CHAPTER 6

EDUCATIONAL FACILITIES

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THIS chapter contains technical, environmental, and design considerations to assist the design engineer in the proper application of heating, ventilation, and air-conditioning systems and equipment for educational facilities.

PRESCHOOLS

General Design Considerations

Commercially operated preschools are generally provided with standard architectural layouts based on owner-furnished designs. A typical preschool facility provides programs for infants (1 to 2 years old), toddlers (2 years old), and preschoolers (3 to 4 years old). Larger facilities also offer programs for older children, such as kindergarten programs (5 years old). Areas such as lobbies, libraries, and kitchens are also included to support the variety of programs. Given this range of age, special attention for the design of the HVAC systems is required to meet the needs of every age group.

All preschool facilities require quiet and economical systems. The equipment should be easy to operate and maintain, and the design should provide warm floors and no drafts. These facilities have two distinct occupant zones: (1) the floor level, where younger children play, and (2) normal adult height, for the teachers. The teacher also requires a place for a desk; consider treating this area as a separate zone.

Preschool facilities generally operate on weekdays from early in the morning to 6:00 or 7:00 PM. This schedule usually coincides with the normal working hours of the children's parents plus one hour for drop-off and pick-up. The HVAC systems therefore operate 12 to 14 h per workday, and may be either off or on at night and weekends, depending on whether setback is applied.

Supply air outlets should be positioned so that the floor area is maintained at about 75°F without the introduction of drafts. Both supply and return air outlets should be placed where they will not be blocked by furniture positioned along the walls or where children can reach them. Coordination with the architect about locating these outlets is essential. Proper ventilation is crucial for controlling odors and helping prevent spread of diseases among the children.

Floor-mounted heating equipment, such as electric baseboards heaters, should be avoided because children must be prevented from coming in contact with hot surfaces or electrical devices. However, radiant-floor systems can be used safely and effectively.

Design Criteria

Table 1 provides typical indoor design conditions for preschools. Table 2 provides typical ventilation and exhaust design criteria using the ventilation rate procedure of ANSI/ASHRAE *Standard* 62.1-2004; the user's manual (ASHRAE 2004a) is also

Table 1 Recommended Temperature and Humidity Design Criteria for Various Spaces in Preschools

Category/Humidity Criteria	Indoor Design Conditions, °F Winter	Summer
Infant, Toddler, and Preschooler Classrooms[a]		
30% rh	68.5 to 75.5	74.0 to 80.0
40% rh	68.0 to 75.0	73.5 to 80.0
50% rh	68.5 to 74.5	73.0 to 79.0
60% rh	67.5 to 74.0	73.0 to 78.5
Administrative, Offices, Lobby, Kitchen		
30 to 60% rh	68.5 to 74.0	74.0 to 78.5
Storage		
No humidity control	64.0	
Mechanical Rooms[b]		
No humidity control	61.0	

Notes:
[a]Based on EPA (2000) and ASHRAE *Standard* 55-2004 for people wearing typical summer and winter clothing, at mainly sedentary activity.
[b]Usually not conditioned.

Table 2 Typical Recommended Design Criteria for Ventilation and Filtration for Preschools

Category	Ventilation and Exhaust[a, g, j] Outdoor Air, cfm/Person	Occupant Density[k] per 1000 ft²	Outdoor Air cfm/ft²	Outdoor Air cfm/Unit	Minimum Filtration Efficiency, MERV[h]
Infant, Toddler, and Preschooler Classrooms[b]	17	25			6 to 8
Administrative and Office Space[c]	17	5			6 to 8
Kitchen[d]			0.3 (exhaust)		i
Toilets[e]				50 (exhaust)	NA
Storage[f]			0.12		1 to 4

Notes:
[a]Based on ANSI/ASHRAE *Standard* 62.1-2004, Table 6-1, default values for ventilation, and Table 6-4 for exhaust rates.
[b]Based on ASHRAE *Standard* 62.1-2004, Table 6-1, default values for educational facilities-daycare.
[c]Based on ASHRAE *Standard* 62.1-2004, Table 6-1, default values for office buildings/office spaces.
[d]Based on ASHRAE *Standard* 62.1-2004, Table 6-4, for kitchenettes.
[e]Based on ASHRAE *Standard* 62.1-2004, Table 6-4, for private toilets (rate is for toilet room intended to be occupied by one person).
[f]Based on ASHRAE *Standard* 62.1-2004, Table 6-1, for storage rooms.
[g]This table should not be used as the only source for design criteria. Governing local codes, design guidelines, and ASHRAE *Standard* 62.1-2004 with current addenda *must* be consulted.
[h]MERV = minimum efficiency reporting values, based on ASHRAE *Standard* 52.2-1999.
[i]See Chapter 31 for additional information on kitchen ventilation.
[j]Consult local codes for exhaust requirements.
[k]Use default occupancy density when actual occupant density is not known.

The preparation of this chapter is assigned to TC 9.7, Educational Facilities.

Table 3 Typical Recommended Design Guidelines for HVAC: Related Background Sound for Preschool Facilities

Category	Sound Criteria[a, b] RC (N); QAI < 5 dB	Comments
Infant, Toddler, and Preschooler Classrooms	25 to 30	
Administrative/Office Areas	30 to 40	For open-plan office
Service/Support Areas	35 to 45	

Notes:
[a]Based on Chapter 47.
[b]RC (Room Criterion), QAI (Quality Assessment Index) from Chapter 7 of 2005 *ASHRAE Handbook—Fundamentals*.

strongly recommended for additional information on applying this standard. Table 3 lists design criteria for acceptable noise in preschool facilities.

Load Characteristics

Preschool cooling and heating loads depend heavily on ambient conditions, because the rooms typically have exterior exposures (walls, windows, and roofs) and also relatively higher needs for ventilation. Although preschool facilities are relatively small, the design engineer must pay special attention to properly calculate the cooling, heating, dehumidification, and humidification loads. Sizing and applying the HVAC equipment is critical for handling the loads and the large amounts of outdoor air from a capacity and occurrence standpoint (peak sensible and latent loads do not always coincide).

Humidity Control

Preschool classrooms require humidity control to provide human comfort and prevent health problems. Maintaining humidity levels between 30 and 60°F dew point satisfies nearly all people nearly all the time. However, the designer should discuss comfort expectations with the owner, to avoid misunderstandings.

In hot and humid climates, it is recommended that air conditioning and/or dehumidification be operated year-round to prevent growth of mold and mildew. Dehumidification can be improved by adding optional condenser heat/reheat coils, heat pipes, or air-to-air heat exchangers in conjunction with humidity sensors in the conditioned space or return air. Additional information on humidity control is in the section on K-12 Schools.

Systems and Equipment Selection

HVAC systems for preschools are typically decentralized, using either self-contained or split air-conditioners or heat pumps (typically air- or water-source). When the preschool is part of a larger facility, utilities such as chilled water, hot water, or steam from a central plant can be used. When natural gas is available, the heating system can be a gas-fired furnace, or, when economically justifiable, electric heat can be used.

The type of HVAC equipment selected also depends on the climate and the months of operation. In hot and dry climates, for instance, evaporative cooling may be the primary type of cooling. In colder climates, heating can also be provided by a hot-water hydronic system originating from a boiler plant in conjunction with radiant floor or hot-water coils.

Decentralized systems are dedicated systems serving a single zone, and typically include the following:

- Direct-expansion (DX) split systems
- Rooftop packaged air conditioners or heat pumps with or without optional enhanced dehumidification (condenser reheat coil)
- Rooftop packaged air conditioners or heat pumps integrated with an energy recovery module, with optional enhanced dehumidification (condenser reheat coil; see Figure 1)
- Water-source heat pumps (with cooling tower and supplementary boiler)

Table 4 Applicability of Systems to Typical Areas[d]

Typical Area	Decentralized Cooling/Heating Systems[c] PSZ/SZ Split	PSZ with Energy Recovery and Dehumidification	WSHP	Geothermal Heat Pump	Heating Only Radiant Floor[b]
Classrooms	X[a]	X[a]	X	X	X
Administrative Areas, Lobby	X		X	X	
Kitchen	X		X	X	
Ventilation (Outdoor Air)	DOAS		DOAS	DOAS	DOAS

SZ = single zone
PSZ = packaged single zone
WSHP = water-source heat pump
DOAS = dedicated outdoor air system
Notes:
[a]PSZ for classrooms requires individual thermostatic control.
[b]Typically with cooling system such as PSZ/SZ split.
[c]Heating system for PSZ/SZ split can be gas furnace, hot-water coil, or electric.
[d]See Table 11 for additional systems if preschool is not a stand-alone facility.

- Geothermal heat pumps (ground-coupled, ground-water-source, surface-water-source)
- Packaged dedicated outdoor air systems (DOAS) with DX system for cooling and gas-fired furnace, electric heating, or part of water-source and geothermal heat pump system

Information about decentralized systems can be found in Chapters 5 and 45 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*. Additional information on geothermal heat pumps can be found in Kavanaugh and Rafferty (1997) and Chapter 32 of this volume. Chapter 6 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment* provides information on radiant heating.

Note that some decentralized systems may need additional acoustical modifications to meet the design criteria in Table 3. Therefore, it is strongly recommended to carefully check the acoustical implications of applying these systems.

Dedicated Outdoor Air Systems (DOAS). Specialized dedicated outdoor air systems (DOAS) should be used to treat outdoor air before it is introduced into classrooms or other areas. DOAS units can bring 100% outdoor air to at least space conditions, which allows the individual space units to handle only the space cooling and heating loads. A detailed description of DOAS is shown in the K-12 Schools section of this chapter. Additional information can be found in Chapter 47 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*.

Systems Selection by Application. Table 4 shows the applicability of systems to areas in preschool facilities.

Energy Considerations

Energy standards such as ANSI/ASHRAE/IESNA *Standard* 90.1-2004 and local energy codes should be followed for minimum energy conservation criteria. Additional energy conservation measures include the following:

- **Energy management systems (EMS)** and **direct digital control (DDC)** for easier maintainability of comfort conditions, optimized operation, troubleshooting, and monitoring
- **Temperature night/weekends setback** (winter) or **setup** (summer) by central EMS or stand-alone programmable thermostats
- **Morning warm-up** (winter) or **cooldown** (summer), typically by the central EMS
- **Ventilation control**, by throttling the space outdoor air damper to minimum position or close during unoccupied hours
- **Air-to-air energy recovery** for ventilation or in conjunction with the HVAC unit
- **Enhanced summer humidity control** by switching DOAS from 100% outdoor air to 100% recirculation and maintaining required summer humidity dew-point temperature

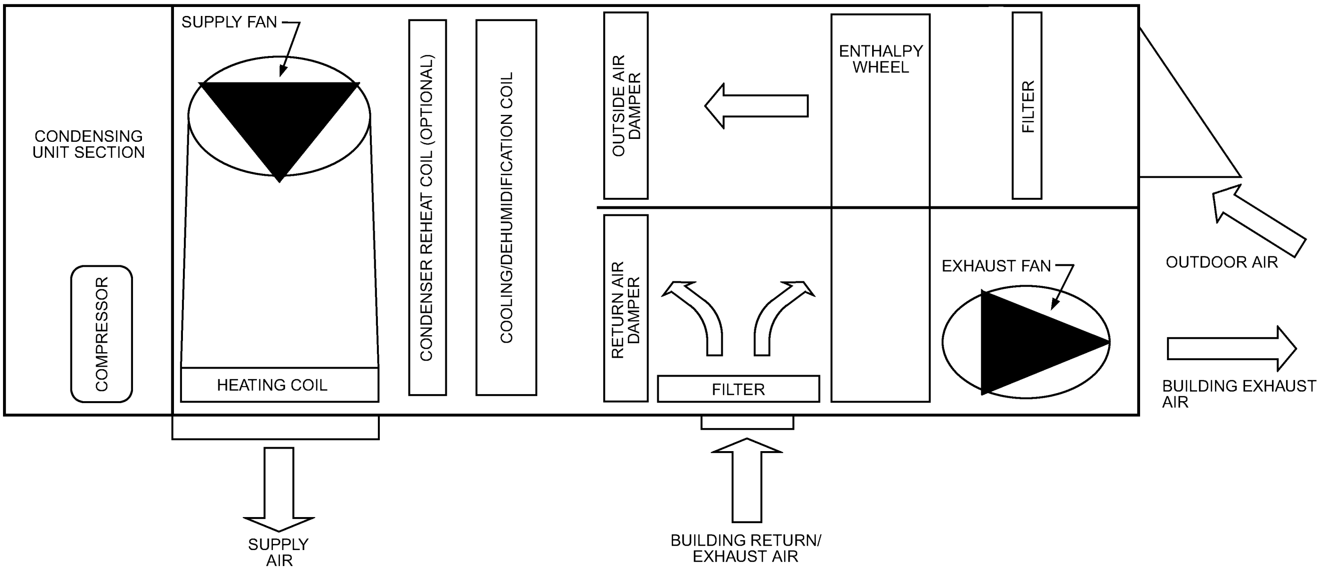

Fig. 1 Typical Configuration of Rooftop Packaged Air Conditioners with Energy Recovery Module and Enhanced Dehumidification (Condenser Reheat Coil)

- **Evaporative cooling systems**, where weather conditions permit
- **Natural ventilation**, when applicable, by using operable windows
- **Passive heating and cooling** techniques, in cooperation with the architect
- **Solar heating**, when economically justifiable for domestic hot-water heating and space heating

K-12 SCHOOLS

General and Design Considerations

K (kindergarten)-12 schools typically include elementary, middle, and high schools. These facilities are typically one- to three-story buildings.

Elementary schools are generally comprised of 10 to 15 classrooms plus cafeteria, administration, gymnasium, and library areas. Elementary schools are typically used during the school season (late August to June); during summer, they are typically closed or have minimal activity. Current trends include science classrooms and a preschool facility. Typical elementary schools operate between 7:00 AM and 4:00 PM.

Middle schools are larger than elementary schools and include additional computer classrooms and locker rooms. Their hours of operation are longer because of extracurricular activities. A recent trend toward eliminating middle schools (retaining traditional K-8 elementary and 9-12 high schools) (Wright 2003) may require that elementary school designs incorporate some middle school features.

High schools also include a cafeteria and auditorium, and may include a natatorium, ice-skating rink, etc. High schools operate longer hours and are often open during the summer, either as a summer school or to use special facilities such as gymnasiums, natatoriums, etc.

Typical areas found in K-12 schools are shown in Table 5.

K-12 schools require an efficiently controlled atmosphere for a proper learning environment. This involves the selection of heating, ventilation, and air-conditioning systems, equipment, and controls to provide adequate ventilation and indoor air quality (IAQ), comfort, and a quiet atmosphere. The system must also be easily maintained by the facility's maintenance staff.

The following are general design considerations for each of the areas typically found in K-12 schools:

Table 5 Typical Spaces in K-12 Schools

Typical Area	School: Elementary (K to 5)[a]	Middle (6 to 8)[a]	High (9 to 12)[a]
Classrooms	X	X	X
Science	X	X	X
Computer	X	X	X
Laboratories and Science Facilities		X	X
Administrative Areas	X	X	X
Gymnasium	X	X	X
Libraries	X	X	X
Auditorium			X
Home Economics Room			X
Cafeteria	X	X	X
Kitchen	X	X	X
Auto Repair Shop[b]			X
Industrial Shop			X
Locker Rooms		X	X
Ice Rink[b]			X
Natatorium[b]			X
School Store[b]			X

Notes: [a]School grades can vary. [b]These zones are not typical.

Classrooms. Classrooms typically range between 900 and 1000 ft^2, and are typically designed for 20 to 30 students. Each classroom should be, at a minimum, heated and ventilated. Air conditioning should be seriously considered for school districts that have year-round classes in warm, humid climates. In humid climates, seriously consider providing dehumidification during summer, even if the school is unoccupied, to prevent mold and mildew.

Science Classrooms. Science rooms are now being provided for elementary schools. Although the children do not usually perform experiments, odors may be generated if the teacher demonstrates an experiment or if animals are kept in the classroom. Under these conditions, adequate ventilation is essential along with an exhaust fan with a local on/off switch for occasional removal of excessive odors.

Computer Classrooms. These rooms have a high sensible heat load because of the computer equipment. They may require additional cooling equipment such as small spot-cooling units to offset the additional load. Humidification may also be required. See Chapter 17 for additional information.

Educational Laboratories. Middle and secondary school laboratories and science facilities may require fume hoods with special exhaust systems. A makeup air system may be required if there are several fume hoods within a room. If there are no fume hoods, a room exhaust system is recommended for odor removal, depending on the type of experiments conducted in the room and whether animals are kept within the room. Associated storage and preparation rooms are generally exhausted continuously to remove odors and vapors emanating from stored materials. The amount of exhaust and the location of exhaust grilles may be dictated by local codes or National Fire Protection Association (NFPA) standards. See Chapter 14 for further information. Additional information on laboratories can be found in McIntosh et al. (2001) and ANSI/AIHA *Standard* Z9.5-2003.

Administrative Areas. The office area should be set up for individual control because it is usually occupied during and after school hours. Because offices are also occupied before school starts in the fall, air conditioning for the area should be considered or provisions should be allowed for future upgrades.

Gymnasiums. Gyms may be used after regular school hours for evening classes, meetings, and other functions. The gym may also be used on weekends for group activities. The loads for these occasional uses should be considered when selecting and sizing the systems and equipment. Independent gymnasium HVAC systems with control capability allow for flexibility with smaller part-load conditions. If a wooden floor is installed, humidity control should be considered to avoid costly damage.

Libraries. Libraries should be air-conditioned to preserve the books and materials stored in them. See Chapters 3 and 21 for additional information.

Auditoriums. These facilities require a quiet atmosphere as well as heating, ventilation, and, in some cases, air conditioning. Auditoriums are not often used, except for assemblies, practice for programs, and special events. For other considerations, see Chapter 4.

Home Economics Rooms. These rooms usually have a high sensible heat load from appliances such as washing machines, dryers, stoves, ovens, and sewing machines. Different options should be considered for exhaust of stoves and dryers. If local codes allow, residential-style range hoods may be installed over the stoves. A central exhaust system could be applied to the dryers as well as to the stoves. If enough appliances are located within the room, a makeup air system may be required. These areas should be maintained at negative pressure in relation to adjacent classrooms and administrative areas. See Chapter 31 for more information.

Cafeteria and Kitchen. Typical schools requires space for preparation and serving of meals. A well-designed school cafeteria includes the following areas: loading/receiving, storage, kitchen, serving area, dining area, dishwashing, office, and staff facilities (lockers, lavatories, and toilets). Chapter 3 provides detailed information on design criteria, load characteristics, and design concepts for these facilities.

Auto Repair Shops. These facilities require outdoor air ventilation to remove odors and fumes and to provide makeup air for exhaust systems. The shop is usually heated and ventilated but not air-conditioned. To contain odors and fumes, return air should not be supplied to other spaces, and the shop should be kept at a negative pressure relative to the surrounding spaces. Special exhaust systems such as welding exhaust or direct-connected carbon monoxide exhaust systems may be required. See Chapter 30 for more information.

Industrial Shops. These facilities are similar to auto repair shops and have special exhaust requirements for welding, soldering, and paint booths. In addition, a dust collection system is sometimes provided and the collected air is returned to the space. Industrial shops have a high sensible load from operation of the shop equipment. When calculating loads, the design engineer should consult the teacher about shop operation, and, where possible, diversity factors should be applied. See Chapter 30 for more information.

Locker Rooms. Building codes in the United States require that these facilities be exhausted directly to the outside when they contain toilets and/or showers. They are usually heated and ventilated only. These areas typically require makeup air and exhaust systems that should operate only when required.

Ice Rinks. These facilities require special HVAC and dehumidification systems to keep spectators comfortable, and to prevent roof condensation and fog formation at the surface. See Chapter 4 of this volume, Chapter 34 of the 2006 *ASHRAE Handbook—Refrigeration*, and Harriman et al. (2001) for more on these systems.

Natatoriums. These facilities, like ice rinks, require special humidity control systems. In addition, special construction materials are required. See Chapter 4 and Harriman et al. (2001) for more on these systems.

School Stores. These facilities contain school supplies and paraphernalia and are usually open for short periods of time. The heating and air-conditioning systems serving these areas should be able to be shut off when the store is closed to save energy.

Design Criteria

A typical HVAC design criteria covers parameters required for thermal comfort, indoor air quality (IAQ), and sound. Thermal comfort parameters (temperature and humidity) are well covered by ANSI/ASHRAE *Standard* 55-2004 and Chapter 8 of the 2005 *ASHRAE Handbook—Fundamentals*. Ventilation and IAQ are covered by ANSI/ASHRAE *Standard* 62.1-2004, the user manual for that standard (ASHRAE 2004), and Chapter 27 of the 2005 *ASHRAE Handbook—Fundamentals*. Sound and vibration are discussed in Chapter 47 of this volume and Chapter 7 of the 2005 *ASHRAE Handbook—Fundamentals.*

Thermal comfort is affected by air temperature, humidity, air velocity, and mean radiant temperature (MRT). In addition, nonenvironmental factors (clothing, gender, age, and physical activity). affect thermal comfort. These variables and how they correlate to the thermal comfort can be evaluated by the *Thermal Comfort Tool CD* (ASHRAE 1997) in conjunction with ANSI/ASHRAE *Standard* 55-2004. It is important to indicate that, in addition to thermal comfort criteria, several zones in schools (libraries, gymnasiums, locker rooms, natatoriums, ice rinks, etc.) require additional considerations to cover issues such as mold prevention, condensation, corrosion, etc., as discussed in more detail in the section on Humidity Control. General guidelines for temperature and humidity applicable for K-12 schools are shown in Table 6.

All schools need outdoor air for ventilation. Outdoor air is introduced to occupied areas and then exhausted by fans or exhaust openings, removing indoor air pollutants generated by occupants and any other building-related sources. ANSI/ASHRAE *Standard* 62.1-2004 is used as the basis for many building codes. To define the ventilation and exhaust design criteria, consult local applicable ventilation and exhaust standards. Table 7 provides recommendations for ventilation design based on the ventilation rate procedure method and filtration criteria for K-12 educational facilities.

Additional information on IAQ for educational facilities can be found in EPA (2000).

Acceptable noise levels in classrooms are critical for a proper learning environment. High noise levels reduce speech intelligibility and student's learning capability. Although Chapter 47 provides information on design noise criteria, additional sources, such as local codes and ANSI *Standard* S12.60-2002, should be consulted for adequate design criteria. Table 8 summarizes applicable noise criteria for K-12 schools.

Load Characteristics

Proper cooling, heating, dehumidification, and humidification load calculations and properly sized equipment are critical to both energy efficiency and cost effectiveness. Many computer programs and calculation methodologies, as described in Chapter 30 of the

Table 6 Typical Recommended Temperature and Humidity Ranges for K-12 Schools

Category/Humidity Criteria	Indoor Design Conditions: Temperature, °F Winter	Summer	Comments
Classrooms, Laboratories, Libraries, Auditoriums, Offices[a, e]			
30% rh	68.5 to 75.5	74.0 to 80.0	
40% rh	68.0 to 75.0	73.5 to 80.0	
50% rh	68.5 to 74.5	73.0 to 79.0	
60% rh	67.5 to 74.0	73.0 to 78.5	
Gymnasiums			
30 to 60% rh	68.5 to 74.0	74.0 to 78.5	For gym with wooden floor, 35 to 50% humidity recommended at all times
Shops			
20 to 60% rh	68.5 to 74.0	74.0 to 78.5	
Cafeteria[b]			
20 to 30% (winter), 50% (summer) rh	70.0 to 73.5	78.5	
Kitchen[b]			
No humidity control	70.0 to 73.5	84.0 to 88.0	
Locker/Shower Rooms			
No humidity control	75.0		Usually not conditioned
Toilets			
No humidity control	72.0		Usually not conditioned
Storage			
No humidity control	64.0		
Mechanical Rooms			
No humidity control	61.0		Usually not conditioned
Corridors			
No humidity control	68.0		Frequently not conditioned
Natatorium[c]			
50 to 60% rh	75.0 to 84.0	75.0 to 84.0	Based on recreational pool
Ice Rink[d]			
35 to 45°F dp (maximum)	50.0 (minimum)	65.0 (maximum)	Minimum 10°F temperature difference between dew point and dry bulb to prevent fog and condensation

Notes:
[a]Based on EPA (2000) for people wearing typical summer and winter clothing, at mainly sedentary activity.
[b]Based on Chapter 3.
[c]Based on Chapter 4.
[d]Based on Harriman et al. (2001).
[e]For libraries, keep minimum humidity of 30°F dp and maximum of 55% rh.

2005 *ASHRAE Handbook—Fundamentals*, can be used for these tasks. Assumptions and data used about infiltration, lighting, equipment loads, occupancy, etc., are critical for proper load calculations. Although equipment is sized by peak cooling and heating, it is extremely important to analyze the occurrences of the peak sensible and latent cooling loads. In many instances, peak sensible cooling load does not coincide with peak latent cooling load. Ignoring this phenomenon can result in unacceptable indoor humidity. By carefully analyzing and understanding the peak loads and the load profiles, the designer can properly apply and size the most suitable equipment to meet the sensible and the latent cooling loads efficiently. Elementary schools are generally occupied from about 7:00 AM to about 3:00 PM; occupation is longer for middle and high schools. Peak cooling loads usually occur at the end of the school day. Peak heating usually occurs early in the day, when classrooms begin to be occupied and outdoor air is introduced into the facility. Although K-12 schools are dominated by perimeter zones (and zones exposed to the roof), careful attention should be given to components of the loads. Typical breakdowns of moisture loads are shown in Table 9.

Typically, the dominant cooling loads in classrooms are occupants and ventilation, and ventilation and roof for heating. Given the dominance of ventilation loads, special effort should be made to effectively treat outdoor air before its introduction to the space, as discussed in more detail in the section on Systems and Equipment Selection.

Humidity Control

School buildings host many activities that require special humidity control. Harriman et al. (2001) provide detailed information on the basics of design and equipment selection for proper humidity control for several applications; Chapter 18 is dedicated to schools.

Classrooms require humidity control to provide comfort and prevent humidity-related problems (e.g., growth of dust mites and fungus, which produce allergens and even toxic by-products). Low humidity, on the other hand, favors longevity of infectious viruses, and therefore their transmission between occupants. Maintaining dew point levels between 30 and 60°F satisfies nearly all people nearly all the time. However, the designer should discuss comfort expectations with the owner, to avoid misunderstandings.

Libraries require humidity control to provide human comfort to the occupants and also to protect books and electronic records. Maintaining dew point levels between 30 and 60°F provides a comfortable environment for the library occupants. However, controlling humidity at this range does not prevent books from absorbing excess moisture. Typically, books take up moisture quickly but lose it slowly. To avoid growth of mold and mildew, a dew point above 30°F and maximum of 55% rh are recommended. As for classrooms, the principal moisture loads for the library are ventilation (the major load) and infiltration.

Gymnasiums with wooden floors require special attention; failure to control humidity in gyms with wooden floors may have costly

Table 7 Typical Recommended Design Criteria for Ventilation and Filtration for K-12 Schools

Category	Ventilation and Exhaust[a]				Minimum Filtration Efficiency, MERV[c]
	Combined Outdoor Air, cfm/Person	Occupant Density,[i] per 1000 ft^2	Outdoor Air cfm/ft^2	Outdoor Air cfm/Unit	
Classrooms, Ages 5 to 8	15	25			6 to 8
Ages 9 and over	13	35			6 to 8
Lecture	8	65			6 to 8
Art	19	20			6 to 8
Lecture Halls (fixed seats)	8	150			6 to 8
Science Laboratories[f]	17	25			6 to 8
Computer Lab	15	25			6 to 8
Media Center	15	25			6 to 8
Music/Theatre/Dance	12	35			6 to 8
Multiuse Assembly	8	100			6 to 8
Libraries	17	10			6 to 8
Auditorium	5	150			9 to 10[g]
Administrative/Office Areas	17	5			6 to 8
Gymnasium (playing floors)			0.3		6 to 8
Wood/Metal Shops	19	20			6 to 8
Locker Rooms			0.5 (exhaust)		1 to 4
Cafeteria	9	100			6 to 8
Kitchen[d, e]			0.7 (exhaust)		NA
Toilets				70 (exhaust)	NA
Storage			0.12		1 to 4
Corridors			0.06		6 to 8
Natatoriums (pool and deck)			0.48		6 to 8
Ice Rinks (spectator areas)[h]	8	150			6 to 8

Notes:
[a]Based on ANSI/ASHRAE *Standard* 62.1-2004, Tables 6-1 and 6-4. For systems serving multiple zones, apply multiple zone calculations procedure. See the section on Demand Control Ventilation (DCV) when DCV is considered.
[b]This table should not be used as the only source for design criteria. Governing local codes, design guidelines, ANSI/ASHRAE *Standard* 62.1-2004 and user's manual (ASHRAE 2004a) *must* be consulted.
[c]MERV = minimum efficiency reporting values, based on ASHRAE *Standard* 52.2-1999.
[d]See Chapter 31 for additional information on kitchen ventilation.
[e]Consult local codes for kitchen exhaust requirements.
[f]This table should not be used as the only source for laboratory design criteria. Governing local codes and design guidelines such as ANSI/AIHA *Standard* Z9.5-2003 and Chapter 14 of this volume *must* be consulted.
[g]When higher filtration efficiency specified, prefiltration is recommended.
[h]Based on ANSI/ASHRAE *Standard* 62.1-2004 values for sports and entertainment; for rink playing area, use gymnasium (playing floors) design criteria. Special attention should be given to internal-combustion ice-surfacing equipment for carbon monoxide control. Consult local code for ice rink design.
[i]Use default occupancy density when actual occupant density is not known.

Table 8 Typical Recommended Design Guidelines for HVAC-Related Background Sound for K-12 Schools

Category	Sound Criteria[a, b] RC (N); QAI < 5 dB	Comments
Classrooms	25 to 30	
Large Lecture Rooms	25 to 30	
Without speech amplification	25	
Science Laboratories	35 to 45	
Libraries	30 to 40	See Table 42 of Chapter 47
Auditorium	30 to 35	Use as guide only; consult acoustician
Administrative	30 to 40	For open-office space
Gymnasium	40 to 50	
Shops	35 to 45	Use as guide only; consult acoustician
Cafeteria	35 to 45	Based on service/support for hotels
Kitchen	35 to 45	Based on service/support for hotels
Storage	35 to 45	
Mechanical Rooms	35 to 45	
Corridors	35 to 45	
Natatoriums	40 to 50	
Ice Rinks	40 to 50	Based on values for gymnasiums and natatoriums

Notes:
[a]Based on Chapter 47.
[b]RC (Room Criterion), QAI (Quality Assessment Index) from Chapter 7 of the 2005 *ASHRAE Handbook—Fundamentals*.

Table 9 Typical Classroom Summer Latent (Moisture) Loads

Category	Moisture Loads, lb/h	Moisture Loads, %
People	7.3	22.5
Permeance	0.2	0.6
Ventilation	20.3	62.5
Infiltration	4.7	14.4
Doors	0	0
Wet Surfaces	0	0
Humid Materials	0	0
Domestic Loads	0	0

Note: Based on Harriman et al. (2001), Chapter 18, Figure 18.2.

consequences. The Maple Flooring Manufacturers Association (MFMA) specifies a floor-level humidity between 35 and 50% rh.

Showers and **locker rooms** require humidity control to prevent corrosion and growth of bacteria and fungus. Therefore, special attention is required to exhaust air quantities and placement of supply and exhaust air registers.

Natatoriums and **ice rinks** are typically isolated areas with more specialized HVAC equipment specifically designed to address ventilation and humidity control. Chapters 27 and 28 of Harriman et al. (2001) provide detailed information on humidity control for natatoriums and ice rinks, respectively.

Systems and Equipment Selection

Selection of HVAC equipment and systems depends on whether the facility is new or existing, and whether it is to be totally or partially renovated. For minor renovations, existing HVAC systems are often expanded in compliance with current codes and standards with equipment that matches the existing types. For major renovations or new construction, new HVAC systems and equipment should be installed. When applicable, the remaining useful life of existing equipment and distribution systems should be considered.

HVAC systems and equipment energy use and associated life cycle costs should be evaluated. Energy analysis may justify new HVAC equipment and systems when an acceptable return on investment can be shown. The engineer must review all the assumptions in the energy analysis with the school administration. Assumptions, especially about hard-to-measure items such as infiltration and part-load factors, can significantly affect the energy use calculated.

Other considerations for existing facilities are (1) whether the central plant is of adequate capacity to handle additional loads from new or renovated facilities; (2) the age and condition of the existing equipment, pipes, and controls; and (3) the capital and operating costs of new equipment. Schools usually have very limited budgets. Any savings in capital expenditures and energy costs may be available for the maintenance and upkeep of the HVAC systems and equipment and for other facility needs.

The type of HVAC equipment selected also depends on the climate and months of operations. In hot, dry climates, for instance, evaporative cooling may be the primary approach. Some school districts may choose not to provide air conditioning. However, in hot, humid climates, it is recommended that air conditioning or dehumidification be operated year-round to prevent growth of mold or mildew.

Chapter 1 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment* provides general guidelines on HVAC systems analysis and selection procedures. Although in many cases system selection is based solely on the lowest first cost, it is suggested that the engineer propose a system with the lowest life-cycle cost (LCC). LCC analysis typically requires hour-by-hour building energy simulation for annual energy cost estimation. Detailed initial and maintenance cost estimates of proposed design alternatives, using sources such as R.S. Means (R.S. Means 2007a, 2007b), can also be used for the LCC analysis along with software such as BLCC 5.1 (FEMP 2003). See Chapter 36 for additional information.

System Types. HVAC systems for K-12 schools may be centralized, decentralized, or a combination of both. Centralized systems typically incorporate secondary systems to treat the air and distribute it. The cooling and heating medium is typically water or brine that is cooled and/or heated in a primary system and distributed to the secondary systems. Centralized systems comprise the following systems:

Secondary Systems

- Building air distribution systems (see Chapter 2 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*)
- Fan-coil systems (see Chapter 3 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*)
- Dedicated outdoor air systems (DOAS) with chilled water for cooling and hot water, steam, or electric heat for heating

Primary Systems

- Central cooling and heating plant (see Chapter 4 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*)

More detailed information on systems selection by application can be found in Table 11.

Typical decentralized systems (dedicated systems serving a single zone) are discussed in the section on Preschools under Systems and Equipment Selection.

It is important to note that, to meet the acoustical design criteria in Table 8, designers should avoid locating HVAC equipment in classrooms, and that some centralized and decentralized systems located close to classrooms might need additional sound-attenuating features. Coordination between the HVAC designer, architect, and acoustical consultant is critical for meeting the desired noise criteria. Siebein and Likendey (2004) provides information on the applicability of systems to classrooms with regard to acoustical criteria. Additional information on how HVAC&R manufacturers' acoustical data and application information can be best used can be found in Ebbing and Blazier (1998). Schaffer (1993) provides a practical guide to noise and vibration control for HVAC systems. Commercial acoustics analysis software can also be helpful.

Dedicated Outdoor Air Systems (DOAS). Although most centralized and decentralized systems are very effective at handling the space sensible cooling and heating loads, they are less effective (or ineffective) at handling ventilation air and the latent loads. As a result, a dedicated outdoor air system (DOAS) should be used. DOAS units bring 100% outdoor air to at least space conditions, which allows individual space units to handle only the space loads. It is preferable, however, to introduce the outdoor air at a lower humidity ratio than the desired space humidity ratio, to allow the zone HVAC unit to handle only the space sensible cooling load. This approach can be easily implemented in a classroom where a significant amount of outdoor air is required for ventilation.

Example. In a typical classroom with 30 students, the ventilation requirements are 450 cfm. If the outdoor air can be introduced at a humidity ratio of 48 gr/lb and the space is designed to be maintained at 70 gr/lb, the space dehumidification capability of the pre-dehumidified outdoor air is the following:

$$\begin{array}{c}\text{Space dehumidification}\\ \text{capability, Btu/h}\end{array} = 0.68 \times \text{cfm} \times \begin{pmatrix}\text{Space humidity ratio} -\\ \text{Supply humidity ratio}\end{pmatrix}$$

Then,

$$\begin{array}{c}\text{Dehumidification}\\ \text{capability, Btu/h}\end{array} = 0.68 \times 450 \times (70 - 48) = 6732 \text{ Btu/h}$$

where

$$0.68 = (60/13.5)(1076/7000)$$

60 = min/h
13.5 = specific volume of moist air at 70°F and 50% rh, ft^3/lb
1076 = average heat removal required to condense 1 lb of water vapor from room air, Btu/lb
7000 = grains per pound

The 6732 Btu/h of space latent load is equivalent to the latent load of 30 occupants (seated, very light work, 155 Btu/h per occupant) and the additional space latent load (e.g., infiltration latent load).

$$\begin{aligned}\text{Occupant latent load} &= 30 \text{ Occupants} \times 155 \text{ Btu/h per occupant}\\ &= 4650 \text{ Btu/h}\end{aligned}$$

$$\begin{array}{l}\text{Remainder of total}\\ \text{dehumidification}\\ \text{capability}\end{array} = 6732 - 4650 = 2082 \text{ Btu/h}$$

This additional dehumidification capability can help in handling infiltration latent load and others.

This simple example demonstrates the ability of pre-dehumidified outdoor air to handle the space latent load, resulting in almost full separation of the space latent cooling load treatment from the space sensible cooling load. This approach allows only thermostatic control without losing humidity control in conditioned classrooms.

Typical DOAS are air-handling units that cool, dehumidify, heat, humidify and filter the outdoor air prior to being introduced to the conditioned space. Typical DOAS include the following major components:

- Mechanical cooling/dehumidification
  - DX coil
  - Chilled-water coil
- Desiccant-based cooling/dehumidification
  - Desiccant (dehumidification) and direct-expansion (DX) coil (post sensible cooling)
  - Desiccant (dehumidification) and chilled-water coil (post sensible cooling)

- Heating
  - Coils (hot-water, steam, electric, heat pump)
  - Gas-fired furnace
- Humidification
  - Passive (in conjunction with enthalpy wheel heat recovery)
  - Active (steam, electric-to-steam, gas-to-steam)
- Exhaust air recovery: air-to-air heat recovery
  - Rotary (enthalpy wheel, sensible wheel)
  - Fixed (heat pipe, plate heat exchanger, run around coils)
- Dehumidification enhancements for air-to-air heat recovery
  - Heat pipe based (wraparound coil)
  - Mini plate heat exchanger based

Which DOAS configuration is most cost-effective depends on variables such as availability of utilities (chilled water, gas, steam), space constraints, climatic data, utility cost, and budget. DOAS can be configured easily by using modular components that meet the design criteria. Selection and analysis software of these systems is readily available from DOAS manufacturers, which simplifies configuration and analysis of the most cost-effective system. Typical configurations of DOAS are shown in Figures 2 and 3. A cooling/dehumidification psychrometrics process of DOAS shown in Figure 4.

Given the need for more stringent and complex control schemes for outdoor air preconditioning, DOAS typically incorporate, direct digital control (DDC) systems, either stand-alone microprocessor-based or with the ability to communicate with central energy management system. The control system can be purchased as an option or installed in the field by the controls vendor. Typical supply air conditions for a DOAS air-handling unit are shown in Table 10.

Typical arrangements of DOAS integrated with local cooling and heating systems are shown in Figure 5.

Displacement Ventilation. Recently, use of displacement ventilation (as opposed to the more traditional mixing ventilation) for classrooms has been extended for enhanced IAQ and thermal comfort. In displacement ventilation, fresh air at colder temperature than the room air is discharged close to the floor level, and warm air is exhausted at or close to the ceiling. After being discharged at a low level, the colder supply air rises as it is heated by heat sources (e.g., people, computers), also allowing effective removal of containments generated in the room. Figure 6 shows a typical displacement ventilation arrangement for cooling.

Guidelines and procedures for designing displacement ventilation systems can be found in Chen and Glicksman (2003) and Skistad et al. (2002).

Typical displacement ventilation systems for classrooms include the following main subsystems (Figure 7):

- DOAS air-handling unit that can cool and dehumidify outdoor air to 60 to 62°F and 40 to 50 gr/lb for summer, and heat air to 65 to 68°F for winter
- Zone fan-powered terminal with sensible cooling capability (located outside the conditioned zone)
- Special displacement ventilation diffusers
- Heating radiators or convectors placed below windows in perimeter zones
- Control systems (thermostats and occupancy sensors)

In addition to the traditional displacement ventilation system described previously, displacement ventilation with induction can also be considered for classrooms. A displacement ventilation system with induction uses special terminals to provide additional cooling and heating with the displacement ventilation effect. These terminals are not equipped with fans, resulting in lower noise levels as required by more stringent noise criteria.

A displacement ventilation system with induction includes the following main subsystems:

- DOAS air-handling unit that can cool and dehumidify outdoor air to 54 to 57°F and 40 to 50 gr/lb for summer, and heat air to 65 to 68°F for winter

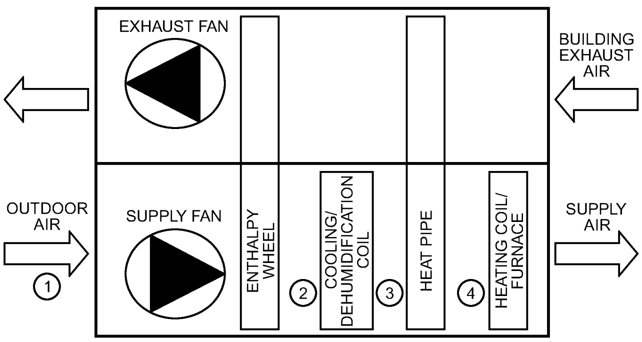

Fig. 2 Typical Configuration of DOAS Air-Handling Unit: Enthalpy Wheel with Heat Pipe for Reheat

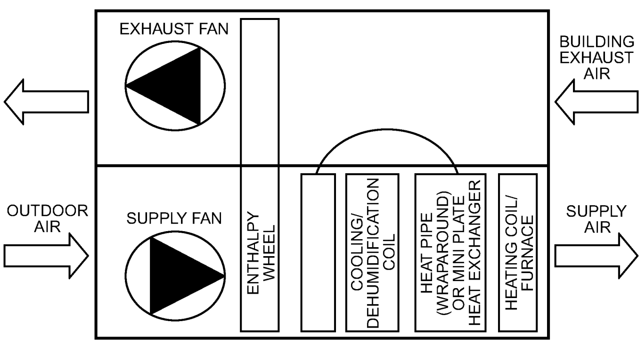

Fig. 3 Typical Configuration of DOAS Air-Handling Unit: Enthalpy Wheel with Wraparound Heat Pipe for Reheat

Table 10 Typical Design Criteria for DOAS Air-Handling Unit

	Supply Air Conditions[a]		Minimum
	Temperature, °F	Humidity Ratio, gr/lb	Air Filtration Efficiency, MERV[b]
Winter	65 to 68	30 to 40	6 to 8
Summer	60 to 65	40 to 60	6 to 8

Notes:
[a]Building location may dictate optimum supply condition in recommended range.
[b]Filter efficiency definition per ASHRAE *Standard* 52.2-1999.
MERV = minimum efficiency reporting values

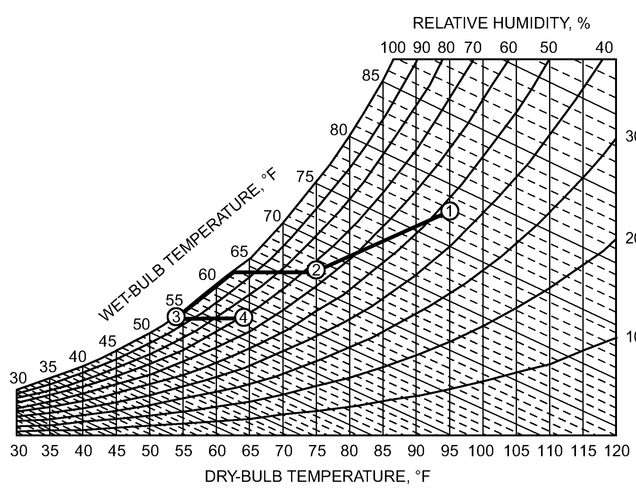

Fig. 4 Cooling/Dehumidification Psychrometric Process of Typical DOAS Air-Handling Unit in Figure 3

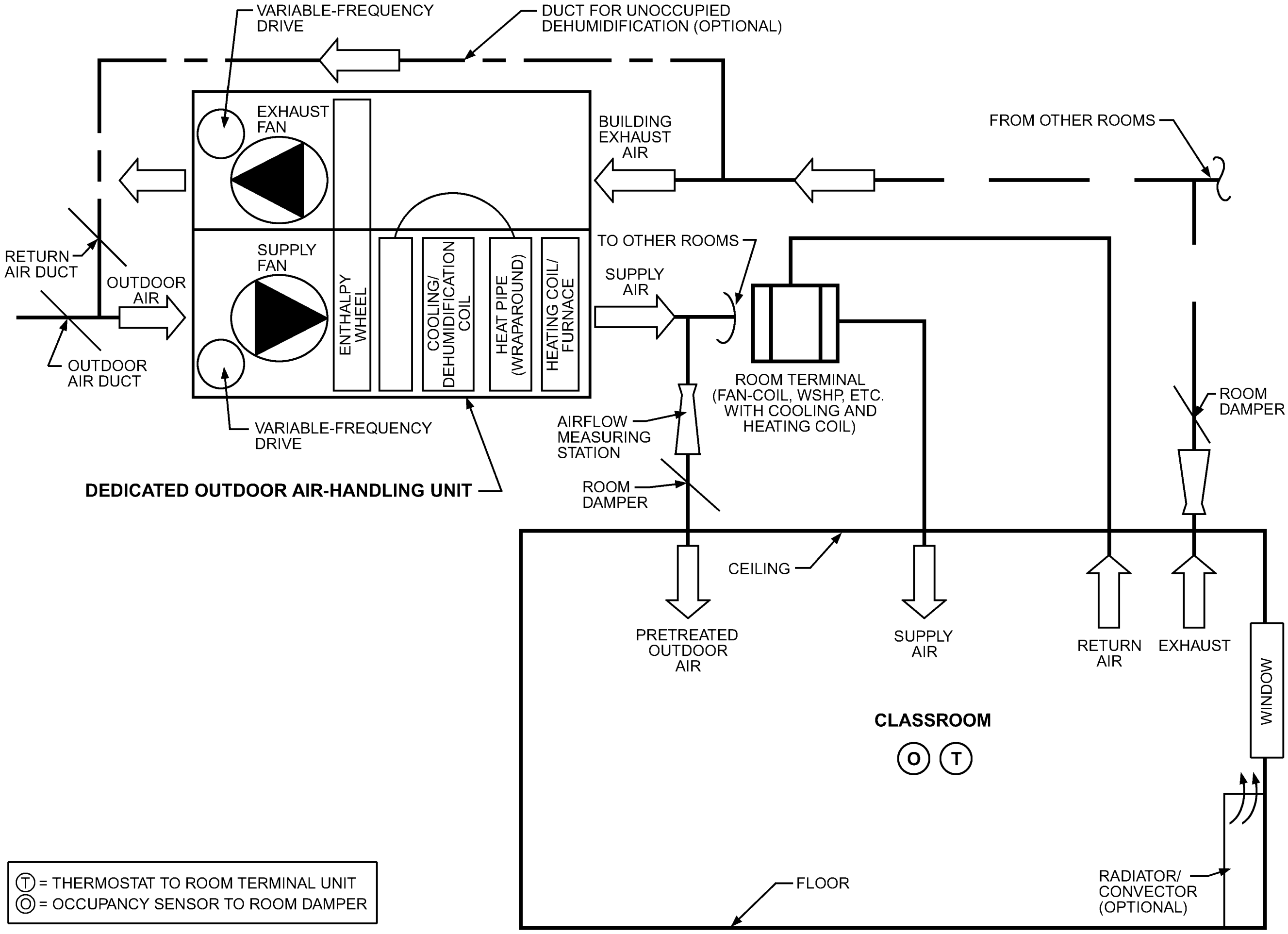

Fig. 5 Typical Schematic of DOAS with Local Classroom Cooling/Heating Terminal

- Zone displacement ventilation with induction terminal, equipped with two- or four-pipe cooling and heating coil mounted along perimeter walls and windows
- Control systems (thermostats and occupancy sensors)

Systems Selection by Application. Table 11 shows the applicability of systems to areas in K-12 school facilities.

Specialized Equipment. Areas such as natatoriums and ice rinks need specialized equipment to address the unique design requirements and the cooling, dehumidification, and heating characteristics of these areas. Natatoriums typically use special units that can introduce large quantities of outdoor air and allow active humidity control (mainly dehumidification). This equipment is similar to DOAS, and typically uses chilled water or a DX system for dehumidification. For systems with air-cooled condensers, condenser heat can be recovered to heat the swimming pool. See Chapter 4 of this volume for more information on natatoriums.

Similarly, an ice rink requires special equipment; selection depends heavily on the school's location and seasonal use. Ice rink HVAC and dehumidification equipment can be desiccant-based or self-contained mechanical refrigeration. See Chapter 4 of this volume and Chapter 35 of the 2006 *ASHRAE Handbook—Refrigeration* for more information on ice rinks.

Chapters 27 and 28 of Harriman et al. (2001) also provide detailed information on humidity control for natatoriums and ice rinks, respectively.

Energy Considerations

Energy design guidelines and standards are well covered by ANSI/ASHRAE *Standard* 90.1-2004 and its user's manual (ASHRAE 2004b) and local energy codes. The designer should consult these standards for minimum energy criteria for schools, and consider the following energy conservation measures:

- **EMS/DDC systems** allow easier maintenance of comfort conditions, optimized operation, troubleshooting, and monitoring
- **Setback** (winter) or **setup** (summer) by central EMS or stand-alone programmable thermostats
- **Morning warm-up** (winter) and **cooldown** (summer), typically by the central EMS or stand-alone microprocessor-based control systems
- **Zone ventilation control** with zone occupancy sensors by throttling the space outdoor air damper to minimum position or closed during unoccupied hours
- **Enhanced summer humidity control** by switching the DOAS unit from 100% outdoor air to 100% recirculation and maintaining the required summer humidity dew-point temperature
- **Evaporative cooling systems**, where and when applicable
- **Geothermal systems**, when applicable
- **Ceiling fans**, typically for gymnasiums
- **Natural ventilation**, when applicable, by operable windows
- **Passive heating and cooling**, incorporated in cooperation with the architect
- **Solar heating**, when economically justifiable for domestic hot-water heating and space heating

- **Hot- and chilled-water temperature reset**, for systems with central plants (chillers and boilers); note, however, that chilled-water temperature reset might compromise the dehumidification capability of the system, and should be applied only if ambient humidity permits

Demand Control Ventilation (DCV). Demand control ventilation can reduce the cost of operating the HVAC systems. To ensure proper IAQ and comply with ANSI/ASHRAE *Standard* 62.1-2004 and local codes that permit DCV, the designer must carefully follow section 6.2.7 (Dynamic Reset) of *Standard* 62.1 and corresponding sections of the user's manual (ASHRAE 2004a). *Standard* 62.1-2004 explicitly allows use of CO_2 levels or occupancy to reset intake airflow in response to space occupancy levels. Special attention should be given to the area served by the HVAC system and the system type. Areas such as gymnasiums and auditoriums can benefit from CO_2-based DCV, commonly used in single-zone systems without DOAS, serving one space with varying occupancy. In these cases, DCV control is simple, reliable, and cost-effective. Systems such as multizone VAV with recirculated air without DOAS require special attention to ensure adequate OA supply to multiple zones under varying loads (such as classrooms). This problem complicates the design, operation, and maintenance of DCV control systems and also adds the cost of additional sensors.

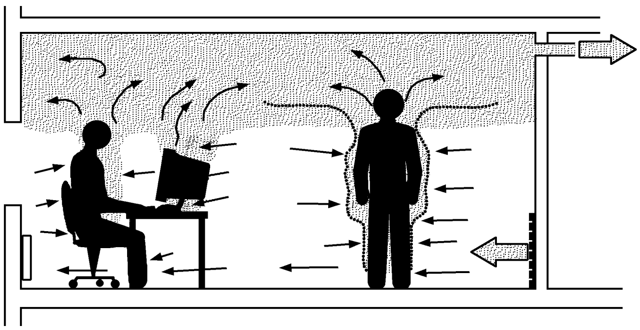

Fig. 6 Displacement Ventilation
(Skistad et al. 2002)

A simpler approach for DCV is in systems that use DOAS: the OA supply to each individual space can be controlled independently by occupancy sensors that can reduce the OA to a preset value (and also turn off the lights), or by CO_2 sensors (see Figure 5).

COLLEGES AND UNIVERSITIES

General and Design Considerations

College and university facilities are similar to those of middle and high schools, except that there are more of them, usually housed in several buildings on the campus. Some colleges and universities have satellite campuses scattered throughout a city or a state. The design

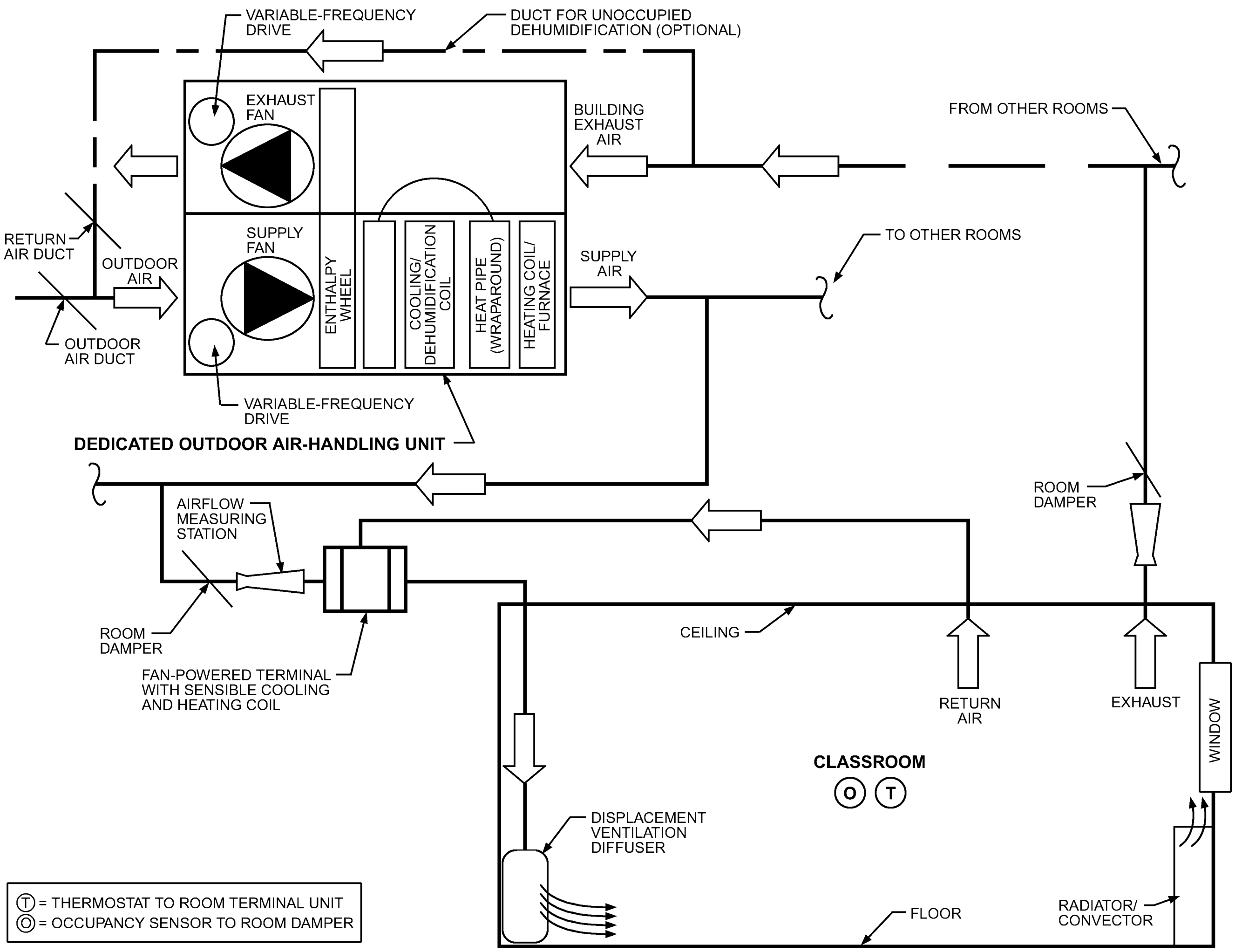

Fig. 7 Typical Displacement Ventilation System Layout

Table 11 Applicability of Systems to Typical Areas

	Cooling/Heating Systems								
	Centralized			Decentralized				Heating Only	
Typical Area[c]	SZ[a]	VAV/ Reheat	Fan Coil (Two- and Four-Pipe)	PSZ/ SZ[a] Split	PVAV/ Reheat	WSHP	Geothermal Heat Pump	Baseboard/ Radiators	Unit Heaters
Classrooms	X	X	X	X	X	X	X	X	
Laboratories and Science Facilities[b]	X	X	X	X	X	X	X	X	
Administrative Areas	X	X	X	X	X	X	X	X	
Gymnasium[e]	X	X		X					X
Libraries	X	X	X	X	X	X	X	X	
Auditorium[e]	X	X		X	X				
Home Economics Room	X	X	X	X	X	X	X	X	
Cafeteria[e]	X			X					
Kitchen[e]	X			X					X
Auto Repair Shop									X
Industrial Shop									X
Locker Rooms								X	X
Ventilation (Outdoor Air)	DOAS	d	DOAS	DOAS	d	DOAS	DOAS	DOAS	DOAS

SZ = single zone
PVAV = packaged variable-air-volume
VAV = variable-air-volume
WSHP = water-source heat pump
PSZ = packaged single zone
DOAS = dedicated outdoor air system

Notes:
[a]SZ and PSZ/SZ split for classrooms requires individual thermostatic control.
[b]Systems for laboratories must comply with local codes and be in accordance with current practices for laboratories.
[c]Systems and equipment for ice rinks and natatoriums not shown; refer to specialized equipment section.
[d]Special attention should be given for adequate OA supply in VAV applications without DOAS; consult ANSI/ASHRAE *Standard* 62.1-2004 Section 6.2.5, and corresponding section in user's manual (ASHRAE 2004a).
[e]In some cases, these areas can be served by SZ, WSHP, and geothermal HP systems without OA from DOAS.

criterion for each building is established by the requirements of its users. The following are major facilities commonly found on college and university campuses, but not usually in middle and high schools:

Administrative Buildings. These buildings should be treated as office buildings. They usually have a constant interior load and additional part-time loads associated with spaces such as conference rooms.

Vivariums (Animal Facilities). These spaces are commonly associated with laboratories, but usually have their own separate areas. Animal facilities need close temperature control and require a significant amount of outdoor ventilation to control odors and prevent the spread of diseases among the animals. Animal facilities are discussed in Chapters 14 and 22 of this volume, and in Chapter 10 of the 2005 *ASHRAE Handbook—Fundamentals*.

Dormitory Buildings. See Chapter 5.

Storage Buildings. These buildings are usually heated and ventilated only; however, part of the facility may require temperature and humidity control, depending upon the materials stored there.

Student and Faculty Apartment Buildings. See Chapter 5.

Large Gymnasiums. See Chapter 4.

Laboratory Buildings. These buildings house research facilities and may contain fume hoods, machinery, lasers, vivariums, areas with controlled environments, and departmental offices. The HVAC systems and control must be able to accommodate diverse functions of the facility, which may have 24 h, year-round operation, and yet be easy to service and quick to repair. Variable-air-volume (VAV) systems can be used in laboratory buildings. Proper control systems should be applied to introduce and extract the required quantities of supply and exhaust air. Maintaining the required space pressure differential to adjacent spaces and the minimum airflow under all circumstances is extremely critical for laboratory safe operation. Energy can be saved by recovering energy from exhaust air and tempering outdoor makeup air. Special attention should be given to containments in the exhaust airstream. Potential carryover of air from exhaust air to supply air, and interaction with the energy recovery device adsorbent for cases with total (sensible and latent) energy recovery, should be examined. In general, air exhausted from fume hoods should not be used for energy recovery. Other energy-saving systems used for laboratory buildings include (1) ice storage, (2) heat reclaim chillers to produce domestic hot water or hot water for booster coils in the summer, and (3) cooling-tower free cooling.

The design engineer should discuss expected contaminants and concentrations with the owner to determine construction materials for fume hoods and fume exhaust systems. Close coordination with health and safety (H&S) personnel is vital for safe laboratory building operation. Back-up or standby systems for emergency use should be considered, such as alarms on critical systems. Maintenance staff should be thoroughly trained in upkeep and repair of all systems, components, and controls. For additional information on laboratories and vivariums, see Chapter 14, ANSI/AIHA *Standard* Z9.5-2003, and McIntosh et al. (2001).

Museums. See Chapter 21.

Central Plants. These facilities contain generating equipment and other supporting machinery for buildings or campus heating and air conditioning. Central plants can serve a single building, cluster of buildings, or the entire campus (district heating and cooling plant). District heating and cooling plants are covered in Chapter 11 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*. Central plants are not conditioned and are generally heated and ventilated only.

Television and Radio Studios. See Chapter 3.

Hospital. Hospitals are discussed in Chapter 7 and ASHRAE's (2003) *HVAC Design Manual for Hospitals and Clinics*.

Chapels. See Chapter 4.

Student Unions. These facilities usually contain dining rooms, kitchens, meeting rooms, lounges, and game rooms. Student unions are generally open every day from early in the morning to late at night. An HVAC system such as VAV cooling with perimeter heating may be suitable. Extra ventilation air is required as makeup air for kitchen systems and for the building's potential high occupancy. See Chapters 3 and **31** for additional information.

Lecture Halls. These spaces house large numbers of students for a few hours several times a day and are vacant the rest of the time, so heat loads vary throughout the day. Systems serving lecture halls must respond to these load variations. In addition, because the rooms are often configured such that students at the rear of the room are seated nearer the ceiling, the systems must run quietly and must not produce drafts. Coordination with the design team is essential for determining the optimal location of diffusers and return grilles and registers. Placement of supply diffusers at the front of the room and return air grilles and registers near the front and rear of the room or under seats should be considered. An analysis of the system noise levels expected in the hall is recommended. See Chapter 47 for further information.

Energy Considerations

All the energy considerations discussed in the section on K-12 Schools can be applied successfully in colleges and universities.

Central Plants. Large central plants can serve a single building, cluster of buildings, or the entire site. District central plants can generate chilled water and/or steam for distribution to the buildings it serves. In many cases, each building is equipped with secondary chilled-water pumps and steam-to-water heat exchangers. See Chapter 11 of the 2004 *ASHRAE Handbook—HVAC System and Equipment* for additional information on district cooling and heating. Chilled-water and steam flow-measuring stations should be used to monitor each building's energy use.

Energy conservation measures applicable to large central plants include the following:

- Chiller plant optimization control system
- Winter free cooling
- Chilled water and ice storage
- Microprocessor-based air/fuel control in conjunction with steam pressure control and optimal boiler sequencing control
- Dual-fuel boilers
- Blowdown heat recovery
- Boiler stack economizer
- Energy monitoring

More information can be found in Wulfinghoff (2000).

Where economically justifiable, chilled water and steam can be purchased from an independent operator.

Combined heat and power (CHP) plants can be considered for large facilities when economically justifiable. Chapter 7 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment* and Orlando (1996) provide information on CHP systems.

SEISMIC AND WIND RESTRAINT CONSIDERATIONS

Seismic bracing of HVAC equipment should be considered. Wind restraint codes may also apply in areas where tornados and hurricanes necessitate additional bracing. This consideration is especially important if there is an agreement with local officials to use the facility as a disaster relief shelter. See Chapter 54 for further information.

COMMISSIONING

Commissioning is a quality assurance process for buildings from predesign through design, construction, and operations. The commissioning process involves achieving, verifying, and documenting the performance of each system to meet the building operational needs. Given the criticality of issues such as indoor air quality, thermal comfort, noise, etc., in educational facilities and the application of equipment and systems such as DOAS, EMS, and occupancy sensors, it is important to follow the commissioning process as described in Chapter 42 and ASHRAE *Guideline* 0-2005. Proper commissioning ensures fully functional systems that can be operated and maintained properly throughout the life of the building.

SUSTAINABLE DESIGN

A trend in the educational community to embrace the principles of sustainable design has increased in the last several years. Begun as a means to educate the students in conserving earth resources, this approach also provides benefits such as enhanced IAQ and lower operating costs. Many schools are seeking Leadership in Energy and Environmental Design (LEED) certification as administrated by the U.S. Green Building Council (USGBC). The LEED system awards credits in six categories:

- Sustainable sites
- Water efficiency
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality
- Innovation and design process

The HVAC&R designer plays a major role in supporting the design team in demonstrating fulfillment of the prerequisites and supporting the analysis for credits.

Typically, the HVAC&R designer is heavily involved in the (1) energy and atmosphere and (2) indoor environmental quality categories. In the energy and atmosphere category, the HVAC&R designer, along with the architect, electrical engineers, and plumbing engineers, demonstrate compliance with ASHRAE *Standard* 90.1-2004 (as a prerequisite). They then typically perform whole-building energy simulation (using ASHRAE *Standard* 90.1-2004, Appendix G procedures) to demonstrate energy cost savings. The number of credits awarded is in correlation to the energy cost reduction. The HVAC&R designer is also involved in specifying HVAC&R equipment with environmentally friendly refrigerants, improved ventilation techniques (e.g., displacement ventilation), water conservation, etc. Additional information on LEED certification can be found in Grumman (2003) and USGBC (2005).

For laboratories, the designer can use information from the U.S. Environmental Protection Agency's (EPA 2000) sustainable design initiative, *Laboratories for the 21st Century (Labs21)*.

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