off (or off-low-high) to maintain the desired condenser water temperature. Adding a variable speed drive (VSD) to the motor offers several advantages. It saves energy by operating continuously at a lower speed rather than cycling between a higher speed and off. It saves the wear and tear that occurs with cyclic operation, and it is less noisy. In addition, it allows more precise control of the condenser water temperature.

EEM 7.3-3.3: Improve Cooling Tower Water Treatment to Reduce Energy Use

The purpose of a cooling tower is to reject heat from an incoming stream of water, cooling the water to a specified setpoint temperature, or as close as possible to the ambient wetbulb temperature, whichever is greater. The heat rejection is achieved by evaporating a portion of the water. The amount of evaporation that occurs depends (among other things) on the amount of wetted surface area and the thickness of the water film on that surface. A good cooling tower water treatment program helps ensure that the wetted surfaces remain unfouled, promoting the best heat rejection performance possible.

Category 7.4: Pumps and Hydronic Distribution

"Hydronic" refers to heat transfer by water. A hydronic distribution system consists of pump motors, pumps, pipe, heat exchangers, valves, and other fittings. All of the measures in this category focus on centrifugal pumps. Basic hydronic systems have pumps that run at constant speed. If the heat transfer requirements vary significantly, additional efficiency can be gained by implementing automatic pump speed control.

EEM 7.4-1: Implement an Efficient Hydronic System

The metric for hydronic system energy efficiency is system input power divided by the total volumetric water flow rate. The lower this ratio, the more efficiently the system delivers water.

The input power a pump system needs to produce a given flow rate is proportional to several variables, as follows:

Power ~ (Flow Rate x Head) / (Pump Efficiency x Motor Efficiency x VSD Efficiency)

where:

Flow Rate depends on the resistance to flow.
Head is the resistance to flow. It is the same as the pressure difference developed between the inlet and outlet of the pump as it works to overcome the resistance.
Pump Efficiency varies with Flow Rate and Head.
Motor Efficiency varies with Power.
VSD Efficiency varies with motor speed.

Given the interplay between the variables, the power requirement tends to increase exponentially with the flow rate.

Increasing the efficiency of the hydronic system can be approached several ways – by reducing the flow rate, decreasing the resistance to flow, and increasing the efficiency of the pump system (pump plus motor plus VSD).

EEM 7.4-1.1: Reduce the Required Flow Rate

In a hydronic cooling system, reducing the flow rate will increase the temperature of the return flow stream, all else held equal. This may or may not be acceptable given your specific cooling equipment specifications and requirements. If it can be reduced – and the pumping pressure setpoint reduced accordingly – the pump power savings will tend to increase exponentially with the amount of flow reduction.

EEM 7.4-1.2: Decrease the Resistance to Flow

There are many ways to implement a low head hydronic system. Some measures, such as specifying large-diameter pipes, are practical only at the design stage. Other measures, such as removing unnecessary fittings, can be retrofits.

For a constant-speed pump system, simply reducing the resistance to flow will increase the flow rate. Unless the current flow rate is deficient, we want to reduce the pump speed after the head is reduced, to regain the original flow rate. Doing so will provide pump power savings that tend to increase exponentially with the reduction in head.

EEM 7.4-1.2.1: Reduce the Supply Pressure Setpoint

Standard control system design calls for the chilled water pump serving the chilled water distribution system to maintain a constant differential pressure at a given location (usually at the most remote cooling coil), regardless of the current cooling load. The pressure setpoint is selected to ensure that adequate flow is delivered to every coil at the extreme load condition (all cooling coil valves are wide open). The setpoint may currently be set higher than necessary. This can occur for several reasons – improper initial balancing; overestimation of peak load; inaccurate load growth projections; changes made to the distribution system but not rebalanced; etc. A pressure setpoint that is higher than necessary will cause the chilled water pump motor to draw more power than is necessary. Optimizing the setpoint for current conditions will save energy.

EEM 7.4-1.2.2: Specify Large Diameter Pipes

For a given, turbulent water flow rate through a straight pipe, the resistance to flow decreases in proportion to the fourth power of the pipe diameter. In other words, doubling the pipe diameter decreases the flow resistance by a factor of 16. It is not necessary to double the diameter, of course – just a modest increase in pipe size will provide a dramatic reduction in friction. During the design stage of the hydronic system, the added cost of slightly larger pipes can be weighed against pump energy savings.

EEM 7.4-1.2.3: Design Smooth Pipe Transitions

Built hydronic systems tend to resemble their design schematics – lots of sharp 90-degree bends. These bends increase the pump power needed to deliver a given flow. During the design stage of the hydronic system, consider using 45-degree elbows and large-radius 90-degree elbows. Figure 1 provides an example for plumbing a pump bank.

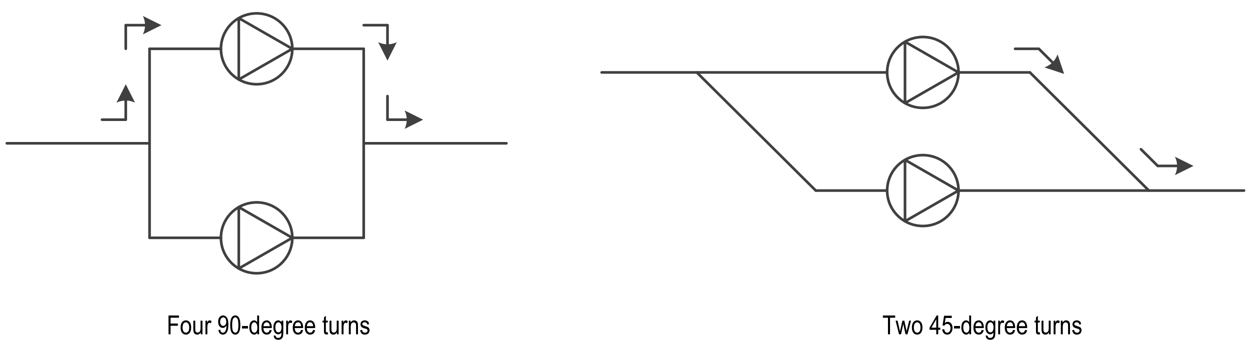

Figure 1. 90-degree vs 45-degree Elbows in a Pump Bank

EEM 7.4-1.2.4: Minimize Fittings

Many hydronic system fittings that appear in standard designs can be omitted to enhance energy efficiency, without impairing functionality or safety.

EEM 7.4-1.2.4.1: Remove Suction Diffusers Where Possible

Suction diffusers on pump inlets serve to straighten out the water flow before it enters the pump. While this helps avoid the drop in pump efficiency that accompanies turbulent inlet flow, it comes at the cost of increased pressure drop. A more efficient arrangement is to design the piping, wherever possible, to provide a straight section of pipe at the pump inlet that is at least ten pipe diameters in length. This is normally sufficient to straighten out the flow and can often be worked into the design with no pressure drop penalty.

EEM 7.4-1.2.4.2: Eliminate Triple-Duty Throttling Valves

Triple duty valves (TDVs) are typically located near pumps, and provide shutoff, throttling, and check (one-way flow) functions in a single unit. Two pressure ports are provided, one on either end of the valve, to determine the flow rate that results from different throttling positions. Using the pressure drop across the valve to determine flow rate does not work properly unless a significant pressure drop is developed -- but this is precisely what we wish to avoid if we want to minimize pumping energy.

Balancing the flow of the system near the pump is not a good choice in terms of energy use. For example, a Bell & Gossett model 3DS-10S triple duty valve that is 80% open at design flow adds about 5.5 feet w.g. of pressure drop. Assuming $0.10/kWh, the pressure drop due to the triple duty valve would account for roughly $2,000 to $3,000 in annual pumping electrical costs (continuous duty). Even at 100% open, it generates a constant parasitic pressure drop of over 4 ft. w.g.

TDVs use a very high pressure drop valve to allow for throttling of the pump to prevent over-pumping. While throttling does reduce pump energy use slightly, it is significantly more efficient to eliminate the throttling valve's pressure drop entirely:

1. Balance the system flow at the far end of the distribution system.
2. Either trim the pump impeller to match the load when balancing is performed (see EEM 7.4-1.2.6: Trim Pump Impeller and Open Triple Duty Valve), or equip the pump motor with a VFD and control flow by varying the pump speed (see EEM 7.4-2: Implement a Variable Flow Hydronic System). VFDs are often a small premium over a standard motor starter and offer greater flexibility. Throttling valves are redundant on speed controlled (VFD) pumps.

Use of a separate, low pressure drop check valve with a standard butterfly valve lowers the loop pressure drop, as well as improving the serviceability of the system by separating the isolation valve from the check valve entirely.

Do not set the peak flow of the hydronic loop by throttling the pump. To match the pump flow to design, have the actual loop pressure drop at design flow measured during balance. The pump impeller can be trimmed to match the actual loop pressure drop at design flow, plus a small safety factor to account for future fouling.

Determine the flow based on either a portable, clamp-on flow meter or, more commonly, by comparing the pressure drop across the chiller barrels to the manufacturer's provided pressure drop curves. The pressure drop across the chiller barrel is often used by chiller manufacturers for low flow monitoring and, on a new machine, is an effective and low cost method of determining loop flow. A low pressure drop (0 to 0.5 ft. w.g.) flow meter may be added to the loop to ease the balancing and provide ongoing monitoring, allowing for improved preventive maintenance and diagnosis.

Any situation requiring such severe pump throttling that a high pressure drop globe-type valve is required (i.e., control is being compromised due to valves be over-pressurized to the point of chatter), indicates severe pump over-sizing. This justifies actually correcting the pump sizing, i.e., trimming the impeller or even changing the pump out entirely for one sized to fit the actual system.

EEM 7.4-1.2.4.3: Eliminate Flow Control Valves and Circuit Setters

Flow control valves and circuit setters serve the same purpose -- they limit flow by imposing a restriction. The pump has to work against this restriction.

These valves traditionally serve two purposes: They limit the maximum flow through a component and they provide a flow measurement point. This functionality is typically not necessary in a water distribution system that uses DDC (Direct Digital Control), even in multiple-building critical facilities. Unless the component is undersized or assigned an unobtainable setpoint, the control valve will automatically throttle it as necessary. Modern DDC control valves sized properly for the system can provide both control and this automatic balance function. To allow for future spot fixes, the addition of one more P-T port can provide the ability to spot balance components using the shutoff valves for balance where required. To determine flow, P-T taps can be installed on either side of the 2-way control valve. Then the flow can be determined by reading the pressure across these taps and the consulting the CV table supplied by the valve manufacturer. A less reliable method of determining the design flow point that requires only the two P-T ports typically installed is to compare the pressure drop across the component to the manufacturer's design pressure drop submittal data. The appropriate CHW pressure setpoint to provide the minimum needed flow to all coils at design conditions is also determined during balancing. Once this value is known the pump impeller can be trimmed as required, or the pump speed can be set by VFD.

EEM 7.4-1.2.5: Specify Oversized Cooling Coils

Specifying cooling coils with a heat transfer capability greater than the expected peak cooling load provides two benefits:

- The resistance to flow of both water and air through the cooling coil will be less, reducing the pump and fan power requirements.
- A smaller approach temperature (the difference between the entering water temperature and the leaving air temperature) can be realized. The same target air temperature can be achieved with a slightly warmer water temperature, which in turn allows the chiller to operate more efficiently.

EEM 7.4-1.2.6: Trim Pump Impeller and Open Triple Duty Valve

In a constant-speed pump system, water flow is typically balanced by imposing a flow restriction via a balancing valve (one of three functions of a triple-duty valve). Fully opening the balancing valve and trimming the pump impeller to provide the same peak flow rate reduces pump head. Trimming the impeller will reduce the pump's hydrodynamic efficiency, but that is usually more than offset by the pump motor power reduction due to the lower head. For a more efficient alternative to trimming the impeller, see EEM 7.4-1.3.2: Specify an Untrimmed Impeller, Use a VFD to Limit Pump Speed, and Match the Pump Motor Size to the Design Flow Rate.

EEM 7.4-1.3: Increase the Efficiency of the Pump System

"Pump system" refers to a pump, a pump motor, and optionally, a VSD controlling the motor speed. All of these components can be the target of efficiency efforts.

EEM 7.4-1.3.1: Install High Efficiency Pumps

The hydrodynamic efficiency of a centrifugal pump is dictated by the physical shape of its impeller blades and the housing around the impeller. A pump does not have a single efficiency value, but rather a "map" that varies according to pump pressure, flow rate, impeller diameter, and impeller speed. If a manufacturer quotes a single efficiency value for a pump, it typically refers to the peak efficiency point on the map. When the pump is put into service, it may or may not operate at this nominal point.

Manufacturers produce pumps with different maps, depending on application. Once the pump is built the map is "cast in place" and can't be altered short of physically removing material from the circumference of the impeller ("trimming").

A thorough search of available pumps for a particular application usually reveals a wide range of efficiencies. Spending the time to do the research and then selecting the most efficient pump is usually a cost-effective activity, particularly in facilities where the pumps are continuously active.

EEM 7.4-1.3.2: Specify an Untrimmed Impeller, Use a VFD to Limit Pump Speed, and Match the Pump Motor Size to the Design Flow Rate

Typical design practice calls for selecting an oversized pump for the given application and then trimming the impeller to match actual conditions, for example specifying a maximum impeller diameter of 85%. This tends to decrease the efficiency of the pump (losses at the larger gap at the cutwater). A more energy-efficient alternative is to retain the full impeller size and use a VFD to limit the maximum pump speed to the value that provides the design flow.

While the impeller is untrimmed, the pump must still be selected to operate at its peak efficiency point at turndown; this is done by scaling the design conditions up to the untrimmed impeller point using the pump laws. Most pumps are already available in differing motor speeds and comparisons of curves for a single pump at 1750 rpm and 1180 rpm will quickly show that lower speeds do not adversely impact efficiency. This selection approach ensures that there are no losses from off-curve operation and will yield the highest possible efficiency. Losses in the VFD are minimal compared to the efficiency improvement that can be realized in the pump as long as the VFD and motor are sized for the actual operating power (not the full speed operating power requirement). The pump motor is selected to provide the necessary power to produce the design flow.

Note that the pump motor VFD can no longer be put on bypass, or the motor will overheat and trip off. Modern VFDs are robust and reliable, so the lack of bypass capability is less of a concern.

Cost concerns must be evaluated on a project basis, but frequently a quality VFD is only marginally more costly than a good quality motor starter. Significant flexibility is gained from having additional pump capacity available with a simple motor and drive replacement (or by turning up the speed, even into the service factor in a temporary, emergency situation).

EEM 7.4-1.3.3: Install Efficient Pump Motors

See EEM 1-4.1: Upgrade All Cooling Supply Fan, Pump, and Cooling Tower Fan Motors to Premium Higher Efficiency. Note that for any constant-speed pump motors, since the pump and motor turn at the same speed, it is important to take motor efficiency and loaded speed (including slip) into account, since more efficient motors typically run at a slightly higher speed, and a 1% increase in pump speed results in about 3% higher power consumption.

EEM 7.4-2: Implement a Variable Flow Hydronic System

This measure refers to hydronic systems whose flow can vary under automatic control. A variable-flow hydronic system offers the greatest opportunity for energy savings in facilities where cooling (or heating) load varies significantly. If such a facility is equipped with constant-speed pumps, the pumps will spend a large portion of their time pushing against control valves that are partially closed during off-peak conditions. Automatically controlling pump speed to deliver only the needed flow rate can greatly reduce pump power demand.

EEM 7.4-2.1: Convert all 3-Way CHW Valves to 2-Way

Older chilled water distribution systems were typically designed with 3-way valves at the cooling coils and constant-speed chilled water pumps. A constant flow of chilled water is delivered to each coil location. Each coil is equipped with a bypass leg, and each 3-way valve modulates to divert as much water through the coil as is currently needed for cooling purposes. The remaining water bypasses the coil. This method is energy intensive. With the advent of inexpensive, reliable variable speed drives for pump motors, the preferred design eliminates the bypasses and replaces the 3-way valves with 2-way valves. The 2-way valves modulate as needed to serve the cooling load, and the pump motor speed varies in response to the demand by maintaining a constant pressure at the far end of the distribution loop. In facilities that experience varying load, it may be cost effective to go one step further and program the control system to vary the pressure setpoint in response to the position of the most-open 2-way valve.

EEM 7.4-2.2: Convert Primary/Secondary Pumping to Primary-Only

Typical chilled water distribution systems have a constant-volume primary loop and a variable-flow secondary loop. This arrangement ensures a constant flow through the chiller evaporator, while allowing the secondary loop to modulate according to demand. Modern chillers are more tolerant of variable chilled water flow through the evaporator. As a result, primary-only variable flow CHW pumping has become more common. This arrangement eliminates the primary CHW pumps (the pumps previously designated as secondary become the primary pumps) and typically results in energy savings. Chillers still have minimum allowable evaporator flow rates, so the control system must monitor and ensure these rates.

EEM 7.4-2.3: Implement a Pumping Pressure Setpoint Reset

A typical control system design calls for the chilled water pump serving the chilled water distribution system to maintain a constant differential pressure at a given location (usually at the most remote cooling coil), regardless of the current cooling load. The pressure setpoint is set to a value that ensures adequate flow through all the coils under the highest possible load condition.

Under lower load conditions, the coils require lower flow rates and the pressure needed to supply the flow is also much lower. With constant pressure control, the CHW control valves at the coils are required to throttle closed to prevent too much flow to the coil at low loads. When all the coil control valves are operating at a partially closed throttling position, it is because the chilled water pump is supplying more pressure than is necessary. Rather than maintaining a constant pressure across the chilled water loop, the pressure setpoint can be lowered during periods of low load.

The usual method is to continuously poll the control valves on the loop for their position. The highest valve position is then used as an input to a control loop that resets the chilled water loop pressure setpoint down until the maximum valve position equals 85% - 90% open. This control approach continuously optimizes the setpoint to reduce energy usage and, in some extreme cases, even noise by reducing the throttling required during low load periods. The chilled water pump pressure setpoint is essentially self-balancing and continuously optimized to the system's operating conditions.

This measure assumes a variable pumping chilled water system is already implemented, either a variable flow primary-only system or a more typical primary-secondary system with variable secondary loop. The cost of controls is sensitive to whether the controls contractor has implemented this type of system before; i.e. whether or not they already have a "canned" routine available for the control. This measure will yield more savings in those cases where there is significant variability in the cooling load, and/or where the cooling system is oversized for the load.

EEM 7.4-2.4: Optimize the Number of Pumps Running in a Bank of Variable-Speed Pumps

Some installations have a bank of variable-speed pumps plumbed in parallel where often more than one pump is active at a time. Given the interaction of the pump flow vs. pressure curve, the pump efficiency curve, and the pump operating speed, it is not always obvious what number of operating pumps minimizes the energy use of the pump bank as a whole. This is best investigated by simply commanding all the pumps on, recording the total pump motor kW, and then taking successive pumps off line and recording the new total kW each time. If the flow demand varies significantly over time, each test should be run for an appropriate amount of time.

Glossary

AC	1. Alternating Current. 2. Air Conditioning.
ACU	Air Conditioning Unit. A direct-expansion cooling system not specifically designed for computer rooms, either "packaged" (all components in a single enclosure), or a "split" system (indoor cooling unit, outdoor condenser). A packaged unit may include a built-in air-side economizer. Typically does not contain a humidifier. ACUs are sometimes used in computer room applications.
AHU	Air Handling Unit, not specifically designed for computer rooms. At minimum, contains a fan and a CHW coil. May include a humidifier and a built-in air-side economizer.
ASE	Air Side Economizer.
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
BAS	Building Automation System.
CCWT	Cold Condenser Water Temperature.
CF	Compact Fluorescent
CHW	Chilled water used for cooling.
CHWRT	Chilled Water Return Temperature.
CHWST	Chilled Water Supply Temperature.
Containerization	
Control Sequence	
COP	Coefficient of Performance.
CRAC	Computer Room Air Conditioner. A direct expansion cooling system designed specifically for computer rooms.
CRAH	Computer Room Air Handler. A chilled water air handler designed specifically for computer rooms.
CW	Condenser Water.
Cx	Commissioning.
DC	1. Data Center. 2. Direct Current.

DCIM	Data Center Information Management.
DDC	Direct Digital Control.
deg F	Degrees Fahrenheit.
dP	Differential Pressure.
DP	Dew Point temperature.
dT	Differential Temperature.
DX	Direct Expansion.
ECM	1. Electronically Commutated Motor. 2. Energy Conservation Measure.
EE	Energy Efficiency.
EEM	Energy Conservation Measure.
EER	Energy Efficiency Ratio.
EMCS	Energy Monitoring and Control System
ESP	External Static Pressure.
FCU	Fan Coil Unit.
FEMP	Federal Energy Management Program.
HACA	Hot Aisle Cold Aisle.
HVAC	Heating, Ventilating, and Air Conditioning.
IT	Information Technology.
IT Equipment	
kVA	
kW	kiloWatts of real power
kWh	kiloWatt hour
LCC	Life Cycle Cost.
LED	Light Emitting Diode.
LV	Low Voltage.
MA	Mixed Air.
MAT	Mixed Air Temperature.

MERV	Minimum Efficiency Reporting Value.
MV	Medium Voltage.
MWh/yr	MegaWatt hours per year (thousands of kWh/yr).
NEBS	Network Equipment Building Standard.
OA	Outside Air.
OAT	Outside Air Temperature.
PDU	Power Distribution Unit.
PF	Power Factor. Ratio of kW to kVA.
PUE	Power Usage Effectiveness.
RA	Return Air.
RAT	Return Air Temperature.
RCI	Rack Cooling Index.
RCx	Re-, Retro-
RDHx	Rear Door Heat Exchanger.
RH	Relative Humidity.
RTI	Return Temperature Index.
SA	Supply Air.
SAT	Supply Air Temperature
SCOP	Sensible Coefficient of Performance.
SEER	Seasonal Energy Efficiency Ratio.
sf	Square Feet.
Support System	Cooling & humidity control, electric power chain, lighting – everything but the IT equipment itself.
T5, T8, T12	
TCO	Total Cost of Ownership.
TDV	Triple Duty Valve.
THD	Total Harmonic Distortion.
UPS	Uninterruptible Power Supply.

US DOE	US Department of Energy.
V	Volts.
VFD	Variable Frequency Drive. For operating motors at variable speed.
Virtualization	
VSD	Variable Speed Drive.
W/sf	Watts per square foot.
WSE	Water Side Economizer.

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