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# White Paper #10

# Energy Efficiency in Computer Data Centers

**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.**

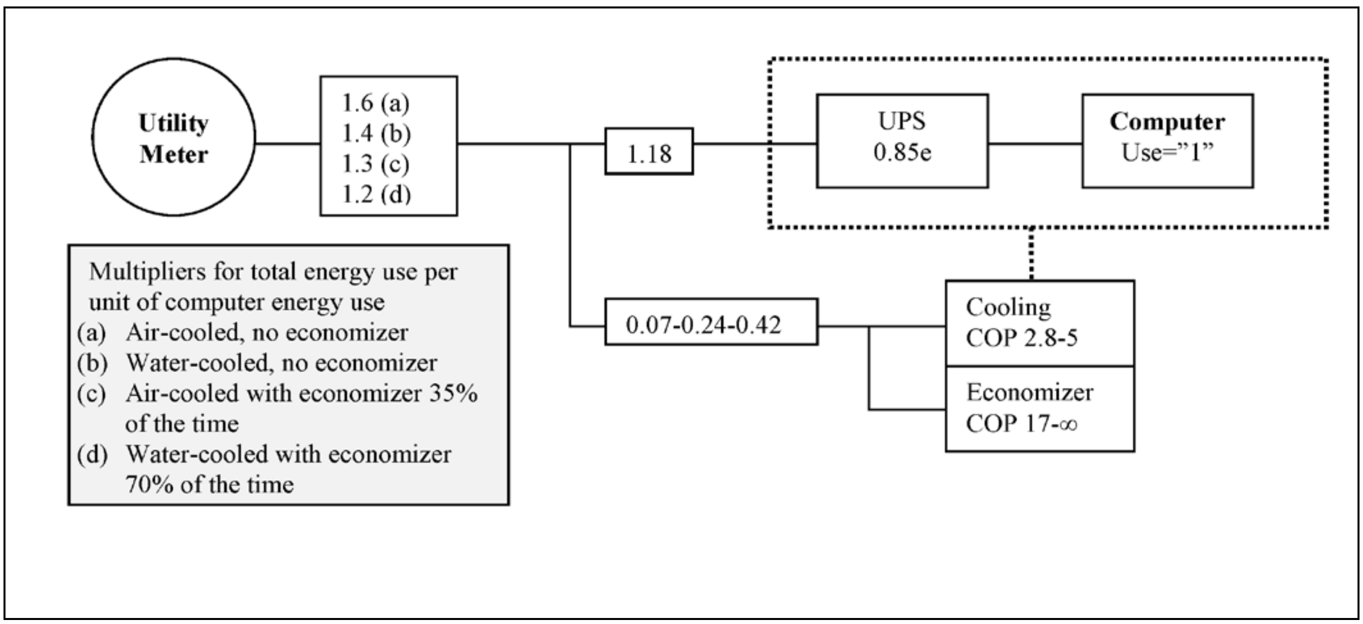
**Finding ways to reduce energy consumption without affecting data center reliability is key. Some items are best 'built-in' to a new facility, while others apply equally well to new and existing facilities.**

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. 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.

**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** is normally provided for Data Centers to reduce static and sparks, but try not to overdo it. Depending on the equipment manufacturer, 30 percent rH may be sufficient. Some humidification will probably be needed; if so, opt for evaporative humidifiers instead of traditional electric resistance or infrared humidifiers. Evaporative units, also called **adiabatic** humidifiers, use a tenth of the energy of their electrically driven counterparts and since they use the heat in the room to evaporate the water, they also provide some beneficial cooling.

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 efficient humidifier equipment and a tight vapor barrier around the humidified area.

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.

**Control coordination** for arrays of cooling units are proper when they behave as one. 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 energy is a fraction of this.

**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 65 degrees leaving water with 58 degree wet bulb temperature (7 degree approach), using only 0.06 kW/ton fan power.*
- Fluid cooler: *full cooling capacity at 68 degrees leaving water with 58 degree wet bulb temperature (10 degree 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.

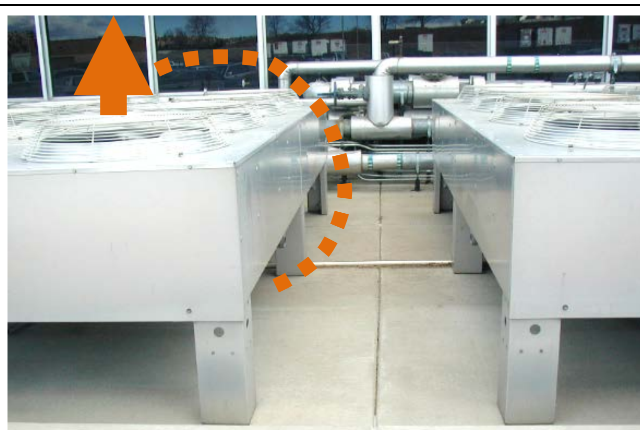
- **General cooling measures**

  **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. 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.

**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 towers with "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

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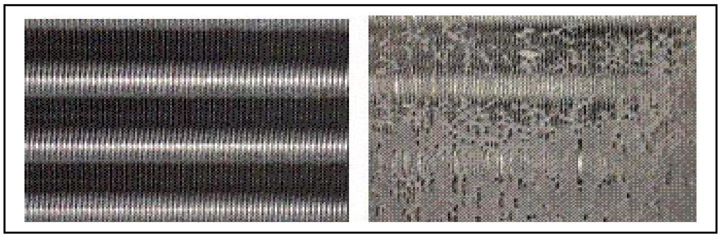
These are for cold winter operation, but are sometimes found active in warm weather, increasing energy use.

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.

**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 bub' instead of 'dry bulb' temperature, the improvements of this change can be significant in hot weather. For example, on a 90 degree day, a dry cooler may produce 110 degree cooling water temperature, where a fluid cooler could produce 70 degree 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.

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## Summary of Data Center Energy Savings Opportunities

| | Measure | New or Retrofit | Basis of Savings |
|---|---|---|---|
| **Common to most Systems** | 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. |
| | | | |
| **HVAC System Variations** | 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**
Unlike comfort cooling 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 can negate most of the 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.

Economizers for Air-Cooled Direct Expansion (DX) systems.
Direct expansion means the refrigerant provides the cooling effect directly. Traditional air-cooled DX systems do not use economizers at all, which means their compressors run even when it is below zero outside. Some newer designs incorporate an economizer function that provide free cooling in cold weather. The compressor turns off and a refrigerant pump circulates the liquid refrigerant in run-around coil fashion using a second coil indoors and using the condenser as a dry cooler.

Economizers for Water-Cooled DX systems.
In its simplest form, these are the same as air-cooled but with a dry cooler for heat rejection. Low temperature refrigerant control is simplified and only requires throttling of the cooling water when it is cold; however, summer energy use 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. 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 is with an economizer pre-cooling coil; it is possible to retrofit existing units with this feature as a kit, but may be cost prohibitive. In hot summer weather, the units will operate 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; depending on load, the compressor(s) respond by either unloading or turning 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
Installing a dry cooler in parallel to the regular chiller, it can be used for free cooling.

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 cooler and drier (mostly drier) it is outside. 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 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.

Economizer hours 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".

> For example, the chart below shows the number of hours of economizer operation, to compare an air-cooled option (dry bulb) and a wet bulb option (wet bulb). Economizer hours per year are the total number of hours below the threshold number. This example presumes 40F for each option.
>
> Bonus for this example: measures that increase supply air temperature or chilled water temperature increase the economizer hours directly. If 40F was the threshold number and now the supply air temperature can be increased 5F from hot aisle containment, the threshold number becomes 45F and the chart shows about 700 additional hours of free cooling for a dry bulb-based economizer and about 1000 additional hours of free cooling for a wet bulb-based economizer.

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## 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**

| | 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 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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 |

References:
Technical information for this paper from Commercial Energy Auditing Reference Handbook, Fairmont Press