CHAPTER 17

DATA PROCESSING AND ELECTRONIC OFFICE AREAS

DATACOM (data processing and telecommunications) facilities are predominantly occupied by computers, networking equipment, electronic equipment, and peripherals. The most defining HVAC characteristic of data and communications equipment centers is the potential for exceptionally high sensible heat loads (often orders of magnitude greater than a typical office building). In addition, the equipment installed in these facilities typically:

- Serves mission-critical applications (i.e., continuous operation)
- Has special environmental requirements (temperature, humidity, and cleanliness)
- Has the potential for disruptive overheating and equipment failure caused by loss of cooling

Design of any datacom facility should also address the fact that most datacom equipment will be replaced at least once with more current technology during the life of the facility. As described in *Datacom Equipment Power Trends and Cooling Applications* (ASHRAE 2005a), typical datacom equipment product cycles are 1 to 5 years, whereas facilities and infrastructure have life cycles of 10 to 25 years. Replacement equipment has historically required more demanding power and cooling requirements.

Understanding these critical parameters is essential to datacom facility design.

DESIGN CRITERIA

Types of datacom (ASHRAE 2005a) equipment that require air conditioning to maintain proper environmental conditions include

- Compute servers (2U and greater)
- Compute servers (1U, blade, and custom)
- Communication (High-density)
- Communication (Extreme-density)
- Tape storage
- Storage servers
- Workstations (standalone)
- Other rack- and cabinet-mounted equipment

Personnel also occupy datacom facilities, but their occupancy is typically transient and environmental conditions are more typically dictated by equipment needs. However, human occupancy in smaller datacom facilities may influence the ventilation air quantity.

Overview

Environmental requirements of datacom equipment vary depending on the type of equipment and/or manufacturer. However, a consortium of manufacturers has agreed on a set of four standardized conditions (Classes 1 to 4), listed in *Thermal Guidelines for Data Processing Environments* (ASHRAE 2004). A fifth classification, the Network Equipment—Building Systems (NEBS) class, is typically used in telecommunications.

- **Class 1:** typically a datacom facility with tightly controlled environmental parameters (dew point, temperature, and relative humidity) and mission-critical operations; types of products typically designed for this environment are enterprise servers and storage products.
- **Class 2:** typically a datacom space or office or lab environment with some control of environmental parameters (dew point, temperature, and relative humidity); types of products typically designed for this environment are small servers, storage products, personal computers, and workstations.
- **Class 3:** typically an office, home, or transportable environment with little control of environmental parameters (temperature only); types of products typically designed for this environment are personal computers, workstations, laptops, and printers.
- **Class 4:** typically a point-of-sale or light industrial or factory environment with weather protection, sufficient winter heating, and ventilation; types of products typically designed for this environment are point-of-sale equipment, industrial controllers, or computers and handheld electronics such as PDAs.
- **NEBS:** per *Telcordia* (2001, 2002), and typically a telecommunications central office with some control of environmental parameters (dew point, temperature and relative humidity); types of products typically designed for this environment are switches, transport equipment, and routers.

Because Class 3 and 4 environments are not designed primarily for datacom equipment, they are not covered further in this chapter; refer to ASHRAE's (2004) *Thermal Guidelines for Data Center Environments* for further information.

Environmental Specifications

Table 1 lists recommended and allowable conditions for Class 1, Class 2, and NEBS environments, as defined by the footnoted sources. Figure 1A shows recommended temperature and humidity conditions for these classes on a psychrometric chart, and Figure 1B shows allowable temperature and humidity conditions. Note that dew-point temperature and relative humidity are also specified.

Air density also affects the ability of datacom equipment to be adequately cooled. ASHRAE's (2004) *Thermal Guidelines for Data Processing Environments* suggests that data center products be designed to operate up to 10,000 ft altitude, but recognizes that there is reduced mass flow and convective heat transfer associated with lower air density at higher elevations. To account for this effect, the guideline includes a derating chart for the maximum allowable temperature of 1°F per 550 ft altitude above 2950 ft (Classes 1 to 4). Figure 2 shows the altitude derating recommended by ASHRAE (2004) for Classes 1 and 2, and for NEBS.

The stated environmental conditions are as measured at the inlet to the data and communications equipment, and not average space or return air conditions.

The preparation of this chapter is assigned to TC 9.9, Mission Critical Facilities, Technology Spaces, and Electronic Equipment.

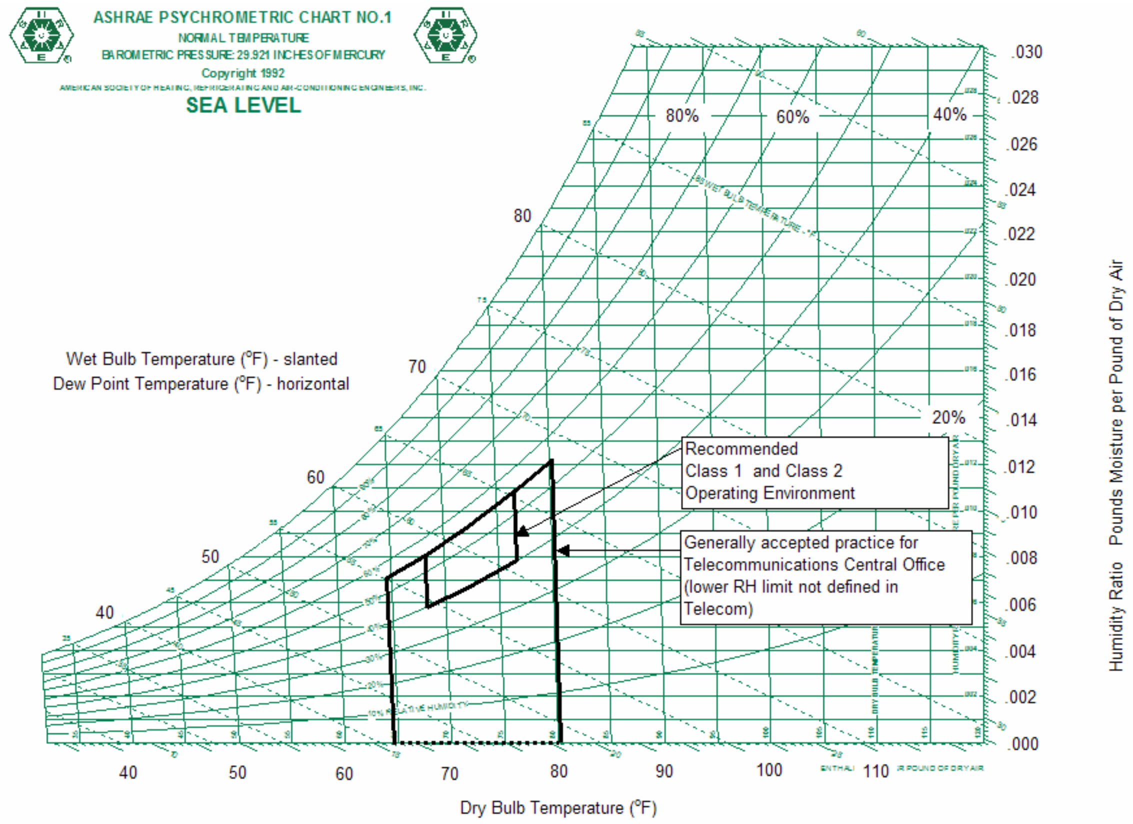


Fig. 1A Recommended Data Center Class 1, Class 2, and NEBS Operating Conditions

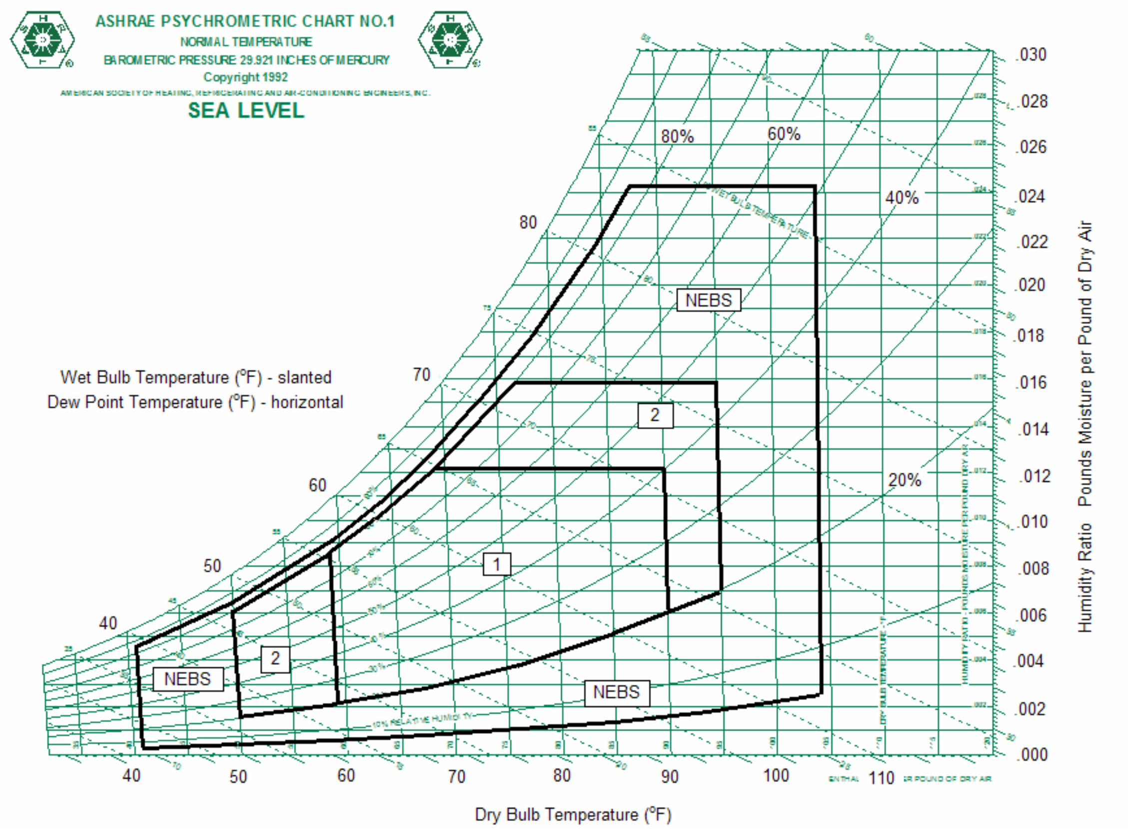


Fig. 1B Recommended Data Center Class 1, Class 2, and NEBS Operating Conditions

Table 1 Class 1, Class 2, and Selected NEBS Design Conditions

	Classes 1 and 2		NEBS	
Condition	**Allowable Level**	**Recommended Level**	**Allowable Level**	**Recommended Level**
Temperature control range	59 to 90°F[a,f] (Class 1) 50 to 95°F[a,f] (Class 2)	68 to 77°F[a]	41 to 104°F[c,f]	65 to 80°F[d]
Maximum temperature rate of change	9°F/h[a]		54°F/h[a,c] 173°F/h[a,d]	
Relative humidity control range	20 to 80%, 3°F max. dew point[a] (Class 1) 70°F max. dew point[a] (Class 2)[e]	40 to 55%[a]	5 to 85%, 82°F max. dew point[c]	Max 55%
Filtration quality	65%, min. 30% (MERV 11, min. MERV 8)[b]			Min. 85% (Min. MERV 13)[b]

[a] Inlet conditions recommended in ASHRAE (2004).

[b] Percentage values per ASHRAE *Standard* 52.1 dust-spot efficiency test. MERV values per ASHRAE *Standard* 52.2.

[c] *Telcordia* (2002).

[d] *Telcordia* (2001).

[e] Generally accepted telecommunications practice. Telecommunications central offices are not generally humidified, but personnel are often grounded to reduce electrostatic discharge (ESD).

[f] See Figure 2 for temperature derating with altitude.

[g] *Telcordia* recommendation.

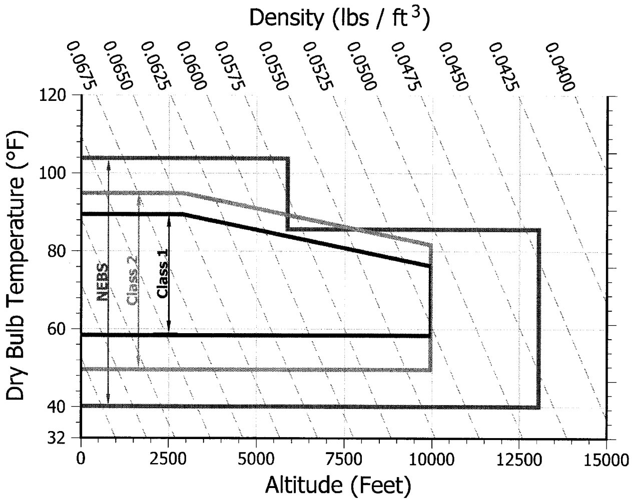


Fig. 2 Class 1, Class 2, and NEBS Allowable Temperature Range Versus Altitude

Temperature

Equipment exposed to prolonged high temperature, or to high temperature gradients, can experience thermal shutdown. Required inlet air conditions to datacom equipment should be checked for all equipment, but a typical recommended range is 68 to 77°F. For telecommunications central offices and NEBS, the ranges are wider (see Table 1). The recommended range for telecommunication and central offices is 65 to 80°F (*Telcordia* 2001).

Operation in the allowable range should usually be considered acceptable for short periods of time. However, facility designers and operators should strive for continuous operation in the recommended range.

Not only is air temperature into the electronics critical for reliable operation of components in the electronic box, but the air discharged from the electronics and flowing over the components (cabling, connectors, etc.) at the exit must also be addressed.

Temperature Rate of Change

Some datacom manufacturers have established criteria for allowable rates of environmental change to prevent shock to the data and communications equipment. These criteria need to be reviewed for all installed datacom equipment. A maximum inlet temperature change of 9°F/h is recommended by ASHRAE (2004a) for Classes 1 and 2. Humidity rate of change is typically most important for tape and storage products. Typical requirements for tape are a rate of change of less than 3.5°F/h and a relative humidity change of less than 5%/h (ASHRAE 2004).

In telecommunications central offices, the NEBS requirement per *Telcordia* (2001) for testing new equipment is a rate change of 54°F/h. However, in the event of an air-conditioning failure, the rate of temperature change can easily be significantly higher. Consequently, *Telcordia* (2001) recommends additional equipment testing with a gradient of 173°F/h for 15 min. Manufacturers' requirements should be reviewed and fulfilled to ensure that the system functions properly during normal operation and during start-up and shutdown.

Procedures must be in place for response to an event that shuts down critical cooling systems while critical loads continue to operate, causing the space temperature to begin rising immediately. Procedures should also be in place governing how quickly elevated space temperatures can be returned to normal to avoid thermal shock damage.

Datacom equipment usually tolerates a somewhat wider range of environmental conditions when not in use (see Table 2.1 in ASHRAE, 2004). However, it may be desirable to provide uninterruptible cooling in the room to maintain operating limits and minimize thermal shock to the equipment.

Humidity

High relative humidity may cause conductive anodic failures (CAF), hygroscopic dust failures (HDF), tape media errors and excessive wear, and corrosion. In extreme cases, condensation can occur on cold surfaces of liquid-cooled equipment. Low relative humidity may result in electrostatic discharge (ESD), which can destroy equipment or adversely affect operation. Tape products and media may have excessive errors when exposed to low relative humidity. In general, facilities should be designed and operated to maintain the recommended humidity range in Table 1, but excursions into the allowable range (more typically the equipment specification) should not significantly shorten equipment operating life.

Filtration and Contamination

Before being introduced into the data and communications equipment room, outside air should be filtered and preconditioned to remove particulates and corrosive gases. Table 1 contains both recommended and minimum filtration guidelines for recirculated air in a data center. Particulates can adversely affect data and communications equipment operation, so high-quality filtration and proper filter maintenance are essential. Corrosive gases can quickly destroy the thin metal films and conductors used in printed circuit boards, and corrosion can cause high resistance at terminal connection points. In addition, the accumulation of particulates on surfaces needed for heat removal (e.g., heat sink fins) can degrade heat removal device performance. Further information on filtration and contamination in data centers can be found in Chapter 8 of *Design Considerations for Datacom Equipment Centers* (ASHRAE 2005b).

Ventilation

Data and communications equipment room air conditioning must provide adequate outside air to achieve two criteria:

- To maintain the room under positive pressure relative to surrounding spaces
- To satisfy ASHRAE *Standard* 62.1 requirements

The need for positive pressure to keep contaminants out of the room is usually the controlling design criterion in data and communication equipment rooms. Pressurization calculations can be performed using the procedures outlined in Chapter 27 of the 2005 *ASHRAE Handbook—Fundamentals*. Chapter 52 of this volume has calculation formulas for achieving pressurization as well as loss of pressure through cracks in walls and at windows.

Although most computer rooms have few occupants, calculations should always be performed to ensure that adequate ventilation for human occupancy is provided in accordance with ASHRAE *Standard* 62.1 and local codes. Internally generated contaminants may make the indoor air quality method the more appropriate procedure; however, maintaining positive pressure usually requires a higher outside airflow.

Envelope Considerations

In addition to meeting state, national, and local codes, there are several other parameters that should be considered in designing the envelope of datacom facilities, including pressurization, isolation, vapor retardants, sealing, and condensation.

- **Pressurization.** Datacom facilities are typically pressurized to prevent infiltration of air and pollutants through the building envelope. An air lock is recommended for a datacom equipment room door that opens directly to the outside. Excess pressurization with outside air should be avoided, because it makes swinging doors harder to use, and wastes energy through increased fan energy and coil loads.
- **Space Isolation.** Datacom equipment centers are usually isolated for both security and environmental control.
- **Vapor Retarders.** To maintain proper relative humidity in datacom facilities in otherwise unhumidified spaces, vapor retarders should be installed around the entire envelope. The retarder should be sufficient to restrain moisture migration during the maximum projected vapor pressure difference between datacom equipment room and the surrounding areas.
- **Sealing.** Cable and pipe entrances should be sealed and caulked with a vapor-retarding material. Doorjambs should fit tightly.
- **Condensation on exterior glazing.** For exterior walls in colder climates, windows should be double or triple-glazed and door seals specified to prevent condensation and infiltration. If possible, there should be no windows. If an existing building is used, windows should be covered.

Human Comfort

Human comfort is not specifically addressed in *Thermal Guidelines for Data Processing Environments* (ASHRAE 2004a) because the facilities typically have minimal and transient human occupancy. Although telecommunications central offices often have permanent staff working on the equipment, human comfort is not the main objective. Following the recommended Class 1 conditions (see Table 1) in a hot-aisle/cold-aisle configuration may result in comfort conditions that are cold in the cold aisle, and warm or even hot in the hot aisle. Personnel working in these spaces need to consider the temperature conditions that exist, and dress accordingly. If the hot aisle is excessively hot, portable spot-cooling should be provided. The National Institute for Occupational Safety and Health (NIOSH) provides detailed guidance on occupational exposure to hot environments (NIOSH 1986). Another concern is contact burns if equipment is too hot. Human tissue reaches the pain threshold at 111°F, and various levels of injury at levels above that (ASTM 2003). Take care that equipment surface temperatures do not represent a hazard.

Flexibility

As described in the introduction, technology is continually changing and datacom equipment in a given space is frequently changed and/or rearranged during the life of a datacom facility. As a result, the HVAC system serving the facility must be sufficiently flexible to allow plug-and-play rearrangement of components and expansion without excessive disruption of the production environment. In critical applications, it should be possible to modify the system without shutdown. If possible, the cooling system should be modular and designed to efficiently handle a wide range in heat loads.

Acoustics

Noise emissions in datacom facilities are the sum of datacom equipment noise and noise from the facility's HVAC equipment. The noise level of air-cooled datacom equipment has generally increased along with the power density and heat loads. Densely populated datacom facilities may run the risk of exceeding U.S. Occupational Safety and Health Administration (OSHA) noise limits (and thus potentially causing hearing damage without personnel protection); refer to the appropriate OSHA (1996) regulations and guidelines. European occupational noise limits are somewhat more stringent than OSHA's and are mandated in EC Directive 2003/10/EC (European Council 2003). Facility noise level calculations can be made following the methodology outlined in Chapter 47, and in Chapter 7 of the 2005 *ASHRAE Handbook—Fundamentals*. An acoustic consultant may be needed to properly predict sound levels from multiple sources and paths, as is typically the case in a datacom facility.

Manufacturers of electronic equipment typically take steps to minimize acoustic noise emissions from datacom equipment. Speed control of air-moving devices, rack- or frame-level acoustic treatments, and reduction of line-of-sight noise emissions are common techniques to reduce datacom equipment noise.

Vibration Isolation and Seismic Restraint

HVAC equipment in datacom facilities should be independently supported and isolated to prevent vibration transmission to the datacom equipment. If required, vibration isolators should be to be seismically rated for the specific environment into which they are installed, to comply with the appropriate codes. Consult datacom equipment manufacturers for equipment sound tolerance and specific requirements for vibration isolation. Many datacom equipment manufacturers test their equipment to the vibration and seismic requirements of *Telcordia* (2001). Additional guidance can be found in Chapter 54 and in the *International Building Code* (ICC 2006).

HVAC LOAD CONSIDERATIONS

HVAC loads in datacom facilities must be calculated in the same manner as for any other facility. Typical features of these facilities are a high internal sensible heat load from the datacom equipment itself and a correspondingly high sensible heat ratio. However, other loads exist and it is important that a composite load comprised of all sources is calculated early in the design phase, rather than relying on a generic overall "watts per square foot" estimate that neglects other potentially important loads.

Also, if the initial deployment or first-day datacom equipment load is low because of low equipment occupancy, the effect of the other loads (envelope, lighting, etc.) becomes proportionately more important in terms of part-load operation.

Datacom Equipment

The major heat source in datacom facilities is the datacom equipment itself. This heat can be highly concentrated, non-uniformly distributed, and variable. Equipment that generates large quantities of heat is normally configured with internal fans and airflow passages to transport cooling air, usually drawn from the space, through the equipment.

Information on datacom equipment heat release should be obtained from the manufacturer. Guidance on industry heat load trends can be obtained from ASHRAE's (2005a) *Datacom Equipment Power Trends and Cooling Applications*. It is important to know the approximate allocation of different types of datacom equipment when designing datacom facility environmental control, because heat loads of different types of equipment vary dramatically. Figure 3 shows projected trends of six equipment classifications through the year 2014; a sample heat load calculation based on these classifications is given in ASHRAE's (2005b) *Design Considerations for Datacom Equipment Centers*.

At the equipment level, ASHRAE (2004) includes a sample equipment thermal report that can provide heat release information in a format specifically suited for thermal design purposes. Nameplate information for data and communications equipment should not be used for thermal design, because it will yield unrealistically high design values and an oversized cooling system infrastructure.

Most current datacom equipment has variable-airflow cooling fans that depend on inlet temperature and/or load. Under typical operating conditions, the flow requirements of these fans may be low, but increase under extreme conditions such as high system inlet temperature. Consideration of this variable flow may be important to HVAC system design.

Load Considerations and Challenges

Similar to commercial loads, datacom loads often operate well below the calculated load. This can be more problematic for datacom facilities, though, because the load densities are so much greater than commercial installations. Further, the source of the load (datacom equipment) is often replaced at least once during the life of the cooling system, requiring consideration of oversized infrastructure or phased construction to accommodate future changes. The part- and low-load conditions must be well understood and equipment selected accordingly.

It is particularly important to understand initial and future loads in detail. Otherwise, the stated initial and future loads could have compounded safety factors or, in the worst cases, guesses. *Datacom Equipment Power Trends and Cooling Applications* (ASHRAE 2005a) identifies the following topics to consider when predicting future load:

- Existing applications' floor space
- Performance growth of technology based on footprint
- Processing capability compared to storage capability
- Change in applications over time
- Asset turnover

Once initial and future loads are understood, as well as the part- and low-load conditions, equipment can be selected. This includes gaining consensus from the project stakeholders regarding acceptable amount of disruption that can occur in an operating facility for upgrades such as cooling capacity or distribution.

Ventilation and Infiltration

For load calculation protocols relating to ventilation and infiltration, refer to Chapter 27 of the 2005 *ASHRAE Handbook—Fundamentals*.

Datacom facilities' outdoor air requirements may be lower than other facilities because of the light human occupancy load. In many cases, it is advantageous to precondition this air, with the space under positive pressure, to allow for 100% sensible cooling in the space. If this approach is adopted, however, preconditioning system failure must also be addressed to avoid the potential for widespread condensation in the space.

Electrical Equipment

In some cases, power distribution units (PDUs) are located in the datacom equipment room as the final means of transforming voltage to a usable rating and distributing power to the datacom equipment. The heat dissipation from the transformers in the PDUs should be accounted for by referencing the manufacturer's equipment specifications.

Lights

High-efficiency lighting should be encouraged, as well as lighting controls, to minimize lighting heat gain.

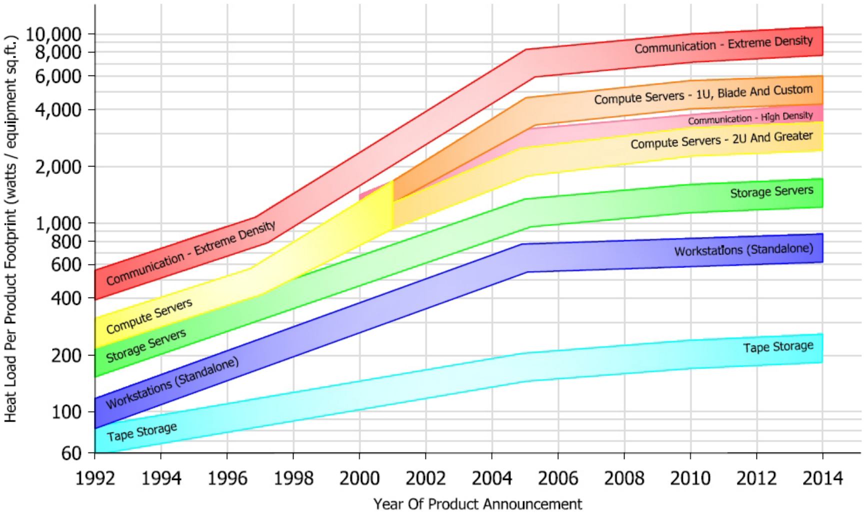


Fig. 3 Projected Power Trends of Datacom Equipment
(ASHRAE 2005a)

People

Occupancy loads should be considered as light work. People often comprise the only internal latent load in a datacom facility, which may be a factor in selecting cooling coils, especially if outdoor air is supplied through a dedicated outdoor air system.

Building Envelope

Heat gains through the building envelope depend on the buildings' location and construction type. More detailed design information on envelope cooling loads can be obtained from Chapter 30 of the 2005 *ASHRAE Handbook—Fundamentals*.

Heating and Reheat

The need for heat in electronic equipment-loaded portions of datacom facilities is typically minimal, because of the high internal heat gains in the spaces. Still, initial or first day loads in many datacom facilities can be low because of low equipment occupancy, so sufficient heating capacity to offset the outdoor air and envelope losses should be included in the design.

Many computer room air-conditioning (CRAC) units include reheat coils for humidity control. Reheat use for humidity control must be carefully monitored, because simultaneous heating and cooling wastes energy.

Humidification

Humidification and/or dehumidification is needed in most environments to meet both the recommended (40 to 55%) and allowable (20 to 80%) humidity ranges specified for Class 1 and Class 2 data centers (ASHRAE 2004a). In most cases, the predominant moisture load is outdoor air, but all potential loads should be considered. Where humidification is not provided, personal grounding is typically utilized to minimize electrostatic discharge (ESD) failures.

Vapor retardant analyses should also be performed where humidity-controlled spaces contain outside walls or ceilings. Refer to Chapter 25 of the 2005 *ASHRAE Handbook—Fundamentals* for additional design information.

High-Density Loads

Heat density of some types of datacom equipment is increasing dramatically. Stand-alone server heat loads (or rack loads) can have heat loads exceeding 30 kW. These increased heat densities require a design engineer to keep abreast of latest design techniques to ensure adequate cooling, and to pay close attention to the loads of installed electronic equipment and future equipment deployments.

Ensure that local high-density loads are provided with adequate local cooling, even when the overall heat density of the general space is below the high-density threshold. Rack inlet conditions should be checked and verified as adequate to meet the manufacturer's requirements. Refer to *Thermal Guidelines for Data Processing Environments* (ASHRAE 2004) for additional information and guidance.

Increases in heat density have made it more difficult to air-cool computers, which has led to increased interest in more efficient liquid-cooling techniques. Liquid cooling media include water, refrigerants, high-dielectric fluorocarbons, or two-phase fluids such as dielectrics. Some computer manufacturers have already taken this approach, and there are also products available that use liquid cooling at the cabinet level. The reader is encouraged to keep abreast of research and development in this area. ASHRAE (2006) has also published a book on liquid cooling, *Design Considerations for Liquid Cooling in Datacom and Telecommunications Rooms.*

New datacom facilities and those slated for major renovation should consider adding appropriate infrastructure (piping taps, feeders, etc.) for future use and load increases. Retrofitting these "backbones" is typically much more expensive, disruptive, and risky.

Note that local high-density areas can have power densities significantly higher than the average for the center. Ideally, high-density computing equipment should be identified during design so appropriate cooling can be provided.

HVAC SYSTEMS AND COMPONENTS

It may be desirable for HVAC systems serving datacom facilities to be independent of other systems in the building, although cross-connection with other systems may be desirable for back-up. Redundant air-handling equipment is frequently used, normally with automatic operation. A complete air-handling system should provide ventilation, air filtration, cooling and dehumidification, humidification, and heating. Refrigeration systems should be independent of other systems and may be required year-round, depending on design.

Datacom equipment rooms can be conditioned with a wide variety of systems, including packaged computer room air-conditioning units and central-station air-handling systems. Air-handling and refrigeration equipment may be located either inside or outside datacom equipment rooms.

Computer Room Air-Conditioning (CRAC) Units

CRAC units are the most common datacom cooling solution. They are specifically designed for datacom equipment room applications and should be built and tested in accordance with the requirements of ANSI/ASHRAE *Standard* 127.

Cooling. CRAC units are available in several types of cooling system configurations, including chilled-water, direct expansion (DX) air-cooled, DX water-cooled, DX glycol-cooled, and dual-cooled (both chilled-water and DX). DX units typically have multiple refrigerant compressors with separate refrigeration circuits, air filters, and integrated control systems with remote monitoring panels and interfaces. Reheat coils and humidifiers are an option. Where weather conditions make this strategy economical, CRAC units may also be equipped with propylene glycol precooling coils and associated drycoolers to allow water-side economizer operation.

Location. CRAC units are usually located within the datacom equipment room, but may also be remotely located and ducted to the conditioned space. With either placement, their temperature and humidity sensors should be located to properly control inlet air conditions to the datacom equipment within specified tolerances (see Table 1). Analysis of airflow patterns in the datacom equipment room [e.g., with computational fluid dynamics (CFD)] may be required to optimally locate datacom equipment, CRAC units, and sensors, to ensure that sensors are not in a location that is not conditioned by the CRAC unit they control, or in a nonoptimum location that forces the cooling system to expend more energy than required.

Humidity Control. Types of available humidifiers within CRAC units may include steam, infrared, and ultrasonic. Consideration should be given to maintenance and reliability of humidifiers. It may be beneficial to relocate all humidification to a dedicated central system. Another consideration is that some humidification methods or improperly treated makeup water are more likely to carry fine particulates to the space.

Reheat is used in dehumidification mode when air is overcooled to remove moisture. On a call for reheat, sensible heat (typically from electric, hot-water, or steam coils) is introduced to supplement the actual load in the space. Using waste heat of compression (hot gas) for reheat may also be an energy-saving option. This overcooling and reheating should be tightly controlled.

Ventilation. Dedicated outdoor air systems have been installed in many datacom facilities to control space pressurization and humidity without humidifiers and reheat in either the CRAC units or other datacom central cooling systems. Figure 4 shows an independent outdoor air preconditioning system in conjunction with a sensible-only recirculation system. The humidifier in the dedicated

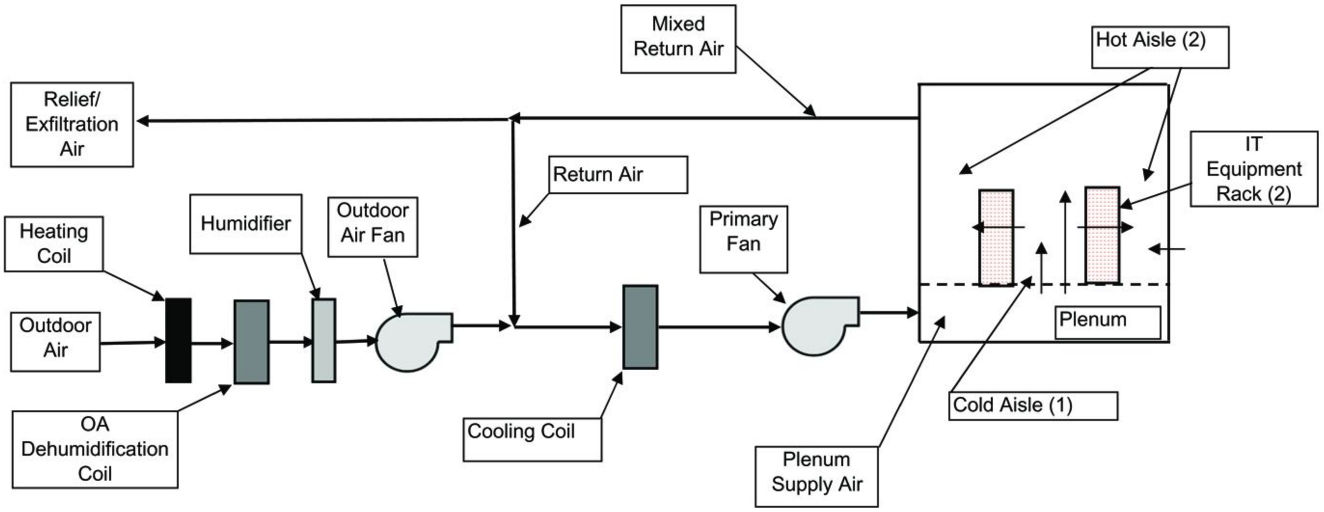


Fig. 4 Datacom Facility with Dedicated Outdoor Air Preconditioning

outdoor air system often controls the humidity in the datacom equipment room based on dew point.

Central-Station Air-Handling Units

Some larger datacom facilities and most telecommunications central offices use central-station air-handling units. Some of their advantages and disadvantages are discussed here.

Coil Selection and Control. A wide range of heating and cooling coil types can be used for datacom facilities, but, ideally, any coil design or specification should include modulating control. In addition, when dehumidifying, control of the cooling coil to maintain dew point can be critical to maintaining the datacom facility within temperature and humidity set points. For more information on cooling coil design, see Chapter 21 in the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*.

Humidification. Various types of central-station humidification systems can be used for datacom facility applications, with each type offering varying steam quality, level of control, and energy consumption. Available water quality and requirements for water treatment must also be considered when selecting the humidifier type.

Flexibility and Redundancy using VAV Systems. Flexibility and redundancy can be achieved by using variable-volume air distribution, oversizing, cross-connecting multiple systems, or providing standby equipment. Compared to constant-air-volume units (CAV), variable-air-volume (VAV) equipment can be sized to provide excess capacity but operate at discharge temperatures or airflow rates appropriate for optimum temperature and humidity control, reducing operational fan power requirements and the need for reheat.

Common pitfalls of VAV include shifts in underfloor pressure distribution and associated flow through tiles. Airflow should be modeled using CFD or other analytical techniques to ensure that the system can modulate without adversely affecting overall airflow and cooling capability to critical areas.

Chilled-Water Distribution Systems

Chilled-water distribution systems should be designed to the same standards of quality, reliability, and flexibility as other computer room support systems. Where growth is likely, the chilled-water system should be designed for expansion or addition of new equipment without extensive or disruptive shutdown. Figure 5 illustrates a looped chilled-water system with sectional valves and multiple valved branch connections. The branches could serve air handlers or water-cooled computer equipment.

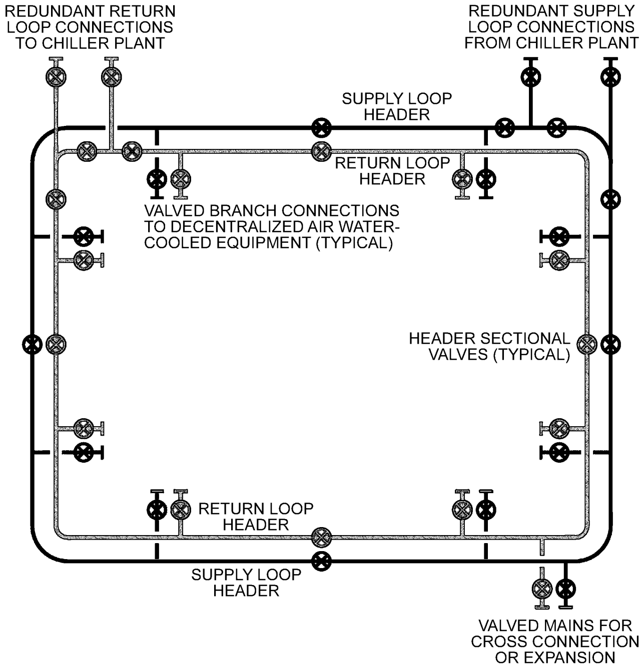


Fig. 5 Chilled-Water Loop Distribution

The valve quantity and locations allow modifications or repairs without complete shutdown because chilled water can be fed from either side of the loop. This loop arrangement is a practical method of improving the reliability of a chilled-water system serving a computer room. “Future taps” should have blind flanges with a pressure gage and drain between the flange and isolation valve to allow the valve to be exercised and checked for holding performance. Sectional valves should be suitable for bidirectional flow and tight shutoff from flow in either direction, to allow maintenance on either side of the valve. In some cases, multiple valves may be required to allow maintenance of the valves themselves.

Where chilled water serves CRAC units or other packaged equipment in the datacom equipment room, select water temperatures that satisfy the space sensible cooling loads without causing latent cooling. Because datacom equipment room loads are primarily sensible, chilled-water supply temperature can be higher than in commercial applications. Greater differentials between the supply and return chilled-water temperatures allow reduced chilled-water flow, which saves pump energy and piping installed costs.

To provide better temperature control of datacom equipment in a data center, numerous manufacturers offer products where liquid (water or refrigerant) is brought close to the datacom rack and used to remove the heat generated by the datacom equipment. Liquid-cooled heat exchangers placed in strategic locations are used to cool hot air exhausted from the datacom equipment, thereby removing either all or part of the equipment's heat load.

Chilled-water pipe insulation with a vapor barrier is required to prevent condensation, but not to prevent thermal loss in a cold plenum; therefore, minimum insulation thickness should be considered, because insulated piping can restrict underfloor air distribution.

Condenser Systems

Heat rejection in datacom facilities can be with either water-cooled or air-cooled systems. Basic information on condenser water systems can be obtained from Chapter 13 in the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*. Where evaporative cooling or open-cell cooling towers are used, consider using makeup water storage as a back-up to the domestic water supply (which provides condenser makeup water).

The "dry-cooler" system incorporates a closed glycol piping loop, which transfers heat from a unit-mounted condenser to an outdoor-air-to-glycol heat exchanger. The same glycol loop is sometimes attached to an economizer cooling coil, installed in the airstream of the CRAC unit, which allows for partial free cooling when the glycol loop temperature is below the unit's return air temperature.

Air-cooled systems generally support CRAC units with built-in refrigeration compressors and evaporating coils. These systems reject heat to remote air-cooled refrigerant condensers. Air-cooled and dry-cooler systems eliminate the need for makeup water systems (and back-up makeup water systems). Cooling towers, dry coolers, etc., need the same level of redundancy and diversity required of the chillers and other critical infrastructure.

Air-Conditioning Systems

Air-conditioning systems should be designed to match the anticipated cooling load and be capable of expansion if necessary; year-round, continuous operation may be required. Expansion of air-conditioning systems while maintaining continuous operation of the data center may also be necessary. A separate system for datacom equipment room(s) may be desirable where system requirements differ from those provided for other building and process systems, or where emergency power requirements preclude combined systems.

Heat recovery chillers may provide an efficient means to recover and reuse heat from datacom equipment environments for comfort heating of typical office environments. The system must provide the reliability and redundancy to match the facility's needs. System operation, servicing, and maintenance should not interfere with facility operation.

Chillers

Because datacom facilities often use large quantities of energy, cooling systems should be designed to maximize efficiency. For many facilities, water-cooled chillers are likely the most efficient system. Basic information on chillers can be obtained from Chapter 38 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*.

Part-load efficiency should also be considered during chiller selection, because data centers often operate at less than peak capacity. Chillers with variable-frequency drives, high evaporator temperatures, and low entering condenser water temperatures can have part-load operating efficiencies of 0.35 kW/ton or less. The relative energy efficiency of primary versus secondary pumping systems should also be analyzed to optimize energy consumption.

Heat recovery chillers may be an efficient way to recover heat from datacom equipment environments for use in other applications. The heat recovery system must provide the reliability and redundancy needed by the facility. System operation, servicing, and maintenance should not interfere with facility operation.

Pumps

Pumps and pumping system design should take into account energy efficiency, reliability and redundancy. It may be possible to design pumps with variable-speed drives, so that the redundant pump is always operational. Ramp-up to full speed occurs on a loss of an operating pump.

Basic information on pumps can be obtained from Chapter 39 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*, and piping systems are covered in Chapter 12 of that volume.

Piping

Chilled-water and glycol piping must be pressure-tested, fully insulated, and protected with an effective vapor retardant. The test pressure should be applied in increments to all sections of pipe in the computer area during construction. In new construction, piping is often installed in trenches below the raised floor to minimize its effect on air distribution. Typically, leak detection is provided along the piping path. When installed overhead, secondary containment is often provided for all piping in datacom equipment room or critical electrical support spaces. Secondary containment systems should incorporate leak detection capability, to detect condensation and identify leaks from damaged piping, valves, fittings, etc. Leak detection should also be placed wherever water piping passes through any critical space, regardless of pipe elevation.

Piping specialty considerations should include a good-quality strainer installed at the inlet to local cooling equipment to prevent control valve and heat exchanger passages from clogging. Strategically placed drains and vents must be included locally at all equipment. Thermometers and other sensors should be installed in a serviceable manner, such as in drywells. Pressure gages should include gage cocks.

If cross connections with other systems are made, the effect of introducing dirt, scale, or other impurities on datacom equipment room systems must be addressed.

Humidifiers

Many types of humidifiers may be used to serve datacom equipment areas, including steam-generating (remote or local), pan (with immersion elements or infrared lamps) and evaporative types (wetted pad and ultrasonic). Ultrasonic devices should use deionized water to prevent formation of abrasive dusts from crystallization of dissolved solids in the water. In general, care must be taken to ensure that particulates or chemicals corrosive to datacom equipment are not used.

The humidifier must be responsive to control, maintainable, and free of moisture carryover. The humidity sensor should be located to provide control of air inlet conditions to the equipment. For additional information, see Chapter 20 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*.

Controls and Monitoring

Controls. Control systems must be capable of reliable control of temperature, relative humidity, and, where required, pressurization within tolerance from set point. Control systems serving spaces requiring high availability must be designed so that component or communication failures do not result in failure of the controlled HVAC equipment.

There are a number of ways to accomplish this, but the general approach is to use multiple distributed control systems in a manner such that no system can cause the failure of another system. Where required, HVAC components and their power supplies should have dedicated controllers installed to ensure automatic and independent operation of redundant HVAC systems in the event of failures.

Based on Table 1, control should be established that provides an inlet condition to data center equipment of 68 to 77°F and telecommunications equipment of 65 to 80°F. Care is needed to ensure that sensors are properly located and tuned, especially if converting from legacy control based on return air temperature. CFD analysis as well as control system simulation may be needed for a successful retrofit.

Where multiple packaged units are provided, regular calibration of controls may also be necessary to prevent individual units from working against each other. Errors in control system calibration, differences in unit set points, and sensor drift can cause multiple-unit installations to simultaneously heat and cool, and/or humidify and dehumidify, wasting a significant amount of energy. Also consider integrated control systems that communicate from unit to unit, sharing set points and sensor data to ensure coordination, and reduce the potential for units to work against each other. Lead/lag control could also be used, if desired.

Monitoring. Datacom facilities often require extensive monitoring of the mechanical and electrical systems. Multiple interface gateways are often used to interface different monitoring and control systems to the head-end monitoring system and ensure that failure of individual system communication components does not remove access to the total system information database.

Monitoring should include control system sensors as well as independent “monitoring-only” sensors and should include datacom equipment areas, critical infrastructure equipment rooms, command/network operations centers, etc., to ensure critical parameters are maintained. Monitoring also should be sufficient to ensure that anomalies are detected early and with adequate time to allow operating staff time to mitigate and restore conditions before equipment is affected. Monitored data can facilitate trending, alarming, and troubleshooting efforts.

Examples of suitable parameters for monitoring include underfloor static air pressure, temperature, and humidity; early-warning smoke detection; ground currents; and rack temperatures and humidity. Monitoring systems can be integral to or separate from control systems and can be as simple as portable data loggers or strip chart recorders or as complex as high-speed (GPS-synchronized) forensic time stamping of critical breakers and status points. New technologies allow distributed monitoring sensors to be connected to the data and communication network without separate wiring systems.

Because datacom equipment malfunctions may be caused by or attributed to improper control of the datacom room environmental conditions, it may be desirable to keep permanent records of the space temperature and humidity. Many datacom equipment manufacturers imbed temperature and humidity sensors in their equipment, which in turn can be correlated with equipment function and also provide for reduced-capacity operation or shutdown to avoid equipment damage from overheating. In the future it may be possible to connect IT sensors to building systems for monitoring and control.

As a minimum, alarms should be provided to signal when temperature or humidity limits are exceeded. Properly maintained and accurate differential pressure gages for air-handling equipment filters can help prevent loss of system airflow capacity and maintain design environmental conditions. All monitoring and alarm devices should provide local indication as well as interface to the central monitoring system.

AIR DISTRIBUTION

To provide effective cooling, air distribution should closely match load distribution. Distribution systems should be flexible enough to accommodate changes in the location and magnitude of heat gains with minimal change in the basic distribution system. Distribution system materials should ensure a clean air supply. Duct or plenum material that may erode must be avoided. Access for cleaning is desirable.

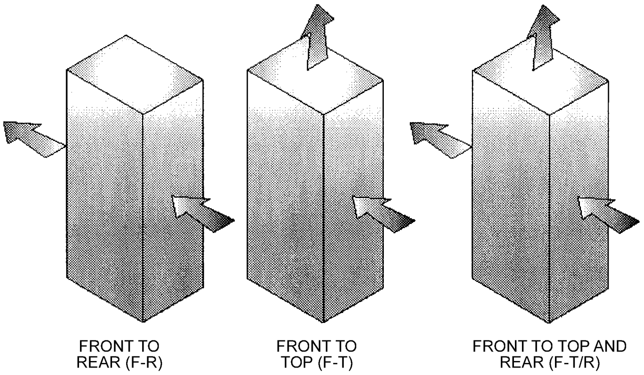


Fig. 6 Recommended Equipment Airflow Directivity

Equipment Placement and Airflow Patterns

Datacom Equipment Airflow Protocols. Datacom equipment is typically mounted in racks or cabinets arranged in rows. In a typical configuration, the “front” of cabinets, racks, or frames (i.e., the side with the air inlets) faces one aisle, and the rear, which includes cable connections, faces another aisle. The cabinets or racks in a datacom environment are usually 78 in. high, whereas telecommunications frames are generally 72 to 84 in. high. Each cabinet or rack may contain a single piece of equipment, or it may contain any number of individual items of equipment, in sizes as small as 1U, where 1U = 1.75 in. (EIA *Standard* 310).

Supply air is drawn into the inlet of the datacom equipment cabinet or rack, picks up heat internal to the equipment, and is then discharged, typically from a different side of the equipment, eventually recirculating to the HVAC cooling coil, where the heat is rejected.

To cool datacom equipment efficiently and effectively, there needs to be complementary directivity for airflow through the equipment and airflow through the datacom equipment room. ASHRAE’s *Thermal Guidelines for Data Processing Environments* (ASHRAE 2004) and *Telcordia* (2001) define recommended airflow protocols through datacom equipment. Figure 6 shows the three communications equipment airflow protocols that are recommended for use in datacom facilities. In the front-to-rear (F-R) protocol has cool air entering the front of the equipment rack (or cabinet), and exiting the rear. The F-T protocol has cool air entering the front of the equipment cabinet, and exiting the top, whereas the front-to-top-and-rear (F-T/R) protocol has cool air entering the front of the equipment, and exiting both the top and the rear. Rack-mounted equipment should follow the F-R protocol only; cabinet-mounted systems can follow any of the three shown.

Other airflow protocols for rack-mounted datacom equipment direct airflow through the left and/or right sides of the equipment within the rack. For these installations, airflow within the rack must be managed to ensure complementary directivity of airflow between independent shelves of data and communications equipment. In addition, spacing between adjacent racks in the same line-up of equipment must be adequate to ensure the appropriate segregation of hot exhaust and cold intake air streams.

Hot Aisle/Cold Aisle Configuration. Using alternating hot and cold aisles promotes separation of the cool supply and warm return streams which generally leads to lower equipment inlet temperatures and greater energy efficiency. Figure 7 shows a schematic view of a hot aisle/cold aisle configuration.

Underfloor Plenum Supply

Datacom facilities often use an underfloor plenum to supply cooling air to the equipment. As shown in Figure 8, the CRAC units push cold air into the plenum, from which it is introduced into data and communications equipment rooms via perforated floor tiles, tile cutouts, and other openings. The raised-floor design offers flexibility in placing computer equipment above the raised floor. Cooling air can, in theory, be delivered to any location simply by replacing a solid floor tile by a perforated tile.

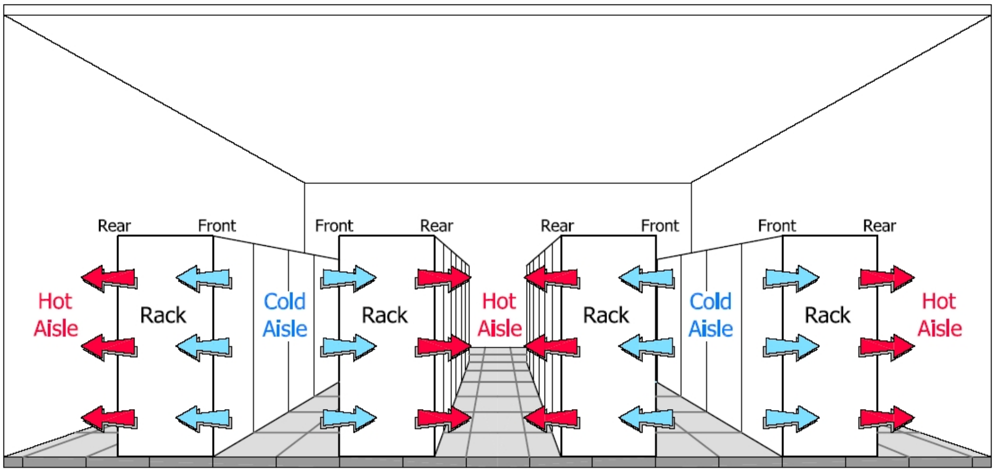
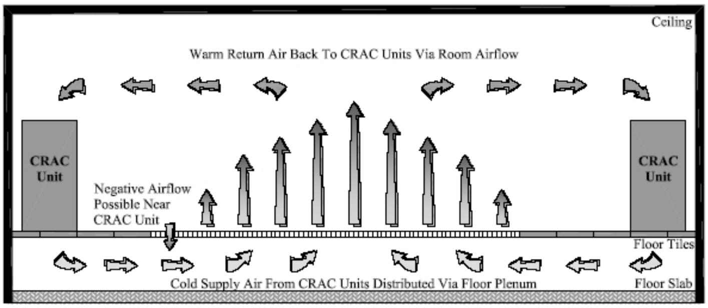
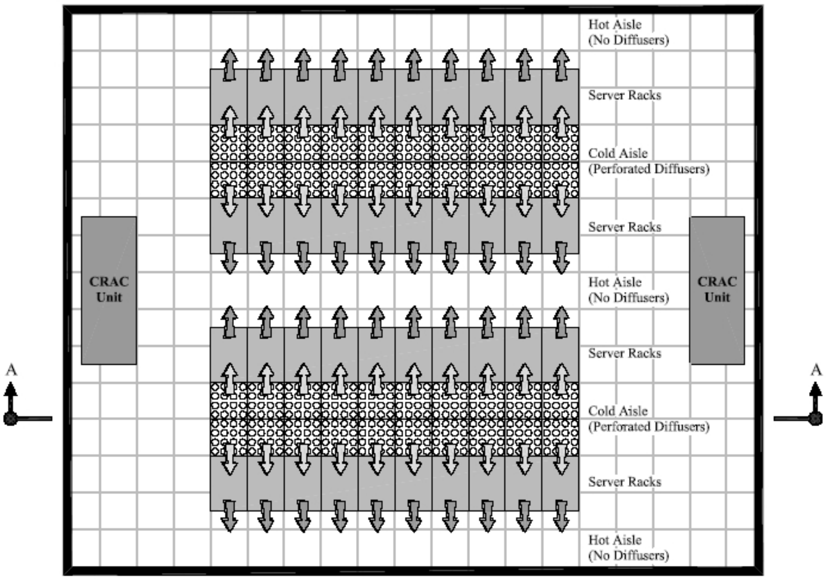


Fig. 7 Schematic of Hot-Aisle/Cold-Aisle Configuration



Sectional View (A-A)



Plan View

Fig. 8 Schematic of Datacom Equipment Room with Underfloor Plenum Supply Air Distribution

With a hot-aisle/cold aisle configuration, perforated tiles are primarily placed in the cold aisle. Cooling air delivered by the perforated tiles is drawn into the front of the racks. Warm air is exhausted from the back of the racks into the hot aisle and is ultimately returned to the CRAC units.

Airflow Inlet Delivery Concerns. For good thermal management, required airflow must be supplied through the perforated tile(s) located near the inlet of each piece of datacom equipment. The heat load can vary significantly across datacom equipment rooms, and changes with addition or reconfiguration of hardware. For datacom equipment to operate reliably, the design must ensure that cooling air distributes properly (i.e., the distribution of airflow rates through perforated tiles matches the cooling air needs of equipment on the raised floor).

When adequate airflow is not supplied through the perforated tiles, internal fans in the equipment racks tend to draw air through the front of the cabinet from the path of least resistance, which typically includes the space to the sides of and above the racks. Because most of this air originates in the hot aisle, its temperature is high. Thus, cooling of the sides and upper portion of the equipment racks can be seriously compromised.

Air tends to stratify, with cold supply air near the floor and hot air near the ceiling, with a temperature gradient between. High discharge air velocity through floor tile or grates is necessary to displace warm air near the highest intakes. Floor grates can be useful, because of their high mass flow discharge rates.

Pressure Variations. Distribution of cooling airflow through perforated tiles is governed by the fluid mechanics of the space below the raised floor and not the large, visible, above-floor space. More specifically, the static pressure and air movement in the proportionately small underfloor space determines how much air flows through each perforated tile. Measurements from hundreds of datacom facilities confirm that flow rates from perforated tiles typically vary considerably, depending on their proximity to the CRAC unit.

Further, the pattern of airflow distribution is somewhat counterintuitive. More flow might be expected through tiles near the CRAC unit, and less away from it. In reality, there is typically very little flow near the CRAC, and greater flow through the perforated tiles located far away. Consequently, IT equipment placed near the CRAC often does not get much cooling air.

The flow rate through a perforated tile depends on the pressure difference across the tile (i.e., the difference between the plenum static pressure just below the tile and the room static pressure above the raised floor). Pressure variations in data and communications equipment rooms are generally small compared to the pressure drop across the perforated tiles. The tiles are fairly restrictive (e.g., 25% or less open area). When substantial numbers of tiles with greater open area are used, airflow through the tiles may also depend on airflow dynamics above the raised floor; CFD analysis or physical measurements may be required to ensure that a design meets equipment airflow requirements.

Under some conditions, nonuniformity of airflow distribution is so severe that perforated tile airflow is directed from the room down into the floor plenum. This effect is caused when most of the CRAC unit fan's total pressure is transformed into velocity pressure by high velocity in a relatively shallow underfloor plenum. This high-velocity underfloor air can create a localized negative pressure and induce small quantities of room air into the underfloor plenum. As distance from the supply fan increases, velocity decreases and the velocity pressure is converted to static pressure, which is required to produce airflow through perforated tiles or grates.

Other Factors Affecting Airflow Distribution. Other factors that influence distribution of airflow through perforated tiles include the following:

- Height of raised-floor plenum
- Percentage of open area of perforated tiles
- Location and size of leakage airflow paths
- Locations and redundancy of CRAC units
- Corresponding spreading of underfloor flow to various perforated tile locations
- Collision or merging of airstreams from different CRACs
- Flow disturbance caused by underfloor blockages such as pipes and cable trays

There is a common misconception that using more open tiles increases the airflow rate. Obviously, for the same static pressure in the plenum, more open tiles produce more airflow than more restrictive tiles. However, static pressure in the plenum cannot be assumed to be constant; it is a result of the tiles' flow resistance and other factors. The airflow rate is controlled by the amount of flow the CRAC unit blower is able to supply. For the blower, the controlling resistance is primarily internal to the CRAC unit, and the additional flow resistance offered by the perforated tiles is insignificant. Lowering perforated tile resistance typically does not significantly increase overall flow.

When very restrictive tiles (for example, 5% open) are used, their flow resistance can influence the flow delivered by the CRAC unit blower. In this case, plenum pressure becomes high enough that the blower operates at a new position on the fan curve. The need for very restrictive tiles should thus be avoided, if possible, although they could be necessary with low floor heights where the plenum is restricted and underfloor pressure distribution variation is high.

Using more restrictive tiles leads to a more uniform airflow distribution, but increases underfloor static pressure and may drive more airflow through leakage paths. Instead of using restrictive tiles everywhere, selective use of restrictive and open tiles in different locations can obtain the desired airflow distribution. To make flow distribution uniform, it is typically necessary to increase the percentage open area of tiles near the CRAC unit and to decrease it further away from the CRAC unit.

Finally, underfloor obstructions can cause significant airflow variations in the underfloor plenum. A raised-floor datacom facility usually contains pipes, cable trays, and structural columns. These obstructions disturb the airflow pattern under the floor, influence pressure distribution, and thus affect airflow coming out of the perforated tiles.

Because obstructions reduce the area available for flow, air velocity increases and leads to more significant pressure changes. Usually, static pressure increases on the upstream side of an obstruction and decreases on the downstream side, with the lowest static pressure at the point with highest velocity. Because of this effect, two adjacent perforated tiles located above an obstruction may yield very different airflow rates.

When redundant (standby) CRAC units are provided, air distribution in the datacom room changes depending on which units are operating.

Another consideration is the effect of dampers on the performance of perforated tiles and floor grates. Typically, dampers are two slotted metal plates installed on the bottom surface of a tile or grate, creating a plenum between the damper and discharge surface. Even in the full open position, there is a pressure drop across the damper, reducing static pressure across the discharge surface and resulting in lower air velocities than tiles or grates without dampers. Low discharge air velocity can cause problems in supplying cooling air to the highest rows of tall racks or cabinets.

Overhead and Ceiling Plenum Supply

As with an underfloor plenum supply, the hot-aisle/cold-aisle configuration should also be used with an overhead supply. Currently, overhead cooling methods are more typically found in telecommunications facilities.

Ducted Supply. Overhead ducted supply, shown in Figure 9, can be used in datacom facilities without a raised-floor plenum. The

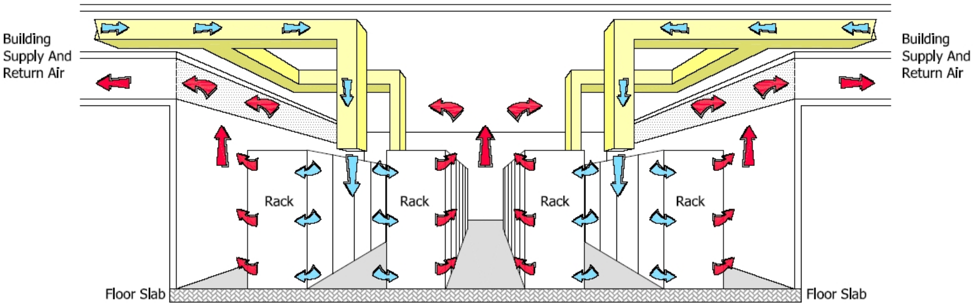


Fig. 9 Typical Ducted Ceiling Distribution Used in Datacom Facilities

vertical overhead (VOH) system is currently the typical and preferred configuration of the large regional phone companies, although this might change to accommodate new technologies. This system can satisfy equipment and personnel comfort requirements, and can be fairly easily balanced to supply air to meet the distributed heat gain in the equipment room.

The vertical overhead supply system is typically limited to a cooling capacity of 130 W/ft^2 (*Telcordia* 2001) in mature telecommunications central offices, where the definition of watts per square foot is the average heat release of the datacom equipment in a 20 by 20 ft building bay. This limitation stems from the large physical duct sizes required near the ceiling. Air distribution is often affected by large overhead cabling installations.

Local and Supplemental Cooling Distribution. Recently, cooling systems have been developed in which small, modular cooling units are located close to the equipment racks, either within the rows of racks themselves, on top of racks, or mounted on the ceiling directly over a cluster of racks. An extreme example is a sealed rack system that provides its own cooling and has no heating effect on air inside the data center. Local cooling units may provide all the cooling for a data center or be used only in some (e.g., high-density).

Local cooling systems can be incorporated into new construction, and are also a good supplemental cooling approach to consider for retrofit applications where existing facilities lack sufficient infrastructure to expand their base cooling capacity. Supplemental cooling equipment may be located in or on a rack and include products that increase cool-air supply to a rack, capture hot-air exhaust from a rack, or partially cool air leaving the rack.

In designing and implementing local cooling, it is important to perform a thorough analysis to ensure that a cooling solution to one part of the facility does not create a problem in another part of the facility.

Other Overhead Cooling Strategies. Other cooling strategies are used, predominantly in telecommunications central offices. **Horizontal displacement (HDP)** air-distribution, mainly used in Europe and Asia, introduces air horizontally from one end of a cold aisle. A large volume of slightly cooled air moves along the aisle with low velocity. Subsequently, the electronic equipment draws necessary cold air from the cold aisle. However, this system requires more floor space to accommodate the displacement of the large diffusers.

Some long-distance carriers in North America use **horizontal overhead (HOH)** air distribution. This system introduces supply air horizontally above the cold aisles, and is generally used where raised floors are used for cabling.

Finally, **natural convection overhead (NOH)** air distribution, not commonly used, suspends cooling coils from the ceiling. Because the coils cool the hot air as it rises (because of buoyancy), there are no fans or ducting in this strategy.

For more information on different air-cooling strategies for telecommunications central offices, including cooling capacities, see *Telcordia* (2001).

Return Air

Return air paths discussed here can be used either with underfloor or overhead supply air systems. Most return air in datacom facilities is not ducted (i.e., heat discharged from datacom equipment enters the datacom equipment room at large and finds a pathway back to a large common return grille or to the inlet of a CRAC unit). This can be effective, but the opportunity for inefficiency, in some circumstances, is great because of potential short-circuiting and mixing of supply and return air. In addition, it is possible to draw hot equipment exhaust from one piece of equipment into the inlet of adjacent equipment. An example of how air can potentially short-circuit with an underfloor supply and unducted return configuration is highlighted in Figure 9.

Using ceiling plenums is an option for return air. Inlets should be located above hot aisles or datacom equipment with high heat dissipation to take advantage of the thermal plume created above the equipment. Ceiling plenum returns can capture part of the heat from data and communications equipment and lights directly in the return airstream. Assuming that the space is allowed to stratify, the return air being at a higher temperature than the average space temperature creates a higher temperature difference across the cooling coil, thereby allowing a reduction in airflow to the space.

Computational Fluid Dynamics Simulation

Air is the main carrier of heat and moisture in data centers. It is challenging but important to optimize the flow paths of both cold supply air and hot return to minimize mixing of these two streams as well as reduce any short-circuiting of cold air back to the air-conditioning systems.

Several factors affect airflow distribution and cooling performance of a data center. Physical measurements and field testing are not only time and labor intensive but sometimes impossible. In such a situation, computational fluid dynamics (CFD) simulations provide a feasible alternative for testing various design layouts and configurations in a relatively short time.

CFD simulations can, for example, predict air velocities, pressure, and temperature distribution in the entire data center facility; assess airflow patterns around racks and identify areas of recirculation; and provide a detailed cooling audit report for the facility, including performance evaluation of individual components such as air-conditioning units, racks, perforated tiles, and any other supplementary cooling systems in the facility.

Facilities managers, designers, and consultants can use these techniques to estimate performance of a proposed layout before actually building the facility. Likewise, CFD simulations can provide appropriate insight and guidance in reconfiguring existing facilities optimize the cooling and air distribution system. For details on performing CFD, see Chapter 34 of the 2005 *ASHRAE Handbook—Fundamentals*.

ANCILLARY SPACES

Space must be allocated within a datacom facility for storing components and material, support equipment, and operating and servicing the datacom equipment. Some ancillary spaces may require environmental conditions comparable to those of the datacom equipment, whereas others may have less stringent requirements. Component and material storage areas often require environmental conditions comparable to those of the datacom equipment. Support equipment often has substantially less stringent environmental requirements, but its continuous operation is often vital to the facility's proper functioning.

Electrical Power Distribution and Conditioning Rooms

Electrical Power Distribution Equipment. Electrical power distribution equipment can typically tolerate more variation and a wider range of temperature and humidity than datacom equipment. Equipment in this category includes incoming service/distribution switchgear, switchboard, automatic transfer switches, panel boards, and transformers. Manufacturers' data should be checked to determine the amount of heat release and design conditions for satisfactory operation. Building codes should be checked to identify when equipment must be enclosed to prevent unauthorized access or housed in a separate room.

Uninterruptible power supplies (UPSs) come in various configurations, but most often use batteries as the energy storage medium. They are usually configured to provide redundancy for the central power buses, and typically operate continuously at less than full-load capacity. They must be air-conditioned with sufficient redundancy and diversity to provide an operable system throughout an emergency or accident. The relationship between load and heat release is usually nonlinear. Verification with the equipment vendor is necessary to properly size the HVAC system.

UPS power monitoring and conditioning (rectifier and inverter) equipment is usually the primary source of heat release. This equipment usually has self-contained cooling fans that draw intake air from floor level or the equipment face and discharge heated air at the top of the equipment. Air-distribution system design should take into account the position of the UPS air intakes and discharges.

Battery Rooms

Installation of secondary battery plants as a temporary back-up power source should be in accordance with NFPA *Standard* 70; IEEE *Standard* 1187 and other applicable standards should also be referenced, in addition to a design review with the local code official. Other relevant sources of guidance are NFPA *Standards* 70E and 76.

Most codes require 1 cfm/ft^2 of forced exhaust from a battery room when hydrogen detectors are not used. The exhaust fan(s) (typically ceiling-mounted) must run continuously. When hydrogen detectors are used, exhaust is also sized for 1 cfm/ft^2, but the fan(s) only need to run when hydrogen is detected.

Because of the potential high hazard associated with hydrogen gas build-up, battery room exhaust systems should be designed with redundancy and failure alarms. Best practice design includes both continuous fan operation and both "high" and "high-high" alarms in case one sensor goes out of calibration. If the system operates when hydrogen gas is detected, or if combustible concentrations of gas are expected, explosionproof motors and/or other provisions may be required to address an explosion hazard.

Nonsparking fan wheels may be required by code, and in any case are highly recommended. For belt-drive systems, the fans should be equipped with controls that periodically exercise them to keep the belts pliable and therefore more reliable.

Temperature in a battery area is crucial to the life expectancy and operation of the batteries. The optimum space temperature for lead-calcium batteries is 77°F. If higher temperatures are maintained, it may reduce battery life; if lower temperatures are maintained, it may reduce the batteries' ability to hold a charge (IEEE *Standard* 484).

Battery rooms should be maintained at a negative pressure to adjacent rooms and exhausted to the outside to prevent migration of fumes, gases, or electrolytic spray to other areas of the facility. It may be possible to provide makeup air from an adjacent datacom area, thereby eliminating the need for a separate HVAC system for the battery room, if temperatures are compatible. Battery rooms typically only have small heat-producing loads.

Battery rooms may require emergency eyewashes and showers. If so, these systems should include leak detection and remote alarm capabilities to alert staff of a possible leak or that an accident has occurred and emergency first aid is required.

Engine/Generator Rooms

Engine-driven generators used for primary or emergency power require large amounts of ventilation when running. This equipment is easier to start if a low ambient temperature is avoided. Low-temperature start problems are often reduced in cold climates by using engine block heaters. Design should ensure that exhaust air does not recirculate back to any building ventilation air intakes.

Spring-return motorized dampers are typically provided on air inlets and discharges and maintained normally closed when power is available to the damper actuator. Damper actuator signals are generally from the generator electrical gear as opposed to the building management system (BMS).

Where acoustical concerns exist, measures may need to be taken both inside the engine/generator room to meet the appropriate OSHA regulations and guidelines [e.g., OSHA (1996)] and on the air intake/discharge openings if the site is near an acoustically sensitive property line.

Burn-In Rooms and Test Labs

Many datacom facilities incorporate a dedicated area for the purpose of assembling, configuring and testing datacom equipment before deployment in the production environment. These areas can be used for testing equipment power supplies, dual-power capabilities, actual power draw, and cooling requirements, as well as for equipment applications testing (both software and hardware functions).

It is recommended that these areas be adjacent to production areas for convenience, yet separated with respect to power, cooling, and fire protection to prevent a power problem or fire from affecting the production environment.

Datacom Equipment Spare Parts

A spare parts room may require immediate use of parts for equipment repair. Therefore, the temperature of the space should be similar to that of the operating data center. ASHRAE's *Thermal Guidelines for Data Processing Environments* (ASHRAE 2004) provides allowable temperatures for "product power-off" conditions that include a spare parts room environment.

Storage Spaces

Storage spaces for products such as paper and tapes generally require conditions similar to those in data and communications equipment rooms, because these products absorb moisture from the air and can expand, contract, or change shape more than electronic equipment. Close-tolerance mechanical devices, such as paper feeders or tape drives, are also affected by room relative humidity.

OTHER SYSTEMS AND CONSIDERATIONS

Fire Suppression

Automatic fire extinguishing and smoke control systems afford the highest degree of protection and must be provided in accordance with the applicable national codes, local codes, and the owner's insurance underwriter. Some new code references require fire protection below the raised floor.

Exhaust Systems. Exhaust systems may be provided to ventilate datacom equipment rooms in the event of a chemical fire suppression system discharge or as required for smoke purge. Locating the exhaust pickup point below a supply plenum floor promotes quick purging of the space.

There is no need for a purge system when datacom equipment rooms are only protected with sprinklers unless required by code. Even so, the ability to purge datacom space (including critical infrastructure rooms) can minimize the effects of combustion contaminants on datacom equipment, regardless of the type of suppression system.

For small computer rooms that use DX compressor-based cooling systems, local codes may require alarm and exhaust in the event of loss of refrigerant. The volume of refrigerant within a system should be checked against local code requirements.

Fire Smoke Dampers. When motorized fire/smoke dampers are installed to seal a clean-agent-protected room, they must be the spring-loaded type, configured to close on loss of power (or upon melting of fusible link). During start-up, it is important to verify proper operation, including making sure that dampers close fully without binding. A binding damper jeopardizes the integrity of the room seal and could prevent the clean agent from reaching the proper concentration level to extinguish a fire. To increase reliability, mechanical systems should be designed to minimize the number of motorized fire/smoke dampers.

Outdoor Air Smoke Detectors. Outside air, and any other air supply, should be equipped with smoke detection that shuts down associated fans and closes associated fire/smoke damper(s). Roof fires, nearby fires, nearby chemical spills, and even generator start-up can introduce smoke and reactive chemicals into the data center through fresh air intakes.

Additional information on fire detection and suppression systems for datacom environments can be found in *Design Considerations for Datacom Equipment Centers* (ASHRAE 2005b).

Commissioning

Commissioning of datacom facilities is critical to their proper functioning and reliable operation. The commissioning process is usually misinterpreted as focusing on systems testing only, and initiated during the construction process.

However, ASHRAE *Guideline* 1 defines commissioning as "the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent. . . . Commissioning begins with planning and includes design, construction, start-up, acceptance and training, and can be applied throughout the life of the building."

It is recommended that commissioning of datacom facilities begin at project inception, so that owner requirements can be better defined, addressed, and verified throughout the entire design and construction process. Five levels of commissioning are described in *Design Considerations for Datacom Equipment Centers* (ASHRAE 2005b):

- Level 1: factory acceptance tests
- Level 2: field component verification
- Level 3: system construction verification
- Level 4: site acceptance testing
- Level 5: integrated systems testing

Mission-critical facilities typically have more demanding performance requirements for responses to expected and unexpected anomalies without affecting critical operations. Systems usually include redundant components and utility feeds, and excess capacity or back up systems or equipment that, during an emergency, can be automatically or manually activated. These redundant or back-up components, systems, or groups of interrelated systems are tested during level 5 commissioning: this level is what generally sets mission-critical facility commissioning apart from typical office building commissioning.

Further information on commissioning can be found in Chapter 42 and ASHRAE *Guidelines* 0 and 1.

Serviceability

There are many serviceability issues to consider for HVAC equipment serving datacom facilities. Above all, the design should seek to coordinate with datacom facility operations to service and maintain equipment with the least amount of disruption to the day-to-day running of the facility. One approach is to locate all cooling equipment (e.g., CRAC or central station air-handling units) outside of the datacom equipment room in dedicated support rooms. Servicing and maintenance operations for this equipment is then performed in areas devoted specifically to air-conditioning equipment. System security for these spaces, however, must be addressed.

HVAC equipment serving datacom facilities can also be located on the roof, when the physical arrangement of the facility and space limitations allow.

Availability and Redundancy

It is extremely important to understand the need for uptime of the datacom facilities. Mission-critical datacom facilities, as their name implies, are often required to run 24 h, 7 days a week, all year round, and any disruption to that operation typically results in a loss of business continuity or revenue for the end user.

Availability is a percentage value representing the probability that a component or system will remain operational. Availability typically considers both component reliability and system maintenance (Beaty 2004). Values of 99.999% ("five 9s") and higher are commonly referenced in datacom facility design, but are difficult to attain. For individual components, availability is often determined through testing. For assemblies and systems, availability is often the result of a mathematical evaluation based on the availability of individual components and any redundancy or diversity that may be used.

Availability calculations for HVAC systems are seldom done and are extremely difficult, because published data on components and systems are not readily available. Further research is needed to allow for calculation of system availability as a function of component availability and level of redundancy.

System availability may be so vital that the potential cost of system failure justifies redundant systems, capacity, and/or components, as well as increased diversity. System simplicity and ease of operation should be a constant consideration; a substantial percentage of reported data center failures are related to human activity or error.

The most common method used to attain greater system availability is adding redundant parallel components to avoid a single component failure that causes a systemwide failure. HVAC system redundancy calculations commonly use the terms $N + 1$, $N + 2$, and $2N$ to indicate how many additional components are to be provided. N represents the number of pieces of equipment that it takes to satisfy the normal load. Redundant equipment is necessary to compensate for failures and allow maintenance to be performed without reducing the remaining online capacity below normal.

In the case of datacom facilities using CRAC units, if $N + 1$ redundancy is required, the number of units required to satisfy the normal N cooling load must first be determined. One additional unit would then be provided, to achieve $N + 1$ redundancy.

In theory, redundancy can be achieved with $N + 1$ (or more air-handling or CRAC units), but the dynamics of underfloor and overhead flow are such that loss of a specific unit can be critical for a specific area. CFD analysis is often performed to determine the effect of losing specific units in critical-use areas. For large spaces, consider using $N + 1$ for every X number of units, to provide one redundant unit for every set of X units required.

Take care to exercise redundant equipment frequently, to prevent conditions that enhance growth of mold and mildew in filters, insulated unit enclosures, and outside air pathways where spores and food sources for microbial growth may accumulate. Another approach is to keep redundant equipment operational at all times, but to use variable-frequency drives (VFDs) to control fan speed. In this manner, the fans operate at a speed to match loads. If a fan fails, the other fans ramp up to maintain required airflows. No schedule is required for exercising equipment, because all equipment is operational (unless loads are so low that it is not practical to operate all equipment).

Diversity. Systems that use an alternative path for distribution are said to have diversity. In an HVAC system, diversity might be used to refer to an alternative chilled-water piping system. To be of maximum benefit, both the normal and alternative paths must each be able to support the entire normal load. One company developed a tiered classification system to rank the level of diversity and redundancy in a data center design (Turner and Brill 2003).

With dual feeds, it is often possible to perform planned datacom air-moving device infrastructure activity without shutting down critical loads, a concept called **concurrently maintainable**. **Fault-tolerant** systems do not lose power or cooling to the datacom equipment when a single component fails.

Measures to Increase Reliability. Practical ways to increase HVAC system reliability for datacom facility design may include any of the examples listed below. A fault tree analysis or other methodology should be used for each facility to examine critical failure paths and necessary design measures to increase system availability.

- Back-up utilities: power generation, second electric service, water supply, etc. Emergency power supplies probably should feed some aspects of HVAC systems as well as datacom equipment to allow for continuous equipment operation within allowable environmental conditions.
- Back-up air moving equipment: air handlers, fans, computer room units, etc.
- Back-up and/or cross-connected cooling equipment: chillers, pumps, cooling towers, dry coolers, cooling coils, makeup water supply, etc.
- Diverse piping systems: chilled water, condenser water, etc.
- Full or partial back-up of air-moving and/or cooling equipment on emergency power.
- Back-up thermal storage: chilled water, ice, makeup water, etc.

Energy Conservation

Dramatic reductions in energy use can be achieved with conservation strategies. Central-station air-conditioning systems using outside air for free cooling (where appropriate), variable-volume ventilation, and evaporative cooling/humidification strategies offer significant opportunities for reducing energy use, depending on the frequency of favorable outdoor conditions. A dew-point control strategy, often consisting of positive pressurization of the datacom facility and humidity control at the point of outdoor air intake, can eliminate the need for humidity-sensing devices and provide precise humidity control.

A significant amount of wasted energy has been identified in many existing facilities, often because of fighting between adjacent air-conditioning units attempting to maintain tight tolerances. Adopting the somewhat less stringent environmental tolerances found in ASHRAE's (2004) *Thermal Guidelines for Data Processing Environments* should minimize this historically significant problem. Control strategies such as underfloor air temperature control and additional monitoring points should be considered to identify and avoid fighting, especially where raised-floor spaces may include a mixture of heat densities in the same open area.

Baseline energy consumption of office and telecommunications equipment was estimated by Roth (2002). Case studies of energy consumption in datacom facilities have been inventoried and are available for public review (LBNL 2003). Tschudi et al. (2003) summarized existing research on energy conservation in datacom facilities and provided a roadmap for further research in this area. Areas covered include monitoring and control, electrical systems, and HVAC systems (including free cooling), and use of variable-speed compressors in CRAC units. A set of recommendations for high-performance data centers has also recently been issued (RMI 2003).

Economizer Cycles. Air-side economizers are generally not used in datacom facilities for several reasons, including their potential effect on humidity levels and concern about dust contamination from the increased outdoor air. They are, however, required by energy conservation codes in some parts of the United States. ASHRAE's (2004) *Thermal Guidelines for Data Processing Environments* also allows increased economizer use in some climates, because of the higher recommended inlet air temperature range (68 to 77°F for Class 1 and 2 environments) relative to a typical office supply air temperature of 60°F or below.

Telecommunications central offices often use air-side economizers to save energy. When evaluating economizers, the potential reduction in cooling costs should be compared with the added costs derived from increased equipment soiling. Herrlin (1996) concluded that significant savings could be expected in most United States climates (except the Southeast) when enthalpy economizers are incorporated.

Fluid or glycol economizers are economically advantageous in many cold climates. Designs should be engineered to minimize cycling between free economizer cooling and mechanical cooling.

REFERENCES

Codes, Standards, and Guidelines

ASHRAE. 2005. The commissioning process. *Guideline* 0-2005.

ASHRAE. 1996. The HVAC commissioning process. *Guideline* 1-1996.

ASHRAE. 1992. Gravimetric and dust-spot procedures for testing air-cleaning devices used in general ventilation for removing particulate matter. *Standard* 52.1-1992.

ASHRAE. 1999. Method of testing general ventilation air-cleaning devices for removal efficiency by particle size. ANSI/ASHRAE *Standard* 52.2-1999.

ASHRAE. 2004. Ventilation for acceptable indoor air quality (ANSI Approved). ANSI/ASHRAE *Standard* 62.1-2004.

ASHRAE. 2001. Method of testing for rating computer and data processing room unitary air conditioners. ANSI/ASHRAE *Standard* 127-2001.

ASTM. 2003. Guide for heated system surface conditions that produce contact burn injuries. *Standard* C1055-03. American Society for Testing and Materials, West Conshohocken, PA.

EIA. 1992. Racks, panels and associated equipment. *Standard* EIA-310, rev. D.

ICC. 2006. *International building code*®. International Code Council, Washington, D.C.

IEEE. 2002. Recommended practice for installation design and installation of vented lead-acid batteries for stationary applications. IEEE *Standard* 484-2002. Institute of Electrical and Electronics Engineers, Piscataway, NJ.

IEEE. 2002. Recommended practice for installation design and installation of valve-regulated lead-acid storage batteries for stationary applications. *Standard* 1187-2002. Institute of Electrical and Electronics Engineers, Piscataway, NJ.

NFPA. 2005. National electric code®. NFPA *Standard* 70. National Fire Protection Association, Quincy, MA.

NFPA. 2004. Standard for electrical safety in the workplace. *Standard* 70E. National Fire Protection Association, Quincy, MA.

NFPA. 2002. Recommended practice for the fire protection of telecommunications facilities. *Standard* 76. National Fire Protection Association, Quincy, MA.

OSHA. 1996. 29 CFR 1910.95: Occupational Noise Exposure. U.S. Dept. Labor, OSHA, Office of Information, Washington, D.C. Available at http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table = STANDARDS&p_id=9735.

Telcordia. 2001. Thermal management in telecommunications central offices. *Telcordia Technologies Generic Requirements* GR-3028-CORE.

Telcordia. 2002. Network equipment—Building Systems (NEBS) requirements: Physical protection. *Telcordia Technologies Generic Requirements* 2, GR-63-CORE.

Other Publications

ASHRAE. 2004a. *Thermal guidelines for data center environments*.

ASHRAE. 2005a. *Datacom equipment power trends and cooling applications.*

ASHRAE. 2005b. *Design considerations for datacom equipment centers*.

ASHRAE. 2006. *Design considerations for liquid cooling in datacom and telecommunications rooms*.

Beaty, D.L. 2004. Reliability engineering of datacom cooling systems. Symposium, ASHRAE Winter Meeting.

European Council. 2003. Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Available at http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_042/l_04220030215en00380044.pdf.

Herrlin, M.K. 1996. Economic benefits of energy savings associated with: (1) Energy-efficient telecommunications equipment; and (2) Appropriate environmental control. Eighteenth International Telecommunications Energy Conference INTELEC ’96, Boston.

LBNL. 2003. http://datacenters.lbl.gov/CaseStudies.html. Lawrence Berkeley National Laboratories.

NIOSH, 1986. Criteria for a recommended standard: Occupational exposure to hot environments (Revised Criteria 1986). *Report* 86-113. National Institute for Occupational Safety and Health, Washington, D.C. Available on the web at: http://www.cD.C.gov/niosh/86-113.html.

RMI. 2003. *Energy efficient data centers: A Rocky Mountain Institute design charette.* Rocky Mountain Institute, Snowmass, CO.

Roth, K., F. Goldstein, and J. Kleinman. 2002. *Energy consumption by office and telecommunications equipment in commercial buildings*. vol. I: *Energy consumption baseline*. Arthur D. Little.

Tschudi, B., T. Xu, D. Sartor, and J. Stein. 2003. Roadmap for public interest research for high-performance data centers. LBNL *Report* 53483.

Turner, W.P., and K. Brill. 2003. Industry standard tier classifications define site infrastructure performance. The Uptime Institute, Santa Fe, NM.

BIBLIOGRAPHY

ASHRAE. 2003. *Risk management guidance for health, safety and environmental security under extraordinary incidents*.

Awbi, H.B. and G. Gan. 1994. Prediction of airflow and thermal comfort in offices. *ASHRAE Journal* 36(2):17-21.

Bash, C.E., C.O. Patel, and R.K. Sharma. 2003. Efficient thermal management of data centers—Immediate and long-term research needs. *International Journal of HVAC&R Research* (now *HVAC&R Research*) 9(2): 137-152.

Beaty, D.L. 2003. Liquid cooling—Friend or foe. Symposium, ASHRAE Winter Meeting.

Brill, K., E. Orchowski, and L. Strong. 2002. *Product certification for fault-tolerance is essential for verification of high availability.* The Uptime Institute, Sante Fe, NM.

ETSI. 2004. Environmental conditions and environmental tests for telecommunications equipment; Part 1-3: Classification of environmental conditions; stationary use at weatherprotected locations. *Standard* EN 300 019-1-3 V2.2.2. European Telecommunications Standards Institute, Sophia Antipolis, France.

Herrlin, M.K. 1997. The pressurized telecommunications central office: IAQ and energy consumption. Healthy Buildings/IAQ ’97, Washington D.C.

ISO. 1999. Cleanrooms and associated controlled environments—Part 1: Classification of air cleanliness. ISO/FDIS *Standard* 14644-1. International Standards Organization, Geneva.

Kang, S., R.R. Schmidt, K.M. Kelkar, A. Radmehr, and S.V. Patankar. 2001. A methodology for the design of perforated tiles in raised floor data centers using computational flow analysis, *IEEE Transactions on Components and Packaging Technologies* 24:177-183.

Karki, K.C., A. Radmehr, and S.V. Patankar. 2003. Use of computational fluid dynamics for calculating flow rates through perforated tiles in raised-floor data centers. *International Journal of HVAC&R Research* (now *HVAC&R Research*) 9(2):153-166.

Krzyzanowski, M.E. and B.T. Reagor. 1991. Measurement of potential contaminants in data processing environments. *ASHRAE Transactions* 97(1):464-476.

Lentz, M.S. 1991. Adiabatic saturation and VAV: A prescription for economy and close environmental control. *ASHRAE Transactions* 97(1): 477-485.

Longberg, J.C 1991. Using a central air-handling unit system for environmental control of electronic data processing centers. *ASHRAE Transactions* 97(1):486-493.

Nakao, M., H. Hayama, and M. Nishioka. 1991. Which cooling air supply system in better for a high heat density room: Underfloor or overhead? Thirteenth International Telecommunications Energy Conference (INTELEC ’91), November 1991.

Noh, H.-K., K.S. Song, and S.K. Chun. 1998. The cooling characteristics on the air supply and return flow systems in the telecommunication cabinet room. Twentieth International Telecommunications Energy Conference (INTELEC ’98).

Patankar, S.V. and K. Karki. 2004. Distribution of cooling airflow in a raised-floor data center. *ASHRAE Transactions* 110(2):624-635.

Patel, C.D., R. Sharma, C.E. Bash, and A. Beitelmal. 2002. Thermal considerations in cooling large scale high compute data centers. ITHERM 2002: Eighth Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems.

Patel, C.D., C.E. Bash, C. Belady, L. Stahl, and D. Sullivan. 2001. Computational fluids dynamics modeling of high compute density data centers to assure system air inlet specifications. *Paper* IPACK2001-15622, InterPack ’01 Kauai.

Schmidt, R. and E. Cruz. 2002. Raised floor computer data center: effect on rack inlet temperatures of chilled air exiting both the hot and cold aisles. *IEEE 2002 Inter Society Conference on Thermal Phenomena*, pp. 580-594.

Schmidt, R. 1997. Thermal management of office data processing centers. InterPack ’97, Hawaii.

Schmidt, R. 2001. Effect of data center characteristics on data processing equipment inlet temperatures. *Paper* IPACK2001-15870. InterPack ’01, Kauai.

Schmidt, R.R., K.C. Karki, K.M. Kelkar, A. Radmehr, and S.V. Patankar. 2001. Measurements and predictions of the flow distribution through perforated tiles in raised-floor data centers. *Paper* IPACK2001-15728. InterPack ’01, Kauai.

Stahl, L. and C. Belady. 2001. Designing an alternative to conventional room cooling, International Telecommunications and Energy Conference (INTELEC), Edinburgh.

TIA. 2003. Telecommunications infrastructure standard for data centers, draft 2.0. *Standard* PN-3-0092. Telecommunication Industry Association, Arlington, VA.

U.S. GSA. 1992. Airborne particulate cleanliness classes in clean rooms and clean zones. U.S. *Federal Standard* FS209E. General Services Administration, Washington, D.C.

Weschler, C.J. and H.C. Shields. 1991. The impact of ventilation and indoor air quality on electronic equipment. *ASHRAE Transactions* 97(1):455-463.

Yamamoto, M. and T. Abe. 1994. The new energy-saving way achieved by changing computer culture (saving energy by changing the computer room environment). *IEEE Transactions on Power Systems* 9(August).