Guidelines for Energy-Efficient Commercial Unitary HVAC Systems

Final Report
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1 INTRODUCTION

1.1 EXECUTIVE SUMMARY

This specification is a compilation of energy-efficient best practices for the sizing, selection, installation and commissioning of unitary air-source air conditioner and heat pump systems up to 30 tons. Commercial new and retrofit construction projects are included. *This document is intended as a tool for improving the energy efficiency of commercial unitary HVAC installations*, which make up approximately 55 percent of the total annual tonnage of commercial HVAC equipment sold in the United States.[15]

The purpose of this document is to facilitate implementation of energy-efficient installation practices by providing a specification guide that can easily be used by key people in the industry, namely installing contractors, service providers, and designers. In addition, this document may be used as a specification for equipment manufacturers and incentive programs, and as a training tool for program managers. *The program goal is a substantial increase in commercial HVAC energy efficiency with reduced construction and energy costs as the incentive.*

The following table highlights key energy-saving practices:

Key Elements for Energy-Efficient Installations

Element	**Specification for Best Practices**	**Potential Energy Savings***
Load Calculations	Section 2.1, calculate loads using ASHRAE Fundamentals[2a], ACCA Manual N[17] or software based upon these methods[34]	Up to 50 percent efficiency increase when compared with substantially oversized equipment[4]
Unit Selection	Section 2.2, CEE HECAC Initiative[1] for new equipment - Minimum Efficiency: Tier 1, Premium Efficiency: Tier 2	10-20 percent compared with U.S. Fed. minimum efficiency units4, or up to 40 percent compared with older units.[15b]
Ductwork Design	Section 3, installation should comply with ASHRAE Fundamentals[2a], ACCA Manual N[1], or SMACNA HVAC Systems – Duct Design[12d]	Varies
System Installation	Sections 2-4, manufacturer's instructions, SMACNA HVAC Duct Construction Stds[12a], and ASHRAE 90.1-1999[2a]	Up to 20 percent supply air leakage can result in a 60-70 percent increase in fan power[19]
Controls	Section 4, design & installation per ASHRAE 90.1-1999[2a]	Economizers may save 15 - 80 percent of cooling energy[4]
Commissioning	Section 5 & mgr's instructions	Up to 20 percent energy savings[18]
Operation & Maintenance	Section 5 & manufacturer's instructions	11-42 percent energy savings[16]

*savings are not additive

1.2 APPLICATIONS

This document provides specifications for energy-efficient installation practices relating to the following commercial systems:

- **Unitary Air Conditioners and Air-to-Air Heat Pumps** up to 30 tons capacity, including packaged rooftop units and matched split systems. Built-up systems, packaged terminal air conditioners (through-the-wall), chilled water systems and water-cooled equipment are not included.
- **Heating systems** integral with the above unitary air conditioners and heat pumps, including gas furnaces, electric resistance, electric heat pumps and water/steam coils.
- **Air Distribution Systems** applicable to the above unitary equipment, including ductwork, accessories, controls, commissioning and maintenance.
- **New Construction and Retrofits** of existing unitary HVAC systems of the above types.

This document covers installation practices relating to energy efficiency and is not meant as a complete guide for installation, nor does it directly address elements of installation that can impact occupant and installer health and safety. This document is a supplement to applicable codes and manufacturers' instructions. Whenever uniform or local codes or standards require stricter measures or differing practices, the codes and standards shall govern.

1.3 BENEFITS DUE TO ENERGY-EFFICIENT INSTALLATION PRACTICES

- **Energy Cost Savings:** When compared to conventional installations, up to 40 percent of energy costs can be saved by sizing equipment properly and selecting equipment with high efficiency ratings and energy-efficient options.[15b] Energy-efficient installation practices such as proper duct installation and sealing can result in energy savings up to 11 percent.[6b] A properly commissioned HVAC system can use up to 20 percent less energy by correcting installation and operation problems, and optimizing system controls.[18]
- **Construction Cost Savings** by avoiding common practices such as equipment oversizing, installation errors, and excessive ductwork.
- **Improved Comfort** by reducing equipment cycling, duct losses, faulty controls and uneven air distribution.
- **Reduced Maintenance & Business Interruption** due to proper equipment selection, installation and commissioning.
- **Decreased Environmental Impact** from consumption and waste products of energy, materials and refrigerants.

1.4 HOW TO USE THIS DOCUMENT

These energy-efficient specifications are recommended for use in full or partial installations of the types listed in Section 1.2. The document is also useful for repairs, upgrades, reconditioning, (re)commissioning and evaluating existing systems. For optimal energy efficiency of new installations, careful compliance with the entire specification is recommended, where applicable. However, most of the specifications can be used and commissioned independently as best practices for energy efficiency.

Proper commissioning is crucial for components that require setting, adjustment or programming, such as economizers, refrigerant charging, fans, controls and damper positions. Failure to properly commission these items can negate energy savings and often increases energy use dramatically.

In the case of unit and ductwork installation, however*, most efforts should be spent on careful installation*, as opposed to testing for leaks afterward when much of the ductwork is difficult and expensive to access. It is highly recommended that these specifications be applied conscientiously and inspected often during installation of ductwork systems.

1.5 REFERENCES AND ACKNOWLEDGEMENTS

Davis Energy Group and the Consortium for Energy Efficiency compiled the information in this document from a number of sources, including published papers, studies and industry standards. Christina Manansala of Davis Energy Group was the principal author. Section 7 lists the referenced source publications, standards and agencies.

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2 UNITARY AIR CONDITIONERS AND HEAT PUMPS

2.1 LOAD CALCULATION – NEW OR RETROFIT CONSTRUCTION

2.1.1 Benefits

Load calculations are crucial for both new and retrofit construction to ensure comfort and efficient operation, as well as to prevent expensive oversizing of equipment or problems due to insufficient capacity. At least 25 percent of rooftop units are oversized by 25 percent or more[7], resulting in inflated construction costs and increased energy usage. Oversized equipment efficiency can drop by up to 50 percent due to part-load operation and excessive short cycling.[4] Oversizing also increases equipment wear and decreases dehumidification capacity. One study of 15 light commercial systems found that 66 percent of the systems tested operated a significant portion of the time with on-time cycles less than ten minutes and 33 percent never had cycles exceeding 10 minutes.[20]

Load calculations are necessary for retrofits in order to evaluate the adequacy of existing equipment and/or specify replacement equipment. Direct tonnage replacement and rule-of-thumb sizing, which are typical for small commercial installations, do not account for current equipment, controls or code requirements and can result in incorrect equipment selection and inefficient energy use.

2.1.2 Methodology

Calculate cooling and heating loads using ASHRAE-based load calculation methodology or modeling software. Calculate the peak block load and airflow rate for each system, as well as for each room/zone. Factor in extreme conditions such as arid or humid climates. Approved methods include:

A. *ASHRAE Fundamentals – Load and Energy Calculations*[2c]
B. *ACCA Manual N – Commercial Load Calculation*[5a]
C. Computer software such as *DOE-2, ASEAM* or other non-proprietary software based upon ASHRAE or ACCA methods[34]

A number of proprietary commercial ASHRAE-based software packages are available as well[3] .

2.1.3 Design Conditions

Indoor cooling and heating design temperatures should be based upon local energy codes. Temperatures of 78°F for cooling and 70°F for heating are commonly used for typical commercial occupancies. Design conditions for specific occupancies are specified in *ANSI/ASHRAE 55-1992*[2f]. For specialized occupancies the facility engineer should be consulted.

2.1.4 Peak Load Reduction

Reducing peak loads results in substantial year-round cost savings due to reduced cooling energy, smaller equipment size and more efficient equipment operation. The following strategies can reduce peak cooling and/or heating loads:

A. Encourage the usage of *ASHRAE 90.1-1999 Energy Standard for Buildings Except Low-Rise Residential*[2a] or *IECC-2000 International Energy Conservation Code*[17] as minimum criteria for the design of the building envelope, lighting and equipment.
B. Base receptacle/equipment loads on anticipated simultaneous usage, rather than on full connected loads.
C. Base outside air amounts on local code or *ASHRAE 62-1999.*[2b] Perform calculations for each occupancy type to avoid excessive outside air. Apply diversity factors allowed by code to account for non-simultaneous occupancy.
D. For occupancies with high indoor humidity such as kitchens, gymnasiums, etc., factor in the reduction in latent cooling load due to ventilation (in dry climates only). Some load calculation software may not apply credit for this, resulting in oversized cooling equipment.
E. Calculate loads accurately. Do not oversize equipment for "safety."

2.1.5 Select Unit to Meet Calculated Loads

In commercial facilities that are cooling-load dominated, selection of unitary equipment is usually based upon the peak-cooling load. In heating dominated climates, selection of the unitary HVAC equipment should also be based upon the cooling load to prevent oversizing of cooling equipment. Auxiliary heating equipment should be provided to meet the peak-heating load if the unitary equipment lacks sufficient heating capacity. If the heating load is much greater than the cooling load, an alternative is to provide heating-only units that are separate from the cooling units.

A. **Peak Sensible Load**: Select unit(s) with a sensible capacity not less than 100 percent of the calculated peak sensible cooling load. The 1989 version of *ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential*[2g] called for selecting units with capacities up to 110 percent of the sensible cooling load, but this was deleted from the 1999 version. In most cases the calculated load will fall between standard unit sizes, so selecting the closest size which provides at least

100 percent of the sensible load will usually result in a margin of extra capacity. Since the equipment runs at part-load a majority of the time, avoiding oversized equipment will result in lower energy use.

B. **Peak Latent Load**: The latent cooling capacity of the unit(s) should equal or exceed the calculated latent-cooling load. For high humidity occupancies, see Section 2.1.4.D.

C. **Multiple Compressors**: Units with multiple compressors, which can be unloaded to match part-load requirements, are highly recommended. Since peak conditions are infrequent, most units run at part-load for a majority of their operating time. Multiple compressors can provide greatly enhanced energy-efficiency and greater comfort due to reduced short-cycling and increased equipment life. Multiple compressors are often an option for smaller units and are usually standard for larger (>10-ton) units. They are recommended when there are varying loads, when climates have wide temperature swings or any other times substantial part-load operation is expected.

D. **Peak Heating Load**: See Section 2.2.4 to verify adequate heating capacity.

2.2 EQUIPMENT SELECTION

2.2.1 Benefits

Selection of high-efficiency new unitary equipment can reduce energy costs by 10-20 percent compared with U.S. Federal minimum efficiency for new units[4]. Replacing older, low-mid efficiency equipment with high-efficiency units can result in energy savings up to 40 percent[15b]. High-efficiency equipment features improved compressors and motors, more insulative cabinets, less resistive configurations and energy-saving accessories.

2.2.2 Efficiency Specifications for New Equipment

Two levels of efficiency specifications are presented below. Tier I is recommended as the minimum specification for energy-efficient installations. Tier II should be used for increased energy savings or when high cooling loads or run time are expected due to climate, internal loads, continuous occupancy or other reasons.

A. **Minimum Efficiency** – Tier I of the *CEE HECAC Initiative*[1] for 10 percent energy savings compared with U.S. Federal minimum standards.

B. **Premium Efficiency** – Tier II of the *CEE HECAC Initiative*[1] for 20 percent energy savings compared with U.S. Federal minimum standards.

2.2.3 Evaluation/Replacement of Existing Units

Existing unitary equipment being considered for reuse should be carefully evaluated for serviceability, remaining life span, capacity and efficiency. Reusing inappropriate equipment can result in poor comfort, high energy costs, excessive repairs, and business interruption due to repairs/replacement. Replacement of 20-year-old units with new high-efficiency units can reduce energy use by up to 40 percent[15b] and provide the opportunity for correct specification. Evaluate the existing unitary equipment as follows:

A. A qualified service technician should examine each component of the unit(s) to assess performance and remaining life, and estimate repairs needed for full reconditioning. If the unit(s) can be reconditioned to operate for a reasonable projected life, proceed with steps B-F.
B. Perform cooling and heating load calculation as described in Section 2.1, using criteria for the retrofit conditions. Loads may have substantially changed due to more efficient equipment or occupancy/use changes.
C. Consider peak load reduction measures in Section 2.1.4.
D. Evaluate the cooling and heating capacities of the unit(s) per Sections 2.1.5 and 2.2.4. If the unit(s) are of insufficient capacity, evaluate the cost of adding capacity versus replacing the unit(s). In some cases, equipment capacity will exceed the calculated loads due to envelope improvements or occupancy change. The use of an oversized unit can decrease unit efficiency by up to 50 percent.
E. Evaluate the blower's capacity to provide minimum ventilation air (see Section 2.1.4.C). Older systems may have been designed without ventilation air, which may be required for the retrofit.
F. Evaluate configuration and location of the unit(s) for delivery of air to the retrofit building. Estimate costs/impact if relocation is required.
G. Compare effective efficiency of the unit(s) with current efficiency standards in Section 2.2.2. Energy cost savings due to increased efficiency often justifies replacing older units.

2.2.4 Selection of Heating Equipment

The most cost effective heating option depends upon the climate and cost of available fuels. When natural gas or propane is available at low cost, it generally results in the lowest heating energy costs. When gas is not available, the most efficient choice of electric heat is a heat pump system.

Air-to-Air Heat Pumps:

A. New equipment should meet minimum efficiency standards described in Section 2.2.2.
B. Size the unit(s) for the cooling load as described in Section 2.1.5. Select the lowest possible heating balance point temperature under 30°F. At this temperature the heat pump output equals the building heat loss.
C. Select a supplemental heat package sized to make up the difference between the unit heating capacity at design conditions and the calculated heating load. Select multiple-stage supplemental heaters when available.
D. Provide controls to prevent supplemental electric resistance heater operation when the heating load can be met by the heat pump alone during both steady-state operation and setback recovery. Supplemental heater operation is permitted during outdoor coil defrost cycles. These controls are not needed when the heat pump's minimum efficiency is regulated by NAECA and its efficiency meets Section 2.2.2 and includes all usage of internal electric resistance heating.[2a]
E. For large supplemental heat loads, provide multi-staged heaters when available.

Gas-Fired Furnaces:

A. Select multi-stage or variable-flame burners when available.
B. Size furnace to meet 100 percent of the calculated heating load when on high setting.
C. New equipment should meet minimum efficiency standards specified in *ASHRAE 90.1-1999*.[2a]

Electric Resistance:

A. This type of heating is not usually recommended due to high energy costs when compared with electric heat-pump heating or fuel-fired heating. Electric resistance heating may be a viable option in areas where natural gas/propane is unavailable or expensive, heating loads are very low, or as back-up heating for heat pumps.
B. If electric-resistance heating is used for substantial loads, consider using increased building insulation and high performance glazing, in excess of levels recommended by ASHRAE 90.1-1999.
C. Size heater to meet 100 percent of calculated heating load. Avoid oversizing.
D. Select multi-stage heaters to reduce electricity use during part-load operation. Separate stage lockout control based on outside air temperature is recommended.

2.3 UNIT CONFIGURATION AND LOCATION

2.3.1 Benefits

Configuration and location of unitary equipment should be selected for good access and to minimize ductwork, thereby reducing energy use, installation costs and maintenance costs.

2.3.2 Best Practices

A. Plan schematic ductwork layout (see Section 3.4.5). Where possible, locate air handling units centrally over zones to minimize duct sizes and lengths for supply, return, exhaust and outside air ducting.
B. If a central return air system is planned, locate the unit(s) near the returns. Consider sound issues before locating a unit directly above an air terminal.
C. For rooftop units with ductwork located within the building, specify downflow configuration to reduce ductwork turns, heat loss and air leakage.
D. Locate units for easy access and serviceability. Provide manufacturer recommended clearance for service access and proper airflow.
E. If possible, locate split-system outdoor units in shaded areas or provide screening to shade the unit from solar heat gain.
F. Locate units away from sources of debris such as leaves or grease, which can inhibit unit performance and increase maintenance costs.
G. Locate outside air intake upstream of prevailing wind and away from sources of pollution and odors such as parking lots, roads, smoking areas, exhaust outlets, plumbing vents, debris, dust or fine particles.
H. Locate outside air intake away from sources of heat, cold, humidity or wind, such as cooling towers or boilers.

I. Ensure that there is adequate drainage at the equipment location to avoid water pooling.
J. Do not locate equipment where it is vulnerable to falling or drifting snow or ice. Provide a rack or platform to elevate and support equipment per manufacturer's instructions when recommended by the manufacturer for protection from snow.
K. Avoid excessive distance between split-system condenser and evaporator components.
L. Level units to avoid water accumulation in the drain pans of rooftop units.

2.4 UNIT INSTALLATION

2.4.1 Benefits

Air leaks are common at the ductwork connections to rooftop air handlers. This connection should be tightly sealed during installation when it is most accessible.

2.4.2 Sealing Around Rooftop Units

A. Seal between rooftop units and curbs according to the manufacturer's instructions. Correctly install manufacturer-supplied gasket during unit placement. This is often overlooked during installation.
B. Provide a solid connection and airtight seal between the ductwork and the unit or curb (see Section 3.5). Manufacturers often recommend a 3-inch flexible connector from the unit to the ductwork to minimize vibration transfer.[30] This connector and connection should be air- and watertight.
C. Seal air leaks at cabinet panels (see Section 3.5.4).
D. Seal around pipe and conduit penetrations with sealant rated for outdoor use.

2.4.3 Split-System Refrigerant Piping

A. For split systems, size refrigeration lines according to the manufacturer's instructions for the installed length to minimize pressure drop and efficiency loss.
B. Install refrigerant line according to the manufacturer's instructions. Provide adequate supports to prevent the pipes from sagging, vibrating or moving.
C. Insulate refrigerant piping as required by *ASHRAE 90.1-1999*[2a], Table 6.2.4.5 or local code, whichever is more stringent. For outdoor installations provide a weather-protective insulation covering for protection from moisture and solar degradation.

2.5 ECONOMIZERS

2.5.1 Benefits

In dry climates, economizers have the potential to save 15-80 percent of cooling energy[4], but only when correctly selected and carefully installed, commissioned and maintained. Cooling energy is saved by automatically shutting down the condensing units and using outdoor air for cooling whenever the outdoor air temperature is cool enough, or by operating the condensing units with 100 percent outside air when the outside air enthalpy is lower than the return air enthalpy. However, an estimated 75 percent of rooftop units suffer from economizer malfunction[7], which can result in energy use that is higher than what would occur if the economizer was not installed. When outdoor air is brought in at the wrong times, extra energy must be used to condition the air. In some cases, wasted energy may be 10 times greater than potential savings.[23]

2.5.2 Best Practices

A. Economizers should be installed as required by local codes or by Section 6.3.1 of *ASHRAE 90.1-1999*.[2a]
B. Install economizers per Section 6.3.1.1 of *ASHRAE 90.1-1999*.[2a]
C. Economizers must be tested and commissioned very carefully for correct operation according to Section 5 and the manufacturer's instructions.
D. Economizers are usually not effective in humid climates and may increase cooling energy use.

2.5.3 Economizer Retrofits

A. Evaluate whether the sizes of the return and outside air ductwork and openings are adequate for 100 percent of the supply airflow. Upgrade as necessary for correct sizing, per Section 3.4.
B. Test the operation of all components and upgrade per Section 2.5.4. Quality components are essential for proper operation. Frozen, broken or disconnected linkages, dampers and actuators are common problems due to corrosion. Sensor malfunction is also common. Newer equipment is improved and more reliable. Install new filters before testing.
C. Test and commission according to Section 5 and the manufacturer's instructions.
D. If A-C above are not cost effective, consider permanently locking the economizer dampers into minimum outside air position to protect against large uncontrolled losses.[23] Economizers are less cost effective with smaller units and in corrosive or humid environments.

2.5.4 Economizer Components – New and Retrofit Systems

A. Differential enthalpy controls are recommended in humid climates. Although they are more costly and require higher maintenance, they have been shown to give twice the energy savings as fixed enthalpy or temperature control.[4] Differential dry bulb controls should not be installed in humid climates.[2a]
B. Dry bulb or differential enthalpy controls are recommended for dry climates. Fixed enthalpy controls should not be installed in dry climates.[2a]
C. Install outside air sensors away from direct sun, wind, or sources of heat and cold.
D. For retrofit systems, correctly size outside air intake louvers and dampers for 100 percent of design supply air quantity.[4]
E. Provide adequately-sized relief louvers, return or exhaust fans for exhausting 100 percent of the design supply air. Powered exhaust or additional relief is recommended if existing barometric relief openings are undersized. Provide gravity or motorized backdraft dampers for exhaust fans. Adequate exhaust is often overlooked in economizer retrofits.[23]
F. See Section 2.3.2 for locating outside air intakes.

When the option is available:

A. Use interlocking damper blades, combined parallel/opposed-blade dampers, or parallel-blade dampers with compensating baffles, for both the outside and return air.[4]
B. Install direct-drive actuators for higher reliability and easier installation.[23]
C. Internal linkages and bearings are less prone to corrosion.
D. Stainless steel dampers resist corrosion much better than aluminum or galvanized steel. They are highly recommended for areas near marine or industrial corrosion sources.[23]

2.6 ENERGY-EFFICIENT VENTILATION

2.6.1 Benefits

Much energy is consumed heating, cooling and blowing the outside air required for ventilation. In facilities with high ventilation requirements, energy costs can be greatly reduced by controlling the ventilation, separating it from the cooling/heating system, or recovering energy from the exhaust air.

2.6.2 Methodology

A. **Perform accurate ventilation calculations** for each occupancy type to avoid specifying excessive outside air. Base calculations on local code *or ASHRAE 62-1999.*[2b] Base ventilation on expected occupancies where codes do not specify occupancies.
B. **Demand-controlled ventilation** controls vary the ventilation rate to limit CO_2 levels. This saves exceptional amounts of energy in facilities that normally operate with light occupancy, but are designed to have sporadic heavy occupancies. These systems are also effective in facilities with intermittent pollution sources, such as fire station bays. Ventilation controls should comply with *ASHRAE 90.1-1999*[2a], *ASHRAE 62*[2b] and local standards. A minimum outdoor air setting may be necessary to control odors in some occupancies.
C. **Dedicated ventilation equipment** provides fresh air systems or exhaust systems that are separate from the cooling/heating system. In some cases make-up air can be untempered, as with compensating hoods. Fresh/make-up air systems may be efficiently tempered with indirect/direct evaporative cooling. This removes a portion of the sensible load from the unitary equipment and may allow specification of smaller sizes. Direct evaporative cooling increases the latent load.
D. **Energy recovery ventilation** uses a heat exchanger to recover heat/cold from exhaust air. This option can be cost effective when large amounts of conditioned room air are continuously exhausted such as in a workshop or laboratory. Equipment costs are partially offset by savings from downsizing unitary equipment.

E. **Programmable thermostats w/ separate fan control** allow scheduling of fan-only operation for ventilation strategies such as night ventilation (see Section 4.6) or outside air ventilation during non-conditioned periods.

F. **Low-toxicity building and furnishing materials** produce less indoor air pollution, thereby reducing ventilation needs. Consult the *Sustainable Building Technical Manual*[9] for more information.

2.7 ADDITIONAL OPTIONS AND ACCESSORIES

2.7.1 Benefits

This section identifies other factory and custom options that increase the energy efficiency of unitary equipment by lowering energy consumption or indicating operation problems.

2.7.2 Options for Increasing Energy Efficiency

A. **Factory roof curbs** are designed to mate with downflow rooftop units and can provide an effective seal when installed with a gasket, per manufacturer's instructions.

B. **Economizers/powered exhaust** – see Section 2.5.

C. **High-efficiency Motors** are available with efficiency ratings of approximately 86-91 percent.

D. **Electronically commutated motors (ECM)** are brushless-dc motors with built-in speed and torque controls. The ECM has the efficiency and speed control advantages of a dc motor without its disadvantages, such as carbon brush wear, short life and noise.

E. **Corrosion protective coating** for condenser coils prevents corrosion that can increase fan and compressor energy and reduce equipment life. They are recommended for equipment exposed to marine or corrosive industrial environments.

F. **2" filter racks w/ pleated filters** are recommended for increased surface area and filtering capacity. Choose low pressure drop filters of about 0.1"w.g. Filters should be located upstream of the supply fan for more uniform airflow and to clean the air before it travels through the coils.[4] Units should never be operated without filters in place. Filters should be properly sized and routinely maintained.

G. **Differential pressure switches** can be used for sensing and indicating fan failure and/or clogged filters via an indication light or warning signal. Dirty or poorly designed filters can increase pressure drop by up to 20 times.[4]

H. **Multiple-stage heating** reduces heating energy and equipment cycling during low to medium loads. This is particularly effective with large equipment and electric resistance heating.

I. **Notched V-belts** can improve supply fan drive efficiency by 2-10 percent.[16]

J. **Dual compressors** – see section 2.1.5.

K. **Evaporative pre-cooling** packages are available to pre-cool outside air and cool the air flowing over the condensing unit. Pre-cooled air is then dehumidified across the unitary cooling coil. This option may result in large energy savings and equipment downsizing in facilities with high outside air requirements.

L. **Air-to-air heat exchangers** can be cost effective when a large amount of ventilation air is required.

3 AIR DISTRIBUTION

3.1 ZONING

3.1.1 Benefits

Proper zoning provides greater comfort, reduces energy use due to over-conditioning, and reduces equipment wear. In some cases, separating central and special use zones can eliminate the need for heating equipment in these areas.

3.1.2 Best Practices

A. When possible, provide separate zones for areas with different occupancies and demand profiles. This has a higher initial cost, but will provide greater comfort and may help avoid retrofits.
B. Group areas with similar occupancies and demand profiles together into common zones. Factors affecting demand profile are exposure to exterior surfaces (especially windows), orientation with respect to the sun, equipment and people loading, activities, and ventilation requirements.
C. Isolate areas with specific conditioning requirements and provide separate zoning or air handling units, if necessary. Examples of this are computer rooms, exercise rooms, chemical storage, and clean rooms.
D. For larger systems, variable air volume is recommended when a method for reducing fan power and/or compressor power is provided. See Section 3.2.

3.2 DISTRIBUTION SYSTEM TYPES

3.2.1 Best Practices for Constant Volume (CV) Systems

This simple and common type of system provides a constant amount of airflow to the zone it serves.

A. Avoid inefficient terminal or zone reheat for constant volume systems. When supplied with temperature reset, this type of system becomes a constant volume/variable temperature system (CVVT). The efficiency is increased somewhat but humidity problems can result.[4] To avoid humidity problems, provide a relative humidity sensor in the return air ductwork. The sensor will indicate when the temperature of cooling air should not be raised.
B. When the size of the building permits, serve zones with similar solar exposure and loads, and in reasonable proximity from the same air handling unit. For example, serve south/west perimeter offices from one unit, north/east perimeter offices from a second unit, and central spaces from a third unit. Central spaces of office buildings often do not require heating due to heat gain from internal loads.

3.2.2 Best Practices for Variable Air Volume (VAV) Systems

Variable air volume systems meet changing loads by adjusting the amount of airflow to the zones. Airflow is modulated by zone dampers and varying the fan output. VAV systems can substantially reduce fan and cooling energy.[4]

A. For blowers over 1 hp, use fans with adjustable-speed drive (ASD) or variable pitch fan blades for the highest efficiency.
B. For blowers under 1 hp, select electronically commutated motors (ECM).
C. Multi-speed motors are less efficient and less effective than adjustable-speed drives or variable pitch fan blades. Avoid outlet dampers and duct bypass for varying airflow.
D. Avoid pairing centrifugal fans and forward-curved fans with variable-inlet guide vanes.
E. Static pressure reset control can improve VAV system efficiency by reducing the static pressure during part-load operation. Place the static pressure sensor two-thirds of the way to the furthest diffuser.[4]
F. Use VAV boxes with linear-response dampers, DDC control and adjustable minimum openings.[4]
G. Commission systems carefully according to Section 5 and the manufacturer's instructions.

3.2.3 Best Practices for Constant to Variable Volume Retrofits

This is a widely employed energy-saving retrofit, since average airflow requirements are about 60 percent of full constant-volume flow. In a study of 10 medium-to-large commercial VAV retrofits nationwide, payback periods ranged from 3-12 years.[4]

A. Follow specifications for 3.2.2 above.
B. Consider fan staging for parallel operation fans.
C. Commission systems carefully according to Section 5 and the manufacturer's instructions.

3.2.4 Best Practices for Variable Volume and Temperature (VVT) Systems

VVT systems vary the volume and temperature of supply air to respond to zone loads with minimal reheat. As cooling loads drop, the supply air volume is lowered and temperature is raised, reducing condenser, reheat and fan power. VVT systems are very energy efficient and are cost effective in larger systems (20-30 tons).

A. Follow specifications for 3.2.2 above.
B. Optimize the tradeoff between resetting supply air temperature and lowering supply air volume.
C. Commission systems carefully, according to Section 5 and the manufacturer's instructions.
D. Avoid air bypass systems to achieve variable volume. Variable volume should be designed to result in decreased fan power.
E. Improper design can result in increased energy use and faulty operation. VVT may not be practical when zones have very diverse loads.

3.3 DUCT SYSTEM TYPES

A. **Low Pressure, Low Velocity Ductwork** – The majority of small- and medium-sized commercial duct systems operate at velocities below 2500 fpm and pressures below 2" w.g. Energy-efficient installation practices can minimize pressure drop, temperature rise and air leaks in these systems, which represent a major potential for energy savings.

B. **Plenums and Chases** – Air plenums and chases are typically building cavities, such as spaces above suspended ceilings, wall cavities, mechanical closets and soffits. Plenums and chases can shorten ductwork runs and reduce pressure drop, thereby reducing construction and energy costs. Many of these airways are extremely leaky and may be poorly insulated, which can cause comfort problems and increase energy use. Energy-efficient installation practices can increase the efficiency of these convenient airways.

C. **Displacement Ventilation** – This type of system feeds low-pressure laminar airflow through the conditioned space, often from a floor plenum. Very little ductwork is required and fan energy requirements are low. As these systems are new to the United States, they are not included in this specification. For more information see the E Source Technology Atlas Series, Volume II, Cooling.[4]

D. **High Pressure, High Velocity Ductwork** – These systems are not commonly used with unitary equipment up to 30 tons and are not included in this specification.

3.4 DUCT SYSTEM PARAMETERS

3.4.1 Benefits

Designing air distribution systems to avoid excessive duct lengths/fittings, high air velocities, and pressure drop can have a major impact on energy. For a given airflow rate, doubling the duct diameter reduces duct pressure drop by 75 percent. Even an increase of one standard duct size can generate significant energy savings.[4] Energy-efficient duct design also includes locating ducts to minimize thermal and leakage losses. These practices promote proper air distribution while reducing noise and energy use.

3.4.2 Duct Location

A. **Ducts in conditioned space** are the most energy-efficient duct location. Heat gains and losses are minimized and go directly to the conditioned space.

B. **Ducts in unconditioned space** are located outside the building thermal barrier, such as attics, basements or covered parking areas. Attics are often hotter than outdoors, resulting in high conductive heat transfer through the ductwork and leakage of unconditioned air into the HVAC system. When ducts are located in an attic, locate them underneath insulation whenever possible.

C. **Building cavities used as ducts**, such as enclosed support platforms, mechanical rooms, ceiling spaces, wall and cavities and chases, are usually less airtight than standard ducts and plenums.

D. **Ducts outside the building** incur the greatest thermal losses and energy penalties, especially when exposed to solar gain. Factors affecting losses include air leakage, heat conduction, solar radiation, and solar reflection effects.

E. **Duct location recommendations**
   1. Locate ductwork within conditioned space whenever possible.
   2. Plan locations to minimize duct lengths, turns and fittings.
   3. Avoid locating ductwork in exterior walls where the ductwork may displace wall insulation.
   4. With the exception of ceiling return plenums and under-floor air delivery, building cavities should not be used for air distribution.[21] Enclosed air-handler support platforms are one of the largest source of leaks in a system.
   5. When chases, furred spaces or other cavities (except ceiling return plenums) are used for air pathways, provide sealed ductwork within the cavity to convey the air.
   6. Ceiling spaces should only be used as return-air plenums when the thermal insulation is located above the plenum.
   7. Ducts in unconditioned spaces and outside the building should be well insulated per Section 3.5.5. Locate away from sources of heat and in shaded areas when possible.
   8. Unconditioned attic spaces containing ducts should be well ventilated.

3.4.3 Ductwork and Accessory Selection

A. **Round ducts** – Round, smooth galvanized-steel ducts are recommended for maximum air-carrying capacity with minimum pressure loss. Round ducts require 27 percent less metal per unit of air-handling capacity than rectangular ducts and have lower installation costs, which may result in substantial capital cost savings. They are also quieter during operation and easier to fabricate and seal than rectangular ducts.[4]

B. **Rectangular ducts** – When rectangular ducts must be used due to space limitations, keep the width-to-height ratio close to 1:1 for lower pressure drop.

C. **Flexible ducts** – Minimize flexible duct use, which can increase pressure drop by 63 percent compared with galvanized-steel ducts.[4] Limit use to diffuser connections with a maximum length of 10 feet each. If flexible ducts must be used, size and install ducts for low pressure drops.

D. **Fiberglass ducts** – Avoid rigid fiberglass ducts and fiberglass-lined ductboard, which increase pressure drop by 28 percent and 41 percent, respectively, compared with galvanized-steel ducts.[4] The fibers may also enter the air stream and/or provide a medium for microbial growth.

E. **Fitting and accessories** – Consult the *ASHRAE Handbook – Fundamentals*[2c], *ACCA Manual Q – Low Pressure, Low Velocity Duct System Design*[5b] and/or *SMACNA HVAC Systems – Duct Design*[12d] to select fittings and accessories with low pressure drop.

F. **Air terminals** – Select an outlet length:width ratio close to 1:1 to minimize pressure drop.[5c]

G. **Outlet collars** – Use a 4" long collar on ceiling, low wall and exposed duct connections to supply outlets. This collar length decreased pressure drop across the outlet by approximately 20 percent.[5c]

H. **Silencers** should be avoided as they add substantial pressure drop, resulting in increased fan energy. Where necessary, select passive silencers with minimal flow restriction. A silencer can be field-built by forming concentric duct sections and filling the interior space with sound-absorbing material such as fiberglass laced with barium or another density-increasing element. The inside surface should be perforated to allow the sound to penetrate the absorbent material.[4] Another simple but effective silencer can be made by forming 6-8 feet of flexible duct into a smooth "S" shape.

3.4.4 Duct System Design

A. Calculate system and room/zone cfm's as described in Section 2.1.2. Rule-of-thumb sizing, which is typically used, does not account for internal load variations, modern equipment, controls or codes and can result in incorrect airflow assignment.

B. Design duct systems using the procedures described in *ASHRAE Handbook – Fundamentals*[2c], *ACCA Manual Q – Low Pressure, Low Velocity Duct System Design*[5b] and/or *SMACNA HVAC Systems – Duct Design*.[12d]

3.4.5 Duct Layout

A. Plan duct layout to minimize duct lengths, turns and fittings while providing good air distribution.

B. Install radius or section elbows at > 45-degree turns.

C. Install turning vanes in supply ducts that turn immediately below a roof penetration. Use vanes with airfoil shape to reduce pressure drop in corners. Correct vane settings are critical. Improper vane settings can result in pressure drops as high as 200 percent of normal.[5c]

D. Ceiling return plenums, when constructed for reasonable air-tightness can reduce construction costs, pressure losses and fan energy.

E. In conditioned rooms without return registers, provide transfer grilles from the room to general return air area. An alternative is to ensure that undercut doors are provided with sufficient free area for face velocities under the door of 100-300 fpm.

F. Avoid opposed-blade dampers. These dampers cannot be relied upon to take more than ¼ - ½ closure without noise.[12a] For air balancing, provide accessible volume dampers near the branch take-off.

G. Avoid designs which require airflow to turn immediately before/after a supply/return outlet.[5c] Installing inlet vanes at return outlets and extractors at supply outlets can reduce pressure losses and correct airflow in sharp turns.

H. Use smooth wye branch fittings.

I. The first elbow in the ductwork leaving the unit should be no closer than 2 feet from the unit, to minimize resistance and noise.[30]

3.4.6 Duct Velocity

A. Size ductwork and airside components for maximum velocities listed in *ACCA Manual Q*[5b], *SMACNA HVAC Systems – Duct Design*[12d], or the *ASHRAE Handbook – Fundamentals*.[2c]

B. Duct-sizing calculators for galvanized steel ducts based upon data from ASHRAE, SMACNA and/or ACCA are useful during design and installation. For flexible ducts, use calculators or charts available from the duct manufacturer or consult the ADC's *Flexible Duct Performance & Installation Standards*.[24] Although duct-sizing calculators are useful for sizing run-outs and very simple duct systems, duct systems with more than a few branches should be properly sized as specified in 3.4.6.A. The maximum velocities specified in 3.4.6.A should be applied when using duct-sizing calculators.

3.4.7 Design Pressure

A. First and operating cost considerations dictate that duct systems should be designed to operate at the lowest possible static pressure.[5b]

B. A shorter total effective duct length (straight run length plus fitting equivalent length) will result in lower pressure losses and lower operating pressure.

C. Select low pressure drop fittings and accessories. Well designed aerodynamic fittings are more expensive but their use is justified because the lower pressure losses result in more economical operation.[5b]

D. Ensure that there is adequate static pressure for proper operation of air side devices such as flow regulators, mixing boxes, distribution boxes and air terminals.

3.5 DUCTWORK INSTALLATION

3.5.1 Benefits

Energy-efficient installation practices can have a major impact on energy costs. Field studies conducted by the Lawrence Berkeley National Labs show that in light commercial buildings supply duct leakage averages 26 percent of the fan flow. Furthermore, computer simulations demonstrated that in large commercial buildings, 20 percent supply leakage into conditioned space can result in a 60-70 percent increase in [constant volume] fan power corresponding to approximately 1 kWh/yr-ft^2 of wasted energy.[19] Even duct leakage within conditioned spaces wastes energy by forcing the fan to operate at higher pressures to deliver air to the intended zones.

Because access for repairs is usually limited, poorly installed duct systems (that must later be resealed) can cost more than a proper installation.[2e] Energy-efficient installations reduce troubleshooting time, maintenance, repairs, comfort problems, disputes and business interruption, while lowering energy costs.

3.5.2 Duct Construction

A. Metal and flexible ducts should be constructed, installed, and connected in accordance with *SMACNA HVAC Duct Construction Standards – Metal and Flexible*, 1995.[12a]

B. Provide duct sealing as specified in Section 3.5.4 below.

C. Connect ducts so that protruding edge of male joint points downstream to reduce friction and turbulence.[4]

D. Avoid compression, kinking and bending of flexible ducts. This increases already large pressure drops associated with flexible ducts.

E. Perform frequent inspections of the duct system during construction, while ducts are accessible, to ensure adherence with correct installation and sealing procedures.

3.5.3 Air Plenum Construction

A. Air plenums should be inspected carefully for leak sites, such as pipe and conduit penetrations, joints in building boards, holes in construction, etc. Holes and seams should be sealed with expandable foam, fibrous mastic, or mastic with mesh tape.

B. T-bar ceilings used as return air plenums should be constructed carefully to minimize leaks between the plenum and the outdoors or unconditioned spaces. The barrier between the plenum and conditioned space need not be airtight, with the exception of large leaks that may cause short circuiting of room supply and return air. Extra ceiling tiles should be provided to replace broken tiles.

C. Ceiling spaces should be used as return air plenums only when the thermal and air barrier are located at the roof or if there is conditioned space above.

3.5.4 Duct Sealing

A. Seal all ducts, including ducts in conditioned space, in accordance with the minimum requirements of Tables 6.2.4.3A and B of *ASHRAE 90.1-1999.*[2a]

B. Seal openings greater than 1/16” wide at duct, plenum and cabinet joints and where equipment such as pipes, conduits, damper levers and sensors penetrate ducts.

C. Approved sealants are flexible gaskets, fiber-reinforced mastic or mastic used with mesh tape. Sealants should be UL 181 listed, water based, non-toxic and water resistant with a high solids content. Sealants used outdoors shall be rated for outdoor use and resistant to weather and solar degradation.

D. Oil base caulking and glazing compounds should not be used.[12b]

E. Apply sealants according to the manufacturer’s instructions with proper surface preparation and in correct temperature conditions.

F. Gaskets should be made of durable materials such as soft elastomer butyl with adhesive backing.

G. Cloth-backed duct tapes should not be used. Pressure sensitive tapes in general are not recommended. Duct systems sealed with mastics generally exhibit lower leakage.[7] If tape is used, methods and materials should comply with the *ADC - Flexible Duct Performance & Installation Standards*.[24]

H. Ensure that the ductwork connections to the air handling units or curb (as specified by the manufacturer) are sealed airtight and that the seals can withstand vibration. This is a common site for large leaks.
I. Provide airtight seals at duct connections to air outlets, duct access panels and equipment cabinet panels. These are commonly overlooked sites for leaks.
J. Do not apply sealant in spiral duct lockseams. This can result in poor seam closure and less satisfactory control.[12b]

3.5.5 Duct Insulation and Liners

A. Insulate ducts in accordance with the minimum requirements of local codes or Section 6.2.4.2 of *ASHRAE 90.1-1999*[2a], whichever are more stringent.
B. Insulation exposed to weather should be suitable for outdoor service and provided with a weather-protective covering. Cellular foam insulation should be provided with a weather-protective covering or painted with a coating that is water retardant and provides shielding from solar degradation of the material.[2a]
C. In cooling load-dominated areas, ducts located on roofs should be covered with a highly reflective coating. In a California retrofit involving additional insulation and a highly-reflective coating applied to the roof and ducts, average air conditioning energy use was reduced by 22 percent.[22]
D. Externally insulated ducts should be sealed according to Section 3.5.4 before being insulated.
E. Avoid compressing insulation against building or hangers.
F. Avoid the use of acoustical duct liners. The fibrous, coated or foam surfaces increase pressure drop by 50-250 percent.[4] In addition, the fibers may enter the air stream and/or provide a medium for microbial growth. To control noise, size airside components for maximum velocities for controlling noise generation listed in Appendix 3 of *ACCA Manual Q*.[5b] Avoid locating air terminals in close proximity to air-handling units. Provide at least one change in direction between air terminals and air-handling units.

3.6 EVALUATION OF EXISTING DUCTWORK SYSTEMS FOR RETROFIT

Duct systems or portions of the system can sometimes be reused in retrofits to save material and construction costs. The existing equipment should be carefully evaluated to prevent equipment failure, energy losses, comfort problems, poor performance and/or extra costs.

A. A qualified ductwork contractor or service technician should thoroughly inspect and evaluate the existing ductwork to generate recommendations and cost estimates for reconditioning ductwork that is suitable for reuse. The technician should also estimate the age and remaining life of the materials and installation. The evaluation should be based upon upgrading and reconditioning the systems to the standards described in Section 3.7.
B. Duct materials, accessories, sealants, insulation, coatings, liners, fasteners and supports should be inspected for dirt, corrosion, degradation and damage.
C. The air distribution system, duct types, locations, layout and installation should be evaluated for compliance with the energy-efficient practices described in this document.

D. If duct sizing or location is inappropriate, consider relocating equipment for use in an upgraded design.
E. Weigh the costs of reusing the system, upgrading the system, and replacing the system with the long-term energy costs and savings.
F. If equipment cannot be reused, consider salvaging and/or recycling the materials.

3.7 RECONDITIONING EXISTING DUCTWORK SYSTEMS

3.7.1 Benefits

In a study of 70 small commercial buildings in central Florida, cooling energy decreased an average of 14.7 percent from repair of uncontrolled airflow, which improved the air-tightness of the duct systems by 58 percent.[10] A conservative estimate of 0.5 kWh/sq. ft.-yr. energy savings is attributed to repairing duct leaks.[25] These savings, along with enhanced comfort and system performance, provide incentives for reconditioning leaky duct systems.

3.7.2 Best Practices

A. Visually inspect the duct system to determine the quality of existing construction, sealing and insulation.
B. Replace damaged equipment such as duct sections, diffusers, fittings, supports, fasteners and insulation in accordance with Section 3.5.
C. Clean ductwork, if needed.
D. Where leaks are apparent or where existing duct sealing is of low quality, reseal ductwork in accordance with Section 3.5. As an alternative, aerosol sealing is a new technology that is proving itself successful in sealing duct leaks in commercial buildings. This technology is now available and recommended for small commercial systems needing moderate-to-extensive leakage repair. It requires little business interruption and can be implemented with minimal duct access.[19] Currently there is a limit to the size of duct system that may be successfully aerosol-sealed.
E. Upgrade the duct insulation, if necessary, to comply with levels and installation specified in Section 3.5.
F. The reconditioned system should be commissioned in accordance with Section 5.

4 CONTROLS

4.1 BENEFITS

Effective HVAC system controls can greatly reduce energy costs by optimizing and scheduling equipment operation, varying equipment output with loads, managing peak loads, enabling energy conserving modes and preventing improper operation of equipment.

4.2 BEST PRACTICES

A. Controls should be installed for energy-efficient HVAC system operation in accordance with ASHRAE 90.1-1999.[2a] This includes:
   1. Programmable Thermostatic Controls

2. Off-Hour Controls
3. Heat Pump Auxiliary Heat
4. Humidification and Dehumidification
5. Freeze Protection
6. Ventilation Controls for High-Occupancy Areas
7. Economizers
8. Simultaneous Heating and Cooling Limitation
9. Fan Power Limitation
10. Variable Air Volume (VAV) Fan Control
11. Condenser Fan Speed Control

B. All controls should be commissioned per the manufacturer's instructions and Section 5.

C. Control components should be well labeled with designation, function and associated zone(s).

D. Thermostats and temperature sensors should be located away from sources of heat, cold, direct sun, and drafts. Thermostats should be mounted on insulated backing and located on interior walls.

E. Dual compressor units should be installed with two-stage cooling controls. Controlling a dual compressor unit with single-stage controls can result in increased energy use and unit wear.[7]

F. See Section 3.2 for Variable Air Volume (VAV) and Variable Volume and Temperature (VVT) systems.

4.3 CONTROLS RETROFITS

4.3.1 Benefits

Faulty or outdated controls can result in excessive energy use, incorrect system operation and poor comfort. Simple or sophisticated controls retrofits may be very cost effective.

4.3.2 Evaluating Existing Controls

A. **Occupancy scheduling** – Scheduling features can prevent or reduce system operation and energy use during unoccupied periods. This retrofit can be as simple as replacing thermostats or adding a time clock.

B. **Load scheduling** to reduce peak demand can result in substantial cost savings in larger facilities. System-wide controls can accomplish this.

C. **Part-load operation** for facilities with substantial part-load operation, retrofitting controls for adjustable or staged operation will save energy and equipment wear.

D. **Pneumatics** – Aging, poorly maintained pneumatic systems are often candidates for replacement with an electronic system.

E. **Enthalpy sensors** – Older enthalpy sensors may use plastic film or thin filament that have high failure rates. Modern solid-state electronic sensors are much more reliable.[23]

F. **Sensor locations** – In areas subject to sources of heat, cold, draft or corrosion often result in poor system operation. Relocating controls and replacing damaged sensors can substantially improve performance.

G. **Damaged equipment** may be an opportunity to upgrade to a higher performance system.

H. **Energy monitoring** may be desirable for tracking/metering operation and costs.

4.4 SYSTEMWIDE CONTROLS

A. **Multi-zone time clocks** provide simple on/off scheduling for multiple zones. They are useful for facilities with frequent unoccupied periods.

B. **Direct digital control (DDC) energy management systems (EMS)** provide a universal, centralized, expandable and networkable system of programmable, automatic controls for scheduling, optimizing, monitoring and operating all aspects of building systems, including HVAC. A major advantage of an EMS is the ability to optimize and integrate system controls and functions into a more efficient package. Multiple facilities can be controlled through network or modem lines.

1. DDC systems are usually designed by the distributor or installing contractor to the owner's performance specifications. To ensure correct equipment and programming, provide detailed specifications for scheduling, operation sequencing, user software, user accessibility, intersystem compatibility, future expansion needs and any other desired features.
2. Initial hardware and software programming should be performed by a manufacturer's representative to the owner's specifications.
3. A basic training program should be provided by a manufacturer's representative for owner's personnel. More advanced training and refresher courses are recommended for the owner's service personnel to fully utilize energy-saving features and prevent incorrect operation.

4.5 FAN CONTROLS

4.5.1 Benefits

Theoretically, the power required to blow air in ductwork varies with the cube of the flow (know as the cube law). In a constant volume system, halving the flow cuts the required power by a factor of eight, making fan modulation very effective for cutting energy costs. With variable volume systems, care should be taken to provide minimum ventilation air to avoid air stagnation and indoor air quality problems. The methods described below can be used in new or retrofit systems.

4.5.2 Methodology

A. **Adjustable speed drives** are the most efficient of the fan modulating methods. A controller varies the speed of the fan(s) to reduce airflow to the zones. Proper operation involves careful placement of pressure transducer/sensor, adjustment of the system and commissioning/programming of controls in accordance with manufacturer's instructions. Poorly commissioned systems can negate energy savings.

B. **Multi-speed motors** are sometimes available with dual compressor units.

C. **Inlet guide vanes and outlet dampers** are not recommended. They may not increase efficiency and can sometimes increase energy use.

4.6 NIGHT VENTILATION

4.6.1 Benefits

Night ventilation strategies use the air-handler and economizer controls to flush the building with cool outside air at night to cool the building mass. The mass then absorbs heat the next day to help keep the building cool. This strategy works well buildings with significant mass (slab floor) and cool night temperatures. Computer analysis of the relative effectiveness of night ventilation cooling in reasonably dry climates show cooling cost savings range from 5 percent in Phoenix, Arizona, to 18 percent in Denver, Colorado.[26] Night ventilation is usually not effective in humid climates.

4.6.2 Best Practices

A. Approximately one square foot of exposed masonry per square foot of floor area is needed for effective cooling storage.

B. In multi-story buildings, a favorable arrangement couples the floor slab of one floor with the return air plenum of the floor below.

C. During unoccupied periods, when the outdoor temperature is at least 5.5°F less than the indoor air temperature, 100 percent outside air is delivered until the indoor temperature drops to 57°F.[4]

D. The cost-effectiveness of night ventilation is increased when night electricity rates are lower than daytime rates.

5 HVAC COMMISSIONING – NEW AND EXISTING SYSTEMS

5.1 BENEFITS

Commissioning is important to verify correct installation and operation of new and retrofit HVAC components and systems. Proper commissioning is crucial for setting, adjusting or programming items such as economizers, refrigerant charge, fans, controls and damper positions. Uncommissioned facilities are often plagued with high energy costs, poor comfort, repairs, business interruption and disputes. The average price to commission a typical new office building is 2-5 percent of the installed cost of the commissioned equipment, resulting in annual operational costs 8-20 percent less, compared to the same uncommissioned building. [18]

5.2 GENERAL

This document highlights commissioning of components that affect energy efficiency and is meant as a supplement to manufacturer's instructions and recommendations. The Contractor should fully comply with manufacturer's instructions and recommendations and applicable codes and standards.

5.2.1 Existing/Retrofit Systems

For existing and retrofit systems, follow the applicable procedures in Section 5. If system evaluation or reconditioning is planned, it should be done in conjunction with commissioning (see Sections 2.2.3, 3.6, 3.7 and 4.3).

5.3 COMMISSIONING PERSONNEL

Commissioning should be provided by the HVAC Contractor and performed by personnel with appropriate qualifications. Final testing and balancing should be performed by a qualified third-party agency. The Contractor should coordinate the participation of equipment manufacturer's representatives as needed.

5.4 DOCUMENTATION

The Contractor should provide three copies of commissioning documentation to the Owner, including a Commissioning Plan, Commissioning Report and Operation & Maintenance Manual, as described below.

5.4.1 HVAC Commissioning Plan

Before the start of construction, the Contractor should submit a Commissioning Plan to the Owner, including the following sections:[2d,29]

- **Commissioning Team** – commissioning personnel and agencies including qualifications and certifications.
- **Design Intent** – as-built drawings, controls schematics, equipment specifications and a description of the system operation and controls sequences.
- **Scope of Work** – outlining commissioning tasks for all systems impacted, installed or retrofitted by the Contractor.
- **Schedule** – of tasks, inspections, tests, and training programs. Notify the Owner at least three days prior to each event so that a representative may be present.
- **Procedure** – a brief description of each task including forms and checklists.
- **Equipment List** – including calibration records.

5.4.2 HVAC Commissioning Report[2d]

- Installation verification records.
- Functional test records.
- Adjustment and calibration records.
- Test and balance reports.
- Corrective action notices.
- Manufacturer's reports and certification records.
- Records of changes to installations or design, including Owner's approval notices.
- Observations, recommendations and conclusions.
- Certification of readiness for all systems.
- **Report Format** – Include the following information for each commissioning task:
  - The name of the company and technician.

  - The date and time.
  - The mark, make, model number and type of equipment being commissioned.
  - List of equipment used in commissioning, including serial number.
  - List of materials, lubricants, etc. used.
  - Intended design/operation basis or specification.
  - Record of commissioning steps, results, deficiencies, and observations.
  - Name, signature and comments from Owner's witness.

5.4.3 Operation and Maintenance Manual[2d]

- Updated as-built drawings.
- Complete wiring diagrams, controls schematics and sequences.
- Equipment submittals including manufacturer's performance data, installation, operation, and maintenance manuals, programming and training materials.
- Detailed descriptions of operation and controls for each system and major component, including start-up, all modes of operation, shutdown, safety precautions, emergency and seasonal instructions.
- Monthly, quarterly and yearly procedures for all components detailing maintenance and replacement requirements, including specifications and supply information for all lubricants, parts and materials needed.
- Listing of the name, address and telephone number for each installing contractor and local manufacturer's representative for each major component.
- Test procedures, including utility, fire department, Owner and tenant notification.
- Material Safety Data Sheets including disposal and handling instructions.
- Copies of all contractor and manufacturer warranties.

5.5 COMMISSIONING BEST PRACTICES

- **Verification** of correct installation procedures, per the design documents, applicable codes, these specifications and the manufacturer's instructions. Inspections should be made at key points during construction, before components are enclosed from view, and at completion of each system.
- **Programming** of equipment for proper operation, including, but not limited to:
  - Setting controls, limits, lockouts and other parameters for each component.
  - Programming/setting thermostats and time clocks to Owners specifications.
  - Installing software for energy management systems to Owner's specifications.
- **Functional testing** to verify correct operation and performance in all modes.
- **Calibration and adjustment** of equipment per manufacturer's instructions.
- **Correction** of items not complying with design and manufacturer's specifications.
- **Start-up** and demonstration tour of the completed systems.
- **Training** for the Owner's representatives as described in Section 5.10.
- **Post-acceptance commissioning** – continued adjustment and optimization of the HVAC system, including maintenance and on-going training of service personnel.

5.6 COMMISSIONING UNITARY EQUIPMENT

5.6.1 General

- Verify correct installation per Sections 2.4, the design documents, codes and manufacturer's instructions.
- Prior to installation, verify clearance and location requirements.
- Ensure that curbs and pads are level before installation.
- Check duct connections and sealing during and after installation.
- Verify sizes, installation, and operation of piping and electrical connections.
- Verify flexible pipe, conduit and duct connections where specified.
- Verify installation of specified options and accessories.
- Check unit for damage and corrosion.
- Perform functional tests of all operation modes, interlocks and emergency modes per the manufacturer's instructions (Section 5.6.2).
- With duct system fully pressurized, check for air leakage at unit cabinet panels, roof curb and at duct connections to unit.
- Check the unit during operation for excessive or unusual vibration or noise.
- Install clean filters before testing. Never operate units without filters.
- Strictly adhere to manufacturer's safety warnings and recommendations.

5.6.2 Functional Testing for Roof Top Units (Rtu)[35]

Equipment Needed: Four temperature and humidity loggers with software, psychometric chart, Rtu manufacturer's literature, and the airflow Test and Balance Report (Section 5.8). The temperature and humidity loggers should be equivalent to Hobos, by Onset Computer Corp.

Step 1 Testing:

- Install the temperature and humidity loggers on four positions – outdoor air (Oa), supply air (Sa), return air (Ra) and mixed air (Ma) temperatures. The mixed air temperature is the combination of Ra and Oa that is entering the evaporator coil.
- Set the loggers to record at least one-minute intervals and leave in place during the commissioning process.
- Check the Rtu economizer and Oa dampers when the Rtu is not running. They should be in the closed position.
- At the Rtu control panel, set the Oa potentiometer to the required minimum Oa intake set point. Adjust the Oa intake dampers to a position where they deliver the code-required outside air.
- For enthalpy-controlled economizers, make sure that the fan and compressors are operating. Set the differential enthalpy controller on the Rtu control panel to its minimum set point. The economizer damper should be at its minimum Oa intake position. Set the controller it to its maximum set point. The economizer damper should move to 100 percent open.
- For differential temperature-controlled economizers, apply an ice pack to the Oa temperature sensor. As the Oa temperature drops below the Ra temperature, the

economizer damper should move to the 100 percent open position. After a couple of minutes, the sensor will drop to below its minimum Oa temperature set point. The economizer damper should return to its minimum Oa intake position.

Step 2 Testing: Remove the loggers and load the data into a computer. Use Ma and Sa temperature data that was recorded before the Oa air damper was set.

- From the Test and Balance Report, record the total cfm delivered by the Rtu.
- Refer to the manufacturer's literature and record the total capacity and the sensible heat capacity at the recorded evaporator entering wet bulb temperature, the entering condenser air (Oa) temperature and at the recorded cfm from the Test and Balance Report.
- Plot the average of the recorded Ma and Sa temperature and humidity data on a psychometric chart.
- From the psychometric chart, record the enthalpy difference in Btu/lb. of air.
- From the Rtu cfm data and the psychometric chart, calculate the total pounds of air delivered to the space.
- Multiply this by the difference in enthalpy per pound of air to determine the total heat capacity of the Rtu.
- Calculate the delta T across the evaporator coil by subtracting the Sa temperature from the Ma temperature. Multiply this by 1.08 and the recorded cfm. This is the sensible heat capacity of the Rtu. (The 1.08 multiplier should be adjusted for locations that are significantly above sea level.)
- Compare these calculated total heat and sensible heat capacities to the reciprocal data from the manufacturer's literature. For normal operation, the manufacturer's and the calculated capacities should be within +/- 15 percent of each other.
- Check the Oa damper setting by solving the following equation (Ma-Ra)/(Oa-Ra). This is the percent Oa that the unit is taking in to satisfy ventilation requirements. Compare this to the percent Oa setting that was made in previous steps.

Step 3 Diagnostics: The following are diagnostic conclusions that can be made after the above commissioning procedures:

- If the calculated total heat and sensible heat capacities are significantly below the rated capacity of the unit, it is an indication that:
  - The Rtu is delivering considerably more air across the evaporator coil than is shown on the Test and Balance Report. This could be an indication that the ductwork system is leaking air. Investigate the duct system and correct air leaks.
  - The vapor compression system is low on its refrigerant charge. For new Rtu's, this is a warranty issue and should be corrected by the manufacturer.
- If the calculated total heat and sensible heat capacity are significantly greater than the rated capacity of the unit it is an indication that:
  - The Rtu is delivering considerably less air across the evaporator coil than is shown on the Test and Balance Report.
  - The vapor compression system has a refrigerant over charge. For new Rtu's, this is a warranty issue and should be corrected by the manufacturer.

- If the calculated percent Oa is significantly greater or lower than the percent Oa set point on the Rtu control panel, readjust the set point in proportion to the calculated error. The Ra, Oa and Ma temperatures should be rerecorded and the set point checked again.
- If the economizer damper fails to operate during any of the test, this is a warranty issue and should be corrected by the manufacturer.

5.6.3 Air Handling Equipment

- Verify installation of efficient motor/control options, where specified.
- Verify installation of smoke detector interlock, where required by code.
- Install clean filters prior to testing and start-up.
- Check the condition of the fan wheels and housings, belt tension and fan motor shaft bearings of existing equipment.
- Check for correct rotation of fan.
- Check for proper speed settings.
- Test blower per Section 5.8 – Testing and Balancing.

5.6.4 Cooling Equipment

- Check cooling coil for correct size.
- Clean cooling coils if needed.
- Check and clean (if needed) condensate drain pans and lines.
- Check condensing units for fin damage.
- Check operating pressures at gauge ports of discharge and suction line valves.[30]
- Verify and adjust refrigerant charge as described in Section 5.6.5.
- Check for proper compressor rotation. With service gauges connected to the suction and discharge pressure fittings, the suction pressure should drop and the discharge pressure should rise when the compressor is energized. If compressor rotation is incorrect, the evaporator fan rotation is probably also incorrect. Turn off the power to the unit and reverse any two of the unit power leads. Test again for correct compressor and fan rotation.[31]
- For split-systems, verify correct refrigerant piping size and installation per manufacturer's specifications.

5.6.5 Refrigerant Charge

- Verify design airflow across coil. Low airflow under-loads the coil, drops the evaporator pressure, can surge liquid into the compressor and reduces efficiency.[7]
- Test and adjust refrigerant charge, if needed, per the manufacturer's instructions. Many new units are charged and tested before leaving the factory and may not need adjustment.
- Obtain manufacturer's refrigerant charge instructions and specifications for the specific equipment model installed. Specifications vary between units.
- Verify refrigerant charge by correlating superheat and subcooling with the manufacturer's published specifications for the measured outside air temperature. Low ambient temperatures reduce head pressure and sometimes lead technicians to add refrigerant when not needed, resulting in excessive head pressure which reduces capacity, efficiency and equipment life.[7]

5.6.6 Heating Equipment

- Verify correct size and staging of heating unit(s).
- Check and clean (if necessary) heat exchanger or coils prior to testing.
- Check heat exchanger temperature rise with manufacturer's specifications.
- Adjust heat anticipator settings, where provided.
- For gas furnaces:
  - Purge gas lines per manufacturer's instructions before testing and start-up.
  - Verify properly sized, installed and operating fuel supplies.
  - Check combustion and ventilation air passages for obstructions.
  - Check condition, operation and sequence of combustion fans and igniter. Clean, service and adjust as needed.
  - Test ignition and safety shut-off controls.
  - Test manifold pressure.

5.6.7 Economizers

- Verify correct installation/retrofit per Section 2.5, design specifications and manufacturer's instructions.
- Verify that non-corrosive materials and finishes have been supplied in corrosive environments (some coastal climates and industrial environments).
- Perform preliminary test for correct operation sequence (Section 5.6.2).
- Set lockout and high temperature limits. Settings that are too high or too low could lead to higher than necessary cooling costs. Consult with local manufacturer's representative for correct settings for the area.
- Verify complete closing of air dampers.
- Verify that mixed-air sensors are correctly installed across the flow area. These sensors are often left in the coiled shipping position.[7]
- Check for proper operation and adequate capacity of exhaust/relief mechanisms with all doors, windows and other openings closed. The building should be only slightly pressurized. Air whistling through stairwells, elevator shafts and open doors is an indication of excessive pressure.
- For existing systems also check/correct the following common problems[23]:
  - Frozen outside air damper due to corrosion.
  - Frozen, broken or disconnected linkage due to dirt accumulation or corrosion.
  - Nonfunctioning actuator or loose actuator mountings.
  - Malfunctioning, aging or incorrectly sensors. Recalibrate or replace ineffective sensors. Locate sensors per Section 4.2.

5.7 COMMISSIONING DUCTWORK SYSTEMS

5.7.1 General

A. Commissioning ductwork during construction is important because access and repairs can be difficult and expensive after installation is complete. Energy-efficient duct installation practices can have a large impact on energy costs when performed correctly, saving up to 70 percent of the fan energy used by typical systems.[19]

B. Use the *SMACNA HVAC Duct Systems Inspection Guide*[12c] during duct system commissioning for checklists, materials, tables, schematic, procedures and other useful information.

C. Observe and verify correct duct installation throughout the construction process. Notify the Owner at least three days before key point of construction to witness commissioning. Key points include:
   - ❑ At the onset of duct and plenum construction, fastening and hanging.
   - ❑ At the onset of the sealing process.
   - ❑ At the onset of insulation installation.
   - ❑ Before any ductwork, plenums, or other air pathways are concealed from view.
   - ❑ At completion of the sealing process (before insulation is installed).
   - ❑ At the completion of ductwork installation, before air testing and balancing.

5.7.2 Duct and Plenum Construction

- ❑ Verify correct ductwork and plenum construction and installation per Section 3.5.
- ❑ Verify correct system layout and sizing per the design documents.
- ❑ Verify correct fastening and connection methods and materials for all ductwork.
- ❑ Verify fire/smoke dampers, detectors, interlocks and/or blankets where required.
- ❑ Verify that access is provided where needed.
- ❑ Check and set adjustable components such as volume dampers, turning vanes, etc.
- ❑ Check that flexible duct lengths do not exceed recommended limits. Flexible duct should only be used at branch connections to air terminals with a maximum length of 10 feet. When used more extensively, verify that correct sizes are installed to minimize pressure drop.
- ❑ Check for compression, kinking or excessive bending of flexible ducts.

5.7.3 Duct Sealing and Air Leakage

- ❑ Adequate air-tightness can normally be assured by sealing the ductwork properly. Simple airflow testing should be performed during Air Testing and Balancing to verify that leakage is not excessive (see Section 5.8).
- ❑ Verify that ductwork, building cavities and plenums are sealed per Section 3.5.4.
- ❑ Prior to installation, ensure that the shelf life of all sealants has not been exceeded.
- ❑ For ceiling return air plenums, check for sealing between the plenum and the outdoors or unconditioned spaces. The barrier between the return plenum and the conditioned space need not be sealed airtight.

5.7.4 Duct Insulation and Liners

- ❑ Verify that insulation value and installation is in accordance with Section 3.5.5.
- ❑ Verify that correct adhesives and fasteners are used. Check shelf life of adhesives.
- ❑ Check that insulation is not compressed by supports or building construction.
- ❑ Verify that all fittings and accessories are insulated where required.
- ❑ Check that protective coatings and/or jackets are suitable and correctly installed.

5.7.5 Air Terminals

- ❑ Verify correct model and accessories are installed and placed correctly.

- Verify correct fastening and sealing of ductwork to air terminals.
- Verify that airflow patterns and directions are correct.
- Verify that undercut doors or transfer grilles are provided where needed.

5.8 TESTING AND BALANCING

- Notify Owner at least three days before conducting testing and balancing.
- Perform functional testing on all equipment and airflow testing and balancing according to the *AABC Testing & Balancing Procedures*.[13b]
- Each outside, supply, return and exhaust air terminal should be balanced to within 10 percent of specified cfm.[2a]
- Variable speed, variable volume distribution systems need not be balanced upstream of a pressure independent device.[2a]
- Perform a simple calculation to identify excessive air leakage. From the Testing & Balancing data, tabulate the sum of the airflow at each supply outlet. The difference between supply air at the fan and the sum of airflows at the outlets should not exceed 10 percent.[12b] If exceeded, check systems for leaks and damage.
- Using a magnahelic with a range of 0-5 Pascal, test for positive/negative pressure from zone-to-zone and from inside-to-outside. Ensure a positive pressure in hot and humid climates and a negative pressure in heating dominated climates.

5.9 COMMISSIONING CONTROLS

5.9.1 Best Practices

- Verify installation per Section 4, design documents, codes and manufacturer's instructions.
- For new unitary equipment, internal controls are usually factory set and may not need adjustment. Test for correct operation.
- For controls external to the unitary equipment, test and calibrate each sensor and adjust control settings.
- Thermostats and sensors should be located away from heat, cold or direct sunlight.
- Provide preliminary settings and programming before beginning functional tests.
- Test the strength of control signal/response for each setpoint at a defined condition.
- Test the sequence of responses to control signals at defined condition.
- Test the electrical demand or power input at defined conditions.
- Test the power quality and related measurements.
- Test control of each HVAC component, each system, and total system through all modes of normal, contingent and emergency operation, including staging, interlocks, limits, setbacks and shutdowns.
- Adjust and calibrate controls to achieve operation per the Owner's specifications.
- Provide complete programming of thermostats and system-wide controls to Owner specified schedules, setbacks, setpoints, and functions. Automatic system setbacks or shutdowns during unoccupied periods may substantially reduce energy costs.
- Repeat functional tests, if necessary, after adjustments or corrective actions. System tests may need to be repeated after a component is changed.

5.9.2 Energy Management Systems

Correct commissioning of direct digital control (DDC) energy management systems (EMS) is important due to their complexity. The Contractor should provide a basic training program for system use, operation and maintenance, as well as information on more extensive training opportunities.

5.10 TRAINING

Training programs should be conducted by the Contractor, qualified technicians and/or manufacturer's representatives. The training should include:

- Operation and Maintenance Manuals (see Section 5.4.3)
- A summary of system design intent.
- Description of operations and controls.
- A complete tour of the HVAC system demonstrations of all operating modes and locating all items requiring maintenance or adjustment.
- Emergency shutdown and notification procedures.
- Complete system maintenance training. Summary of service, repair and replacement issues.
- Training in programming, adjustment and setting of controls.
- Review of contractor and manufacturer warranties.
- Summary of contacts, resources and recommendations for further information, training and service personnel.

5.11 OPERATION AND MAINTENANCE (O&M)

5.11.1 Benefits

When a system is properly commissioned for efficient operation, continued attention to operation and maintenance protects against high energy costs, poor comfort, business interruption and costly repairs. A Louisiana project involving 23 air conditioners and a New England project with 25 commercial rooftop units showed energy savings of 11-42 percent after complete professional tune-ups.[16]

5.11.2 Best Practices

A. The Operation & Maintenance Manual should be kept updated (see Section 5.4.3).
B. Conduct O&M training per Section 5.10 with periodic retraining sessions.
C. A qualified service contractor may be an effective option for ensuring regular maintenance.
D. Periodic recommissioning per Sections 5, as applicable, is recommended after substantial changes in occupancy, equipment, function, remodeling, or to ensure/correct system operation and efficiency.

5.11.3 O&M Checklist

Operation and Maintenance should be performed in accordance with the equipment manufacturer's instructions. Typical preventative maintenance includes: [30,31,33,16]

A. Monthly
- ❑ Filter inspection/replacement.

B. Quarterly
- ❑ Check/tighten fan belts. Look for signs of wear, slippage or improper alignment.
- ❑ Grease/lube fans.
- ❑ Grease bearings.
- ❑ Clean unitary equipment cabinet and screens.
- ❑ Inspect/clean condensate pan and drain.
- ❑ Review controls settings/programming/operation.

C. Semi-Annual
- ❑ Inspect/test damper operation. Check linkages.
- ❑ Adjust/calibrate sensors.
- ❑ Adjust/calibrate thermostats.
- ❑ Adjust/calibrate pneumatic controls.
- ❑ Test/adjust economizer controls.
- ❑ Grease/lube motors.

D. Annual
- ❑ Clean evaporator coils.
- ❑ Clean condenser coils.
- ❑ Inspect/clean furnace heat exchangers.
- ❑ Test/adjust furnace controls and burner.
- ❑ Inspect/replace economizer gaskets.
- ❑ Inspect fuel and electrical systems. Check fuses.
- ❑ Inspection/adjustment of ductwork system.
- ❑ Inspect unitary equipment cabinets, mountings, etc.
- ❑ Repair seals around access doors.
- ❑ Check/adjust refrigerant charge.
- ❑ Check amp draw of compressor and fans for variation from specifications.
- ❑ Clean blower.

6 DEFINITIONS

AABC: Associated Air Balance Council.

ACCA: Air Conditioning Contractors of America.

Accumulator: In refrigeration systems, a storage tank at the evaporator exit or suction line used to prevent floodback to the compressor.

ACH: Air changes per hour.

ADC: Air diffusion council.

Aerosol-Applied Duct Sealant: A sealant that is delivered to and deposited at duct leaks in the form of aerosol particles carried by an air stream that pressurizes the duct system under controlled pressure, flow and particle-injection conditions.

Annual Fuel Utilization Efficiency (AFUE): An efficiency rating that measures the percentage of heat from the combustion of gas or oil that is transferred to the space being heated during a heating season. Based on a test protocol and meant to estimate the seasonal efficiency.

Anticipator: A small electric, variable resistance heater element in most heating thermostats which causes false indications of temperature in the thermostat for the purpose of minimizing the natural tendency of the thermostat control to override the set temperature. Setting the anticipator control properly can save energy and reduce too-frequent cycling of heating unit.

ANSI: American National Standards Institute.

ARI: Air Conditioning and Refrigeration Institute.

ASHRAE: American Society of Heating, Refrigerating, and Air Conditioning Engineers.

ASTM: American Society for Testing and Materials

Balance Point Temperature: For air-source heat pumps, the outdoor temperature at which the heat pump output, without supplemental heat, equals the heat loss of the building. A balance point temperature of less than 30^{o} F is considered ideal.

British thermal unit (Btu): The energy required to raise (or lower) the temperature of a pound of water by one Fahrenheit degree.

Btuh: The number of Btu's (British thermal units) transferred during a period of one hour.

cfm: Cubit feet per minute.

Coefficient of Performance (COP), Heating: Ratio of the rate of net heat output to the rate of total energy input calculated under designated operating conditions and expressed in consistent units.

Conditioned Space: Space in a building that is either directly or indirectly conditioned by a space-conditioning system. Examples include conditioned kitchens and bedrooms. Basements are usually considered conditioned spaces if they are not thermally insulated from the occupied spaces of the dwelling.

COP: See Coefficient of Performance.

Crawl Space: A space immediately under the first floor of a building and above the ground. Typically, crawl spaces are unconditioned.

DSM: Demand-side management

Design capacity: Output capacity of a system or piece of equipment at design conditions.

Design conditions: Specified environmental conditions, such as temperature, required to be produced and maintained by a system and under which the system must operate.

Differential dry bulb or enthalpy controls: In economizers, measure both the outside air and return air conditions and select the cooler or drier airstream to minimize the use of mechanical cooling.

Direct digital control (DDC): A type of control where controlled and monitored analog or binary data (e.g., temperature, contact closures) are converted to digital format for manipulation and calculations by a digital computer or microprocessor, then converted back to analog or binary form to control physical devices.

Drop: For cooled air, the vertical distance between the bottom of a supply air outlet and the bottom of the airstream where it reaches its terminal velocity, often assumed to be 50 feet per minute.

Drybulb Temperature: Air temperature as measured by a standard thermometer, which does not take humidity into account.

Duct Run-out or Branch: A duct running from a trunk to a terminal unit (register or grille).

ECM: Electronically commutated motor, a brushless-dc motor with built-in speed and torque controls. The ECM has the efficiency and speed control advantages of a dc motor without it's disadvantages: i.e. carbon brush wear, short life, and noise.

Economizer, air: A duct and damper arrangement and automatic control system that together allow a cooling system to supply outside air to reduce or eliminate the need for mechanical cooling during mild or cold weather.

Emergency Heat, Heat Pump: The backup heat required by some code jurisdiction in case of heat pump operation failure. Requires that the emergency heat be sufficient to maintain some minimum room temperature when the heat pump compressor is out of operation.

Energy Efficiency Ratio (EER): The ratio of net cooling capacity (in units of Btu/hr) to total electrical energy use (in units of Watts) of a cooling system under designated operating conditions.

Energy factor (EF): A measure of water heater overall efficiency.

Enthalpy: A measure of the energy content of air that takes into account both drybulb temperature and humidity.

Expansion Valve Superheat: The difference between the temperature of the external bulb, and the corresponding system refrigerant saturation temperature at the bulb location.

fpm: Feet per minute, a measure of air velocity.

HVAC: Heating, ventilating and air conditioning.

Heating Seasonal Performance Factor (HSPF): The total heating output of a heat pump during its normal annual usage period for heating (in Btu) divided by the total electric energy input during the same period.

ICC: International Code Council.

IECC: International Energy Conservation Code.

NAECA: U.S. National Appliance Energy Conservation Act of 1987.

Pascal: A metric system unit of pressure, the units for which are Newtons per square meter. There are 249.0889 Pascals per inch of water column.

Peak Block Load: Simultaneous peak load for the entire building/system.

Pick-up time: The period during which the space heating system is increasing the temperature in a conditioned space after a manual or automatic temperature setback.

Plenum: An air compartment or chamber to which one or more ducts are connected, forming part of either the supply or return systems.

Pulldown Time: For space cooling, the time required to reduce dwelling temperature to a comfortable level after a manual or automatic temperature setup.

Refrigerant Charge: The actual amount of refrigerant in the closed cooling system or the weight of refrigerant required for proper functioning of the closed refrigerant system.

Refrigerant Metering Device: This device controls the flow of liquid refrigerant to the system evaporator coil(s).

Reset: Automatic adjustment of the controller set point to a higher or lower value

R-value of insulation: The thermal resistance of the insulation alone as specified by the manufacturer in units of $h \cdot ft^2 \cdot {}^oF/Btu$ at a mean temperature of 75^o F. Rated R-value refers to the thermal resistance of the added insulation in framing cavities or insulated sheathing only and does not include the thermal resistance of other building materials or air films.

Seasonal Efficiency: The efficiency of a space heater averaged over the entire heating season. Annual Fuel Utilization Efficiency is an estimate of seasonal efficiency. Contrast this with the steady-state efficiency, the efficiency during burner operation.

Seasonal Energy Efficiency Ratio (SEER): The total cooling output of a central air conditioner in Btu's during its normal usage period for cooling, divided by the total electrical energy input in Watt-hours during the same period.

Setback: Reduction of heating (by reducing the set point) or cooling (by increasing the set point) during hours when a building is unoccupied or during periods when lesser demand is acceptable.

Set point: Point at which the desired temperature (^oF) of the heated or water cooled space is set.

Single-zone system: An HVAC system serving a single HVAC zone.

SMACNA: Sheet Metal and Air Conditioning Contractors National Association.

Space Conditioning System: A system that provides, either collectively or individually, heating, ventilating or cooling within or associated with conditioned spaces in a building.

Subcooling: The temperature of a liquid when it is cooled below its condensing temperature.

Superheat: The temperature of a vapor refrigerant above its saturation change-of-state temperature.

Supplemental Heat, Air-Source Heat Pump: Also referred to as auxiliary heat. The additional heat required to heat a building when the outdoor temperature is below the balance point temperature. As the outdoor temperature drops, more supplemental heat is needed.

Thermostatic Expansion Valve (TXV) Cooling System: A cooling system uses the TXV for regulating the flow of refrigerant into the cooling unit, actuated by the changes in evaporator pressure and superheat of the refrigerant leaving the cooling unit. The basic response of the TXV is to superheat.

Throw: The vertical or horizontal distance air travels from the face of an air outlet to its terminal velocity, often assumed to be 50 feet per minute.

UL: Underwriter's Laboratory.

Unitary Cooling Equipment: One or more factory-made assemblies that normally include an evaporator or cooling coil and a compressor and condenser combination. Units that perform a heating function are also included.

Unitary Heat Pump: One or more factory-made assemblies that normally include an indoor conditioning coil, compressor(s), and outdoor refrigerant-to-air coil or refrigerant-to-water heat exchanger. These units provide both heating and cooling functions.

Variable Air Volume (VAV) System: HVAC system that controls the drybulb temperature within a space by varying the volumetric flow of heated or cooled supply air to the space.

w.g.: Water gauge, denotes a measure of air pressure in inches of water, such as the static pressure rating of a fan or the pressure drop in ductwork.

Zone, HVAC: a space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout with input from a single sensor or averaged input from multiple sensors.

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