

**Finding ways to reduce energy consumption without affecting data center reliability is key. Some items are best 'built-in' to a new facility, while others apply equally well to new and existing facilities.**

Computer Data Centers use a lot of electricity in a small space, commonly ten times or more energy per SF compared to a regular office building. For facilities with both office and Data Center functions, it is not uncommon for a few percent of the building area to use the majority percent of the electricity. Most of the energy used in computer data centers is from the equipment itself, which is often beyond the control of energy improvement efforts. Still, the cooling and other 'house' systems serving these machines are substantial energy users and can usually be improved on.

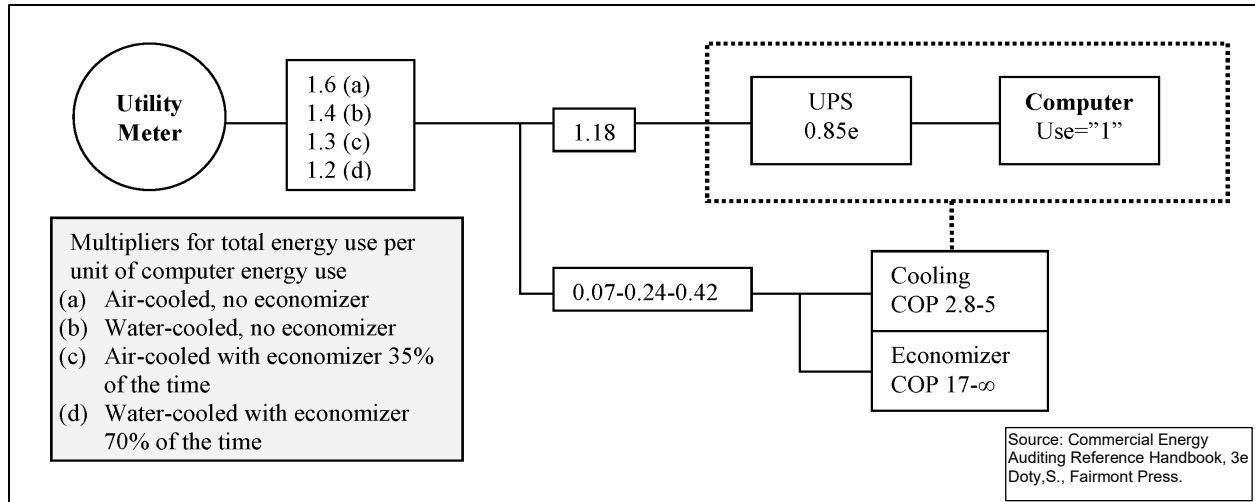


Please remember that the mission of any Data Center is to reliably process its work, so Energy Conservation Measures (ECM's) should only be considered if they do not impact system reliability.

### **Start with the computers themselves**

If the computer equipment efficiency and energy consumption can be affected, this should be the very first place to look for savings, since it dominates all other energy uses. Unfortunately, there is usually not much that can be done to reduce this load, and so the attention is focused on the remaining facility piece. While there are improvements that can, and should be made to the facility piece, the savings achieved may appear small compared to the total bill. For example, if a 10 percent improvement is made to the cooling system energy use through efficiency gains; this would only end up reducing the overall bill by 2-3 percent.

In data centers there is a 'food chain' of energy use, and at the top of the food chain is the computers themselves. The series-effect of how energy is used in a data center produces an amplifying effect that is shown in the diagram. *Each unit of energy reduction at the computer itself will yield 1.2 to 1.6 units of energy savings at the meter.* Because of the amplifying effect, the #1 thing to look at for energy reduction in a data center is the computers themselves.



**Amplifying Effect of Computer Energy Use through Data Center Ancillary Equipment**

Amplification factor varies by UPS efficiency, cooling efficiency, and economizer hours.

**IT power saving tips in a data center: Focusing on the top of the food chain**

**Virtual server technology**

Allows computer energy use to reduce when computing activity reduces. Unlike a household personal computer, data center servers are not good at ‘throttling’ energy use up and down as the computing work varies – a full vs. idling server use nearly the same amount of energy.

**Higher efficiency UPS equipment**

UPS units are essential for reliable power, but when arranged in pairs or arrays for redundancy the operating load on the units is low, which creates efficiency losses. *In applications where UPS load is 25% or less, UPS losses can equal the cooling energy for the computers*, and this loss is often overlooked. Some UPS units have higher efficiencies initially and hold onto their efficiency better at reduced load. So, definitely tune in to part load efficiencies for your UPS choices.

- Some UPS systems can be configured with supervisory controls that keeps some ‘hot spares’ available in a blink, thereby maintaining a higher load on the active UPSs, to avoid the high losses when a gang of them are operated collectively at very low load.

**Computers where the power use follows load**

A standard energy management theme is ‘load following’ where the input power goes up and down with the load. Traditional server equipment is designed to run continuously and is very good at it, although for many servers the power use is near constant even when actual computing work is light. Process and reliability always outweigh efficiency, but when choices exist for equal performance, a hardware attribute that allows good ‘turndown’ of power use at light load would be a fundamental improvement for data center utility expense where computing demands vary. The advent of solid-state drives may be instrumental in this change, but the most potent source of change will be customers requesting it.

**Computers that are tolerant of higher ambient temperatures**

Enabler for higher room temperatures and higher supply air temperatures, hot aisle design, etc.

**Computers that are tolerant of lower ambient relative humidity**

Enabler for reducing humidification loads, especially when operating at higher space temperatures.

### Non-cooling saving tips in a data center

**Measure it.** It is clear data centers use a lot of energy, but do you know how much? A basic enabler for energy management is measuring usage for significant unique loads. Consider measurement for total data center, IT power (UPS output), and water use.

**Lighting** directly adds to Data Center kW and cooling load. Each 3-4 watts of extra light becomes a watt of extra cooling energy, in addition to the lighting energy. So, using as little as you can, and using highest efficiency lighting to do it with, is the energy-saving answer. Occupancy sensors can be used to advantage for rarely occupied areas.

**Heating** should not be needed, since Data Centers are already full of ‘heaters’ and are a cooling-only load. As a general rule, picking your Computer Room Air Conditioners (CRAC units) and Computer Room Air Handlers (CRAH units) without heaters is appropriate. If your CRAC or CRAH (Computer Room Air Handlers) came with heaters – unless you think they are needed – disable the heaters by pulling the fuses to be sure they are never silently active.

**Humidification** should be limited to the Data Center, and not extended to the whole building. Remembering that humidification is expensive, try to keep it contained to the areas it’s really needed. Suggestions on this topic include an air lock vestibule, air barrier, and **vapor barrier** between adjacent spaces and exterior surfaces, all intended to keep the humidity “in.” For example a ceiling plenum connecting the Data Center to a general office area would add operating expense, since the moisture will freely migrate toward the dryer areas, causing increased run time and energy use from humidifiers.

- Note that elevating data center room temperatures while controlling to a *relative* humidity will increase the amount of moisture put into the air, underscoring the need for lower rH settings and compatible equipment, efficient humidifier equipment and a tight vapor barrier around the humidified area.

**Coordinating control for arrays of HVAC units so they don’t fight.** There may be local areas needing more cooling due to equipment density, which is fine, but any calls for heating or humidification should be monitored to avoid adjacent systems bucking each other. Using multiple units, each with their own “stand-alone” controls is a built-in opportunity for simultaneous heating / cooling and humidification / de-humidification, and should be avoided if possible. Control **re-calibration** each two years is advised.

### Cooling saving tips in a data center

**Cooling energy is a reflection** of the power used by the computer equipment.

For every 10 watts of computer power, you can expect 2-3 watts of refrigeration cooling power, and more if you count pumps and fans that go with it. In economizer mode, the mirror breaks, and cooling power is a fraction of computer **power**.

#### Cooling choices.

- New cooling systems can be air-cooled and water-cooled, with a variety of options. Water-cooled systems offer reduced summer demand and longer economizer hours but incur water costs. Determining which makes most sense from an operating cost standpoint depends on the relative cost of water compared to electricity. When electric cost is high and water cost is low, water-cooled wins every time. But when water cost is not low and electric cost is not

high, the electric savings are given to water costs and, in some cases can negate the added electric savings from water cooling.

Choose efficient equipment. This includes equipment with low power demands and high economizer potential. When choosing a cooling tower or evaporative cooler, opting for a generously sized body of 'fill' material reduces fan power and allows leaving water to be as cold as possible which, in turn, reaps savings from the refrigeration units or economizer modes it is serving. Sample performance specifications, for Colorado Springs:

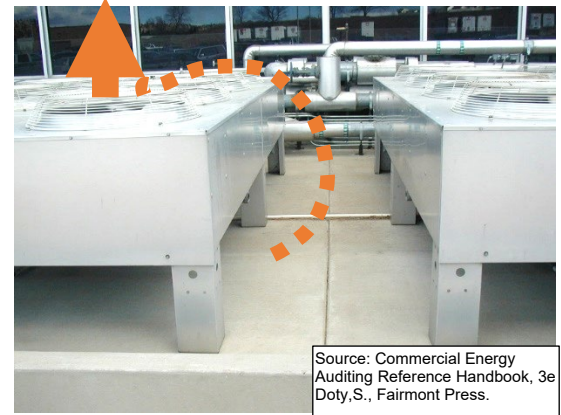
- Cooling tower: Full cooling capacity at 65F leaving water with 58F wet bulb temperature (7F approach), using only 0.05 kW/ton fan power.
- Fluid cooler: full cooling capacity at 68F leaving water with 58F wet bulb temperature (10F approach), using only 0.075 kW/ton power for fan and spray pump combined.

Of course, not everyone gets a 'new equipment choice'. Getting the most out of existing systems is also part of this paper.

### General cooling measures

- **Divide and conquer.** The Data Center HVAC systems will have advantages if fully separate from any adjacent system, such as the balance of a building it shares. This applies to both air and water systems. To the extent that the Data Center and other areas share mechanical systems, there will be an operational cost penalty. For example, a return air vent from another system will 'vacuum' the moisture out of the data center, causing humidifier run time to increase. Another example is chilled water shared with comfort cooling: here, the water temperature serving the data center will be colder than it needs to be, causing refrigeration efficiency penalty and unintentional dehumidification. So..... s-e-p-a-r-a-t-e them !
- **Hot spots.** When one particular area is hot, it can lead to operating with all supply air or chilled water service operating at a low temperature, increasing cost. Arranging computer equipment for average heat density will make it easier to cool.
- **Fan power.** Air-based systems circulate a great deal of air and operating fan horsepower can be high. You can ease this burden by using angled filter racks or 4-inch filters, allowing design air flow with a slower motor speed and reduced fan power. Annual coil cleaning and reducing cable congestion below the raised floor also helps control air resistance. Note that without a variable speed fan, reduced resistance increases air flow but does not reduce fan power.
- **Room to breathe.** Whether air-cooled or water-cooled, providing ample room around the outdoor heat rejection equipment prevents re-circulation of the hot leaving air back into the condenser air inlets. When re-entrainment occurs, the compressor work and energy cost will increase as if it were a hotter day outside.

Breathing hot air is bad for air-cooled equipment. Because the equipment is too close together, some of the hot air coming out the top is drawn in the bottom where only cool air should be. This makes the machine behave as though it were a hotter day than it really is. Spreading the equipment out prevents this.



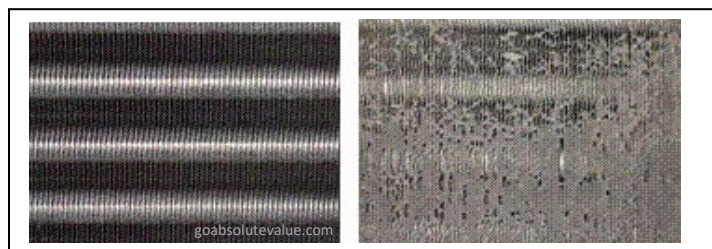
Source: Commercial Energy Auditing Reference Handbook, 3e Doty, S., Fairmont Press.

- Cold weather controls.** Where air-cooled refrigeration systems are used, they will include provisions to maintain head pressure in cold weather. Improperly adjusted, or if defective, these devices can be active in warm weather and rob system performance. Flooded condenser, condenser bypass valves, and other head pressure control methods should be dormant except in very cold weather. Likewise, cooling tower basin heaters can silently rob you of economizer savings if they are allowed to heat the water while the cooling tower works to cool it. Water-cooled CRAC units come with water regulating valves that reduce water flow when the water is too cold – if improperly adjusted, these can thwart energy saving measures from condenser water reset.



These are for cold winter operation, but are sometimes found active in warm weather, increasing energy use.

- Heat exchanger cleaning.** For all systems and all modes of operation, efficiency is promoted by maintaining all heat exchanger surfaces in a clean state. If an open cooling tower is used to provide cooling water, plan to inspect and clean the heat exchanger regularly; this includes water-cooled CRAC units. If allowed to 'foul' from cooling tower water, energy use will increase. Where fluid coolers are used (cooling tower with a heat exchanger built into it), these are very difficult to clean and assertive water treatment is the best prevention against fouling. Regular cleaning is suggested for indoor and outdoor air-coils for sustained as-new performance.



You decide which is more efficient

**Specific cooling measures**

- Hot aisle containment** 'concentrates' the data center heat at the outlet of the servers. Higher temperature means less air must be moved to convey it away, translating to less fan power; these savings are captured with variable speed drives. Hot aisle containment can be the enabler for other measures like warmer supply air temperature and warmer chilled water temperature for refrigeration cycle savings (1% per degree F). In turn, warmer supply air and chilled water temperatures allow more economizer hours with big compressor motors off. If done properly, this measure can amplify the benefits of other measures.



- **Dry cooler conversion.** Some systems use a “dry cooler” which is like a radiator in your car. The water leaving your car’s radiator is not “cool” at all, which is your clue. Simple to operate and suitable for economizer in very cold weather, a dry cooler creates high electric demand in summer. For closed systems, consider a fluid cooler (or cooling tower with plate heat exchanger) instead of a dry cooler, for cooler water and reduced power. Since they operate on ‘wet bulb’ instead of ‘dry bulb’ temperature, the improvements of this change can be significant in hot weather. For example, on a 90F day, a dry cooler may produce 110F cooling water temperature, where a fluid cooler could produce 70F cooling water temperature. This can reduce cooling power demand by 40% percent in hot weather. This requires comparing extra savings to extra water cost.
- **Liquid-cooled computers** are sometimes used when power density is very high. From an energy standpoint, there are advantages mostly from eliminating fan energy (no air, no fan). This design path is easily integrated with a chilled water economizer.
- **Indirect evaporative cooling** is the remote version of back-outlet heat exchanger. It uses the cooling effect of evaporating water through a heat exchanger and does not introduce moisture into the building. The approach temperature of the evaporative cooler and air heat exchanger becomes a limiting factor. Supplemental fan energy is needed to move the air through the heat exchanger. The cooling coil would be located at the air handler air inlet point. This has retrofit potential for CRAC units that do not have an economizer cycle.

For example, if it is 60F wet bulb outside, the fluid cooler (or cooling tower/heat exchanger combination) may produce 70F leaving water temperature, which is pumped to the indirect air-cooling coil. The coil may have a 5F approach temperature of its own, which means it could produce 75F air temperature....probably not enough to cool the computer. But with 65F supply air temperature and hot aisle containment with 95F rack outlet air, 2/3 of the heat load is removed and the conventional system can deal with the rest.

- **Back-outlet heat exchanger** cooling is a strap-on liquid cooling accessory to a standard air-cooled server rack. Performance and heat rejection options are similar to indirect evaporative cooling, except that the air handlers would not be used. Conventional cooling equipment backing up the evaporative cooling performance would normally be conventional water-cooled chillers and cooling towers with economizer cycle, although this could also be used as a supplement to a conventional CRAC system and to add economizer function.

**Table: Summary of Data Center Energy Savings Opportunities**

Source: Commercial Energy Auditing Reference Handbook, 3e Doty, S., Fairmont Press.

	Measure	New or Retrofit	Basis of Savings
<b>Common to most Systems</b>	Increase room temperature	Either	Reduced heat gain through envelope. Reduced refrigeration cycle lift and economizer hours when supply air temperature or chilled water supply temperature increases.
	Decrease room relative humidity	Either	Reduced humidity loss through envelope.
	Decrease unintended dehumidification	Either	Reduced moisture loss from the space.
	Increase chilled water temperature	Either	Reduced refrigeration lift, reduced unintentional dehumidification, increased economizer hours.
	Increase supply air temperature	Either	Reduced refrigeration lift (same condensing temperature, higher evaporating temperature), and increased economizer hours.
	Reduce chilled water flow	Either	Reduced pump energy.
	Reduce supply air flow	Either	Reduced fan energy.
	Separate data center HVAC systems from adjoining systems	Either	Reduced moisture loss from the space.
	Calibrate and coordinate cooling unit controls	Either	Reduced overlapping heating/cooling, overlapping humidification / dehumidification from control fighting.
	Clean heat exchanger surfaces	Either	Reduced approach temperatures and reduced refrigeration cycle lift; also extended economizer hours.
	Reduce ventilation	Either	Reduced humidification in winter.
	Verify correct operation of cold weather controls	Either	Reduced false loading energy in mild weather.
	Reduce lighting	Either	Reduced internal load which reduces cooling load.
	Envelope (glass and vapor barrier)	Either	Reduced envelope load in summer. Reduced humidification load in winter
Sub metering	Either	Early detection of dysfunction once baseline is established.	
<b>HVAC System Variations</b>	Hot aisle containment	Either	Reduced air flow from higher differential temperature felt by the cooling unit entering air, resulting in reduced fan energy. Increases benefits of other measures.
	Adiabatic humidifiers	Either	Using the heat of the data center to evaporate the water instead of a new source of heat.
	Dry cooler conversion to evaporative cooling	Retrofit	Reduced refrigeration lift, increased economizer hours.
	Direct air exchange economizer	Either	Cooling without ancillary energy related to heat exchangers. Increased economizer hours from no heat exchanger approach penalty.
	Liquid cooling	New	Reduced heat conveyance energy (pumping vs. fans).
	In-row cooling	New	Reduced fan power by eliminating friction loss of raised floor air plenum.
	Evaporative pre-cooling for air-cooled heat rejection	Either	Reduced refrigeration lift, and increased economizer hours.
	Indirect evaporative cooling supplement	Either	Pre-cooling with via evaporation reduces load on mechanical cooling. For systems without any economizer, this can create savings from compressor-off hours.
	Back outlet heat exchanger	Either	Eliminates or reduces load on air handlers and their fan energy. In drier climates, when coupled with hot aisle containment, heat removal can be achieved without any mechanical cooling at all.

## Economizers

Data centers always need cooling, even in cold weather, so they are excellent candidates for economizers of all types. Economizers provide low cost of operation by either allowing the compressor(s) to be off, or to operate at reduced capacity, saving energy. Not all data center cooling systems have an economizer cycle.

Unlike conventional air economizers, the data center is usually not operated with direct contact with the outside air – this is because the cold air, free as it is, is very dry and creates a very low relative humidity condition in the data center where sensitive equipment is. If data center humidification is by electric resistance or infrared, the humidification costs will negate cooling savings when economizing in very cold weather. But there are other economizers that work very well with data centers, depending on the type of cooling system you have.

Economizer benefits come from reduced load that results in cooling units that are either lightly loaded or off. When fully off, additional benefits come from avoided wear and tear, extending equipment life.

### Economizers for Air-Cooled Direct Expansion (DX) systems

Direct expansion means the refrigerant provides the cooling effect directly, with compressors located in each HVAC unit (vs. central chilled water). For standard DX computer room air conditioner (CRAC) systems, heat is rejected by a remote condenser outdoors; for these systems, there is no economizer system and their compressors run even when it is below zero outside.

Some newer designs of DX package CRAC units offer an economizer function that provide free cooling in cold weather, where the compressor turns off and a refrigerant pump turns on. In economizer mode (when it is very cold outside) liquid refrigerant is circulated in run-around coil fashion using a second coil indoors and using the condenser as a dry cooler. Compared to no economizer hours at all, this is a great improvement. However, free cooling hours are limited due to the addition effect of two liquid-to-air heat exchanger coils, meaning the system can only carry the full cooling load at very low outside temperatures. Cutoff values vary, but for 65F supply air, highest outside air temperature for free cooling might be 25F.

### Economizers for Water-Cooled DX systems

In its simplest form, these are the same as air-cooled DX but with a 'dry cooler' for heat rejection. Efficiency is good for these systems in cold weather, but summer energy use and demand is higher than standard air-cooled equipment due to the additional heat exchange step and the final rejection point still being outside air dry bulb temperature. For example, on a 100F day, a dry cooler will produce 120F water for 'cooling', so power requirements go up on hot days.

A fluid cooler can be used instead of a dry cooler, in which case power and energy use will be reduced according to wet bulb temperature being lower than dry bulb temperature.

An option available for water-cooled DX CRAC units using a dry cooler or fluid cooler is an economizer pre-cooling coil; it is possible to retrofit existing units with this feature as a kit but may be cost prohibitive. With this option, operation in hot summer weather is the same as any water-cooled DX unit. The economizing function becomes active when it is cold and dry enough outside to make very cold condenser water – when this happens, the colder water is passed through the supplemental pre-cooling coil which reduces the load on the main DX coil, allowing the compressor(s) to either unload (reduced power) or turn off. Typical sizing of the pre-cooling coil allows for about half of the capacity of the main coil.



### **Economizers for Air-Cooled Chilled Water System**

This design requires chilled water to be available at all times.

Economizer savings can be achieved by installing a dry cooler in parallel to the regular chiller, such that chilled water can be provided during very cold weather without the compressors.

### **Economizers for Water-Cooled Chilled Water System**

The cooling tower can be leveraged for economizing. Cooling towers cool by evaporating water, a process that works better the drier it is outside, and moisture content of air is low in cold winter weather. In cold dry weather, free chilled water can be had by *using the cooling tower in lieu of the chiller*. This system does require running the chiller plant pumps with the cooling tower, but not the chiller itself. Also, a heat exchanger is needed to keep the relatively dirty cooling tower water out of the chilled water system.

### **Economizer Savings**

Data centers are a very good place to apply and maximize a cooling economizer since the cooling load is year-round including winter. Without an economizer, it is normal to see large cooling equipment running in zero-degree weather. Obviously, we'd like to take advantage of as much free cooling from mother nature as we can.

Economizer savings are a combination of reduced power use, hours per year, and water cost (if any). Systems with economizer capacities to fully supplant (turn off) cooling equipment will offer greater savings than those that displace only a portion of it. Systems with auxiliary pumps, supplemental fan energy, or additional water use lose some of the cooling savings for these added items. Systems that use water evaporation for cooling have some of the savings given up to water cost and water treatment cost.

Economizer hours – the hours that free cooling savings are harvested - depend on where you live and what type of economizer you have. Water-cooled economizers follow “wet bulb” temperature, while air-cooled measures follow “dry bulb temperature”. An example is provided.

This example uses a chart on the following page. With data like this showing hours by temperature 'bins', 'hours the compressors can be off' can be found, which is a good indicator of savings potential. The example city is Colorado Springs, CO. Free cooling hours vary by city, and climate.

To find the approximate number of hours of economizer operation for an air-cooled option (dry bulb) and a wet bulb option (wet bulb), we must know the threshold number. Economizer hours per year are the total number of hours below the threshold number. The circled hours for the example city are based on a system that can cool the data center without compressors. This example presumes a design that will carry the data center load when the outside air *wet bulb* temperature is below 40F, or when the outside air *dry bulb* temperature is below 30F.

You may wonder what determines the threshold number and also why the 'dry bulb' economizer option requires a lower threshold than wet bulb threshold. Good questions!

Threshold begins with the end value of temperature needed for the cooling medium in the data center. Designs vary and details of equipment involved are left out for brevity:

- Water economizer: Presume 60F supply air temperature is needed to cool the computers, and this is done using 50F chilled water. Using a water-cooled design and typical heat exchanger values, this can be reasonably be accomplished whenever outside air wet bulb temperature is below 40F. We pick the hours for bins below 40F *wet bulb* (4377 hours, circled in red on the chart).
- Air economizer: Presume the same 60F supply air temperature and 50F chilled water values are needed; the difference is this water chiller is air-cooled instead of water-cooled. Using an air-cooled design and typical heat exchanger values, this can be accomplished whenever outside air *dry bulb* temperature is below 30F. We pick the hours for bins below 30F dry bulb (1451 hours, circled in red on the chart).

The other question was why the larger differential for air-cooled designs. Leaving out some background engineering details, the answer is rooted in the fact that water-cooled heat exchangers transfer heat more easily than air-cooled heat exchangers.

However, this leads us to a very important strategic message for customers when replacing major cooling equipment.

- **Through careful equipment selection and judicious maintenance, the differential temperatures needed to get the cooling job done can be reduced...with the reward of even greater hours of free cooling.** For our example, compare the basic design values of hours of free cooling to an alternate high performing design that reduces the differential by virtue of aggressive equipment selection (we call it the 'approach temperature') by 5 degrees. What this "5 degrees" does for you is move to another row, where the cooling load can now be met with outside air conditions of 45F wet bulb (970 extra hours) or 35F dry bulb (670 extra hours). Same load, same town, more hours of free cooling.
- This also points to the virtue of designs like 'hot aisle' where the supply air temperature is raised. This also increases free cooling hours. With just hot aisle and raising the supply temperature 5F, we will get the same extra hours as forcing the 5F with better equipment. So, what if you do both? Yep, they add.

Now look one more time at the chart to see the hours benefit of doing both - a 10F reduction in approach by equipment selection PLUS a 5F rise at the supply air end. In this wonderful scenario, the cooling load can be met with outside air conditions of 50F wet bulb or 40F dry bulb outside air. In the case of wet bulb economizer with water-cooled chiller, in the example city of Colorado Springs, this would allow the chillers to be fully off 6200 hours per year while cooling the data center.

### Hours Per Year Below Outside Dry Bulb and Wet Bulb Temperatures

Representative U.S. cities in defined climate zones

Climate zone convention: ASHRAE 90.1-2010, IECC-2009

Hours from TMY3 weather data, **8760 hour bins**

Source: Commercial Energy Auditing Reference Handbook, 3e Doty, S., Fairmont Press.



Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5B	6A	6B	7	8	
	Miami, Florida	Houston, Texas	Phoenix, Arizona	Memphis, Tennessee	El Paso, Texas	San Francisco, California	Baltimore, Maryland	Albuquerque, New Mexico	Salem, Oregon	Chicago, Illinois	Boise, Idaho	Colorado Springs, Colorado	Burlington, Vermont	Helena, Montana	Duluth, Minnesota	Fairbanks, Alaska	
Dry Bulb Hours Per Year	< 65F	934	3244	2997	4453	4410	7775	5721	5740	7222	6309	6718	6852	6995	7384	7710	8109
	< 60F	454	2294	2068	3472	3500	6136	4818	4773	6334	5461	5887	5917	6087	6636	6874	7441
	< 55F	178	1670	1338	2868	2741	3366	4097	4028	5076	4784	5031	5079	5382	5860	6101	6727
	< 50F	32	1100	668	2256	1912	1076	3284	3302	3685	4143	4139	4312	4702	5125	5407	6018
	< 45F	8	778	339	1716	1320	346	2701	2739	2577	3735	3414	3721	4189	4540	4898	5609
	< 40F	0	406	71	1154	756	56	2069	2018	1394	3140	2577	3000	3478	3785	4347	4634
	< 35F	0	139	0	678	267	0	1313	1133	554	2275	1581	2126	2709	2792	3681	4220
	< 30F	0	34	0	354	79	0	773	498	229	1516	811	1451	1997	1942	3018	4220
Wet Bulb Hours Per Year	< 65F	1819	4186	6838	5724	7931	8740	6696	8729	8570	7345	8717	8759	8066	8760	8447	8757
	< 60F	1149	3190	5600	4778	6350	8357	5903	7760	7850	6427	8364	8481	7253	8603	7812	8672
	< 55F	597	2419	4128	3932	5336	6252	5130	6418	6531	5591	7552	7357	6392	7916	6840	7998
	< 50F	296	1747	2777	3169	4470	2807	4369	5555	4825	4869	6276	6296	5551	6836	6037	7097
	< 45F	62	1111	1530	2351	3354	865	3562	4792	3143	4197	4840	5354	4729	5798	5416	6256
	< 40F	7	654	441	1701	2098	124	2797	3837	1634	3549	3629	4377	4075	4822	4784	5623
	< 35F	0	343	84	1070	1042	7	1943	2606	736	2923	2375	3378	3317	3763	4169	5064
	< 30F	0	93	4	634	396	0	1233	1343	298	2011	1266	2372	2603	2749	3461	4512

Circled values of hours correspond to the base scenario example on the prior page. Available hours of free cooling for a given locale depend upon 'how cold' the free cooling medium needs to be which, in turn varies based on cooling design, data center room temperature, equipment selection, and other factors. In Colorado Springs, a data center using chilled water and a cooling tower can see 4000-6000 hours of free cooling.

**Credits:**

Information for this paper was drawn from *Commercial Energy Auditing Reference Handbook*, 3e Doty, S., Fairmont Press.