technical BOOK

TECNAIR LV
CLOSE CONTROL AIR CONDITIONING

Side notes for designing air conditioning plants for **Data Centers**

Techline

Side notes for designing air conditioning plants for Data Centers

High energy efficiency and minimum environmental impact

Under many aspects, the current Data Center derive from the original CED, highly computerised environments, dedicated to housing high powered computers and related equipment.

The internal thermohygrometric conditions had to be accurately controlled within very restrictive limits in order to respond to the conditions required by the electronic equipment. Data available at that time were however limited and existing standards were also poor and insufficient.

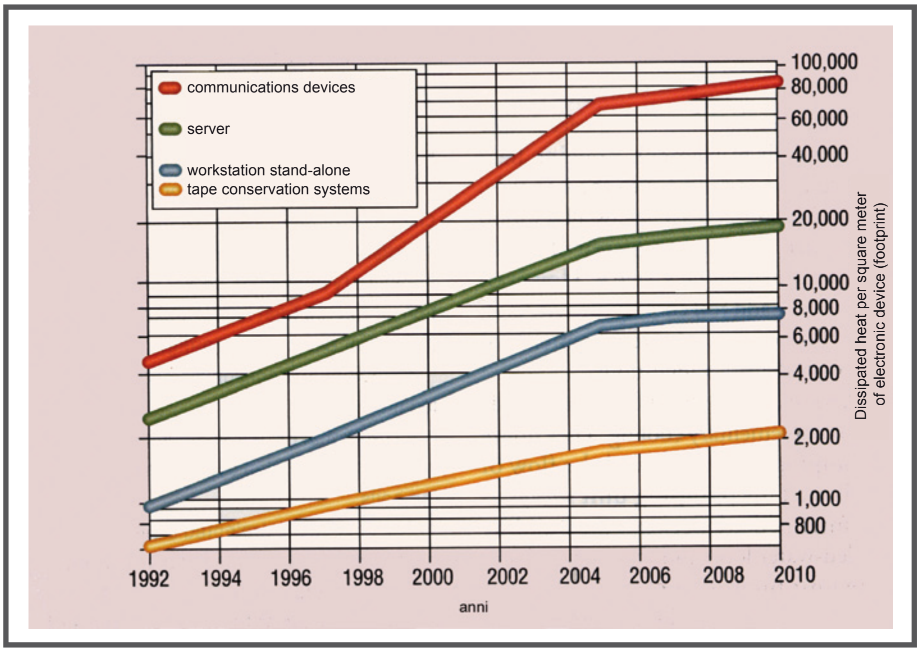


Figure 1 - Rate of the power installed on Information Technology equipment over time (ASHRAE).

Today modern Data Centers are structures that are first of all dedicated to holding high capacity servers and other Information Technology equipment.

In the mean time, the concentration of thermal loads in Data Center has reached extremely high levels: an individual rack of electronic equipment can concentrate a thermal power of up to 25 - 30 kW, as shown in **fig. 1.**

For this reason Data Centers and telephone exchange centres represent a true problem when designing cooling systems, both under the aspect of the most suitable choice, and as far as energy use and therefore their energy efficiency. As a matter of fact, the quantity of energy required by cooling systems can even approach 50% of the total quantity used by the Data Center, as shown in **fig. 2.**

Inside Data Centers, as is for all close control environments, they must not only keep thermohygrometric conditions that are capable of ensuring the best possible operational environment, but they must also guarantee absolute service continuity.

In order to respond to these fundamental requisites, specific standards have been developed recently, especially by ASHRAE.

Specific plant engineering has been developed that integrates with the actual layout of the racks containing electronic equipment to be cooled.

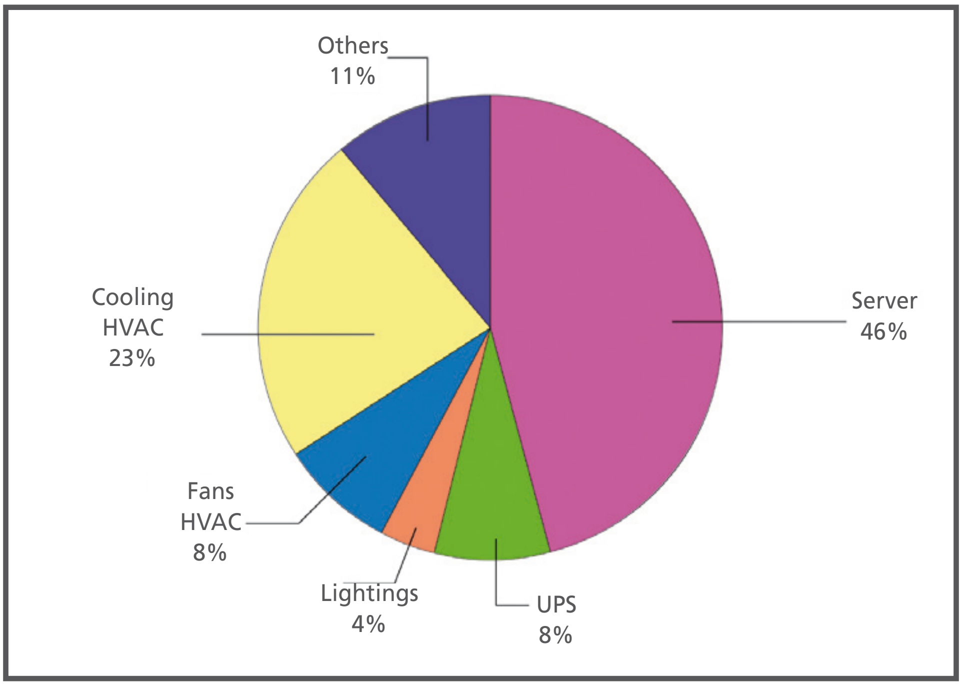


Figure 2 - Indicative subdivision of energy consumption on the part of different systems and equipment contained in a modern Data Center.

Recent standard and system engineering developments

Among the main standards, technological and system engineering developments that have occurred up till today, it is possible to include:

- **definition of specific environmental classes** and thermohygrometric conditions to be followed *(see below)*;
- **high temperature cooling systems,** compared to the past, in order to extend as much as possible the number of operation hours without intervention of the machine refrigeration compressors in a year. This has been achieved by developing various types of so called "free cooling" systems;
- **rack alignment according to "cold aisles" and "hot aisles".** For the first ones cooling air enters from the raised floor through specific square vents located at the feet of the rack, while for "hot aisles", this occurs on the back of the rack, sending hot air towards the air return of the cooling unit. See **fig. 3**;
- **equipping with fans inside of the rack** to keep the cooling air flow under control based on the actual load the rack is subject to during 24 hours;
- **"cold pool" or "hot pool" systems** made of overhead guards (usually transparent) installed above cold or hot aisles, in order to keep cold air from mixing with hot air and therefore increasing energy efficiency of the cooling equipment.

The characteristics of these systems are described in detail in the ***Air distribution*** chapter.

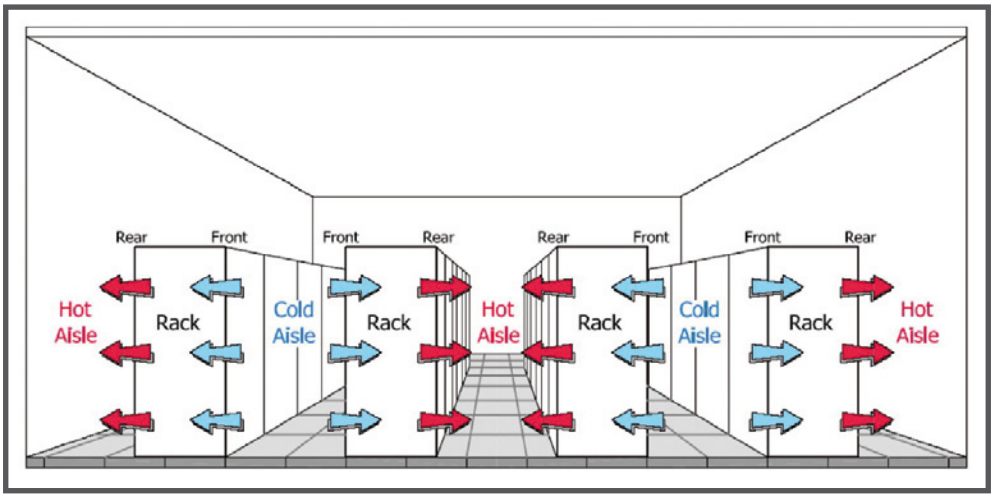


Figure 3 Representation of rack arrangement according to hot aisles and cold aisles in a Data Center.

The recommended thermohygrometric conditions

As mentioned above, recently ASHRAE has determined 4 environmental classes that refer to as many types of applications, where the reference thermohygrometric conditions have been defined for each one.

- **Class 1.** Data Centers with environmental parameters that are strictly controlled (dew point, temperature, R.H.) for critical operations. High capacity servers and analogue systems.
- **Class 2**. Spaces designated to information technology, offices, and laboratories with a certain amount of environmental parameters control that are the same as above. Small capacity servers, personal computers and workstations.
- **Class 3.** Offices, homes or movable or transportable environments with limited environmental parameter control only for temperature.
- **Class 4**. Point of sale or light industrial environments with winter heating and ventilation.

Only Classes 1 and 2 will be considered for this report, since they are the most critical one and are more pertinent to Tecnair LV production.
The thermohygrometric conditions for the first two environmental classes, those that specifically involve Data Centers and their auxiliary spaces, are outlined in the psychrometric chart contained in **figure 4**. Operational limits are also specified in **table 1**. This makes it possible to correctly establish plant characteristics and operational conditions necessary to regulate Data Center operability.

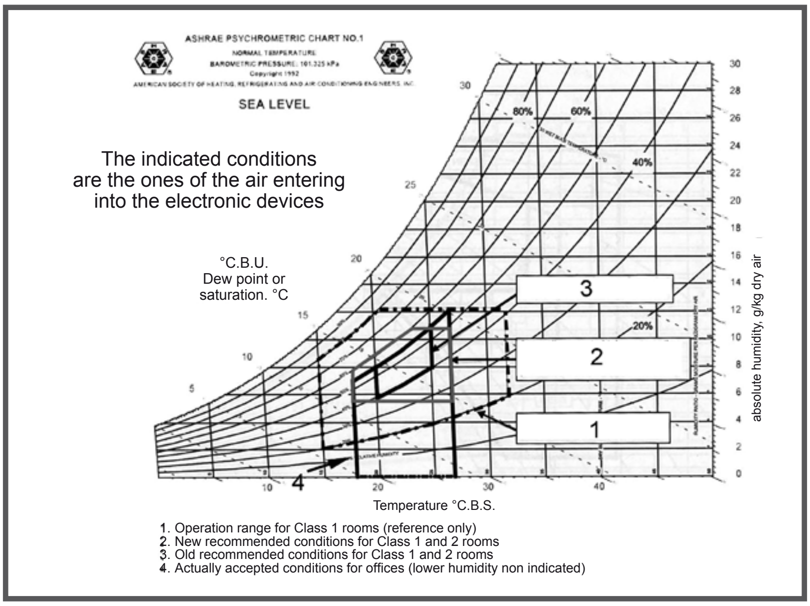


Figure 4 - Design conditions for environmental classes 1 and 2 according to ASHRAE regulations.

Table 1 Specifications and operational limits for environmental class 1 and 2 Data Centers

Environmental class	D.B. Temperature °C		Relative humidity % (absence of condensation)		Max dew point, °C
	Allowed	Recommended	Allowed	Recommended	
1	15 to 32	20 to 25	20 to 80	40 to 55	17
2	10 to 35	20 to 25	20 to 80	40 to 55	21

Source: ASHRAE

The design thermohygrometric conditions: risks for IT equipment.

There are various risk conditions for Information Technology (IT) equipment when subject to thermohygrometric conditions that are beyond the recommended limits.
It is especially relative air humidity, possibly when airborne corrosive substances are present, which creates the greatest risk.

Relative humidity

A high level of relative humidity influences the malfunction rate for electronic components. The cause of malfunctioning are especially related to anodic conductivity breakdown, malfunction caused by hygroscopic dust, magnetic memory errors, excessive wear and corrosion.
Even relative humidity that is too low may cause malfunctions because electronic devices are susceptible to damage resulting from electrostatic discharges, while tapes and magnetic media can be subject to an elevated number of errors in environments with relative humidity that is too low.

Relative humidity must therefore be kept between 40% and 55%. This is valid both in the summer and in the winter, since the influence of external air conditions (in unimportant quantities, not more than ½ volume hour, with the only purpose of maintaining environment over pressurised compared to the outside or surrounding rooms) and heat transmission through walls, are considered unimportant compared to the high level of endogenous heat generated by the servers. Basically all heat produced by the servers is of sensible type, therefore, potentially, there is no need for dehumidification, except for the Data Center cool down phase after building completion or any restructuring.
Cooling equipment could therefore be manufactured without condensation collection trays, without including discharge lines or at least without the usual hydrophilic paint for the cooling element fins that guarantee elimination of condensation drops dragging but significantly reduce their exchange and therefore machine performance.
This possibility is valid especially in dry climate areas such as many Countries in the Middle East. It deserves being explored due the economic savings that it allows for in plant installation.

The humidification function can also be useless; it remains related to treating primary air in the dedicated unit.
Relative humidity in a data center normally stabilises at around 40%.

Temperature

Even excessively elevated temperature conditions of the air supplied to the rack may cause malfunctioning: they put reliability and longevity of IT equipment at risk. As mentioned above, recent standards admit that the temperature is higher compared to what it was in the past. Currently, because of energy savings necessities, design tendencies are moving towards the allowed maximum temperatures; it is known that the higher the temperature maintained in the Data Center, the less energy the HVAC system consumes. This also favours the use of "free cooling" systems by extending their operational hours range.

A few years ago the tendency instead was to aim for lower temperatures to have more time to compensate for a breakdown of the air conditioning system; especially for peripheral telephone exchange centres, internal temperatures as low as 18°C were selected. Centralisation of users into great data centres equipped with internal assistance and maintenance and design redundancies currently in use: local network, remote managements, etc, minimise, or basically eliminate, the risk of an inhibiting breakdown and therefore make it possible to set internal temperature of 25-26°C.

The PUE and the DciE: the new parameters for evaluating efficiency of Data Centers

As a result of the significant energy consumption of Data Centers, two new parameters have been recently defined with the purpose of measuring their total energy efficiency. They are:

1. Power Usage Effectiveness (PUE) = ratio between total energy consumption of the structure and energy consumption of IT equipment. It should be less than 2, with optimal values that trend towards 1.
2. Data Centers Infrastructure Efficiency (DCiE) = ratio, multiplied by 100, between energy consumption of the equipment and total energy consumption of the structure. The resulting value is a percentage: the higher the number and the higher the yield

These parameters compare the quantity of electrical power that the Data Center uses to power and cool the structure with the quantity of energy used to power computer equipment.

The layout of racks and air conditioners

The characteristic that is common to the different Data Center layout solutions is the presence of a double floor that is normally pretty high: at least 600 mm. There are different solutions developed for positioning cooling equipment.

Perimeter positioning

This solution, adopted for the first Data Centers, aligns the air conditioners along the perimeter of the room, with the air discharge pointed downwards, with the racks and servers at the centre of it. The air is discharged through grilles in the double floor, while the air return is from the top. A representative diagram is shown in **figure 5**.

External positioning

Where possible, air conditioners are installed outside of the Data Center, normally behind it, in a hall, or an adjacent technical room, so that it is possible to discharge the air in the elevated floor of the room. This solution reduces the ambient sound pressure level and makes air conditioner maintenance easier. A negative effect of installing air conditioners outside of the server room, however, is that they are exposed to the danger of non authorised interventions. The temperature is adjusted thanks to a probe installed on the air return of the air conditioners.

"In row" positioning

Air conditioners are aligned in the middle of the racks. The air discharge is through grilles from under the floor. The advantage of this solution is that the space under the floor is not taken up as much by air passages and can be dedicated to electrical cable and other applications.
This solution however carries the risk of obstructing the air flow since there may be an uncontrolled presence of cables resulting from subsequent interventions.
For this solution there must be a double main switch to be able to stop the machine, in case of emergency, from no matter what side one is on compared to the row of racks.
Temperature is regulated thanks to probes installed on the air returns of the machines.

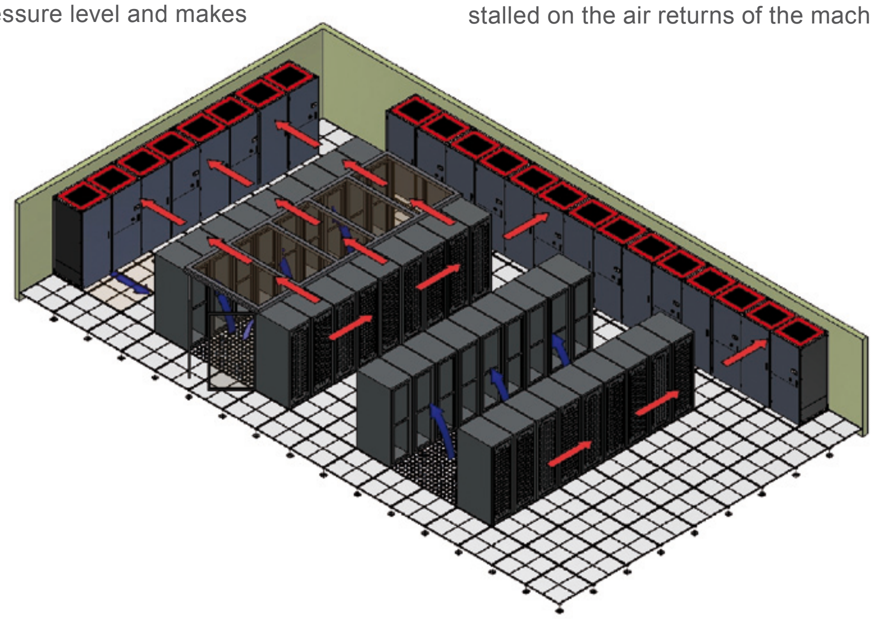


Figure 5 - Installation example of conditioners in the room, with downward air discharge and cold pool

Air distribution

From under the floor

It is the solution traditionally considered for data processing centres. Air comes out of the elevated floor through grilles that have been suitable placed near the servers and it is sucked up by them. Hot air then comes out of the top of the servers and returns to the conditioners.
It is the most simple and flexible solution, suitable for small or medium size Data Centers.
The inconvenience of this distribution model is that unavoidably cold air, that is not all sucked up by the servers, is mixed with the hot air coming from the servers and is therefore taken up by the conditioners. This causes a reduction in cooling and air processing efficiency of the air conditioners, unavoidably resulting in a greater consumption of electrical power.

With hot and cold aisles

In order to avoid the danger that treated air bypasses the servers, the current established tendency is to align the racks according to a hot and cold aisles configuration. (*See **figure 3***). In this way, pieces of equipment face each other with air inlets and the hot air discharge in the back.
The air supply is always from under the floor, but there is significant improvement compared to the previous solution. However, a portion of the cooled air is still taken by the air conditioners without passing through the rack.
Even in this case the temperature is adjusted thanks to a probe installed inside the machines.

Cold pool

This is the evolution of the "cold aisles - hot aisles" solution and it is the most functional one for eliminating air bypass and therefore suitable for higher powered servers. It basically consists in a delimitation of cold aisles by installing a top, usually transparent, above the rack and the walls, with access doors at the ends of the halls, as shown in **figure 6**. This way cold air is totally sucked up by the servers and there is no type of bypass, with a significant level of energy efficiency yield.
Even with this solution the temperature is regulated thanks to a probe installed inside the machine.

Hot pool

It is a variation of the "cold pool". Instead of the cold aisle, here hot air is compartmentalised. Server maintenance is normally carried out from the cold aisle therefore the hot one does not foresee the presence of operators and therefore the air conditioners suck out the hot air directly, at 35 or 40 °C, reaching very high efficiency levels.
Even in this case "in row" air conditioners installation guarantees the best performance.
The temperature is regulated thanks to a probe installed inside the air discharge section of the conditioner. The air discharge temperature set point is about 20 °C.

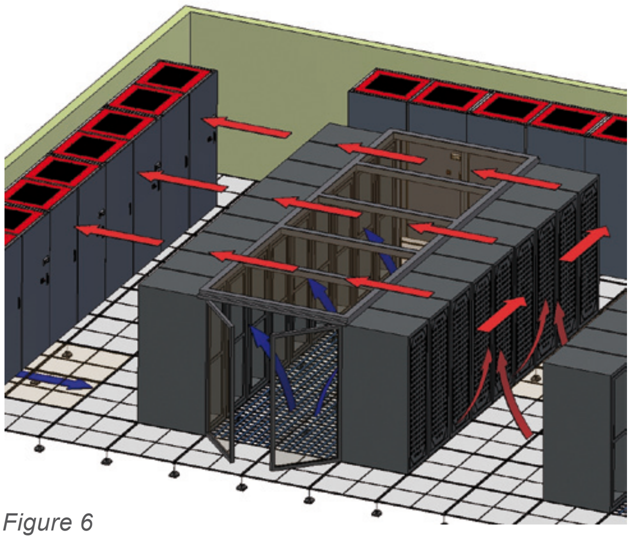


Figure 6

Chilled water or direct expansion?

Air conditioning systems for Data Centers can basically be of two kinds as far as production and distribution of cooling power:

- chilled water;
- direct expansion.

Both have specific functional and operational characteristics that the system designer must carefully evaluate.

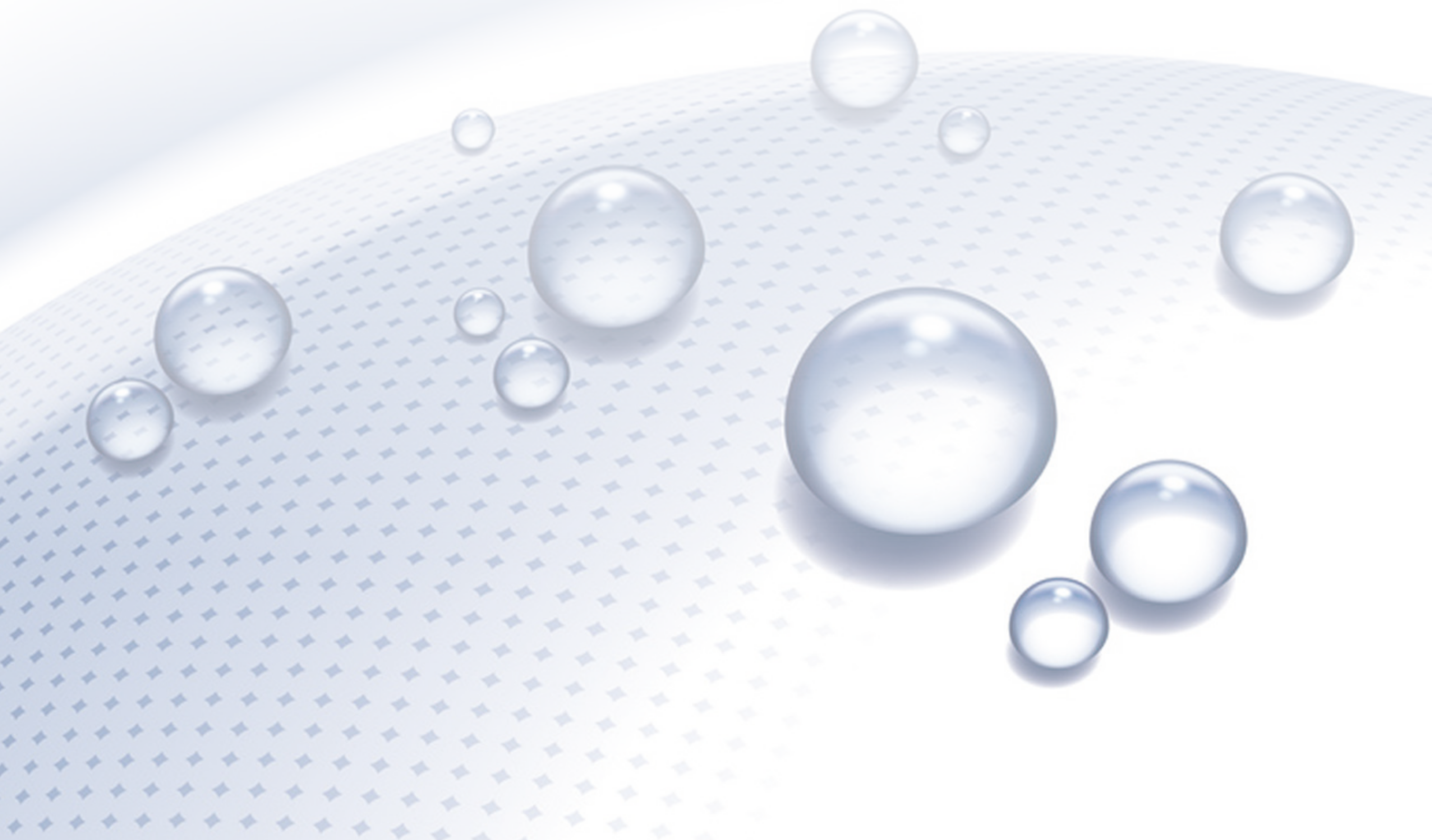
The advantages of the chilled water solution are:

- Better handling of the winter “free cooling”
- Cooling power modulation is proportionate to demand

The advantages of the direct expansion solution instead are:

- Greater energy efficiency – at equal conditions – since there is only one heat exchange: between the refrigerant and the air coming through the coil. Instead, in the chilled water solution, there are two heat exchanges: between the refrigerant and the water (in the water chiller) and between water and air in the air conditioning unit.
- Greater simplicity of the system and therefore of maintenance
- An elimination of risks related to the presence of water under the double floor.

In absence of binding regulations, the choice normally falls on chilled water systems for power requirements above 200 – 400 kW, and direct expansion for power requirements below this limit.



Operational safety

Direct expansion systems

- **Local network**
  It is necessary for machines selected for operation on a local network. In local network applications, one or more machines are assigned the “slave” function and the remaining ones take on the “master” role. The slave unit must intervene when there are emergency conditions in one of the other machines or when demand spikes exceed the design value. The “cascade” intervention function also offers a valid resource for energy savings in those rooms where the thermal load is not constant over time, activating the number of units that is actually necessary to guarantee thermohygrometric comfort for operators and equipment. The slave are also rotated at a user determined frequency (for instance, every 12 or 24 hours) and switched to master role to equalise the number of operating hours of regulations components.

- **Remote management**
  In remote management applications, machines can be controlled from remote locations through supervision systems (BMS) thanks to serial communication using supervision software, or through Gateway (BacNet – Lonworks).

Chilled water systems

- **Local network**
  Even in this case, though there is no risk of a machine block resulting from a malfunction of the frigorific circuit, typical of direct expansion units, it is necessary for the air conditioners to work on a local network to guarantee the necessary redundancy.

- **Remote management**
  In remote management applications, machines can be controlled from remote locations through supervision systems (BMS) thanks to serial communication using a supervision software, or through Gateway (BacNet – Lonworks), as was explained above for direct expansion systems.

- **Chilled water circuit**
  The double hydraulic circuit is recommended for systems of greater importance, obviously with double pumps and redundancy also for the chiller. In this case it is pre-set for “two sources” system conditioners, so that it can be connected to the two hydraulic circuits.

- **Danger of water under the floor**
  As was already mentioned, this is a danger that must be carefully evaluated. It is therefore necessary to plan for containment pools under the air conditioners and connected to a suitable drain. There must also be water presence sensors to be installed in critical points, with the task of using a motorised valve to intercept the circuit and interrupt the chilled water flow. Another interesting possibility, though it has some aesthetic disadvantages, is to transit the chilled water piping close to the room ceiling, in a position that is well visible, so that even the beginning of a leak can be immediately detected.

Energy savings

Chilled water systems

- **Variation of cooling capacity of chilled water units**
  In medium-large chilled water systems, the continual variation of cooling power coming from the air conditioners can offer additional energy savings contributions. For this purpose Tecnair LV offers accessories such as particular modulating valves that replace the floating ones. They allow for greater precision adjustments with a faster response time. Based on the type of hydraulic circuit, the valves can be two or three-way.

- **An increase in energy efficiency of the air processing section**
  The increase in total energy efficiency can be obtained using special EC (Electronically Commutated) electronic fans. These fans are the newest and most important innovation in energy savings for the ventilation sector. These are basically “Plug Fan” ventilators coupled with an external rotor direct current brushless motor. These motors are generally 30% more efficient than normal alternating current asynchronous motors. They also allow for continual speed variation based on the control signal coming from the machine microprocessor (0-10 V), without the need for Inverter or other electronic devices. The Plug-Fan ventilators are also known for the various advantages they offer compared to the centrifugal fans normally used in air conditioning units. The combination between EC motors and Plug-Fan therefore offers significant advantages: functional, energy efficiency, noiselessness and absence of vibrations during operation and less current is absorbed at start-up *(soft start)*.

- **Variable air flow depending on the cooling capacity required by the system.**
  This is the classic situation for VAV (Variable Air Volume) systems, which respond to a demand increase through a proportional increase in air capacity. It is known that this type of system offers interesting energy advantages for partial loads that occur extensively throughout the year. The VAV system requires a setting for modulating chilling power adjustment.

Direct expansion systems

Even for direct expansion systems, an increase in energy efficiency for the air processing section can be obtained using special EC (Electronically Commutated) fans in combination with Plug Fan ventilators, as was mentioned above.

Free cooling air-water: using renewable energy sources

This system uses external air - a renewable energy source - instead or in addition to mechanical cooling; it is made of a separate cold water coil, with a three-way modulating valve that is controlled by the microprocessor. Therefore, three different operation speeds are possible:

- Only free cooling, when the temperature of the external air is sufficiently low to bring the temperature of the water circulating in the coil to a value that corresponds to the cooling request in the Data Center or, more in general, the space that is to be cooled. This is the maximum energy savings solution as the compressors are constantly excluded from operation.
- Free Cooling + mechanical cooling. If the temperature of the external air is higher than necessary, to keep the water cooled at the desired temperature, the compressor/s are activated solely for the time required for the desired conditions to be reached. This is also an energy saving solution, however, not as optimal as the previous one.
- Only mechanical cooling without free cooling. This occurs when the temperature of the external air is too high to produce sufficient cooling. In this case, the machine activates the normal operation of the compressors. This still provides high energy efficiency of the cooling circuits and the compressors. Therefore, compared to other systems, even mechanical cooling limits energy consumption.

Water ring circuits

The characteristics of these circuits positively respond to requirements of Data Centers, especially because they offer the necessary reliability for service continuity, even when extensive maintenance on the piping circuits is necessary, without stopping the system. Besides, they make it possible to establish the position of IT equipment according to the desired Data Center plan.
Regarding this, attachments for feeding the equipment cooling systems can be made in different points, therefore offering significant flexibility. Another important characteristic consists in the fact that the water flow direction can be in two different directions coming from the source and, in theory, at approximately the half point of the circuit, a "flow absence" area is created. When needing to carry out Data Center maintenance or implementations, the air conditioners downstream of the isolated section can be fed from the remaining portion of the circuit by inverting the flow direction.
Water ring circuits offer different solutions that make it possible to achieve a greater or lesser number of sectioning levels and modes.
A basic reference circuit is illustrated in **figure 9** and only includes one connection to the water chiller. This is a self-balancing system and it allows service continuity, even when sectioning the main lines for maintenance or for adding new IT equipment over time.
It represents one of the most functional solutions when the air conditioners are arranged along the room perimeter. This functionality is confirmed, even when the machines are arranged perpendicularly to the collector tubes.

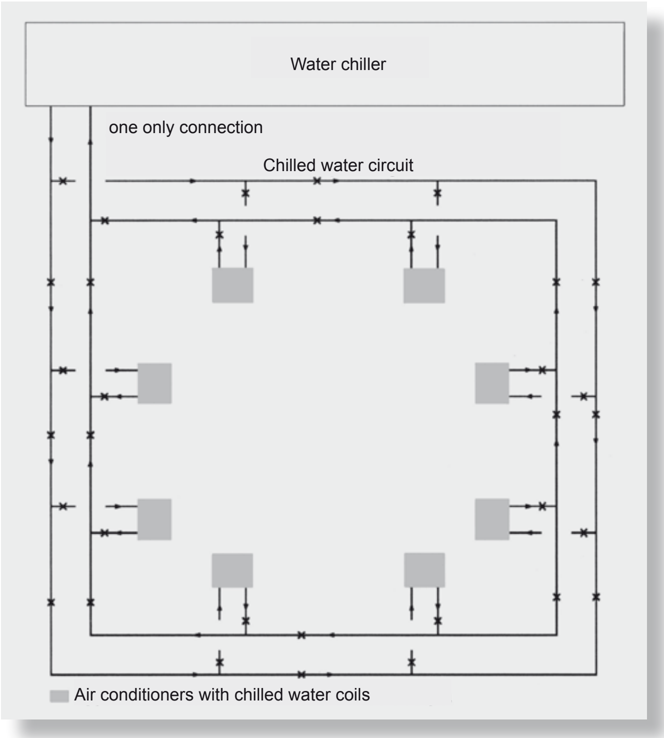


Figure 9 - Fundamental diagram of a simple water ring system. The conditioners are aligned along the walls (ASHRAE)

Figure 10 contains an illustration of a version with greater functionality compared to the previous circuit. It makes it possible to distribute the equipment along the entire surface of the room and its specificity is in the transversal branches that allow indirect feeding of usages compared to the main ring, behaving like common pipes, for both the water supply and the return. The system also allows for a two-directional water flow not only in the main circuit of the ring, but even through the same common pipes.

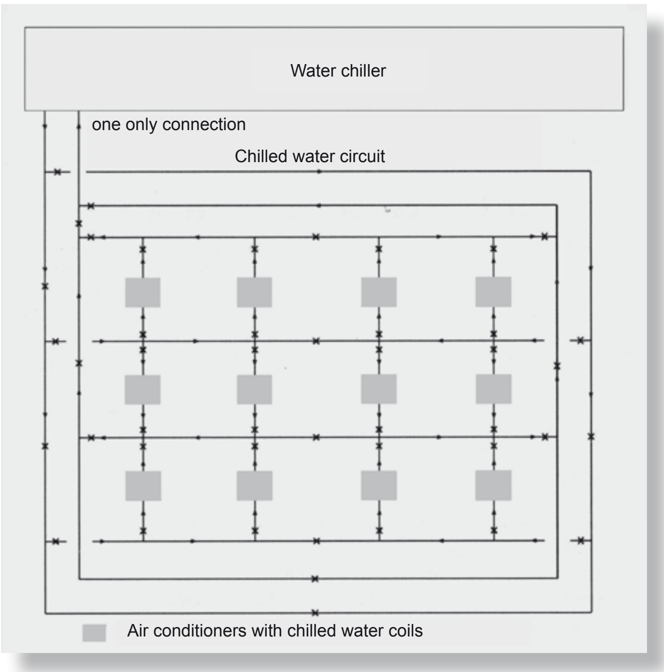


Figure 10 - Further evolution of a ring circuit where the conditioners are distributed along the entire room surface (ASHRAE).

An even more advance variation of this circuit is illustrated in **figure 11**. It incorporates a double supply from two different points. This is not all; they also may be two completely different systems, completely independent from each other, that supply chilled water to the ring. This circuit therefore offers a higher level of reliability compared to the previous one, a redundancy that can double, keeping the above mentioned advantages and the self-balancing characteristic. It must however be recognised that this circuit has greater cost and complexity compared to the previous ones.

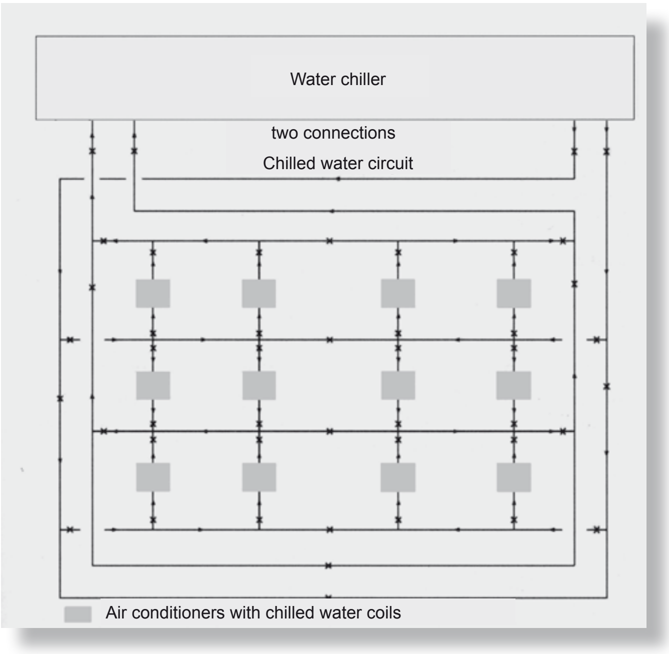


Figure 11 Ring circuit with double supply of the hydraulic circuit that can also be achieved through two different systems. It offers greater reliability compared to the previous ones and redundancy that can even be double, maintaining the self-balancing characteristic.

Handling energy efficiency in the Data Centers

The choice of water chillers and air conditioners for Data Centers is usually made with reference to operational standards, often without considering the fact that even small variations can produce sensible energy savings and increases in power yield. It is sufficient to say, for example, that for a 0,6°C increase of evaporating temperature a frigorific circuit increases energy efficiency by 1% to 3%, even without considering a possible free cooling system.
An additional characteristic is the temperature difference between the infeed and outfeed of the chilled water from the evaporator: efficiency basically remains constant between 5.5° and 11°C. This may cause the temperature differential to increase, so that a lesser water capacity is moved and there is a savings on the amount of energy absorbed by the pump.

An insufficient air flow to the condensing coil may penalise energy efficiency of the machine. Currently the design condensation temperature (10° C for tropical climate environments) is 14 – 15°C more than the external air temperature. If however, due to restrictions on the airways, the air flow is reduced compared to the design value (at equal external temperature levels); it produces an increase in condensation temperature that has two negative effects:

- a decrease in cooling capacity of the water chiller, and
- a decrease in energy consumption, even if in a lesser amount than the previous one

It therefore produces a total decrease in energy efficiency. The same phenomenon occurs for partial recirculation between air expelled and entering the coil.
The partial load operational conditions, in particular, offer the most interesting energy savings opportunities, but also the greatest waste. Scroll compressors respond to partial load conditions by starting/stopping or through a speed variation by way of Inverter. In various rotary screw compressors, instead it is the slide valve action that modulates the cooling capacity. The result obtained is a proportional variation of cooling capacity yield and a decrease in electric power absorbed. One of the advantages of scroll compressors with inverter is that they can operate for short periods with a frequency above 50 Hz; this way they can supply a greater cooling capacity that is able to better control any load peaks or bring the environment up to temperature more quickly.

Machine installation in a way that does not penalise energy efficiency

An incorrect installation of chilling equipment and condensing units may also penalise performance, negating any steps taken by the manufacturer to increase energy efficiency.
The installation remains mostly to the discretion of the installer, often unprepared when it comes to choosing the best conditions for favouring and not penalising energy efficiency.
All air condensed machines require suitable free space for collecting and discharging cooling air from the condensers. Tight spaces, obstacles to the air flow, etc. may have two negative effects:

- insufficient air capacity for cooling the condenser foreseen in the design phase, with the above mentioned consequences, and
- air recirculation of expelled hot air towards the coils, achieving insufficient cooling, with the same consequences.

In medium and large installations, the number of external air condensers can be great, while the available space may be insufficient for them to be installed correctly, with the risk of subsequent malfunctioning or capacity reductions and an increase in energy consumption.
For cooling units, condensing units and air condensers, a distance of 1000 to 1500 mm between the coils and the closest solid walls is usually recommended. The upwards discharge requires it to be completely without obstacles for a height of at least 1800 mm from the upper edge of the fan exhaust.
When cooling unit power is between 400 and 1000 kW, the distance between the two parallel units should be at least 3 metres. Each one of the two facing circuits would lose 0.5% of cooling power with a 1% increase in electric power absorbed, a tolerable penalization in most cases. If the distance is less, performance may decrease substantially, as shown in table 2.

Table 2 - Lowering of cooling yield and increase in absorbed power based on the distance between two air condensed machines installed in parallel

Distance between the two machines, m	Yield lowering of the circuit across from the opposing machine, %	Increase in absorbed power of the circuit across from the opposing machine, %
3,5	0	0
3	0,5	1
2,5	1	2
2	1,5	3

Not following minimum distances between coils and obstacles to the air flow and between discharge fans and any covers, indicated by the manufacturer, is one of the cases where yield and machine energy efficiency is penalised.
Energy efficiency of external units is also influenced by the coil surface that air passes through. Progressive clogging over time, caused by contaminants and airborne substances, causes a progressive reduction in the useful surface and a constant condensation temperature increase, resulting in the above mentioned consequences.

Conclusions

The design of modern Data Centers, also in relation to containing energy consumption, requires a total approach that considers all aspects that influence performances, from the expected operating conditions, up to the choice of installation spaces for water chillers and condensing units.

There is no doubt that these structures are among the most complex and, for large installations, require a multidisciplinary approach that integrates all involved parts: system designer, machine manufacturer, energy manager, manufacturer of control and monitoring systems (BMS) and the installer.

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