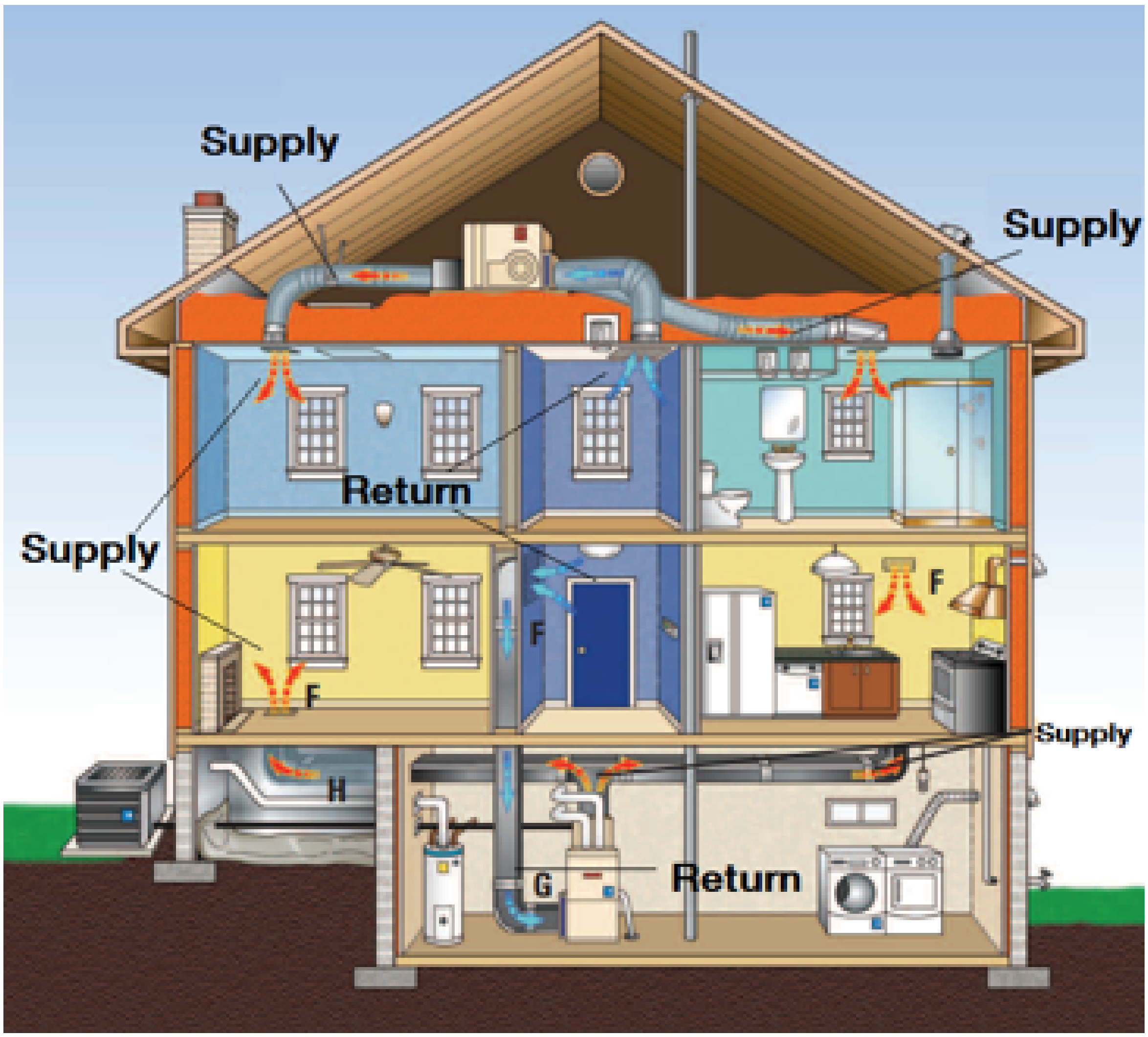
HAVC SYSTEM

(Heating Ventilation & Air Conditioning)



DESIGN & INSTALLATION

PROCEDURES

Procedures For HVAC System Design and Installation

The goal for a Heating, Ventilation and Air Conditioning (HVAC) system is to provide proper air flow, heating, and cooling to each room. This page sets out key criteria that describe a quality system, and key design and installation considerations that should be met to achieve this goal. The pages following contain more detailed information on design, fabrication, installation, and performance testing.

Criteria for a Quality HVAC System

An HVAC system should:

1. Be properly sized to provide correct air flow, and meet room-by-room calculated heating and cooling loads.
2. Be installed so that the static air pressure drop across the handler is within manufacturer and design specifications to have the capacity to meet the calculated loads.
3. Have sealed supply ductwork that will provide proper air flow.
4. Be installed with a return system sized to provide correct return air flow.
5. Have sealed return ductwork that will provide proper air flow to the fan, and avoid air entering the HVAC system from polluted zones (e.g., fumes from autos and stored chemicals, and attic particulates).
6. Have balanced air flows between supply and return systems to maintain neutral pressure in the home.
7. Minimize duct air temperature gain or loss between the air handler and room registers, and between return registers and the air handler.
8. Be properly charged with refrigerant.
9. Have proper burner operation and proper draft.

Procedures to Design and Install an Air Distribution System

The following steps should be followed in the design and installation of the HVAC system to ensure efficiency and comfort (for details, see Appendix 1):

1. Determine room-by-room loads and air-flows using ACCA Manual J calculation procedures (or substantially equivalent).
2. Layout duct system on floor plan, accounting for the direction of joists, roof hips, fire-walls, and other potential obstructions. Determine register locations and types, duct lengths, and connections required to produce layout given construction constraints.
3. Size duct system according to ACCA Manual D calculation procedures (or substantially equivalent).
4. Size HVAC equipment to sensible load using ACCA Manual S procedures (or substantially equivalent).
5. Install equipment and ducts according to design specifications, using installation requirements and procedures from the Uniform Mechanical Code, the Air Diffusion Council, SMACNA, California Residential Energy Efficiency Standards, and manufacturers' specifications (Title 24); Using these procedures and those in Appendix A, the duct system should be substantially air tight.
6. Charge the system appropriately, and verify charge with the evaporator superheat method or subcooling method (or substantially equivalent).
7. Check for proper furnace burner operation and fire-box drafting.
8. Test the system to ensure that it performs properly by determining (1) that the system is properly sized, (2) it does not leak substantially, and has either (3a) proper air handler fan flow, and proper plenum static pressures, or (3b) proper room and return air flows, and proper plenum static pressures. (Procedures are detailed in Appendix A.)

APPENDIX A
Recommended Details for an HVAC System: Materials, Fabrication, Design, Installation, and Performance Testing

MINIMUM MATERIALS SPECIFICATIONS

The following are minimum materials specifications recommended to achieve a substantially tight installation that will last:

All Materials

- Shall have a minimum performance temperature ratings per UL181 (ducts), UL181A (closure systems for rigid ducts), UL181B (closure systems for flexible ducts) and/or UL 181BM (mastic);
- Shall have a flame spread rating of no more than 25 and a maximum smoke developed rating of 50 (ASTM E 84)

Factory-Fabricated Duct Systems

- All factory-fabricated duct systems shall include UL 181 listed ducts with approved closure systems including collars, connections and splices;
- All pressure-sensitive and heat-activated tapes used in the manufacture of rigid fiberglass ducts shall be UL 181A listed;
- All pressure-sensitive tapes and mastics used in the manufacture of flexible ducts shall be UL 181B (tape) or UL 181BM (mastic) listed.

Field-Fabricated Duct Systems

- Ducts:
    - Factory-made ducts for field-fabricated duct systems shall be UL 181 listed.
- Mastic sealants and mesh:
    - Sealants shall be UL 181BM listed, non-toxic, and water resistant;
    - Sealants for interior applications shall pass ASTM tests C 731 (extrudability after aging) and D 2202 (slump test on vertical surfaces);
    - Sealants and meshes shall be rated for exterior use;
    - Sealants for exterior applications shall pass ASTM tests C 731, C 732 (artificial weathering test), and D 2202.
- Pressure-sensitive tapes:
    - Pressure sensitive tape shall be that recommended by and meet the requirements of the flexduct manufacturer;
    - Tape used for duct board shall be UL 181A listed and so indicated with a UL 181A mark or aluminum-backed butyl adhesive tape (15 mil. minimum).
- Drawbands:
    - Shall be either stainless-steel worm-drive hose clamps or uv-resistant nylon duct ties;
    - Shall have a minimum performance temperature rating of 165 degrees Fahrenheit (continuous, per UL 181A-type test) and a minimum tensile strength rating of 50 pounds;
    - Shall be tightened as recommended by the manufacturer with an adjustable tensioning tool.

DESIGN, FABRICATION AND INSTALLATION

The following are design, fabrication and installation guidelines, that, if carefully followed, will provide a duct installation that is substantially airtight:

General Issues

- Ducts, plenums, and fittings should be constructed of galvanized metal, duct board, or flexible duct. Building cavities may not be used as a duct or plenum without a sealed duct board or metal liner.

- The air handler box should be air-tight;
- Air filters should be easily accessible for replacement, and evaporator coils should be easily accessible for cleaning;
- Ducts should be configured and supported so as to prevent use of excess material, prevent dislocation or damage, and prevent constriction of ducts below their rated diameter;
- Flexible duct bends should not be made across sharp corners or have incidental contact with metal fixtures, pipes, or conduits that can compress or damage the ductwork;
- Sheet metal collars and sleeves should be beaded to hold drawbands.

DESIGN HVAC SYSTEM

Loads and CFM Calculation

- ACCA Manual J Load Calculation or equivalent required;

- Calculate heat loss and heat gain for each room;
- Total room loads to determine system requirements.

Lay Out Air Distribution System

- Lay out duct system on floor plan and determine register positions and duct paths to optimize room air circulation and minimize duct length;

- Duct paths must account for locations and directions of joists, roof hips, fire walls, and other potential obstructions;
- Duct paths must be planned to avoid sharp turns of flexduct that will kink the duct.

Size Air Distribution System

- ACCA Manual D Duct Design or equivalent required;

- Calculate correct cfm for each room and total for building for both supply and return;
- Size ducts according to Manual J loads, Manual D air flows, and final layout on plans;
- Choose registers to optimize air distribution and duct static pressure;
- Size and locate returns to optimize air flow per Manual D;
- For return-filter grills, calculate minimum return filter area per Manual D.

Select System

- ACCA Manual S Residential Equipment Selection or equivalent required. ACCA, 1515 16th St., NW, Washington, DC 20036, (202)483-9370;

- From Manual J loads and Manual D cfm, determine appropriate equipment
- Equipment should be sized to sensible loads;
- Equipment sensible capacity should not be more than 15% larger than the total sensible design load (as specified in Manual S).

FABRICATE AND INSTALL AN AIRTIGHT DUCT SYSTEM

All Duct Types

- All joints and seams of duct systems and their components should be sealed with mastic, mastic and embedded mesh, or pressure-sensitive tape approved for use by the duct manufacturer and meeting UL181 specifications ("approved tape"); this includes around junctions of collars to distribution boxes and plenums;

- All sealants should be used in strict accordance with manufacturer's installation instructions and within sealants moisture and temperature limitations;
- All tapes used as part of duct system installation should be applied to clean, dry surfaces and sealed with manufacturer's recommended amount of pressure or heat. If oil is present, taped surfaces should be prepared with a cleaner / degreaser prior to application;
- It is recommended that all register boxes should be sealed to the drywall or floor with caulking or mastic.

Flexible Ducts

- Flexible ducts should be joined by a metal sleeve, collar, coupling, or coupling system. At least 2 inches of the beaded sleeve, collar, or coupling must extend into the inner core while allowing a 1 inch attachment area on the sleeve, collar, or coupling for the application of tape;

- The inner core should be mechanically fastened to all fittings, preferably using drawbands installed directly over the inner core and beaded fitting. If beaded sleeves and collars are not used, then the inner core should be fastened to the fitting using #8 screws equally spaced around the diameter of the duct, and installed to capture the wire coil of the inner liner (3 screws for ducts up to 12" diameter, and 5 screws for ducts over 12" diameter);
- The inner core should be sealed to the fitting with mastic or approved tape;
- Tape used for sealing the inner core should be applied with at least 1 inch of tape on the duct lining, 1 inch of tape on the fitting of flange, and wrapped at least three times;
- The outer sleeve (vapor barrier) should be sealed at connections with a drawband and/or three wraps of approved tape;
- The vapor barrier should be complete. All holes, rips, and seams must be sealed with mastic or approved tape.

Metal Ducts and Plenums

- Metal-to-metal connections should be cleaned and sealed in accordance with manufacturer's specifications;

- Openings greater than 1/16 inch should be sealed with mastic and mesh, or butyl adhesive tape;
- Openings less than 1/16 inch should be sealed with mastic or UL-181A listed tape;

- Special attention should be paid to collar connections to duct-board and/or sheet metal; seal around the connection with mastic;
- Connections between collars and distribution boxes should be sealed with mastic or approved tape;
- At least three equally-spaced #8 screws should be used to mechanically fasten round ducts (3 screws for ducts up to 12" diameter, and 5 screws for ducts over 12" diameter);
- Crimp joints should have a contact lap of at least 1-1/2 inches;
- Square or rectangular ducts should be mechanically fastened with at least one screw per side.

Duct Board

- Duct board connections should be sealed with adhesive, mastic, or UL 181A listed pressure-sensitive or heat-activated tape in accordance with manufacturer's specifications.

Duct Support

- Supports should be installed per manufacturer's specifications or per UMC requirements;

- Supports for flexible ducts should be spaced at no more than 4 foot intervals;
- Flexible ducts should be supported by strapping having a minimum width of 1-1/2 inches at all contact points with the duct;
- Supports should not constrict the inner liner of the duct;
- Flexible ducts should have maximum of 1/2 inch sag per foot between supports;
- Flexible ducts may rest on ceiling joists or truss supports as long as they lie flat and are supported at no more that 4 foot intervals.

Boots

- After mechanically attaching the register boot to floor, wall, or ceiling, all openings between the boot and floor, wall, or ceiling should be sealed with caulk or mastic.

Seal Air Handler

- Openings greater than 1/16 inch should be sealed with mastic and mesh, or butyl adhesive tape;

- Openings less than 1/16 inch should be sealed with mastic or UL 181A listed tape;
- Unsealed access doors should be sealed with UL 181A listed tape.

CHECK REFRIGERANT CHARGE

- For systems with fixed metering devices use evaporator superheat method:
    - Indoor coil airflow must be greater than 350 cfm/ton;
    - Refrigerant system evacuation must be complete (all non-condensables must be removed from the system;
    - In hot, dry climates be cautious to be within range of superheat charging chart or use a different method.
- For systems with thermostatic expansion valves use the subcooling method.

CHECK COMBUSTION PERFORMANCE

- Check each chamber for correct flame;
- Check for proper drafting.

TEST SYSTEM PERFORMANCE

The following are testing requirements and procedures that must be followed to ensure that the HVAC system has been properly installed. The tests are designed to determine whether:

1. **Room-by-room air flows are correct;**
2. **Total supply is as designed;**
3. **Total return = total supply;**
4. **Ducts, plenum, and air handler are tight;**
5. **Static pressure is correct.**

- Test the system to ensure that it performs properly, by (1) verifying HVAC equipment sizes installed are those specified, (2) measuring duct leakage, and measuring either (3) fan flow or (4) supply and return flows and plenum static pressures:
    1. Air conditioner sensible capacity must be no more than 15% greater than the calculated sensible load; fan flow must be greater than 350 cfm/ton; check that the correct size air handler is installed.
    2. Ensure that the duct system does not leak substantially:
        1. A rough system, including both supply and return but without the air handler, should not leak more than 0.03*conditioned floor area (ft^2) per system measured in cfm @ 50 Pa;
        2. The finished installation, including supply, return, the air handler and finished registers, must not leak more than 0.07*conditioned floor area (ft^2) per system measured in cfm @ 50 Pa;
    2. Measure air handler air flow and static pressure across fan; ensure that total air handler output is within 5% of design and manufacturer specifications at a static pressure within 0.1 in wg of design.
    3. Supply and return air flow, and static pressure requirements: Ensure that supply and return flows are correct, and that the static pressure across the fan is correct:
        1. Measure room-by-room air flows to ensure that each register is within 15% of Manual D design air flow, and that the entire supply is within 5% of design;
        2. Measure return air flow to ensure that it is within 5% of the total supply air flow;
        3. Test static pressure drop across the blower to ensure that it is within 0.1 in wg of design and manufacturer specifications.
- Duct leakage can be determined using a pressurization or depressurization technique; for details, see Minneapolis Duct Blaster? manual, or other commercially available duct pressurization or depressurization devices;
- Duct leakage to unconditioned space can be determined with the house pressurization or LBL simplified technique; for details see California Energy Commission report P400-91-031CN, Section Six;
- Fan flow, supply flow and return flow measurements, see Minneapolis Duct Blaster™ manual (or equivalent); alternatively for supply and return flows, use a calibrated flow hood. Do not use a pitot tube, or any type of anemometer to determine these air flows;
- Static pressure drop across the fan is measured using a small probe in the return plenum and in the supply plenum.

APPENDIX B

PROBLEMS WITH ACCEPTED PRACTICE SIZING METHODS

Relationship Between Duct System Performance,
ACCA Design Procedures, and Installed-System Quality

Background

The Air Conditioning Contractors of America (ACCA) association publishes four manuals related to residential heating and air conditioning that address many of the issues associated with residential duct systems. ACCA Manual J (Load Calculation for Residential Winter and Summer Air Conditioning, Copyright 1986) is the industry-standard design-load calculation procedure for residences. ACCA Manual S (Residential Equipment Selection, 2/92) provides procedures for choosing residential heating and cooling equipment based on the loads calculated with Manual J. ACCA Manual D (Residential Duct Systems, Copyright 1995, 2nd Printing) provides design procedures for residential duct systems, focusing on how to produce the desired air delivery at each register, as well as discussions of the magnitudes and impacts of duct-system inefficiencies. ACCA Manual T (Air Distribution Basics for Residential and Small Commercial Buildings, UPB592-10M) addresses room air motion issues, focusing on the impacts of register/grille location and diffuser performance.

Treatment of Duct Performance in ACCA Manual J

ACCA Manual J addresses residential duct system performance in three ways: 1) it provides room-by-room loads, which are intended to be used to calculate the energy that needs to be transported by the ducts to each room, 2) it provides a table of duct-loss multipliers that are used to calculate the extra design load associated with conduction losses from the ducts, and 3) it provides a table of recommended levels of duct insulation, and states that "All ducts should have their seams sealed with tape".

In calculating the energy load impacts of ducts and room-by-room loads, Manual J makes two fundamental assumptions: 1) that there is no duct leakage, and 2) that the load due duct conduction is independent of the length and design of the ducts. The implication of the first assumption is that the actual load associated with duct losses is in general significantly higher than that assumed in Manual J. The second assumption implies that even if the average conduction losses in the duct-loss multipliers are correct, the calculated room-by-room loads are incorrect due to non-uniform conduction losses.

A significant body of research performed over the past five years in California and other states that install ductwork in attics and crawlspaces demonstrates that duct leakage increases space-conditioning energy use by 15-20% on average, even in new construction. This loss needs either to be eliminated, or to be added to the losses associated with conduction gains to obtain correct loads seen by the equipment. Field research has also demonstrated the effective increase in heating and cooling system capacity associated with improving duct performance (Modera and Jump, 1995). Those studies show reduced fractional on-times and increased cycling under the same weather conditions after duct retrofit.

A logical question that arises with respect to these duct leakage losses is why Manual J is not resulting in significantly undersized systems because of the fact that it does not include these duct leakage losses. The reasons for why this is not the case seem to stem principally from the application of Manual J, rather than the manual itself. In general, Manual J leaves quite a bit to the discretion of the user, leaving numerous opportunities for increasing the size of the unit. Some of the common points at which safety margins seem to creep in are:

- The use of the worst house orientation for load calculations,
- The choice of the next size up in the piece of heating/cooling equipment,
- The assumption of 50% RH indoor conditions in most manufacturer's capacity data, which is higher than what is found in much of California, and which results in a lower estimated sensible capacity for a piece of equipment as compared to the sensible capacity the equipment would have at a lower indoor humidity level,
- Using a somewhat lower indoor design temperature,
- Using a higher outdoor design condition, such as 1%, or utility-peak outdoor design temperature rather than the 2.5% values recommended in Manual J.
- Using the next-highest outdoor-temperature rating point, rather than interpolating manufacturer's capacity data.
- The recommendation of 0-15% oversizing of sensible capacity in Manual S.

To be fair, it should also be noted that there are some factors that tend to decrease the size of the equipment chosen with the ACCA procedures, including:

- ARI capacities are normally quoted at 80ºF, whereas Manual J requires capacities at 75ºF, which will be smaller.

It is very difficult to quantify exactly how much the above trends influence equipment sizing. A contractor survey performed in Florida indicated that there is a large variability in the equipment-sizing practices used by contractors (Home Energy 1995). It is safe to say that there are numerous opportunities for a contractor to increase equipment size within the ACCA procedures so as to maintain the sizing with which they are comfortable. A related study of equipment sizing and ACCA manuals is published in Home Energy magazine (Proctor et al. 1995).

The assumption of constant duct-loss multipliers for all duct sections (or in other words, that duct loads scale with room load, and not with duct design or length) is more of a design-flaw and comfort problem, rather than an energy-use or equipment-sizing problem. Namely, after calculating room-by-room loads including constant duct-loss multipliers, the air flow required for each room is calculated from the loads, the duct system is laid out, and the cross-sectional area of the ductwork is calculated and checked with Manual D based upon the ability of the system to supply the required air flow. This implies that the percentage energy loss from the longest duct run is the same as that from the shortest run. It seems clear that this is not a realistic assumption, however the magnitude of the resulting disparity, based upon field measurements, is striking. Namely, the bedroom closest to the furnace for an R-4 duct system in a Sacramento attic was measured to have 12% of the duct energy lost by conduction on the way to the register. The equivalent losses for the master bedroom at the end of the duct run were more than 40% (Modera and Jump, 1995). The 12% loss is line with the losses that are calculated from the Manual J duct loss multipliers, and the 40% loss clearly indicates that the master bedroom duct is most likely undersized. Sure enough, the homeowner commented on the improvement in master-bedroom conditions after the retrofit. The end result of this disparity is that the entire duct-design process is skewed so as to provide far less than optimal distribution of heating and cooling.

There is another assumption within Manual J that is likely to result in inaccurate estimates of room-by-room loads. Namely, it is assumed that the infiltration load is split between rooms based on the estimated relative external leakage area of that room. The problem with this assumption is that it ignores the fact that a significant fraction of residential air infiltration is driven by the stack effect. The implication of ignoring the stack effect in two-story houses is that in general the upstairs flows will be oversized for heating, resulting in unnecessary stratification and discomfort in the winter. This upstairs-duct oversizing should actually help reduce stratification in the summer.

In addition, it is also worth noting that the duct loss multipliers for an attic and a crawlspace are the same, which is clearly inconsistent with intuition and field experiments. The result is that cooling equipment with attic ductwork is likely to be relatively undersized as compared to cooling equipment with crawlspace ductwork.

Treatment of Duct Performance in ACCA Manual D

As noted above, the principal function of Manual D is to assure that a given duct layout delivers the appropriate air flows to each room, based upon the room-by-room loads calculated with Manual J. Thus, if the total load seen by the duct run to a given room is not correct, the size of the ductwork leading to that zone will not be correct, resulting in poorly designed system (i.e., one that does not provide uniform heating or cooling, and which is difficult or impossible to balance).

There is however a disconnect within Manual D. Namely, Manual D contains an entire, fairly complete section on duct-system energy efficiency, however this section is not connected to the load calculation procedures used to size the equipment and ductwork.

Treatment of Duct Performance in ACCA Manual T

As noted above, Manual T focuses on the room-air motion aspects of air distribution systems. The way that this relates to duct performance and quality HVAC installations is through the performance of the diffusers. In particular, if a diffuser is designed to provide a given throw at a specific air flow rate, that throw will be reduced (potentially significantly) by supply-duct leakage or by flow restrictions within the ductwork (e.g., flexduct that is not fully extended, that is bent at hangers, or that is bent at too sharp of a radius).

Recommended Strategy for California

Based upon the discussion above, a two-phase strategy for improving the quality of HVAC installations is recommended. The first phase of the strategy simply addresses the issue of duct leakage, focusing on the interaction between duct leakage and equipment sizing with Manual J and Manual S. The second phase addresses the quality of the design, focusing on a methodology for accurately laying out and sizing ductwork so as to provide better occupant comfort.

The essence of the Phase-I strategy is to develop a modification to Manual J duct loss/gain multipliers that takes into account duct leakage losses, and to combine this with an appropriate training course designed to help contractors take some of the oversizing trends out of their Manual-J calculations.

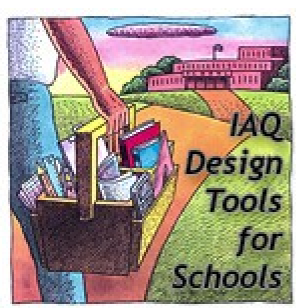
The essence of the Phase-II strategy is to address the duct-design problems in the combination of Manual J and Manual D. This can be accomplished by inserting an overall duct-loss calculation procedure for each register in the house into the process. This may require some iteration between the duct-sizing procedure and the duct-loss calculation procedure, however one or two iterations will most likely be adequate, and the final design will not only provide better comfort, but should ultimately result in better energy efficiency. This overall duct-loss calculation procedure should most-likely be based on the simplified procedure developed by Palmiter (1995) that is likely to be adopted into the proposed ASHRAE Standard 152P. This procedure should be used separately for heating and cooling operation.

HVAC SYSTEMS

Heating, Ventilation and Air-Conditioning (HVAC) Systems

Indoor Air Quality Design Tools for Schools

- Preliminary Design Phases
- Controlling Pollutants and Sources
- Heating, Ventilation, and Air-Conditioning (HVAC)
- Moisture Control
- Construction
- Commissioning
- Renovation and Repair
- Operations and Maintenance
- Portable Classrooms



The main purposes of a Heating, Ventilation, and Air-Conditioning (HVAC) system are to help maintain good indoor air quality through adequate ventilation with filtration and provide thermal comfort. HVAC systems are among the largest energy consumers in schools. The choice and design of the HVAC system can also affect many other high performance goals, including water consumption (water cooled air conditioning equipment) and acoustics (See Acoustics).

The following actions detail how engineers can design a quality system that is cost-competitive with traditional ventilation designs, while successfully providing an appropriate quantity and quality of outdoor air, lower energy costs, and easier maintenance.

Contents

Codes and Standards

The national consensus standard for outside air ventilation is ASHRAE Standard 62.1-200, Ventilation for Acceptable Indoor Air Quality (available online via www.ashrae.org EXIT Disclaimer) and its published Addenda. This standard is often incorporated into state and local building codes, and specifies the amounts of outside air that must be provided by natural or mechanical ventilation systems to various areas of the school, including classrooms, gymnasiums, kitchens and other special use areas.

Many state codes also specify minimum energy efficiency requirements, ventilation controls, pipe and duct insulation and sealing, and system sizing, among other factors. In addition, some states and localities have established ventilation and/or other indoor air quality related requirements that must also be followed.

- **Design in accordance with ASHRAE standards** Design systems to provide outdoor air ventilation in accord with ASHRAE Standard 62.1-2007 (available at www.ashrae.org EXIT Disclaimer) and thermal comfort in accord with ASHRAE Standard 55–1992 (with 1995 Addenda) Thermal Environmental Conditions for Human Occupancy EXIT Disclaimer

- **Ensure familiarity with, and adherence to, all state and local building codes and standards.**

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Potential for Natural Ventilation and Operable Windows

In some parts of the country, where temperature and humidity levels permit, natural ventilation through operable windows can be an effective and energy-efficient way to supplement HVAC systems to provide outside air ventilation, cooling, and thermal comfort when conditions permit (e.g., temperature, humidity, outdoor air pollution levels, precipitation). Windows that open and close can enhance occupants' sense of well-being and feeling of control over their environment. They can also provide supplemental exhaust ventilation during renovation activities that may introduce pollutants into the space.

However, sealed buildings with appropriately designed and operated HVAC systems can often provide better indoor air quality than a building with operable windows. Uncontrolled ventilation with outdoor air can allow outdoor air contaminants to bypass filters, potentially disrupt the balance of the mechanical ventilation equipment, and permit the introduction of excess moisture if access is not controlled.

Strategies using natural ventilation include wind driven cross-ventilation and stack ventilation that employs the difference in air densities to provide air movement across a space. Both types of natural ventilation require careful engineering to ensure convective flows. The proper sizing and placement of openings is critical and the flow of air from entry to exit must not be obstructed (e.g., by closed perimeter rooms).

- **Designers should consider the use of natural ventilation and operable windows to supplement mechanical ventilation.** Consider outdoor sources of pollutants (including building exhausts and vehicle traffic) and noise when determining if and where to provide operable windows.

- **If operable windows will be used to supplement the HVAC system, ensure that:**
  - openings for outdoor air are located between 3-6 feet from the floor (head height);
  - the windows are adjustable and can close tightly and securely;
  - the windows are placed to take maximum advantage of wind direction, with openings on opposite sides of the building to maximize cross-ventilation.

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Selection of HVAC Equipment

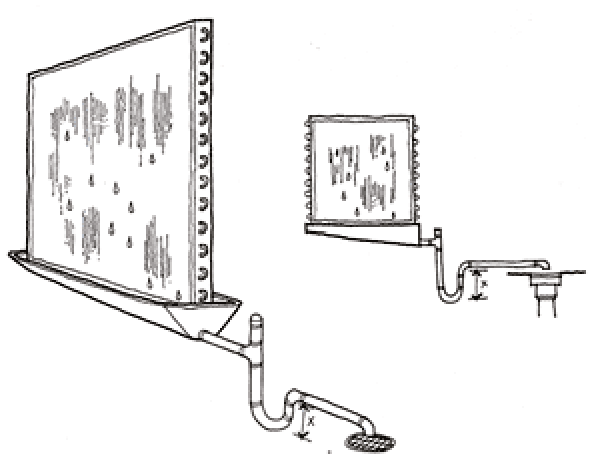
In most parts of the country, climatic conditions require that outdoor air must be heated and cooled to provide acceptable thermal comfort for building occupants, requiring the addition of HVAC systems. The selection of equipment for heating, cooling and ventilating the school building is a complex design decision that must balance a great many factors, including heating and cooling needs, energy efficiency, humidity control, potential for natural ventilation, adherence to codes and standards, outdoor air quantity and quality, indoor air quality, and cost.

- **Where feasible, use central HVAC air handling units (AHUs) that serve multiple rooms in lieu of unit ventilators or individual heat pumps.**

  Although there are many different types of air handling units, for general IAQ implications in schools, air handling units can be divided into two groups: unit ventilators and individual heat pump units that serve a single room without ducts; and central air handling units that serve several rooms via duct work. Unit ventilators and heat pumps have the advantage of reduced floor space requirements, and they do not recirculate air between rooms. However, it is more difficult to assure proper maintenance of multiple units over time, and they present additional opportunities for moisture problems through the wall penetration and from drain pan and discharge problems. Central air handling units have a number of advantages as compared to unit ventilators and heat pumps serving individual rooms. They are:

  - Quieter, and therefore more likely to be turned on or left on by teachers and staff;
  - Less drafty due to multiple supplies and a return that is away from occupants;
  - Better at controlling humidity and condensed moisture drainage;
  - Easier to maintain due to reduced number of components and few units to access;
  - More space around units and can be accessed without interfering with class activities;
  - Space for higher efficiency air filters, and more surface area;
  - Made of heavier duty components;
  - Less likely to have quantity of outdoor air supply inadvertently reduced.

- **Specify the following features for all air handling units:**



Double-sloped drain pan and drain trap depth

- Double-sloped drain pan - A double-sloped pan prevents water from standing and stagnating in the pan.
- Non-corroding drain pan - Made from stainless steel or plastic. Prevents corrosion that would cause water to leak inside the AHU.
- Easy access doors - All access doors are hinged and use quick release latches that do not require tools to open. Easy access to filters, drain pans, and cooling coils is imperative.
- Double wall cabinet - The inner wall protects the insulation from moisture and mechanical damage, increases sound dampening, and is easier to clean.
- Tightly sealed cabinet - Small yet continuous air leaks in and out of the AHU cabinet can affect IAQ and energy. The greatest pressure differentials driving leaks occur at the AHU.
- Double wall doors with gaskets - Double wall doors provide better thermal and acoustic insulation, and will remain flatter, allowing a better seal against door frame gaskets
- Minimum 2 inch thick filter slots - For better protection of the indoor environment, as well as the equipment and ducts, the filters slots should be able to accommodate 2 in. or thicker filters.
- Extended surface area filter bank - To reduce the frequency of filter maintenance and the cost of fan energy, the bank is designed to allow more filter area, such as the deep V approach or bags.
- Air filter assemblies (racks & housings) designed for minimum leakage - The filter bank should have gaskets and sealants at all points where air could easily bypass the air filters, such as between the filter rack and the access door. Use properly gasketed manufacturer supplied filter rack spacers.
- Air filter monitor - A differential pressure gauge to indicate the static pressure drop across the filter bank. This feature could easily be installed as an option in the field.
- Corrosion resistant dampers & links - **All moving parts such as pivot pins, damper actuators, and linkages are able to withstand weather and moisture-induced corrosion for the full life of the system**

Energy Recovery Ventilation

Consider specifying energy recovery ventilation equipment.

Indoor air can be 2 to 5 times more polluted than outdoor air; therefore, most HVAC system designers understand that increased amounts of outdoor air supply is generally better for IAQ. Yet there are concerns over the implications that this added amount of outdoor air supply has on the first cost and operating cost of the HVAC system, as well as moisture control for the school (too wet or too dry). As a result, school designers often try to reduce the amount of outdoor air equal to – or even below -- 15 cubic feet per minute (cfm) of outside air per person, the minimum for school classrooms, as established by the American Society of Heating, Refrigerating and Air -conditioning Engineers (ASHRAE) www.ashrae.org EXIT Disclaimer. In many parts of the country these concerns can easily be addressed by application of basic engineering principles and off-the-shelf HVAC equipment.

First cost, energy costs, and moisture control do not have to be at odds with good IAQ. Energy recovery ventilation equipment can make the negative implications of 15 cfm per person of outdoor air behave like 5 cfm, while retaining the IAQ advantage of 15 cfm. This approach has been proven in many schools in various regions east of the Rockies, where advanced HVAC systems cost roughly the same as conventional systems, yet provide significant operating cost savings and IAQ advantages.

EPA has developed the School Advanced Ventilation Engineering Software (SAVES) package as a tool to help school designers assess the potential financial payback and indoor humidity control benefits of Energy Recovery Ventilation (ERV) systems. See also:

- Overview of ERV Systems
- Financial Aspects of ERV Systems

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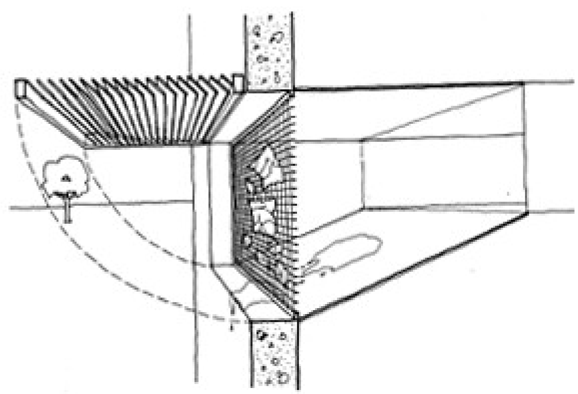
Location of Outdoor Air Intakes and Exhaust



Sloped Intake Plenum and Accessible Intake Screen

- **Proper location of outdoor air intakes can minimize the blockage of airflow and intake of contaminated air.**

  The bottom of air intakes should be at least 8 inches above horizontal surfaces (generally the ground or the roof) to prevent blockage from leaves or snow. In northern locations, more separation may be needed due to greater snow depths or drifting snow.

- **Intakes should not be placed within 25 feet of any potential sources of air contaminants, including sewer vents, exhaust air from the school, loading docks, bus loading areas, garbage receptacles, boiler or generator exhausts, and mist from cooling towers.**

  If the source is large or contains strong contaminants, or if there is a dominant wind direction in the area, the minimum separation distance may need to be increased. Air admittance valves, an inexpensive and code-approved one-way air valve, can be added to sewer vents to eliminate the potential for release of gases into the surrounding air.

- **Grilles protecting air intakes should be bird- and rodent-proofed to prevent perching, roosting, and nesting.**

  Waste from birds and other pests (e.g., rats) can disrupt proper operation of the HVAC system, promote microbial growth and cause human disease. The use of outdoor air intake grilles with vertical louvers, as opposed to horizontal louvers, will reduce the potential for roosting.
- **Intake Screens must be accessible for inspection and cleaning.**

  In existing schools, an insufficient amount of ventilation air is often the result of clogged intake screens that are inaccessible for inspection and cleaning. Screens hidden by an intake grille should be designed with a grille that is easily opened, such as a hinged grille with two quick-release latches, or in the worst case, a grille with four one-quarter turn fasteners. All screens should be easily removable for cleaning.
- **Consider adding a section of sloped intake plenum that causes moisture to flow to the outside or to a drain if intake grilles are not designed to completely eliminate the intake of rain or snow.**

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Outdoor Air Quantity

Classrooms and other school spaces must be ventilated to remove odors and other pollutants. The national consensus standard for outside air ventilation is ASHRAE Standard 62.1-2001 - available at www.ashrae.org EXIT Disclaimer

If outside air is provided through a mechanical system, then at least 15 cubic feet per minute (cfm) of outside air must be provided for each occupant. A typical classroom with 30 people requires a minimum of 15 x 30 or 450 cfm of outside air.

In spaces where the number of occupants is highly variable such as gyms, auditoriums and multipurpose spaces, demand controlled ventilation (DCV) systems can be used to vary the quantity of outside air ventilation in these spaces in response to the number of occupants. One technique for doing this is to install carbon dioxide (CO_2) sensors that measure concentrations and vary the volume of outside air accordingly. If an auditorium fills up for school assembly, then CO_2 concentrations will increase, a signal will be provided to the HVAC system and outside air volumes will be increased accordingly. When the spaces served by an air handler have highly variable occupancy, this type of control can both save energy and help control moisture (and mold) by reducing the quantity of humid outside air when it is not needed for ventilation. CO_2 and other sensors must be periodically calibrated and maintained.

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Air Filtration

In addition to "atmospheric dust," airborne particulates can include pollen, mold (fungal) spores, animal dander, insect proteins, pesticides, lead, and infectious bacteria and viruses. Designers can integrate features into the ventilation system that will provide benefits for the school occupants as well as the efficiency and longevity of the HVAC system. In addition, these features can reduce the need for expensive cleaning of the duct work and air handling units.

Filter Efficiency

- **Air filters should have a dust-spot rating between 35% and 80% or a Minimum Efficiency Rating Value (MERV) of between 8 and 13.**

  The higher the rating, the better the protection for the equipment and the occupants. It has been estimated that a 30% increase in static pressure across a coil results in a $200 per 10,000 cfm of air movement (at 7 cents per KWH). This does not include the added cost of cleaning dirty heating or cooling oils, drain pans, or air ducts. Designers should consider specifying a low efficiency (~10%) pre-filter upstream of the main filters. The pre-filters are generally easy and inexpensive to change, and will capture a significant amount of the particulate mass in the air thereby extending the useful life of the more expensive main filters. See ASHRAE Standard 52.2-1999 Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size available at www.ashrae.org EXIT Disclaimer

Pressure Drop

- **Design more filter surface area into ventilation systems.**

  This has two advantages: the number of filter changes each year is reduced, thereby reducing the cost of labor to properly maintain the filters; and static pressure loss is lower, which saves money by reducing the amount of power needed to operate fans and blowers. Since different filter media are approximately proportional in their efficiency/pressure drop ratio, the most effective method for reducing pressure drop is to design more filter surface area into the filter system. This can be done by the specification of a filter with larger amounts of surface area, such as a pleated filter or bag filter. The next method is to increase the number and/or size of the filters in the airstream, for example, by mounting the filter slots in a "V" pattern, rather than a filter rack that is simply flat and perpendicular to the airstream.

Monitoring Pressure

- **Consider installing a simple pressure differential gauge across all filter banks.**

  This will prevent school facilities personnel from having to guess whether the filter is ready for replacement. A gauge with a range of zero to 1.0 in. w.g. can save money and the environment by preventing premature disposal of filters that still have useful life, and can prevent health and maintenance problems caused by overloaded filters that have blown out. The gauge should be easily visible from a standing position in an easily accessed location near the air handling unit.

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Air Cleaning for Gaseous Contaminants

The most effective means of reducing exposure of occupants to gases and VOCs is to manage and control potential pollution sources. Filters are available to remove gases and volatile organic contaminants from ventilation air; however, because of cost and maintenance requirements, these systems are not generally used in normal occupancy buildings or schools. In specially designed HVAC systems, permanganate oxidizers and activated charcoal may be used for gaseous removal filters. Some manufacturers offer "partial bypass" carbon filters and carbon impregnated filters to reduce volatile organics in the ventilation air of office environments. Gaseous filters must be regularly maintained (replaced or regenerated) in order for the system to continue to operate effectively. See also "Residential Air Cleaning Devices: A Summary of Available Information."

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Ventilation Controls

Although a typical HVAC system has many controls, the control of outdoor air quantity that enters the building can have a significant impact on IAQ, yet typically is not part of standard practice. Demand controlled ventilation is addressed as a method of humidity control, but is not otherwise discussed here because its primary use is to reduce the supply of outdoor air below the recommended minimum for the purposes of saving energy, not for improving IAQ.

Outdoor Air Volume Monitoring and Control

Supplying acceptable quantities of outdoor air to occupied spaces is a critical component of good indoor air quality. Yet nearly all school ventilation systems cannot indicate whether outdoor air is even being supplied to the school, much less gauge the quantity of that air. Virtually all existing school ventilation systems rely upon a fixed damper to regulate the amount of outdoor air. Yet wind, stack effect, unbalanced supply and return fans, and constantly changing variable air volume (VAV) systems can cause significant under- or over-ventilation, which can affect IAQ and energy costs. Combinations of these effects can even cause the intake system to actually exhaust air.

- **Specify the addition of a measuring station that actively controls the amount of outdoor airflow by modulating the outdoor air damper and the return (recirculation) damper, if needed to overcome wind and stack effects.**

  These measuring stations are designed to work in limited duct space and with low air velocities. This is an easy task, as some manufacturers offer their airflow measuring stations in separate packages with dampers and actuators, and others are built into the AHU at the factory.

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Moisture and Humidity Control

Uncontrolled moisture indoors can cause major damage to the building structure, as well as to furnishings and to finish materials like floors, walls, and ceilings. Uncontrolled moisture can trigger mold growth which not only damages the school facility, but can lead to health and performance problems for students and staff.

Primary causes of indoor moisture problems in new schools include:

- Use of building materials that were repeatedly or deeply wetted before the building was fully enclosed
- Poor control of rain and snow, resulting in roof and flashing leaks
- Wet or damp construction cavities
- Moisture-laden outdoor air entering the building
- Condensation on cool surfaces

Controlling moisture entry into buildings and preventing condensation are critical in protecting buildings from mold and other moisture-related problems, including damage to building components.

Follow these links for more moisture information:

- Building Materials
- Precipitation Control
- Building Envelope
- Controlling Moisture in Ventilation Air
- Energy Recovery Ventilators
- Summer Breaks and Humidity Control
- Condensation

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Air Distribution and Duct Insulation

Dirt and moisture should not be present in duct systems, and must be controlled to prevent mold growth. However, it is not always possible to assure that ducts remain dirt and moisture free. In many existing schools, sheet metal ducts, as well as those constructed of or lined with insulation products, are often contaminated with mold because dirt and moisture found their way into the system.

Duct board and duct liner are widely used in duct systems because of their excellent acoustic, thermal, and condensation control properties. If the HVAC system is properly designed, fabricated, installed, operated and maintained, these duct systems pose no greater risk of mold growth than duct systems made of sheet metal or any other materials.

However, the very properties that make duct board and duct liner superior insulators (e.g., a fibrous structure with large surface area that creates insulating air pockets), also makes them capable of trapping and retaining moisture if they do get wet (though the fibers themselves do not absorb moisture).

While there is an ongoing debate about the wisdom of using insulation materials in duct systems that might retain moisture longer, all sides agree that extraordinary attention to preventing moisture contamination of the duct work should be the primary strategy for preventing mold growth. See ANSI/ASHRAE Addenda 62t and 62w, Addenda to ANSI/ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality (available at www.ashrae.org EXIT Disclaimer).

As a secondary strategy, designers should consider methods of reducing the potential for future problems to occur due to unforeseen moisture contamination by investigating insulation products now on the market that minimize the potential for moisture to penetrate the insulation material. These include foil vapor retarders, tightly bonded non-woven vapor retarders, butt or shiplap edges, and other techniques that have been developed by insulation manufacturers to address concerns about moisture.

- **Pay special attention to preventing moisture from entering duct work.**

  Preventing moisture from entering duct work is critical to preventing mold problems in all types of ducts. Moisture in ducts is usually due to penetration of precipitation through inlet louvers, excess moisture in outdoor air, or condensation droplets from cooling coils that are not properly drained or ducts that are not properly sealed. Under certain circumstances, when exceeding recommended maximum cooling coil face velocity, water droplets can escape cooling coils and be carried into the air stream, saturating any dirt or dust downstream. Because dust and dirt serve as a food source for mold and are usually present in all but brand new duct systems, mold will grow on any duct surface that remains wet.

- **If specifying duct board or internal duct lining for thermal and/or acoustical control, be sure to consider the potential for uncontrolled moisture to enter the duct over the life of the system.** Select products that will minimize the potential for moisture retention in the event of unforeseen contamination of the duct system, such as those with properties that reduce the potential for moisture to penetrate the air stream surface. Ensure that all duct systems are properly fabricated and installed.

- **Degrease sheet metal air ducts.**

  The sheet steel used to make ducts has a thin petroleum or fish oil coating primarily intended to inhibit corrosion during transportation and storage of the steel. This coating may trap dirt particles, some people find the odor objectionable, and there are concerns that the emissions from the coating could affect individuals with asthma or allergies. One solution is to remove the coating from the duct using a mild cleaning agent, such as a household dishwashing liquid, in conjunction with a heated high-pressure sprayer.

- **Seal air ducts to prevent HVAC system air leakage.**

In addition to significant energy losses, air leakage from HVAC ducts and air handling units can cause significant IAQ problems due to unexpected airflow between indoors and outdoors, and between areas within the school. Air leakage from supply or return duct work contributes to the condensation of humid air in building cavities and/or on the neighboring surfaces. Air leakage can be especially problematic for ducts or AHUs that are located outside the conditioned spaces. The primary goals for the designer are to keep all air ducts within the conditioned space, and to specify that the joints and seams of all ducts, including return ducts, are sealed using an appropriate material.

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Types of Air Distribution

Nearly all schools currently use the mixed-airflow method for distribution and dilution of the air within the occupied space. Designers should investigate a method called vertical displacement ventilation or thermal displacement ventilation. This approach successfully uses natural convection forces to reduce fan energy and carefully lift air contaminants up and away from the breathing zone.

[Click on the image to begin the animation. Cool supply air (blue) slowly flows out of the two heating/cooling registers in the corners of the room, and spreads across the floor. As it is warmed by people (brown columns represent students) and other warmer objects in the room, it rises upward, continuously lifting polluted air up and away from the occupants. It is then collected and exhausted outdoors. This animation requires Windows Media Player or RealPlayer. Animation used courtesy of Dunham Associates, Minnesota, MN.]

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Exhaust Air

Quick removal of concentrated air contaminants and building pressurization are two ways that exhaust systems affect IAQ. Special use areas such as science labs, vocational/technical shops, cafeterias, and indoor pools already have well established regulatory codes regarding ventilation with outdoor air and negative pressure requirements with respect to adjacent spaces. Less well recognized areas in schools where special exhaust ventilation is desirable are janitor closets, copy/work rooms and arts/crafts preparation areas where off-gasing from significant quantities of materials or products may occur. These areas should be maintained under negative pressure relative to adjacent spaces.

- **Provide exhaust ventilation for janitor's closets.**

  If housekeeping and maintenance supplies are properly stored in janitor closets, only enough air need be exhausted to place the closet under negative pressure relative to surrounding rooms. As long as air does not easily leak into or from the closet through openings such as plenums or utility chases, 10 CFM of air exhausted from the room will typically make it negative, and prevent the buildup of air pollutants.

- **Provide exhaust ventilation for copy/work rooms.**

  In addition to the code-required amount of outdoor air being supplied to this room for general ventilation, it is desirable to determine what types of equipment and activities the school plans for this room, and to supply special exhaust ventilation for concentrated pollutant sources. Two examples of sources are copy machines and work areas for adhesives. Most copier manufacturers can provide an optional vent kit, which is usually a simple plastic fitting, that allows a piece of 3" or 4" diameter flexible duct to be connected between the copier and an exhaust fan. This captures much of the heat, particles, ozone, and other pollutants and exhausts them outdoors before they can spread throughout the workroom. A small exhaust hood over a work surface, similar to a fume hood in a science lab, would also be helpful to reduce exposure when adhesives, sprays, paints, and solvents are being used in the workroom.

- **Provide exhaust ventilation for arts and crafts preparation areas where off-gasing from significant quantities of materials or products may occur.**

- **Consider specifying a differential pressure monitor to monitor building pressurization.**

  IAQ problems are often traced to improper pressurization, which causes unexpected airflow between indoors and outdoors, and between areas within the school. To reduce introduction of unconditioned moist air and pollutants from outdoors, the building should be designed to operate between zero and 0.03 in. w.g. (0 to 7 Pa) positive, relative to outdoors.

- **Do not operate exhaust systems when the HVAC system is turned off to avoid bringing in unconditioned moist air that may condense on cooler indoor surfaces.**

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Designing for Efficient Operations and Maintenance

- **Ensure that all system components, including air handling units, controls, and exhaust fans are easily accessible.**

To help ensure that proper operation and maintenance of HVAC system components will be performed, it is critical that the designer makes the components easily accessible. AHUs, controls, and exhaust fans should not require a ladder, the removal of ceiling tiles, or crawling to gain access. Rooftop equipment should be accessible by way of stairs and a full-sized door, not a fixed ladder and a hatch.

- **Label HVAC system components to facilitate operations and maintenance.**

Labeling of HVAC components is an inexpensive and effective method for helping facilities personnel properly operate and maintain the HVAC systems. The labels should be easy to read when standing next to the equipment, and durable to match the life of the equipment to which they are attached. At a minimum, the following components should be labeled in each ventilation zone of the school and should correspond with the HVAC diagrams and drawings. "AHU" refers to any air handling unit that is associated with outdoor air supply.

✓The number or name of the AHU (e.g., AHU ##, or AHU for West Wing)
✓The outdoor air (OA), supply air (SA), return air (RA), and exhaust or relief air (EA) connections to the AHU, each with arrows noting proper airflow direction
✓The access door(s) for the air filters and the minimum filter dust-spot (or MERV) efficiency (Air Filters, minimum xx% dust spot efficiency)
✓The filter pressure gauge and the recommended filter change pressure (Filter Pressure, max 0.x in. w.g.)
✓The access door(s) for the condensate drain pan (Drain Pan)
✓Other pertinent access doors such as to energy recovery ventilation wheels or plates (Energy Recovery Ventilation Unit)
✓The minimum amount of outdoor air for each AHU (### CFM minimum during occupied times)
✓The outdoor air damper (OA Damper), with special marks noting when the damper is in the fully closed (Closed), fully opened (open), and minimum designed position (Min)
✓If a motorized relief damper is installed (EA Damper), note the same positions as above.
✓The access door to any outdoor air controls (OA Control(s)) such as damper position adjustments, outdoor airflow measuring stations, resets, fuses, and switches)
✓Breakers for exhaust fans (Exhaust Fan ##), AHU, unit ventilators
✓Access doors for inspection and maintenance of air ducts
✓Any dampers and controls for air side economizers (as appropriate)
✓The number or name of all exhaust fans, including the air quantity exhausted (EF##, ###CFM)

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Commissioning

(see also www.epa.gov/iaq/schooldesign/commissioning.html)

Building commissioning is a quality assurance program that is intended to show that the building is constructed and performs as designed. Click here for more information on commissioning HVAC and other building systems.

Commission key building systems.

- Engage a commissioning agent (the person responsible for implementing the commissioning plan) during the schematic design phase or earlier. The agent may be a

member of the design team, an independent contractor, or a member of the school district staff;
- Collect and review documentation on the design intent;
- Make sure commissioning requirements are included in the construction documents;
- Write a commissioning plan and use it throughout design and construction;
- Verify installation and functional performance of systems;
- Document results and develop a commissioning report.

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References and Resources

- I-BEAM -- IAQ Building Education and Assessment Model EPA document # 402-C-01-001

- IAQ Tools for Schools Program and Tool Action Kit EPA document 402-K-95-001, Second Edition, December 2000

- Building Air Quality: A Guide for Building Owners and Facility Managers EPA document # 402-F-91-102, December 1991

- Energy Efficiency and Indoor Air Quality in Schools Businesses : ENERGY STAR EXIT Disclaimer

- New York City High Performance Building Guidelines EXIT Disclaimer

- Collaborative for High Performance Schools EXIT Disclaimer

- *Humidity Control Design Guide for Commercial and Institutional Buildings*. Harriman, Brundrett, and Kittler. American Society of Heating, Refrigerating, and Air Conditioning Engineers. ISBN 1-883413-98-2. www.ashrae.org EXIT Disclaimer

- The Sheet Metal and Air Conditioning Contractor's National Association (SMACNA) *IAQ Guidelines for Occupied Buildings Under Construction* EXIT Disclaimer

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