Related Commercial Resources

CHAPTER 2. RETAIL FACILITIES

THIS chapter covers design and application of air-conditioning and heating systems for various retail merchandising facilities. Load calculations, systems, and equipment are covered elsewhere in the Handbook series.

Other relevant ASHRAE resources include the following.

- **ASHRAE's Epidemic Task Force (ETF)** (www.ashrae.org/technical-resources/resources). Established in March 2020, the ETF has developed an array of guidance documents on engineering improvements to reduce the risk of infection in the built environment. One-page overviews of guidance for industrial settings, safe vaccine transportation, reducing exposure to airborne aerosols, and various applications can be found at www.ashrae.org/technical-resources/covid-19-one-page-guidance-documents.
- **ASHRAE Task Force for Building Decarbonization (TFBD)**. The ASHRAE position statement on reducing carbon in buildings is available at www.ashrae.org/about/position-documents. Research is ongoing to develop additional guidance, which is anticipated to begin release in 2023.
- **Operational excellence.** To help ensure that building HVAC systems are designed and installed in ways that achieve excellent operation throughout the building's life, an ASHRAE Presidential Elect Advisory Committee led by ASHRAE President Darryl Boyce developed and released *Designing for Operational Excellence—Intentional Design for Effective Operation and Maintenance* (ASHRAE 2022).

1. GENERAL CRITERIA

To apply equipment properly, the construction of the space to be conditioned, its use and occupancy, the time of day in which greatest occupancy occurs, physical building characteristics, and lighting layout must be known.

The following must also be considered:

- Electric power: size of service
- Heating: availability of steam, hot water, gas, oil, or electricity
- Cooling: availability of chilled water, well water, city water, and water conservation equipment
- Internal heat gains
- Equipment locations
- Structural considerations
- Rigging and delivery of equipment
- Obstructions
- Ventilation: opening through roof or wall for outdoor air duct
- Exposures and number of doors
- Orientation of store
- Code requirements
- Utility rates and regulations
- Building standards

Specific design requirements, such as the increase in outdoor air required to make up for kitchen exhaust, must be considered. Ventilation requirements of ASHRAE *Standard* 62.1 must be followed. Objectionable odors may necessitate special filtering, exhaust, and additional outdoor air intake.

Security requirements must be considered and included in the overall design and application. Minimum considerations require secure equipment rooms, secure air-handling systems, and outdoor air intakes located on the top of facilities.

More extensive security measures should be developed based on overall facility design, owner requirements, and local authorities.

Load calculations should be made using the procedures outlined in the *ASHRAE Handbook—Fundamentals*.

Almost all localities have some form of energy code in effect that establishes strict requirements for insulation, equipment efficiencies, system designs, etc., and places strict limits on fenestration and lighting. The requirements of ASHRAE *Standard* 90.1 must be met as a minimum guideline for retail facilities. The *Advanced Energy Design Guide for Small Retail Buildings* (ASHRAE 2006) provides additional energy savings suggestions. In addition, see ASHRAE *Standards* 90.1 and 189.1 for guidance on achieving further energy savings.

Retail facilities often have a high internal sensible heat gain relative to the total heat gain. However, the quantity of outdoor air required by ventilation codes and standards may result in a high latent heat removal demand at the equipment. The high latent heat removal requirement may also occur at outdoor dry-bulb temperatures below design. Unitary HVAC equipment and HVAC systems should be designed and selected to provide the necessary sensible and latent heat removal. The equipment, systems, and controls should be designed to provide the necessary temperature, ventilation, filtration, and humidity conditions.

HVAC system selection and design for retail facilities are normally determined by economics. First cost is usually the determining factor for small stores. For large retail facilities, owning, operating, and maintenance costs are also considered. Decisions about mechanical systems for retail facilities are typically based on a cash flow analysis rather than on a full life-cycle analysis.

HVAC system provisions are provided initially in most retail facilities, including strip centers, malls, and retail centers in high-rise buildings. Provisions may include condenser water pipes or stub out for fresh air intake in multiple points to satisfy a 93 m^2 module. In strip centers, roof top unit provisions should be provided.

2. SMALL STORES

Small stores are typically located in convenience centers and may have at least the store front exposed to outdoor weather, although some are free standing. Large glass areas found at the front of many small stores may cause high peak solar heat gain unless they have northern exposures or large overhanging canopies. High heat loss may be experienced on cold, cloudy days in the front of these stores. The HVAC system for this portion of the small store should be designed to offset the greater cooling and heating requirements. Entrance vestibules, entry heaters, and/or air curtains may be needed in some climates.

Design Considerations

System Design. Single-zone unitary rooftop equipment is common in store air conditioning. Using multiple units to condition the store involves less ductwork and can maintain comfort in the event of partial equipment failure. Prefabricated and matching curbs simplify installation and ensure compatibility with roof materials.

Air to air heat pumps, offered as packaged equipment, are readily adaptable to small-store applications. Ground-source and other closed-loop heat pump systems have been provided for small stores where the requirements of several users may be combined. Winter design conditions, utility rates, maintenance costs, and operating costs should be compared to those of conventional heating HVAC systems before this type of system is chosen. Consider providing a defrost cycle: in cold climates, snow cover may not allow fresh air into the building.

Water-cooled unitary equipment is available for small-store air conditioning. However, many communities restrict the use of city water and groundwater for condensing purposes and may require installation of a cooling tower. Water-cooled equipment generally operates efficiently and economically.

Air Distribution. External static pressures available in small-store air-conditioning units are limited, and air distribution should be designed to keep duct resistances low. Duct velocities should not exceed 6 m/s, and pressure drop should not exceed 0.8 Pa/m. Average air quantities, typically range from 47 to 60 L/s per kilowatt of cooling in accordance with the calculated internal sensible heat load.

Pay attention to suspended obstacles (e.g., lights, soffits, ceiling recesses, and displays) that interfere with proper air distribution.

The duct system should contain enough dampers for air balancing. Volume dampers should be installed in takeoffs from the main supply duct to balance air to the branch ducts. Dampers should be installed in the return and outdoor air ducts for proper outdoor air/return air balance and for economizer operation.

Control. Controls for small stores should be kept as simple as possible while still providing the required functions. Unitary equipment is typically available with manufacturer-supplied controls for easy installation and operation.

Automatic dampers should be placed in outdoor air inlets and in exhausts to prevent air entering when the fan is turned off.

Heating controls vary with the nature of the heating medium. Duct heaters are generally furnished with manufacturer-installed safety controls. Steam or hot-water heating coils require a motorized valve for heating control. Take care in preventing coil freezing.

Open platform units for any direct digital control (DDC) should provide the necessary options for remote control. Time clock control can limit unnecessary HVAC operation. Unoccupied reset controls should be provided in conjunction with timed control.

Maintenance. To protect the initial investment and ensure maximum efficiency, maintenance of air-conditioning units in small stores should be provided by a reliable service company on a yearly basis. The maintenance agreement should clearly specify responsibility for filter replacements, lubrication, belts, coil cleaning, adjustment of controls, refrigeration cycle maintenance, replacement of refrigerant, pump repairs, electrical maintenance, winterizing, system start-up, and extra labor required for repairs.

Improving Operating Cost. Outdoor air economizers can reduce the operating cost of cooling in most climates. They are generally available as factory options or accessories with roof-mounted units. Increased exterior insulation generally reduces operating energy requirements and may in some cases allow the size of installed equipment to be reduced. Most codes now include minimum requirements for insulation and fenestration materials. The *Advanced Energy Design Guide for Small Retail Buildings* (ASHRAE 2006) provides additional energy savings suggestions.

3. DISCOUNT, BIG-BOX, AND SUPERCENTER STORES

Large discount, big-box, and supercenter stores attract customers with discount prices. These stores typically have high-bay fixture displays and usually store merchandise in the sales area. They feature a wide range of merchandise and may include such diverse areas as a food service area, auto service area, supermarket, pharmacy, bank, and garden shop. Some stores sell pets, including fish and birds. This variety of activity must be considered in designing the HVAC systems. The design and application suggestions for small stores also apply to discount stores.

Each specific area is typically treated as a traditional stand-alone facility would be. Conditioning outdoor air for all areas must be considered to limit the introduction of excess moisture that will migrate to the freezer aisles of a grocery area.

Hardware, lumber, furniture, etc., is also sold in big-box facilities. A particular concern in this type of facility is ventilation for merchandise and material-handling equipment, such as forklift trucks.

In addition, areas such as stockrooms, rest rooms, break rooms, offices, and special storage rooms for perishable merchandise may require separate HVAC systems or refrigeration.

Load Determination

Operating economics and the spaces served often dictate indoor design conditions. Some stores may base summer load calculations on a higher indoor temperature (e.g., 27°C db) but then set the thermostats to control at 22 to 24°C db. This reduces the installed equipment size while providing the desired indoor temperature most of the time.

Heat gain from lighting is not uniform throughout the entire area. For example, jewelry and other specialty displays typically have lighting heat gains of 65 to 85 W/m^2 of floor area, whereas the typical sales area has an average value of 20 to 40 W/m^2. For stockrooms and receiving, marking, toilet, and rest room areas, a value of 20 W/m^2 may be used. When available, actual lighting layouts rather than average values should be used for load computation. With LED lighting, these watt gains should be reduced substantially. See ASHRAE *Standard* 189.1 for further ideas for reduction.

ASHRAE *Standards* 62.1 and 90.1 provide data and population density information to be used for load determination. Chapter 34 of this volume has specific information on ventilation systems for kitchens and food service areas. Ventilation and outdoor air must be provided as required in ASHRAE *Standard* 62.1 and local codes.

Data on the heat released by special merchandising equipment, such as amusement rides for children or equipment used for preparing specialty food items (e.g., popcorn, pizza, frankfurters, hamburgers, doughnuts, roasted chickens, cooked nuts, etc.), should be obtained from the equipment manufacturers.

Design Considerations

Heat released by installed lighting is often sufficient to offset the design roof heat loss. Therefore, interior areas of these stores need cooling during business hours throughout the year. Perimeter areas, especially the storefront and entrance areas, may have highly variable heating and cooling requirements. Proper zone control and HVAC design are essential. Location of checkout lanes in the storefront or entrance areas makes proper environmental zone control even more important.

System Design. The important factors in selecting discount, big-box, and supercenter store air-conditioning systems are (1) installation costs, (2) floor space required for equipment, (3) maintenance requirements, (4) equipment reliability, and (5) simplicity of control. Roof-mounted units are most commonly used.

Air Distribution. The air supply for large interior sales areas should generally be designed to satisfy the primary cooling requirement. For perimeter areas, the variable heating and cooling requirements must be considered.

Because these stores require high, clear areas for display and restocking, air is generally distributed from heights of 4.3 m and greater. Air distribution at these heights requires high discharge velocities in the heating season to overcome the buoyancy of hot air. This discharge air velocity creates turbulence in the space and induces airflow from the ceiling area to promote complete mixing. Space-mounted fans, and radiant heating at the perimeter, entrance heaters, and air curtains may be required.

Control. Because the controls are usually operated by personnel who have little knowledge of air conditioning, systems should be kept as simple as possible while still providing the required functions. Unitary equipment is typically available with manufacturer-supplied controls for easy installation and operation.

Automatic dampers should be placed in outdoor air inlets and in exhausts to prevent air entering when the fan is turned off.

Heating controls vary with the nature of the heating medium. Duct heaters are generally furnished with manufacturer-installed safety controls. Steam or hot-water heating coils require a motorized valve for heating control.

Open-platform DDC control should provide the necessary options for remote control.

Maintenance. Most stores do not employ trained HVAC maintenance personnel; they rely instead on service contracts with either the installer or a local service company. (See the section on Small Stores).

Improving Operating Cost. See the section on Small Stores.

4. SUPERMARKETS

Load Determination

Heating and cooling loads should be calculated using the methods outlined in Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*. In supermarkets, space conditioning is required both for human comfort and for proper operation of refrigerated display cases. The air-conditioning unit should introduce a minimum quantity of outdoor air, either the volume required for ventilation based on ASHRAE *Standard* 62.1 or the volume required to maintain slightly positive pressure in the space, whichever is larger.

Many supermarkets are units of a large chain owned or operated by a single company. The standardized construction, layout, and equipment used in designing many similar stores simplify load calculations.

It is important that the final air-conditioning load be correctly determined. Refer to manufacturers' data for information on total heat extraction, sensible heat, latent heat, and percentage of latent to total load for display cases. Engineers report considerable fixture heat removal (case load) variation as the relative humidity and temperature vary in comparatively small increments. Relative humidity above 55% substantially increases the load; reduced absolute humidity substantially decreases the load, as shown in Figure 1. Trends in store design, which include more food refrigeration and more efficient lighting, reduce the sensible component of the load even further.

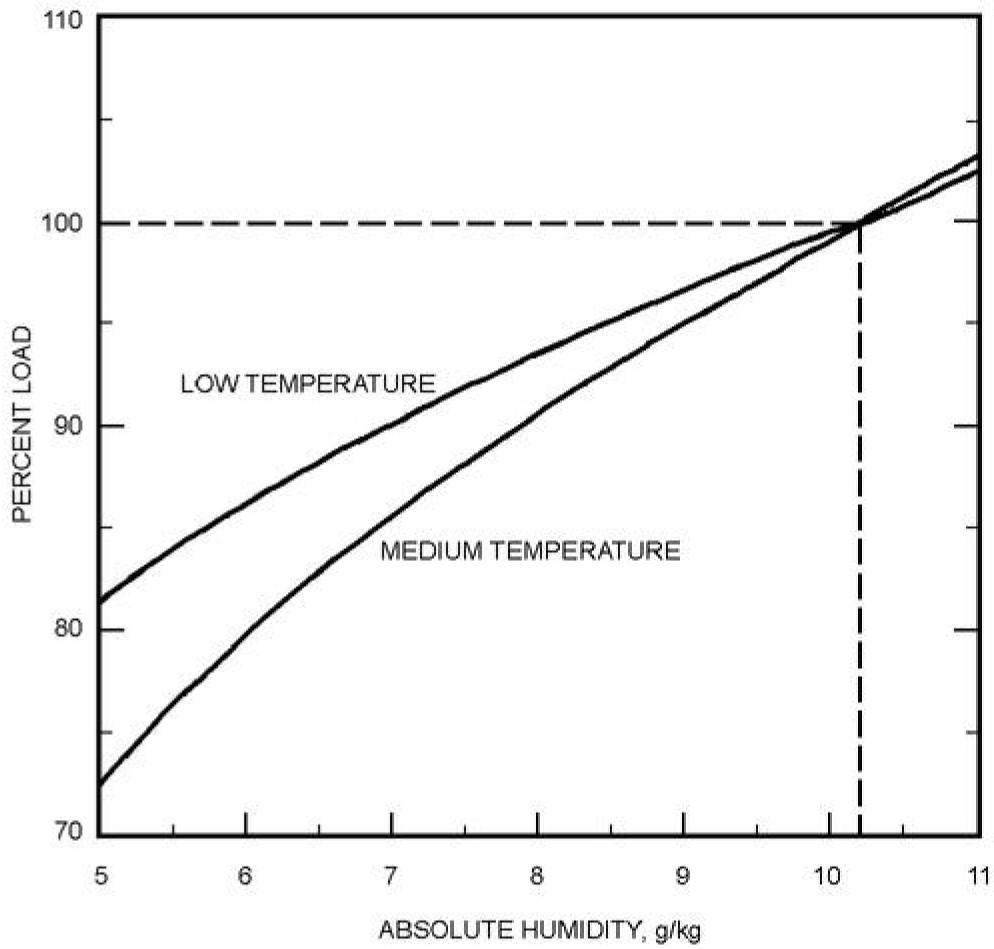

Figure 1. Refrigerated Case Load Variation with Store Air Humidity

Table 1 Refrigerating Effect (RE) Produced by Open Refrigerated Display Fixtures

	RE on Building Per Unit Length of Fixture*			
Display Fixture Types	**Latent Heat, W/m**	**% Latent to Total RE**	**Sensible Heat, W/m**	**Total RE, W/m**
Low-temperature (frozen food)				

Single-deck	36	15	199	235
Single-deck/double-island	67	15	384	451
2-deck	138	20	554	692
3-deck	310	20	1238	1548
4- or 5-deck	384	20	1538	1922
Ice cream				
Single-deck	62	15	352	414
Single-deck/double-island	67	15	384	451
Standard-temperature				
Meats				
Single-deck	50	15	286	336
Multideck	211	20	842	1053
Dairy, multideck	188	20	754	942
Produce				
Single-deck	35	15	196	231
Multideck	184	20	738	922

* These figures are general magnitudes for fixtures adjusted for average desired product temperatures and apply to store ambients in front of display cases of 22.2 to 23.3°C with 50 to 55% rh. Raising the dry bulb only 2 to 3 K and the humidity to 5 to 10% can increase loads (heat removal) 25% or more. Lower temperatures and humidities, as in winter, have an equally marked effect on lowering loads and heat removal from the space. Consult display case manufacturer's data for the particular equipment to be used.

To calculate the total load and percentage of latent and sensible heat that the air conditioning must handle, the refrigerating effect imposed by the display fixtures must be subtracted from the building's gross air-conditioning requirements (Table 1).

Modern supermarket designs have a high percentage of closed refrigerated display fixtures. These vertical cases have large glass display doors and greatly reduce the problem of latent and sensible heat removal from the occupied space. The doors do, however, require heaters to minimize condensation and fogging. These heaters should cycle by automatic control.

For more information on supermarkets, see Chapter 15 in the 2022 *ASHRAE Handbook—Refrigeration*.

Design Considerations

Store owners and operators frequently complain about cold aisles, heaters that operate even when the outdoor temperature is above 21°C, and air conditioners that operate infrequently. These problems are usually attributed to spillover of cold air from open refrigerated display equipment.

Although refrigerated display equipment may cause cold stores, the problem is not excessive spillover or improperly operating equipment. Heating and air-conditioning systems must compensate for the effects of open refrigerated display equipment. Design considerations include the following:

- Increased heating requirement because of removal of large quantities of heat, even in summer.
- Net air-conditioning load after deducting the latent and sensible refrigeration effect. The load reduction and change in sensible-latent load ratio have a major effect on equipment selection.
- Need for special air circulation and distribution to offset the heat removed by open refrigerating equipment.
- Need for independent temperature and humidity control.

Each of these problems is present to some degree in every supermarket, although situations vary with climate and store layout. Methods of overcoming these problems are discussed in the following sections. Energy costs may be extremely high if the year-round air-conditioning system has not been designed to compensate for the effects of refrigerated display equipment.

Heat Removed by Refrigerated Displays. The display refrigerator not only cools a displayed product but also envelops it in a blanket of cold air that absorbs heat from the room air in contact with it. Approximately 80 to 90% of the heat removed from the room by vertical refrigerators is absorbed through the display opening. Thus, the open refrigerator acts as a large air cooler, absorbing heat from the room and rejecting it via the condensers outside the building. Occasionally, this conditioning effect can be greater than the design air-conditioning capacity of the store. The heat removed by the refrigeration equipment *must* be considered in the design of the air-conditioning and heating systems because this heat is being removed constantly, day and night, summer and winter, regardless of store temperature. Display cases should be provided with sliding doors to minimize heat loss (see ASHRAE *Standard* 189.1).

Display cases increase the building heating requirement such that heat is often required at unexpected times. The following example shows the extent of this cooling effect. The desired store temperature is 24°C. Store heat loss or gain is assumed to be 8 kW/K of temperature difference between outdoor and store temperature. (This value varies with store size, location, and exposure.) The heat removed by refrigeration equipment is 56 kW. (This value varies with the number of refrigerators.) The latent heat removed is assumed to be 19% of the total, leaving 81% or 45.4 kW sensible heat removed, which cools the store 45.4/8 = 5.7 K. By constantly removing sensible heat from its environment, the refrigeration equipment in this store will cool the store 5.7 K below outdoor temperature in winter and in summer. Thus, in mild climates, heat must be added to the store to maintain comfort conditions.

The designer can either discard or reclaim the heat removed by refrigeration. If economics and store heat data indicate that the heat should be discarded, heat extraction from the space must be included in the heating load calculation. If this internal heat loss is not included, the heating system may not have sufficient capacity to maintain design temperature under peak conditions.

The additional sensible heat removed by the cases may change the air-conditioning latent load ratio from 32% to as much as 50% of the net heat load. Removing a 50% latent load by refrigeration alone is very difficult. Normally, it requires specially designed equipment with reheat or chemical adsorption.

Multishelf refrigerated display equipment requires 55% rh or less. In the dry-bulb temperature ranges of average stores, humidity in excess of 55% can cause heavy coil frosting, product zone frosting in low-temperature cases, fixture sweating, and substantially increased refrigeration power consumption.

A humidistat can be used during summer cooling to control humidity by transferring heat from the condenser to a heating coil in the airstream. The store thermostat maintains proper summer temperature conditions. Override controls prevent conflict between the humidistat and the thermostat.

The equivalent result can be accomplished with a conventional air-conditioning system by using three- or four-way valves and reheat condensers in the ducts. This system borrows heat from the standard condenser and is controlled by a humidistat. For higher energy efficiency, specially designed equipment should be considered. Desiccant dehumidifiers and heat pipes have also been used.

Humidity. Cooling from refrigeration equipment does not preclude the need for air conditioning. On the contrary, it increases the need for humidity control.

With increases in store humidity, heavier loads are imposed on the refrigeration equipment, operating costs rise, more defrost periods are required, and the display life of products is shortened. The dew point rises with relative humidity, and sweating can become so profuse that even nonrefrigerated items such as shelving superstructures, canned products, mirrors, and walls may sweat.

Lower humidity results in lower operating costs for refrigerated cases. There are three methods to reduce the humidity level: (1) standard air conditioning, which may overcool the space when the latent load is high and sensible load is low; (2) mechanical dehumidification, which removes moisture by lowering the air temperature to its dew point, and uses hot-gas reheat when needed to discharge at any desired temperature; and (3) desiccant dehumidification, which removes moisture independent of temperature, supplying warm air to the space unless postcooling is provided to discharge at any desired temperature.

Each method provides different dew-point temperatures at different energy consumption and capital expenditures. The designer should evaluate and consider all consequential trade-offs. Standard air conditioning requires no additional investment but reduces the space dew-point temperature only to 16 to 18°C. At 24°C space temperature this results in 60 to 70% rh at best. Mechanical dehumidifiers can provide humidity levels of 40 to 50% at 24°C. Supply air temperature can be controlled with hot-gas reheat between 10 and 32°C. Desiccant dehumidification can provide levels of 35 to 40% rh at 24°C. Postcooling supply air may be required, depending on internal sensible loads. A desiccant is reactivated by passing hot air at 80 to 121°C through the desiccant base. Consider adding a heat recovery system to maintain low humidity and using the recovered heat for reheat.

System Design. The same air-handling equipment and distribution system are generally used for both cooling and heating. The entrance area is the most difficult section to heat. Many supermarkets in the northern United States are built with vestibules provided with separate heating equipment to temper the cold air entering from the outdoors. Auxiliary heat may also be provided at the checkout area, which is usually close to the front entrance. Methods of heating entrance areas include the use of (1) air curtains, (2) gas-fired or electric infrared radiant heaters, and (3) waste heat from the refrigeration condensers.

Air-cooled condensing units are the most commonly used in supermarkets. Typically, a central air handler conditions the entire sales area. Specialty areas like bakeries, computer rooms, or warehouses are better served with a separate air handler because the loads in these areas vary and require different control than the sales area.

Most installations are made on the roof of the supermarket. If air-cooled condensers are located on the ground outside the store, they must be protected against vandalism as well as truck and customer traffic. If water-cooled condensers are used on the air-conditioning equipment and a cooling tower is required, provisions should be made to prevent freezing during winter operation.

Air Distribution. Designers overcome the concentrated load at the front of a supermarket by discharging a large portion of the total air supply into the front third of the sales area.

The air supply to the space with a standard air-conditioning system is typically 5 L/s per square metre of sales area. This value should be calculated based on the sensible and latent internal loads. The desiccant system typically requires less air supply because of its high moisture removal rate, typically 2.5 L/s per square metre. Mechanical dehumidification can fall within these parameters, depending on required dew point and suction pressure limitations.

Being denser, air cooled by the refrigerators settles to the floor and becomes increasingly colder, especially in the first 900 mm above the floor. If this cold air remains still, it causes discomfort and does not help to cool other areas of the store that need more cooling. Cold floors or areas in the store cannot be eliminated by the simple addition of heat. Reduction of air-conditioning capacity without circulation of localized cold air is analogous to installing an air conditioner without a fan. To take advantage of the cooling effect of the refrigerators and provide an even temperature in the store, the cold air must be mixed with the general store air.

To accomplish the necessary mixing, air returns should be located at floor level; they should also be strategically placed to remove the cold air near concentrations of refrigerated fixtures. Returns should be designed and located to avoid creating drafts. There are two general solutions to this problem:

- **Return Ducts in Floor.** This is the preferred method and can be accomplished in two ways. The floor area in front of the refrigerated display cases is the coolest area. Refrigerant lines are run to all of these cases, usually in tubes or trenches. If the trenches or tubes are enlarged and made to open under the cases for air return, air can be drawn in from the cold area (Figure 2). The air is returned to the air-handling unit through a tee connection to the trench before it enters the back room area. The opening through which the refrigerant lines enter the back room should be sealed.

  If refrigerant line conduits are not used, air can be returned through inexpensive underfloor ducts. If refrigerators have in-sufficient undercase air passage, consult the manufacturer. Often they can be raised off the floor approximately 40 mm. Floor trenches can also be used as ducts for tubing, electrical supply, and so forth.

  Floor-level return relieves the problem of localized cold areas and cold aisles and uses the cooling effect for store cooling, or increases the heating efficiency by distributing the air to areas that need it most.

- **Fans Behind Cases.** If ducts cannot be placed in the floor, circulating fans can draw air from the floor and discharge it above the cases (Figure 3). Although this approach prevents objectionable cold aisles in front of the refrigerated display cases, it does not prevent an area with a concentration of refrigerated fixtures from remaining colder than the rest of the store.

Control. Store personnel should only be required to change the position of a selector switch to start or stop the system or to change from heating to cooling or from cooling to heating. Control systems for heat recovery applications are more complex and should be coordinated with the equipment manufacturer.

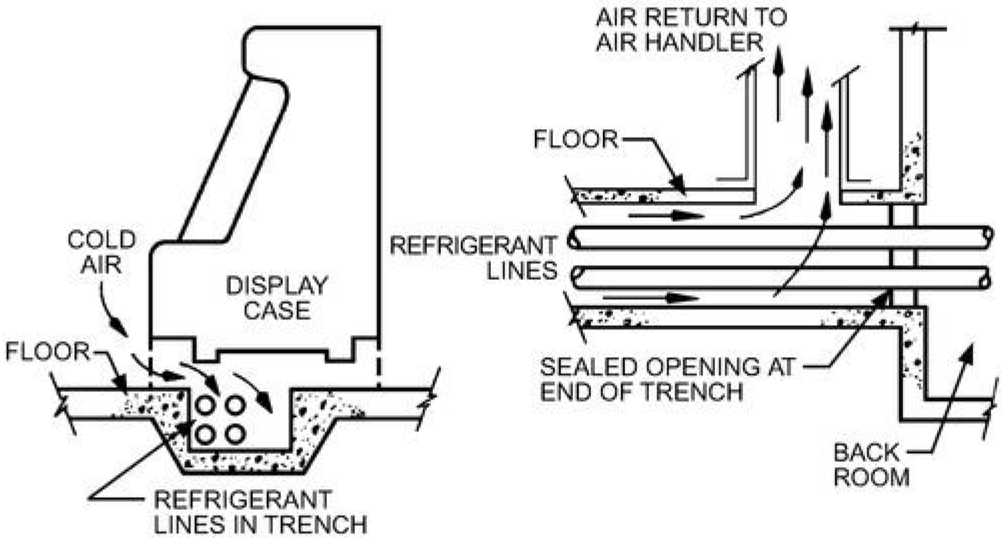

Figure 2. Floor Return Ducts

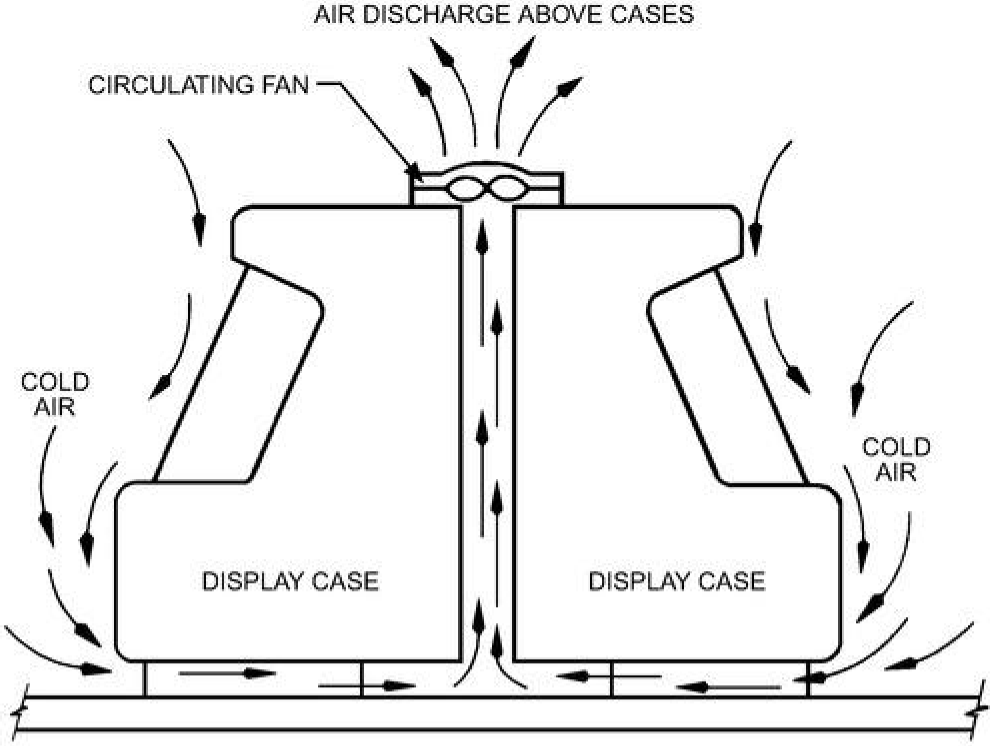

Figure 3. Air Mixing Using Fans Behind Cases

Maintenance and Heat Reclamation. Most supermarkets, except large chains, do not employ trained maintenance personnel, but rather rely on service contracts with either the installer or a local service company. This relieves store management of the responsibility of keeping the air conditioning operating properly.

Heat extracted from the store and heat of compression may be reclaimed for heating cost saving. One method of reclaiming rejected heat is to use a separate condenser coil located in the air conditioner's air handler, either alternately or in conjunction with the main refrigeration condensers, to provide heat as required (Figure 4). Another system uses water-cooled condensers and delivers its rejected heat to a water coil in the air handler.

The heat rejected by conventional machines using air-cooled condensers may be reclaimed by proper duct and damper design (Figure 5). Automatic controls can either reject this heat to the outdoors or recirculate it through the store. Consider using warm liquid defrost for evaporator coils on refrigerated cases, coolers, and freezers (Mei et al. 2002).

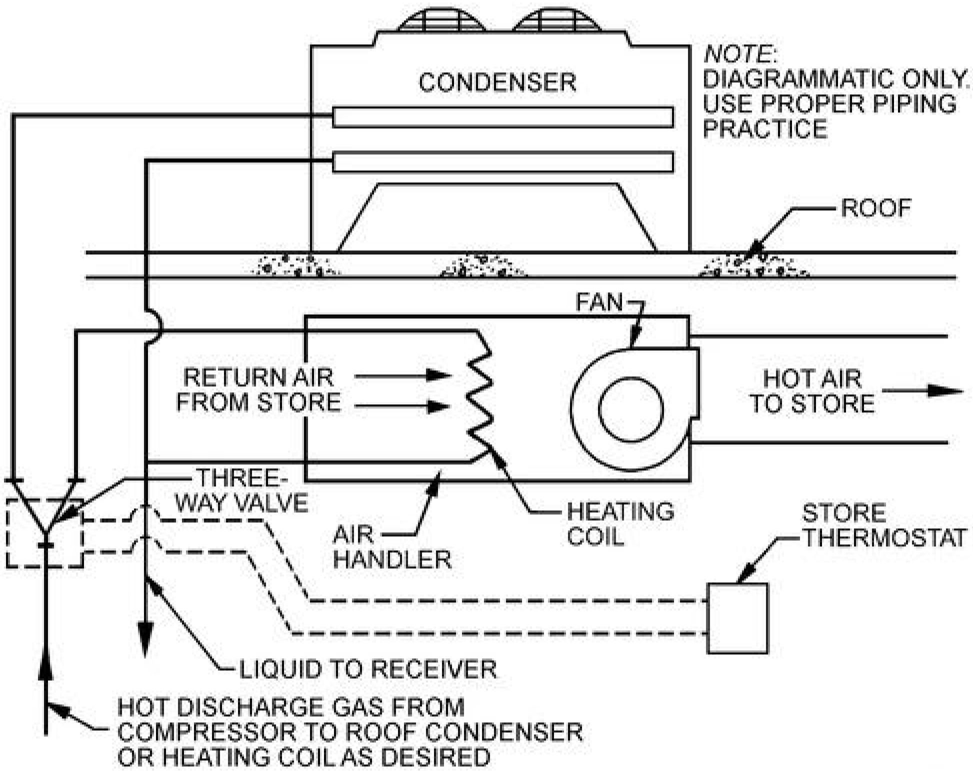

Figure 4. Heat Reclaiming Systems

5. DEPARTMENT STORES

Department stores vary in size, type, and location, so air-conditioning design should be specific to each store. Essential features of a quality system include (1) an automatic control system properly designed to compensate for load fluctuations, (2) zoned air distribution to maintain uniform conditions under shifting loads, and (3) use of outdoor air for cooling during favorable conditions. It is also desirable to adjust indoor temperature for variations in outdoor temperature. Although close control of humidity is not necessary, a properly designed system should operate to maintain relative humidity at 50% or below. This humidity limit eliminates musty odors and retards perspiration, particularly in fitting rooms.

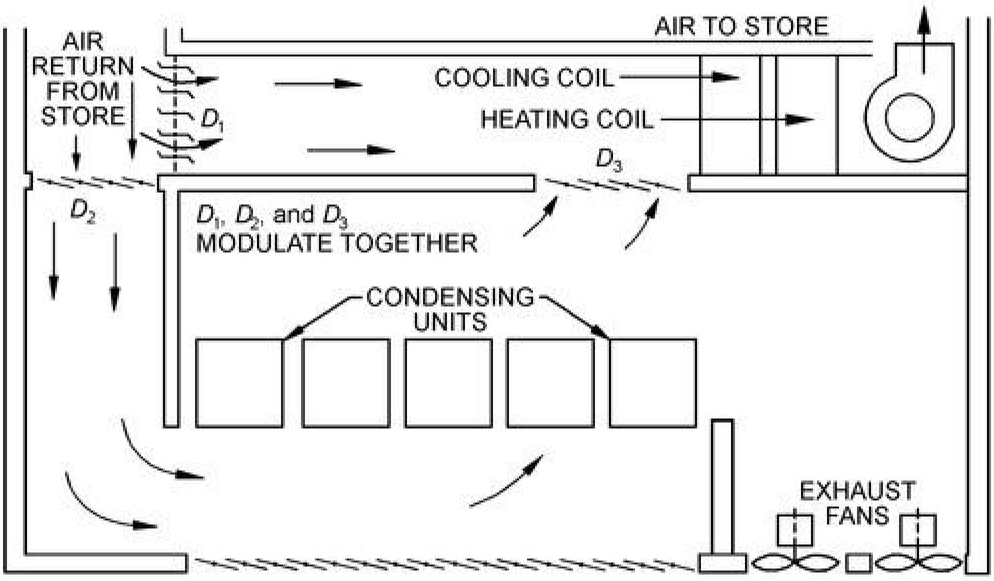

Figure 5. Machine Room with Automatic Temperature Control Interlocked with Store Temperature Control

Table 2 Approximate Lighting Load for Older Department Stores

Area	W/m^2
Basement	30 to 50
First floor	40 to 70
Upper floors, women's wear	30 to 50
house furnishings	20 to 30

Load Determination

Because the occupancy (except store personnel) is transient, indoor conditions are commonly set not to exceed 26°C db and 50% rh at outdoor summer design conditions, and 21°C db at outdoor winter design conditions. Winter humidification is seldom used in store air conditioning.

ASHRAE *Standard* 62.1 provides population density information for load determination purposes. Energy codes and standards restrict installed lighting watt density for newly constructed facilities. However, older facilities may have increased lighting watt densities. Values in Table 2 are approximations for older facilities.

Other loads, such as those from motors, beauty parlors, restaurant equipment, and any special display or merchandising equipment, should be determined.

Minimum outdoor air requirements should be as defined in ASHRAE *Standard* 62.1 or local codes.

Paint shops, alteration rooms, rest rooms, eating places, and locker rooms should be provided with positive exhaust ventilation, and their requirements must be checked against local codes.

Design Considerations

Before performing load calculations, the designer should examine the store arrangement to determine what will affect the load and the system design. For existing buildings, actual construction, floor arrangement, and load sources can be surveyed. For new buildings, examination of the drawings and discussion with the architect or owner is required.

Larger stores may contain beauty parlors, food service areas, extensive office areas, auditoriums, warehouse space, etc. Some of these special areas may operate during hours in addition to the normal store-open hours. If present or future operation could be compromised by such a strategy, these spaces should be served by separate HVAC systems.

Because of the concentrated load and exhaust requirements, beauty parlors and food service areas should be provided with separate ventilation and air distribution.

Future plans for the store must be ascertained because they can have a great effect on the type of air conditioning and refrigeration to be used.

System Design. Air conditioning systems for department stores may use unitary or central station equipment. Selection should be based on owning and operating costs as well as special considerations for the particular store, such as store hours, load variations, and size of load.

Large department stores have often used central-station systems consisting of air-handling units having chilled-water cooling coils, hot-water heating coils, fans, and filters. Some department stores now use large unitary units. Air systems must have adequate zoning for varying loads, occupancy, and usage. Wide variations in people loads may justify considering variable-volume air distribution systems. Water chilling and heating plants distribute water to the various air handlers and zones and may take advantage of some load diversity throughout the building.

Air-conditioning equipment should not be placed in the sales area; instead, it should be located in mechanical equipment room areas or on the roof whenever practicable. Ease of maintenance and operation must be considered in the design of equipment rooms and locations.

Many locations require provisions for smoke removal. This is normally accommodated through the roof and may be integrated with the HVAC system.

Air Distribution. All buildings must be studied for orientation, wind exposure, construction, and floor arrangement. These factors affect not only load calculations, but also zone arrangements and duct locations. In addition to entrances, wall areas with significant glass, roof areas, and population densities, the expected locations of various departments should be considered. Flexibility must be left in the duct design to allow for future movement of departments. It may be necessary to design separate air systems for entrances, particularly in northern areas. This is also true for storage areas where cooling is not contemplated.

Air curtains may be installed at entrance doorways to limit infiltration of unconditioned air, at the same time providing greater ease of entry.

Control. Space temperature controls are usually operated by personnel who have little knowledge of air conditioning. Therefore, exposed sensors and controls should be kept as simple as possible while still providing the required functions.

Control must be such that correctly conditioned air is delivered to each zone. Outdoor air intake should be automatically controlled to operate at minimum cost while providing required airflow. Partial or full automatic control should be provided for cooling to compensate for load fluctuations. Completely automatic refrigeration plants should be considered.

Heating controls vary with the nature of the heating medium. Duct heaters are generally furnished with manufacturer-installed safety controls. Steam or hot-water heating coils require a motorized valve for heating control.

Time clock control can limit unnecessary HVAC operation. Unoccupied reset controls should be provided in conjunction with timed control.

Automatic dampers should be placed in outdoor air inlets and in exhausts to prevent air entering when the fan is turned off.

Maintenance. Most department stores employ personnel for routine housekeeping, operation, and minor maintenance, but rely on service and preventive maintenance contracts for refrigeration cycles, chemical treatment, central plant systems, and repairs.

Improving Operating Cost. An outdoor air economizer can reduce the operating cost of cooling in most climates. These are generally available as factory options or accessories with the air-handling units or control systems. Heat recovery and desiccant dehumidification should also be analyzed.

6. CONVENIENCE CENTERS

Many small stores, discount stores, supermarkets, drugstores, theaters, and even department stores are located in convenience centers. The space for an individual store is usually leased. Arrangements for installing air conditioning in leased space vary. Typically, the developer builds a shell structure and provides the tenant with an allowance for usual heating and cooling and other minimum interior finish work. The tenant must then install an HVAC system. In another arrangement, developers install HVAC units in the small stores with the shell construction, often before the space is leased or the occupancy is known. Larger stores typically provide their own HVAC design and installation.

Design Considerations

The developer or owner may establish standards for typical heating and cooling that may or may not be sufficient for the tenant’s specific requirements. The tenant may therefore have to install systems of different sizes and types than originally allowed for by the developer. The tenant must ascertain that power and other services will be available for the total intended requirements.

The use of party walls in convenience centers tends to reduce heating and cooling loads. However, the effect an unoccupied adjacent space has on the partition load must be considered.

7. REGIONAL SHOPPING CENTERS

Regional shopping centers generally incorporate an enclosed, heated and air-conditioned mall. These centers are normally owned by a developer, who may be an independent party, a financial institution, or one of the major tenants in the center.

Some regional shopping centers are designed with an open pedestrian mall between rows of stores. This open-air concept results in tenant spaces similar to those in a convenience center. Storefronts and other perimeters of the tenant spaces are exposed to exterior weather conditions.

Major department stores in shopping centers are typically considered separate buildings, although they are attached to the mall. The space for individual small stores is usually leased. Arrangements for installing air conditioning in the individually leased spaces vary, but are similar to those for small stores in convenience centers.

Table 3 Typical Installed Cooling Capacity and Lighting Levels: Midwestern United States

Type of Space	Area per Unit of Installed Cooling, m^2/kW	Installed Cooling per Unit of Area, W/m^2	Lighting Density of Area, W/m^2	Annual Lighting Energy Use,[a] kWh/m^2
Dry retail[b]	9.69	104.1	43.1	174.4
Restaurant	3.59	277.6	21.5	87.2
Fast food				
Food court tenant area	4.23	236.6	32.3	131.3
Food court seating area	3.88	258.7	32.3	131.3
Mall common area	7.61	135.6	32.3	131.3[c]
Total	6.97	142.0	38.8	157.2

Source: Based on 2001 Data—Midwestern United States.

[a] Hours of operating lighting assumes 12 h/day and 6.5 days/week.

[b] Jewelry, high-end lingerie, and some other occupancy lighting levels are typically 65 to 85 120 W/m^2 and can range to 120 W/m^2. Cooling requirements for these spaces are higher.

[c] 62.4 kWh/m^2 for centers that shut off lighting during daylight, assuming 6 h/day and 6.2 days/week.

Table 3 presents typical data that can be used as check figures and field estimates. However, this table should not be used for final determination of load, because the values are only averages.

Design Considerations

The owner or developer provides the HVAC system for an enclosed mall. The regional shopping center may use a central plant or unitary equipment. The owner generally requires that the individual tenant stores connect to a central plant and includes charges for heating and cooling services. Where unitary systems are used, the owner generally requires that the individual tenant install a unitary system of similar design. Because of different functions and load profiles, systems should be designed to recover heat transfer from one area and transfer to the other to save annual energy consumption.

The owner may establish standards for typical heating and cooling systems that may or may not be sufficient for the tenant's specific requirements. Therefore, the tenant may have to install systems of different sizes than originally allowed for by the developer.

Leasing arrangements may include provisions that have a detrimental effect on conservation (such as allowing excessive lighting and outdoor air or deleting requirements for economizer systems). The designer of HVAC for tenants in a shopping center must be well aware of the lease requirements and work closely with leasing agents to guide these systems toward better energy efficiency.

Many regional shopping centers contain specialty food court areas that require special considerations for odor control, outdoor air requirements, kitchen exhaust, heat removal, and refrigeration equipment.

System Design. Regional shopping centers vary widely in physical arrangement and architectural design. Single-level and smaller centers usually use unitary systems for mall and tenant air conditioning; multilevel and larger centers usually use a central system. The owner sets the design of the mall and generally requires that similar systems be installed for tenant stores.

A typical central system may distribute chilled air to individual tenant stores and to the mall air-conditioning system and use variable-volume control and electric heating at the local use point. Some plants distribute both hot and chilled water. Some all-air systems also distribute heated air. Central plant systems typically provide improved efficiency and better overall economics of operation. Central systems may also provide the basic components required for smoke removal.

Air Distribution. Air distribution in individual stores should be designed for the particular space occupancy. Some tenant stores maintain a negative pressure relative to the public mall for odor control.

The total facility HVAC system should maintain a slight positive pressure relative to atmospheric pressure and a neutral pressure relative between most of the individual tenant stores. Exterior entrances should have vestibules.

Smoke management is required by many building codes, so air distribution should be designed to easily accommodate smoke control requirements.

Maintenance. Methods for ensuring the operation and maintenance of HVAC systems in regional shopping centers are similar to those used in department stores. Individual tenant stores may have to provide their own maintenance.

Improving Operating Cost. Methods for lowering operating costs in shopping centers are similar to those used in department stores. Some shopping centers have successfully used cooling tower heat exchanger economizers.

Central plant systems for regional shopping centers typically have lower operating costs than unitary systems. However, the initial cost of the central plant system is typically higher.

8. MULTIPLE-USE COMPLEXES

Multiple-use complexes are being developed in many metropolitan areas. These complexes generally combine retail facilities with other facilities such as offices, hotels, residences, or other commercial space into a single site. This consolidation of facilities into a single site or structure provides benefits such as improved land use; structural savings; more efficient parking; utility savings; and opportunities for more efficient electrical, fire protection, and mechanical systems.

Load Determination

The various occupancies may have peak HVAC demands that occur at different times of the day or year. Therefore, the HVAC loads of these occupancies should be determined independently. Where a combined central plant is considered, a block load should also be determined.

Design Considerations

Retail facilities are generally located on the lower levels of multiple-use complexes, and other commercial facilities are on upper levels. Generally, the perimeter loads of the retail portion differ from those of the other commercial spaces. Greater lighting and population densities also make HVAC demands for the retail space different from those for the other commercial space.

The differences in HVAC characteristics for various occupancies within a multiple-use complex indicate that separate air handling and distribution should be used for the separate spaces. However, combining the heating and cooling requirements of various facilities into a central plant can achieve a substantial saving. A combined central heating and cooling plant for a multiple-use complex also provides good opportunities for heat recovery, thermal storage, and other similar functions that may not be economical in a single-use facility.

Many multiple-use complexes have atriums. The stack effect created by atriums requires special design considerations for tenants and space on the main floor. Areas near entrances require special measures to prevent drafts and accommodate extra heating requirements.

System Design. Individual air-handling and distribution systems should be designed for the various occupancies. The central heating and cooling plant may be sized for the block load requirements, which may be less than the sum of each occupancy's demand.

Control. Multiple-use complexes typically require centralized control. It may be dictated by requirements for fire and smoke control, security, remote monitoring, billing for central facilities use, maintenance control, building operations control, and energy management.

9. SUSTAINABILITY AND ENERGY EFFICIENCY

Many large retail chains have made significant advances in implementing sustainability programs. Many retailers have added leaders who focus on energy efficiency and sustainability to their executive leadership teams, and some even establish and report sustainability goals (Jamieson et al. 2013). ASHRAE *Standard* 90.1 and appropriate design guides and tools should be used to achieve energy efficiency and sustainable design in a retail facility. ASHRAE *Standard* 189.1 also provides guidance on sustainable solution.

A dedicated integrated design group is helpful in developing and implementing energy efficient design strategies. The design team should be open to new and innovative energy-efficient designs that may include geothermal heating and cooling, high-performance lighting, heat recovery systems, high-efficiency HVAC, and renewable energy systems (Duarte 2013; Genest and Charneux 2005).

Design engineers should take advantage of ASHRAE's *Advanced Energy Design Guides* (www.ashrae.org/technical-resources/aedgs) to reduce energy-related expenses and to achieve retailer's corporate sustainability targets. While incorporating energy efficiency measures, HVAC design engineers should consider items such as heating and cooling loads, ventilation, energy management systems, variable-speed fan controls, variable-speed pumps, variable-frequency drives, and energy recovery systems; it is most important, however, to understand the needs of the facility. When energy-efficient measures are properly implemented, they can lead to achieving a retailer's corporate sustainable mission, higher employee morale, and reduced energy costs. Integrated design process (IDP), described in Chapter 60, should be used. IDP promotes collaboration between a retailer's sustainability goals and actual energy-saving strategies. In IDP, all stakeholders work together on a common goal, "result[ing] in a coordinated, constructible, and cost-effective design" (ASHRAE 2011).

Important elements of IDP are

- Project kickoff
- Programming and project design
- Schematic design
- Design development
- Construction documents
- Bid phase
- Construction administration
- Commissioning
- Operations and maintenance
- Continuous improvement
- Controlling costs

Building energy modeling and energy benchmarking tools should be used to estimate energy consumptions, building behavior, evaluation of energy use, and tracking. Chapter 19 of the 2021 *ASHRAE Handbook—Fundamentals* provides more information on energy modeling methodologies. Commonly used benchmarking tools include U.S. EPA ENERGY STAR Portfolio Manager (portfoliomanager.energystar.gov) and Lawrence Berkeley National Laboratory's (LBNL) Standard Energy Efficiency Data Platform^{TM} (www.energy.gov/eere/buildings/standard-energy-efficiency-data-platform). To achieve sustainability and energy efficiency in a retail facility, combined heat and power (CHP) and renewable energy technologies such as solar thermal, solar photovoltaic, wind, and biomass can be considered in conjunction with energy-efficient measures.

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ASHRAE members can access *ASHRAE Journal* articles and ASHRAE research project final reports at technologyportal.ashrae.org. Articles and reports are also available for purchase by nonmembers in the online ASHRAE Bookstore at www.ashrae.org/bookstore.

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