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design brief

INTEGRATED DESIGN FOR SMALL COMMERCIAL HVAC

Summary

Small HVAC systems are the workhorses of the light commercial building market, which represents more than half of the annual commercial new construction floor area in California. Design, installation, and operations issues can prevent these systems from performing up to their full potential. This design brief focuses on actions that the architects, engineers, and design/build contractors can take to improve the energy efficiency of small HVAC systems, reduce operating costs, and improve indoor comfort and environmental quality. These actions include:

- Practice energy-efficient design strategies such as reduced lighting power, high-performance glass and skylights, cool roofs, and improved roof insulation techniques in the overall building design.
- Size units appropriately using American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) approved methods that account for the energy efficiency strategies implemented in the design, and use reasonable assumptions on plug load power and ventilation air quantities when sizing equipment.
- Select unit size and airflow based on calculated sensible loads without oversizing. Consider increasing unit flow rate to improve sensible capacity in dry climates.
- Specify units that meet the Consortium for Energy Efficiency Tier 2 efficiency standards; and incorporate premium efficiency fan motors, thermostatic expansion valves, and factory-installed and run-tested economizers.
- Design distribution systems with lower velocities to reduce pressure drop and noise. Seal and insulate duct systems located outside the building thermal envelope.

By using recommended design methods for rooftop heating, ventilation, and air conditioning (HVAC) systems, significant improvements in operational savings, energy efficiency, and indoor comfort can be achieved.

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- Operate ventilation systems continuously to provide adequate ventilation air. Incorporate demand-controlled ventilation to reduce heating and cooling loads.
- Specify commercial grade thermostats with the capability to schedule fan operation and heating and cooling setpoints independently.
- Commission the systems prior to occupancy through a combination of checklists and functional testing of equipment control, economizer operation, airflow rate, and fan power.
- Develop clear expectations of the services provided by HVAC maintenance personnel.

Introduction

This design brief incorporates findings from a recent study of small HVAC systems in commercial buildings conducted for the California Energy Commission (CEC).[1] A total of 75 buildings and 215 roof top units were studied. The project identified a number of issues with HVAC systems that are installed and operated in the field. The problems included broken economizers, improper refrigerant charge, fans running during unoccupied periods, fans that cycle on and off with a call for heating and cooling rather than providing continuous ventilation air, low airflow, inadequate ventilation air, and simultaneous heating and cooling. Correcting these problems represents a major opportunity for improvements in energy efficiency, operations, and indoor comfort.

Why Small HVAC?

Packaged direct expansion (DX) air conditioners and heat pumps cool more than half of the total commercial new construction floor space in California.[2] Of these, single package rooftop air conditioners dominate the market, representing approximately three-quarters of the total DX system capacity.

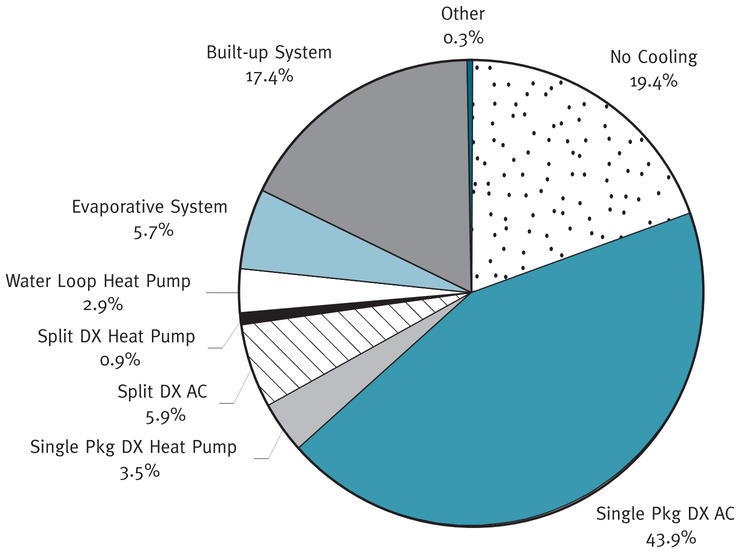
The rooftop air conditioner market is dominated by small systems, defined here as systems 10 tons and smaller, representing almost 60 percent of the total installed DX cooling capacity. The most popular unit size (in terms of units sold) is five tons (Figures 1 and 2).

These small rooftop units are the workhorses of the commercial building industry, yet many systems fail to reach their full potential due to problems with design, installation, and operation.

Figure 1: Floor space distribution of HVAC systems in new commercial buildings in California

Single package DX air conditioners are the most popular HVAC system type in new construction in the state, cooling about 44 percent of the total floorspace. Built-up systems are the second most popular, conditioning about 17 percent of the total floorspace. The combined total of single package and split DX air conditioners and heat pumps represents slightly more than half of the total floorspace in California. Note that a significant portion (about 19 percent) of the total floorspace is not cooled.

Cooling System Type Distribution by Floorspace

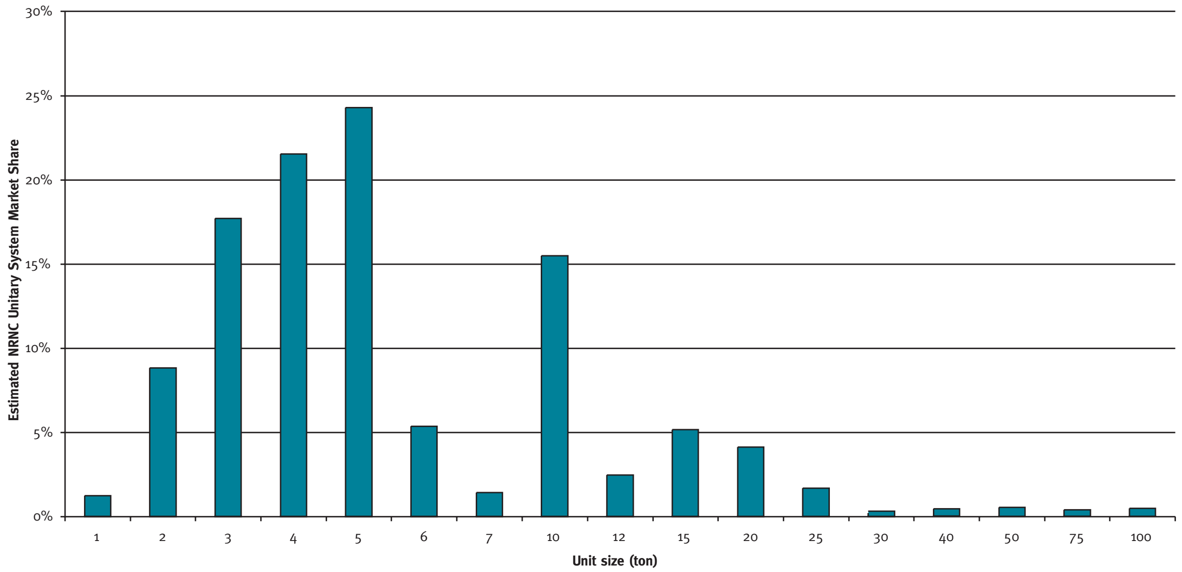


Source: Architectural Energy Corporation

Figure 2: Distribution of packaged DX system size

In terms of number of systems installed, the most popular packaged DX system size is five tons. Units between one and 10 tons represent close to 90 percent of the total unit sales in new buildings in California.

HVAC Unit Size Distribution by Quantity



Source: Architectural Energy Corporation

Building Design

HVAC systems, like all systems in the building, do not function in isolation, but are part of an interactive system of components. Before addressing the design of the HVAC system, it is important to address several aspects of building design that influence the loads imposed on the HVAC system. By including these energy efficiency strategies in the building design, the size and energy consumption of the HVAC system can be reduced.

Reduce Lighting Power

Lighting represents a major opportunity for energy savings in small buildings. Although Title 24 is one of the most stringent energy codes in the country, there is ample opportunity to reduce lighting power below Title 24 allowances. New generation T-5 and T-8 lamps, fluorescent high-bay fixtures, task/ambient lighting design, lighting controls, and daylighting represent opportunities to reduce lighting energy and the size of the HVAC system required to remove heat generated by lighting systems. Lighting amounts to approximately 30 percent of the energy consumed in typical office buildings. The lighting designer should try to design to lighting power density levels that are 10 percent less than Title 24 allowances.

Use High-Performance Glazing and Skylights

High-performance glass also represents a major opportunity for energy efficiency in commercial buildings. Tinted, low-e glazing systems that reduce solar heat gain and conduction losses are available from most glass suppliers, thereby reducing the size of the air conditioning system. High-performance glass also improves occupant thermal comfort and reduces glare. Similarly, high-performance skylights are available that reduce solar heat gains and heat conductance, while maintaining sufficient visible light transmission for daylighting applications.

Title 24 requirements exclude single pane glass from most applications, and require double pane, low-e glass in many climate zones. However, glazing systems with higher performance are available in virtually all applications.

Use Cool Roofing Materials

Roofing materials with low solar absorptance and high thermal emittance ("cool" roofs) can reduce peak HVAC loads and energy consumption. Cool roofs reflect solar radiation while enhancing radiant heat transfer to the sky, thus reducing the "roof" load of the building. Reductions in heat gains through the roof have an effect on the temperature of the plenum space located between the drop ceiling and the roof, which contains the majority of the ductwork in small commercial buildings. Duct heat gains and air leakage losses (especially on the return side) can increase HVAC loads on the order of 30 percent, so a cool plenum can reduce energy consumption and improve occupant comfort, especially in commercial buildings where systems run continuously during occupied hours. Cool roofs can also reduce the outdoor air temperature at the roof level.

Figure 3: Lay-in insulation applied to a warehouse-to-office conversion. Note the poor insulation coverage and ductwork located in an unconditioned space.

Source: Architectural Energy Corporation

Avoid Lay-in Insulation

The roof or ceiling insulation location can also have a major effect on HVAC system performance. Roof insulation can be installed directly on the roof deck, while ceiling insulation is sometimes applied on top of the drop ceiling (called “lay-in” insulation).[3] When the insulation is applied to the roof, the plenum is located within the thermal envelope of the building, and the impacts of duct conductive losses and duct leakage on HVAC system efficiency is substantially less. Although the surface area of the thermal boundary of the building expands due to the inclusion of the plenum walls, overall conductance losses decrease due to improved insulation coverage.

Lay-in insulation generally has incomplete coverage due to lighting fixtures, HVAC diffusers, fire sprinklers, and other devices installed into the dropped ceiling grid that interfere with insulation installation. Insulation installed on ceiling tiles inevitably gets displaced as ceiling tiles are moved to gain access to the plenum space for data and telecom wiring, reconfiguring the HVAC diffuser layout, and other maintenance activities. The use of lay-in insulation increases the likelihood of increased duct losses and lower HVAC system efficiency.

These seemingly unrelated aspects of building design can have a profound effect on the size and cost of the HVAC system. Architects and design/build contractors should consider including the above-listed aspects into their designs to achieve superior performance. The incremental costs of these energy-efficiency strategies can be offset by reduced HVAC system size and cost.

Unit Sizing

Many small HVAC systems are significantly oversized, resulting in inefficient operation, reduced reliability due to frequent cycling of compressors, and poor humidity control. Oversized systems also result in wasted capital investment in both the HVAC unit and distribution system. System oversizing affects the ability of the system to provide simultaneous economizer and compressor operation, and exacerbates problems with distribution system fan power, since larger units are supplied with larger fans.

Use Sizing Methods Responsive to Efficiency Strategies

A variety of sizing methodologies are used to determine HVAC system size, including "rule of thumb" sizing based on square foot per ton (sf/ton), manual methods (e.g. ACCA Manual N), and computerized load calculations. A recent survey of design practices in the small commercial building market indicated that although computerized load calculations are used more often than manual methods, the assumptions used in the load calculations are based on conservative assumptions about the building shell, lighting design, and occupant densities.[4] To reap the advantages of lower first costs, energy efficiency strategies that reduce peak loads should be included in the load calculations.

Use Reasonable Assumptions for Plug Loads and Ventilation Air

Engineers often base HVAC sizing decisions on the full nameplate or "connected" load of computers, copiers, printers, and so on; and assume simultaneous operation of such equipment. In fact, most of this equipment operates at a fraction of the nameplate value, and rarely operates simultaneously.[5] Many HVAC designs are based on plug load assumptions on the order of five W/sf in office spaces. According to an ASHRAE study (see sidebar), one W/sf is a reasonable upper bound when equipment diversity and reasonable estimates of the true running load are included.

The peak occupant load and the corresponding ventilation load can contribute substantially to equipment capacity in certain spaces such as lobbies and public assembly areas. Often actual occupant loads are substantially less than peak

ASHRAE Study on Plug Loads in Offices

An ASHRAE study on plug loads measured equipment load densities in 44 commercial office buildings. The measured equipment power ranged between 0.4 and 1.2 W/sf. Values above 1.0 W/sf occurred in only five percent of the square footage studied.

Source: ASHRAE Journal, December 1997.

egress loads to which building codes often defer. While code changes may be in order, it also makes sense for designers to be knowledgeable about the applicable code and balance good air quality with energy efficiency. Many building codes reference ASHRAE Standard 62, which allows the designer to base the design on the actual anticipated occupant density, so long as justification is provided.

Avoid Oversizing

California Title 24 limits cooling capacity to 121 percent of the calculated peak cooling load. Since most sizing methods are based on conservative assumptions, it is recommended that designers use the calculated load and round up to the next available unit size only to avoid excessive oversizing.

Unit Selection

Efficiency

Energy codes are generally set to correspond to the basic "standard efficiency" HVAC unit. High efficiency units are available in most size ranges that are up to 30 percent more efficient than code. These units generally incorporate larger condenser and evaporator coils, efficient compressors, improved cabinet insulation, and higher efficiency fans and motors. Designers should consider specifying units that meet the Consortium for Energy Efficiency (CEE) Tier 2 efficiency standards. It is also important to consider both the rated full load energy efficiency ratio (EER), and the seasonal energy efficiency ratio (SEER) when selecting a unit. However, if the unit design is optimized for efficient part-load rather than peak load operation, multi-compressor units with high SEERs may not perform much better than a standard unit at peak cooling conditions, since the SEER includes part-load efficiency in the overall calculation.

Table 1. Title 20 (2003), Title 24 (2001) and CEE Tier 2 Efficiency Standards

Size	Title 20/24	Tier 2
<5.4 ton	9.7 SEER	13 SEER/ 11.2 EER
5.4–11.2 ton.	10.3 EER	11 EER

Source: CEC and CEE

Select Capacity Based on Design Conditions

Designers should consider the unit capacity under actual design conditions, not nominal values. The peak cooling capacity is reduced as outdoor temperatures increase. This can be especially important in desert climates where peak cooling conditions on the roof can exceed the data in manufacturers' standard catalogs. The unit should be sized to meet the calculated sensible load, and the latent cooling capacity should be reviewed. High-efficiency equipment generally has less latent cooling capacity than standard equipment. Also, energy-efficient buildings have reduced sensible loads but comparable outdoor air requirements compared to standard buildings; thus the sensible heat ratio of an energy-efficient building may be reduced.

Select Airflow Rate to Meet Sensible Loads

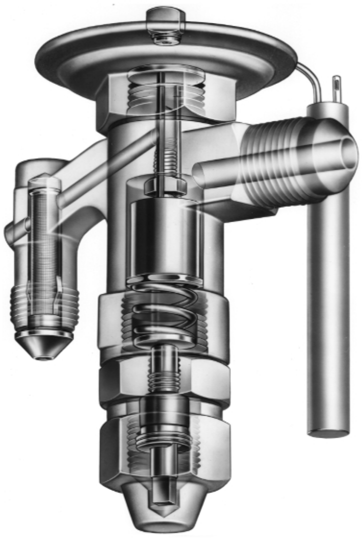
The cooling capacity of most packaged air conditioners is based on a nominal flow rate of 400 cfm (cubic feet/minute) per ton of cooling capacity. Nominal flow rates in packaged equipment are selected to provide adequate dehumidification in climates that are more humid than California. Increasing the flow rate can extract extra sensible cooling capacity out of the unit, allowing the selection of a smaller "nominal" unit. However, the designer should assess the fan energy, which may increase dramatically with higher flow rates, if the unit capacity is near the maximum offered in a particular case size.

Specify Premium Efficiency Fan Motors

Premium efficiency fan motors are important in commercial applications, since fans in general run continuously during occupied periods. In systems equipped with economizers in mild climates such as coastal California, fan energy can be a significant portion of the total HVAC energy consumption. Selection of a premium efficiency motor on the supply fan is cost effective in all climates.

- When selecting a unit, designers should consider peak rooftop temperature and sensible heat ratio under design conditions.
- Designers should also evaluate the trade-off between additional sensible cooling capacity and fan power when selecting air flow rate.

Figure 4: Thermostatic expansion valves (above) and direct drive economizer actuators (below) can improve unit reliability.



Source: Sporlan Valve Company
www.sporlan.com

Source: Belimo Aircontrols
www.belimo.com

Specify Thermostatic Expansion Valves

Refrigerant charge in units degrades over time, due to refrigerant leaks and/or poor maintenance practices. Specifying units with thermostatic expansion valves makes the units more tolerant of refrigerant charge variations by maintaining unit efficiency over a wide range of under- or over-charged conditions. Thermostatic expansion valves are available as a factory option in most units.

Specify Reliable Economizers

Economizers are required by code in units exceeding 6.25 tons and are used in many smaller units. Energy savings from functioning economizers can exceed 50 percent in certain climates and building types. Although most manufacturers offer a factory-installed economizer, the majority of economizers are installed by the distributor or in the field. Specifying a factory installed and fully run-tested economizer can improve reliability.

Distribution Systems

After sizing and selection, the distribution system (ductwork and diffusers) is the next important part of the HVAC system. Installed costs for duct systems can approach the cost of the HVAC unit itself. Often, there is intense pressure to reduce duct system costs. However, the quality of the duct system can have a profound effect on the efficiency and comfort delivered by the HVAC system. Fan energy in small commercial buildings can approach the cooling energy consumption. Duct losses through leakage and conduction can affect the efficiency of the system and the amount of cooling delivered to the space. A poorly balanced distribution system is one of the leading causes of poor indoor comfort in small systems.

Reduce Duct System Pressure Drop

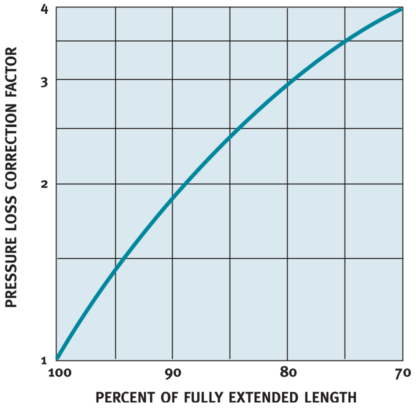
Poor ductwork design can lead to inadequate HVAC unit airflow and excessive fan power. Tested airflow rates in buildings averaged about 325 cfm/ton, rather than the nominal 400 cfm/ton used in system efficiency ratings. Reduced airflow can contribute to coil icing, comfort problems, and a reduction in cooling efficiency of approximately 10 percent.

Design values. Duct systems in small buildings are generally sized using the equal friction or modified equal friction method. Principle design variables are the design velocity (chosen for noise control) or the design friction loss (in Water Columns per 100 ft.). Typical design friction rates are 0.1 inch WC per 100 ft. in commercial buildings. Reducing the design friction rate to 0.05 inch WC per 100 ft. increases the duct size and costs by 15 percent, but cuts the portion of the total pressure drop attributable to the ductwork by 50 percent, and the overall distribution system pressure drop by approximately 40 percent when diffuser losses are included. Upsizing the duct system can provide fan energy savings on the order of 15 to 20 percent.

Use of flex duct. Flex duct, which is used extensively in light commercial construction, has more than a 60 percent higher pressure drop than galvanized metal duct of the same diameter. Flex duct runs should be limited to six feet or less. Flex duct should also be fully extended and well supported at five-foot intervals to minimize pressure losses. The bend radius should be greater than one times the duct diameter to avoid kinking.

Duct layout and fittings. The duct system should be laid out to minimize duct length, turns, and fittings. Radius or section elbows are suggested for all turns greater than 45 degrees. Other recommendations include:

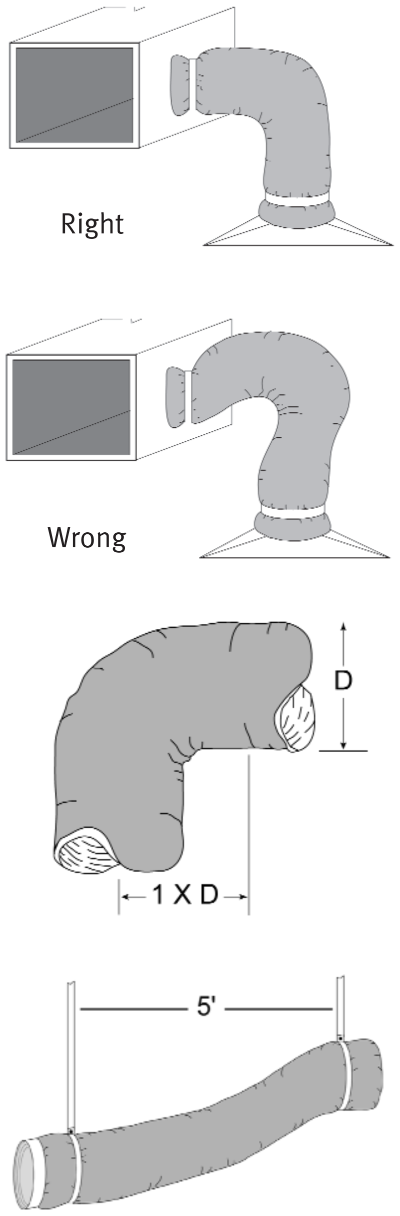
Figure 5: Flex duct should be fully extended to minimize pressure drop. A 30 percent reduction in flex duct extension causes a four-fold increase in pressure drop.



Source: ASHRAE Handbook of Fundamentals (2001)

Figure 6: Flex duct installation guidelines

These installation guidelines should be followed to insure adequate airflow is maintained through distribution systems containing flex duct. See www.flexibleduct.org for more information.



Source: Architectural Energy Corporation

- Use smooth wye branch fittings instead of right angle fittings for branch takeoffs, and avoid turns immediately before a supply or return air register.
- Avoid duct connection details at the unit that degrade fan performance (called the “system effect”).
- Provide at least two feet of straight duct before the first turn to minimize noise and loss of fan capacity.
- Install turning vanes in supply ducts at the first turn after entering the building.

Seal Duct Leakage

Leaky ductwork is a common problem plaguing small commercial systems. A recent study of 350 small commercial HVAC systems in Southern California found that 85 percent of the systems tested had excessive duct leakage.[6] The average combined supply and return leakage in these systems exceeded 35 percent of the total air volume, causing energy waste and poor thermal comfort. Cooling energy savings from sealing leakages in duct systems approaches 20 percent. Peak cooling loads are reduced even more when ducts are sealed since attic or outdoor air is extremely warm under peak conditions. Duct leakage testing and sealing should be done prior to installation of a dropped ceiling while access to the duct system is uncomplicated. Contractors should use sealing materials that meet UL Standard 181 such as mesh tape and mastic. Duct tape should not be used to seal duct leaks, since it tends to degrade over time. The duct systems should be sealed to allow a maximum of six percent combined supply and return leakage rate at 25 Pa test pressure.

Aeroseal is a new technique that combines duct leakage testing and sealing into one operation. A calibrated duct pressurization fan is attached to the duct system, and the leakage flow is measured at a preset duct system pressure. An elastomeric aerosol-sealing compound is injected into the duct system until the leakage level is reduced to an acceptable level.

Increase Duct Insulation Levels to R-8

Most duct systems are insulated with one inch of fiberglass insulation (R-4.2). Duct wrap and duct liner two inches thick are commonly available, and improve the insulation level to R-8. Increased insulation is cost effective in duct systems located outside the conditioned space, such as attics or plenum spaces with lay-in insulation, or outdoors.

Reduce Duct System Noise

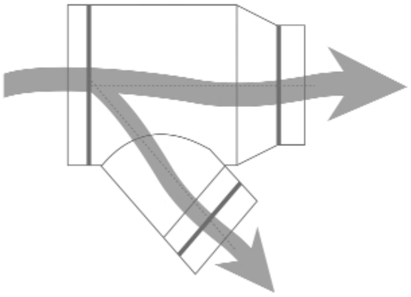
Poorly designed duct systems produce and/or convey noise. Excessive noise can degrade indoor environmental quality (IEQ) and productivity in certain spaces, especially classrooms. Research conducted by the Heshong-Mahone Group for the CEC (see listing under "For More Information" section) listed noise as a leading problem in school HVAC systems.

Reducing the design friction rates also reduces duct velocity, which reduces duct noise. The use of lined ducts should be avoided for noise control, since the duct lining increases pressure drop. A common problem is to solve a noise problem related to high duct velocity with duct liners or silencers, which further increases pressure drop. Increasing duct size and following good design practices at diffuser connections can address noise and pressure drop problems simultaneously.

Ventilation

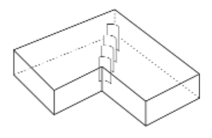
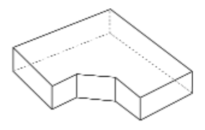
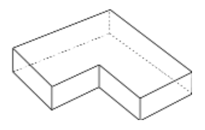
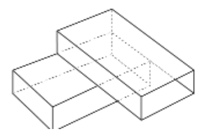
Providing adequate ventilation is a key component of indoor air quality. Strategies to provide adequate ventilation are often at odds with energy efficiency; however, meeting ventilation code requirements should be the first priority of designers and operators of buildings, with the goal of meeting these requirements in the most energy efficient manner possible.

Figure 7: A wye-branch takeoff is recommended instead of a right-angle takeoff since wye-branch creates less pressure loss.



Source: Architectural Energy Corporation

Figure 8: Techniques for reduced pressure loss in 90 degrees turns with rectangle ductwork.

Relative Pressure Loss	
BEST 1.0	
GOOD X 1.3	
FAIR X 4.7	
POOR X 13.0	

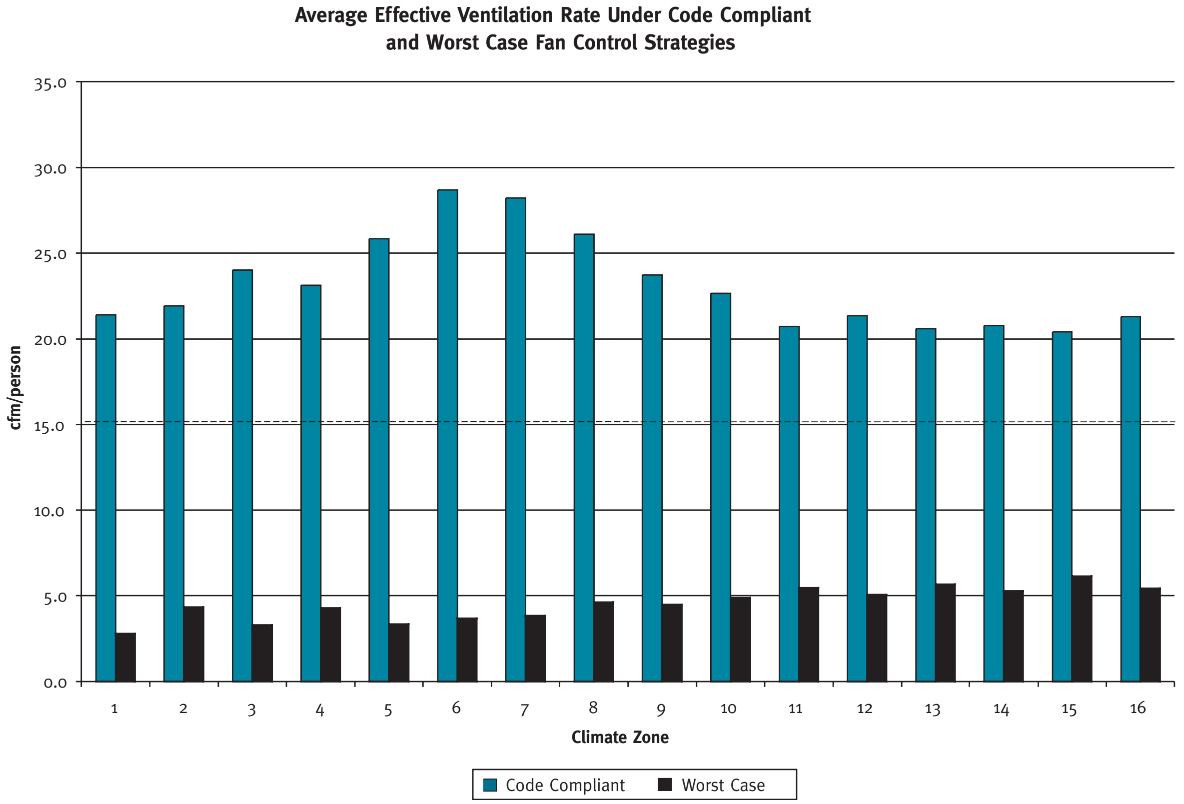
Source: Architectural Energy Corporation

Operate Unit Fans Continuously

Building codes generally require continuous ventilation during occupied hours. This is generally accomplished by operating the HVAC unit fan continuously and introducing fresh air at the unit. When HVAC unit fans are cycled on and off with a call for heating or cooling, the ventilation rates drop dramatically. The effect of cycling fans on effective ventilation rates is shown in Figure 9. It should be noted that the effective ventilation rate for units with cycling fans is on the order of five cfm/person, or about one third the minimum rate mandated by the Title 24 Standards. Continuous fan operation also reduces stuffiness and localized temperature variations that are among the most common complaints in buildings served by small rooftop units.

Figure 9: Effective ventilation rate for HVAC units with continuous and cycling fans

In both cases, the minimum outdoor air damper is set to provide 15 cfm/person of outside air. The code compliant case used continuous ventilation and an air-side economizer. Economizer operation increased the effective ventilation rate above the nominal 15 cfm/person rate. A unit not equipped with an economizer and operated with cycling fans provided an effective ventilation rate of less than five cfm/person in most climate zones.



Source: Architectural Energy Corporation

Use Demand-Controlled Ventilation

Demand-controlled ventilation systems modulate outdoor air quantities based on measured indoor air quality. Indoor CO^2 concentration is commonly used as an indicator of indoor air quality. Many economizer controllers have the built-in capability to implement demand-controlled ventilation with the simple addition of a CO^2 sensor. This strategy can reduce outside air requirements during periods of partial occupancy, and provide energy savings and reduced humidity.

Demand-controlled ventilation is commonly used in systems serving spaces with highly variable occupancies, such as auditoriums, meeting rooms, and so on. These systems can also save energy in other space types with high design occupant densities to prevent over-ventilating the spaces.

Alternative Ventilation Strategies

The HVAC unit supply flow rate is generally four times larger than the required outdoor air ventilation rate, requiring excessive fan power during ventilation-only operation. Alternative design strategies for providing ventilation air, such as two-speed or variable-speed fan systems interlocked with the OA (outdoor air) damper and/or a CO^2 sensor, can be used to reduce fan power during ventilation-only mode. Another strategy is to use a dedicated ventilation fan that brings in a constant supply of fresh air rather than relying on the HVAC unit fan. In this case, the ventilation fan would run continuously during occupied hours, and the HVAC unit fan would cycle on a call for heating or cooling.

Natural ventilation using operable windows can also be used to supply ventilation in lieu of mechanical ventilation. This strategy can be effective in serving perimeter zones in mild climates. Proximity switches installed on operable windows should be used to lock out the HVAC systems when windows are open to prevent energy waste.

Figure 10: CO^2 Sensors

CO^2 sensors attached to a standard economizer controller add demand-controlled ventilation to many rooftop units.

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Honeywell International, Inc.
www.honeywell.com

Figure 11: Thermostat location

Thermostats controlling three different units serving three different computer labs at a community college are located in the corridor, where they are unable to effectively sense the temperature of the rooms they are controlling.

Source: Architectural Energy Corporation

Thermostats and Controls

Controls used in small HVAC systems come from a variety of sources and may not provide the full range of control options required for optimal system performance. A simple room thermostat is used to control most systems, though energy management systems (EMS) are making inroads into the small commercial building market.

Use Two-Stage, Commercial Grade Thermostats

The primary function of the thermostat is to control the heating and cooling output of the unit, but most thermostats also control the operation of the supply fan. Fans are required to run continuously during operating hours, and cycle on and off with a call for heating or cooling during unoccupied hours. Most of the systems studied have the capability to implement this strategy, yet were not set up correctly. Commercial (not residential) thermostats should be used to provide continuous fan operation/ventilation during occupancy. The thermostat should be programmed for intermittent fan operation during unoccupied hours, and provide a one hour "purge" of the building prior to occupancy. Designers should specify controls with default settings that are appropriate for commercial applications. Systems with economizers should use thermostats with two-stage cooling to allow integrated operation of the economizer and mechanical cooling system.[7]

The location of the thermostat can dramatically affect system loads and occupant comfort. Since the system responds to the air temperature at the thermostat, proper location is key to comfort and energy efficiency. Locating several thermostats in the same general area with conflicting heating and cooling setpoints can invite problems with simultaneous heating and cooling, where adjacent units "fight" each other to maintain selected setpoints.

Controller Options and Interfaces

Modern HVAC units can be configured with a variety of controller options, including standard electromechanical controls, microprocessor controls, and controllers with EMS interface capability. Standard controls allow the use of thermostats from a variety of vendors. In some units with microprocessor control, the thermostat control logic is contained within the unit controller and the zone thermostat is merely a temperature sensor. Interfaces to energy management systems allow the units to be controlled by one of several energy management systems, including both manufacturer-supplied systems and third party systems. These interfaces allow the energy management system to take over most of the unit control function, including calls for heating and cooling, fan operation and scheduling, and economizer control. Additional digital I/O channels are included to provide alarm capability for fan failure, dirty filters, compressor high- or low-pressure lockout, and economizer status. Supply and return air temperature information can also be transmitted to the EMS console. These systems are very popular in chain retail and foodservice environments, allowing central control over HVAC system operation and limited unit diagnostic capability. The systems work best in buildings that are occupied on a regular schedule; applications in schools have been problematic.

Commissioning

Commissioning is a quality-assurance process that increases the likelihood that a new building will meet the intent of the design team and, ultimately, the client's expectations. In large projects, the commissioning process can encompass the entire design and construction process:

- During the design phase, commissioning begins with the selection of a commissioning agent—who helps ensure that the project documentation reflects the intentions of both the designer and owner.

- Next, the designer incorporates commissioning requirements into the design specifications.
- During construction, the commissioning agent is responsible for inspecting the building to identify construction defects that are difficult to correct after the building is finished.
- When the project is near completion, the commissioning agent and contractors conduct performance tests of the systems to be commissioned.
- At the end of the commissioning process, the designer and vendors train the building operators on how to properly operate and maintain the building.

Commissioning of small HVAC systems generally focuses on providing documentation of the design intent, including commissioning testing in the building plans and specifications, testing the system, correcting deficiencies, and providing operation and maintenance training to the building occupants. Incorporating the commissioning requirements into the specifications is very important, since the contractor will base the bid on the plans and specifications. Also, setting the expectation up front that commissioning will be done will save a lot of trouble during the construction process. The commissioning plan should also include a sample maintenance contract to assist the building owner or operator in obtaining ongoing maintenance services.

Figure 12: Flow grid measures airflow

A flow grid is used to measure as-installed airflow rate. A series of flow grids (see below) are installed in place of the filters; the airflow rate through each flow grid is displayed on a digital manometer.

Source: Architectural Energy Corporation

Perform Pre-Functional Inspections

Prior to conducting any commissioning tests, the units are inspected according to a checklist called a pre-functional checklist. Items on the checklist generally include:

- Document submittal (spec sheets, operations and maintenance instructions).
- Verification of correct make and model number.

- Installation checks, such as tight curb connections, operable cabinet door with gaskets in place, shipping materials and hold-downs removed, and adequate maintenance access.
- Duct insulation installed and in good condition.
- Filters installed properly.
- Fan motor aligned and belt tension correct.
- Economizer linkages tight, with smooth operation.
- Safety disconnect properly installed.

Perform Functional Performance Tests

The heart of the commissioning process is a series of tests called functional performance tests. For small packaged units, functional performance testing usually includes:

- Cycling unit through its various operating modes and observing unit response according to the control sequence of operations. For example, does the outdoor air damper close when the unit is turned off? Does the second compressor come on during a second stage call for cooling?
- Performing economizer tests—Does the economizer actuator work? Do the dampers move freely over their full range? Are the sensors calibrated? Does the unit respond correctly when subjected to conditions where the economizer should operate?
- Checking sensor calibration—Are the room temperature, outdoor air temperature, and/or supply air temperature sensors installed in a reasonable location and properly calibrated?
- Verifying correct rotation of supply and condenser fan motors.
- Checking for correct thermostat programming, including fan controls—Are the set points and operating schedule correct according to the design documents? Does the fan run continuously during occupied hours?

Additional functional tests may also be included. These tests can detect less obvious, but important problems with HVAC installations:

- Verify airflow through unit is correct. This generally requires the use of a flow grid to measure unit airflow.
- Verify duct leakage is within acceptable limits. This generally requires the use of a duct pressurization device to measure duct leakage rate.
- Verify correct refrigerant charge. Refrigerant pressure measurements combined with refrigerant line temperatures should be checked to verify correct superheat (for fixed throttling devices) or correct sub cooling (for thermostatic expansion valve units).
- Verify adequate outdoor airflow. A flow grid can be used to make this measurement.

Operations and Maintenance

Packaged rooftop units are generally designed for a shorter service life than other HVAC equipment. The units are also exposed to various weather elements that can be stressful to the equipment operation. Both factors can contribute to more frequent maintenance needs. Problems tend to occur during periods of system stress caused by extremely hot or cold weather. This discourages timely inspection and repair. If the problems occur during wet or icy weather, maintenance and repair can actually be hazardous.

Keeping these issues in mind will help building owners better plan maintenance of units. A little preventive maintenance during nice weather should help optimize operation, energy use, and comfort while minimizing "surprises" during inclement weather.

Provide Reasonable Access to Rooftop

Maintenance of packaged rooftop units is often ignored because the units are on the roof. Typical access is by a vertical ladder and roof hatch. Stored items can block access to the ladder, which does not encourage frequent inspections. Building owners should be sure the roof access is kept free of obstructions, and maintenance personnel have access to the key to the roof hatch padlock.

Routine Maintenance

Regular maintenance is an important component of energy efficiency, comfort, and the prevention of premature equipment failure. Simple routine checks can avoid costly contractor calls to diagnose or fix simple maintenance problems. A few routine maintenance items include:

- Check fan belts—tension/wear
- Check filters
- Verify economizer damper linkage/movement
- Check refrigerant—check site glass and test refrigerant charge
- Lubricate moving parts (including dampers and linkage)
- Check access panels for tight fit
- Inspect electrical wiring/connections
- Check coils for debris and clean as necessary

Annual maintenance contracts are common. If considering one, ensure the staff has good experience. Maintenance staff in buildings with rooftop units are often under skilled with limited training and experience. Routine maintenance tasks should be placed on easy-to-use reference sheets and lists posted in locations that encourage pro-active maintenance. Maintenance logs and manufacturer service instructions for all units should be kept in a readily accessible binder. Maintenance contracts should require a log that remains on site.

Figure 13: Maintenance Hall of Shame

The following photos were taken at a newly constructed restaurant soon after a visit by the HVAC service contractor. Note the roof was littered with old, filthy filters and bent and discarded "bird screens" intended to protect the unit's outdoor air opening (top). A closer inspection revealed several instances of missing filters and filthy cooling coils (bottom).

Source: Architectural Energy Corporation

A less obvious problem can occur when well-meaning but improper maintenance procedures are employed. A recent study conducted in California indicated that over half of the units tested were either over- or under-charged, with an average energy penalty on the order of 10 percent of the annual cooling costs.[6] Adding refrigerant until the suction line is “beer can cold” rather than following more rigorous procedures can impact comfort and energy efficiency. This particular problem is likely due to inadequate staff training, experience, or time allocated for the procedure.

Conclusion

In this design brief, a number of topics have been discussed relating to the design, installation, operation, commissioning, and maintenance of small HVAC systems. Most problems documented in the field have roots traceable to one or more of these areas. How can the industry avoid these problems in the future? Design teams and contractors should ensure rooftop HVAC systems are properly sized and the appropriate components selected and properly placed. The distribution, ventilation, thermostat, and control systems should be integrated. Also, the entire HVAC system should be commissioned to ensure it performs as designed, and regular maintenance checkups should be scheduled. By emphasizing these areas, building owners can improve the level of indoor comfort and lower operating costs associated with small HVAC systems.

For More Information

New Buildings Institute
The New Buildings Institute hosts a website that contains additional information about this project and other elements of their PIER research program. For more information, consult:

www.newbuildings.org/pier

California Energy Commission
The California Energy Commission is responsible for conducting Public Interest Energy Research on a number of topics. For more information on this and other PIER Research, consult:

www.energy.ca.gov/pier/buildings

Consortium for Energy Efficiency
The Consortium for Energy Efficiency (CEE) is a non-profit, public benefit corporation that actively promotes the use of energy-efficient products and services through its members, including electric and gas utilities, public benefit administrators (such as state energy offices, non-profit organizations, and regional energy groups), and research and development laboratories. They have established efficiency guidelines for commercial rooftop units, and have published a small commercial HVAC design guideline. For more information, consult:

www.cee1.org

Air Conditioning and Refrigeration Technology Institute
The Air Conditioning and Refrigeration Technology Institute (ARTI) conducts the Twenty-First Century Research (21-CR) initiative, which is a private-public sector research collaboration of the heating, ventilation, air-conditioning and refrigeration (HVAC/R) industry. ARTI has conducted research into design practices for small commercial HVAC systems. For more information, consult:

www.arti-21cr.org

Northwest Energy Efficiency Alliance
The Northwest Energy Efficiency Alliance (NEEA), along with Portland Energy Conservation Inc. (PECI), is conducting a pilot program to assess the market opportunities for enhanced operation and maintenance services for packaged heating and cooling systems in small commercial buildings. The pilot project is developing and testing an array of diagnostic tools and procedures, training selected contractors, developing marketing materials, and documenting the market acceptance of the service in selected markets around the Northwest. For more information, consult:

www.nwalliance.org

Air Conditioning Contractors Association

The Air Conditioning Contractors Association (ACCA) publishes several manuals on design practices for small commercial HVAC systems. For more information, consult:

www.acca.org

Air Diffusion Council

The Air Diffusion Council publishes an installation guideline for flexible duct systems. For more information, consult:

www.flexibleduct.org

Sheet Metal and Air Conditioning Contractors' National Association

The Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) publishes technical manuals and construction standards relating to the construction and installation of air distribution systems. For more information, consult:

www.smacna.org

Notes

1 For more information about this project, see www.newbuildings.org/pier. Follow the links to Element 4—Integrated Design of HVAC Systems for Small Commercial Buildings.

2 See the results of the market research conducted for this project at www.newbuildings.org/pier.

3 Applications of lay-in insulation were not allowed in earlier versions of Title 24, and the practice, while not widespread, is permissible under the current (2001) Standards.

4 See State-of-the-Art Review, Whole Buildings and Building Envelope Simulation and Design Tools, Air Conditioning and Refrigeration Technology Institute (ARTI), www.arti-21cr.org.

5 Modera, M. and Proctor, J. "Combining Duct Sealing and Refrigerant Charge Testing to Reduce Peak Electricity Demand in Southern California," Final Project Report for Southern California Edison, July 2002.

6 Proctor, et al., Small commercial HVAC system inspections in Sacramento.

7 Heat pumps may require three dedicated cooling stages. The additional stage is for the reversing valve.

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