IMPROVING ENERGY EFFICIENCY AND OCCUPANT COMFORT IN PUBLIC SECTOR BUILDINGS

Heating, ventilation and air conditioning (HVAC) systems each represent a systematic method for controlling the various aspects of the environment within an enclosure, whether it is a room, a group of rooms, or a whole building.

MAINTAINING A COMFORTABLE ENVIRONMENT FOR OCCUPANTS INVOLVES CONDITIONING THE AIR BY:

- Heating/cooling to control temperature
- Humidifying/dehumidifying to control relative humidity
- Circulating air to provide movement
- Ventilating to supply fresh air
- Filtering to remove air contaminants

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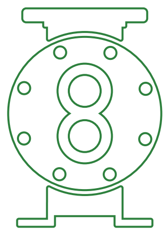
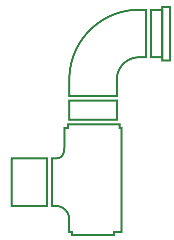
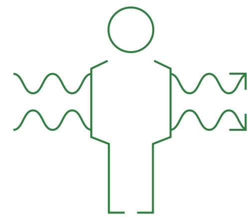
INTAKE → / ← EXHAUST	PRODUCTION/ MOTION 	DISTRIBUTION 	RESULTS 
FUEL, COMBUSTION, AIR → **HEAT** ← HEAT, CARBON DIOXIDE (CO_2)	Boilers Furnaces Pumps Fans Filters Heat pumps	Pipes Ducts Electrical conduits Diffusers Grilles Radiators Thermostats Valves Dampers	Warm air or surfaces Air motion (often controlled) Humidity control (sometimes needed)
AIR, WATER, FUEL → **COOL** ← AIR, VAPOUR, WATER, HEAT, CO_2	Evaporative coolers Heat pumps Chillers and cooling towers Coils Pumps Fans Filters	Pipes Ducts Diffusers Grilles Radiators Thermostats Valves Dampers	Cool air or surfaces Air motion (usually controlled) Humidity control (usually provided)
AIR → **VENT** ← AIR	Fans Filters	Ducts Diffusers Grilles Switches Dampers	Fresh air Air motion (usually controlled) Air quality control (often needed)

COMMON PROBLEMS ASSOCIATED WITH HVAC IN THE PUBLIC SECTOR

Problem type	Potential causes	Impacts
Indoor air quality (IAQ)	Ineffective mechanical and natural ventilation fails to deliver sufficient fresh air and to remove contaminated air and moisture.	Poor IAQ affects human health, particularly the young, the elderly and those with sensitivities.
Thermal comfort	Incorrectly sized HVAC equipment, air leakage, inefficient windows/walls and thermal bridging cause occupant discomfort during periods of hot and cold weather.	Increased difficulty in concentration, leading to a higher likelihood of accidents.
High operating and maintenance costs	Inefficient building enclosures, hydronic or air distribution systems (e.g., leaky ducts, constant volume fans, single-stage pumps) can result in energy waste.	Energy waste increases operating costs, while non-durable materials and equipment (e.g., filters, gaskets, etc.) require excessive maintenance and repair.

THE V IN HVAC – WHY VENTILATION MATTERS

Ventilation is important in public sector buildings to maintain indoor air quality, enhancing the health and comfort of occupants. Ventilation systems work to:

- **Remove pollutants:** Indoor air can be polluted from cleaning products and building materials that may off-gas, especially during periods of renovation. Common air pollutants include: excess moisture, carbon dioxide, carbon monoxide, volatile organic compounds (VOCs), fungus particles, dust mites, hazardous bacteria and viruses, radon gas, methane and other soil gases.
- **Control odours:** Ventilation works to exchange polluted air with fresh air, eliminating odours that would otherwise accumulate.
- **Prevent mould and mildew:** Ventilation provides air flow, which prevents moisture from building up.
- **Inhibit the spread of airborne contaminants:** Ventilation helps dilute and remove dust, allergens and pathogens from the air, reducing the risk of illness and improving overall air quality.
- **Allow occupants to breathe easier:** Healthy indoor air quality is linked to improved health.

PROVIDING ACCEPTABLE IAQ

Take the following steps to provide acceptable IAQ in public sector buildings:

1 Limit pollution at its source.

2 Isolate unavoidable sources of pollution.

3 Provide for an adequate supply and filtering of fresh air (and recirculated air).

4 Keep buildings and equipment clean.

- The following standards and codes exist for minimum allowable ventilation and exhaust rates.
  - ANSI/ASHRAE Standards 62.1 and 62.2 are the recognized standards for ventilation system design and acceptable indoor air quality (IAQ). Expanded and revised for 2022, both standards specify minimum ventilation rates and other measures in order to minimize adverse health effects for occupants.
  - ASHRAE 62.1 for all buildings except residential. ASHRAE 62.2 for residential buildings.
  - Additional standards exist for specific building types: ASHRAE 241 "Control of Infectious Aerosols" for health care facilities, public buildings and high-rise multi-unit residential buildings.
  - CSA Group standards for health care facilities (HCF) address various crucial aspects of their design, mechanical systems installation, commissioning, operation, and technology integration. These standards are highly relevant for day-to-day activities in any well-functioning facility.
- Simple measurement of CO_2 concentration is typically used as a proxy for potential IAQ problems for occupants.
- Demand controlled ventilation (DCV) is an energy-saving strategy that controls the air change rate according to building occupancy and indoor pollutant load.
  - The CO_2 concentration monitored by sensors is used to control the air supply rate.
  - If there is low or no occupancy, DCV systems can save large amounts of energy.

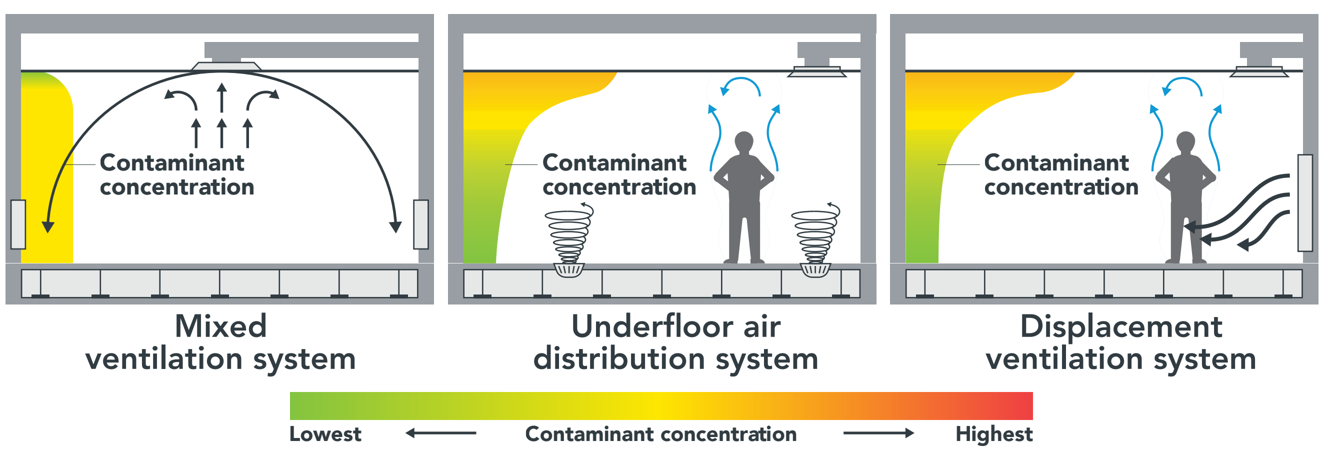


Figure 1: Comparison of contaminant concentration in mechanical ventilation systems

Source: ASHRAE Journal, Vol. 64, no. 12, December 2022

COMMON DESIGN OPTIONS FOR PUBLIC SECTOR VENTILATION

- An air distribution system consists of two major subsystems:

1 Air-handling units (AHUs) that produce conditioned air under sufficient positive pressure to circulate it to and from the conditioned space.

2 A distribution system that only carries air from the AHU to the space being conditioned. The air distribution subsystem often includes means to control the amount or temperature of air delivered to each space.

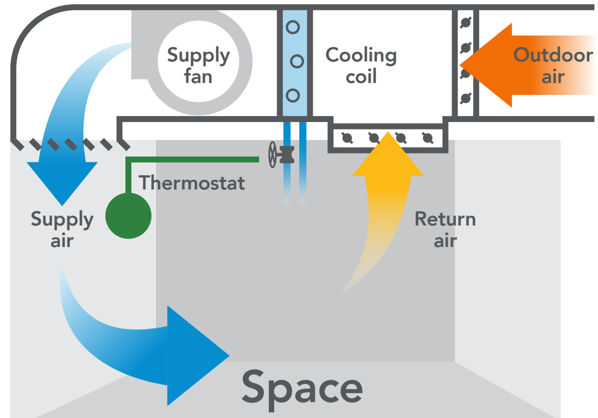


Figure 2: A CV variable temperature system

Ventilation Systems

1 A constant volume (CV) single zone system delivers a constant volume of air to the space and, to maintain the required space temperature at all load conditions, varies the temperature of this air.

2 A CV terminal reheat system has a heating coil in each space to temper the air to satisfy the space load.

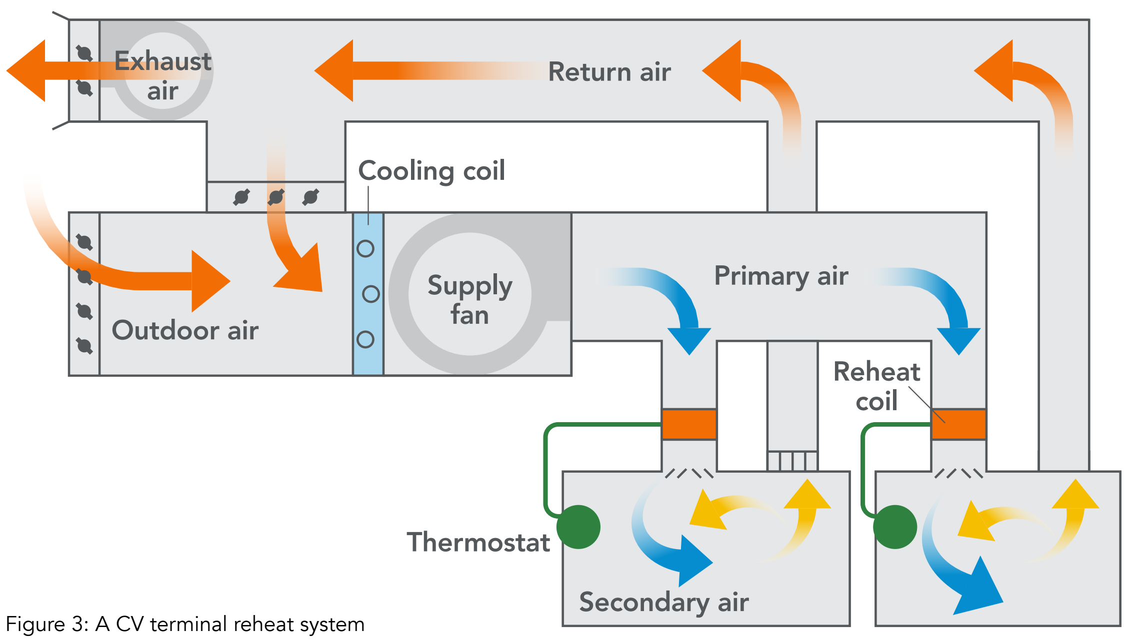


Figure 3: A CV terminal reheat system

COMMON DESIGN OPTIONS FOR PUBLIC SECTOR VENTILATION

3 A variable air volume (VAV) system delivers the primary air at a constant temperature and varies the airflow to maintain the required space temperature at all load conditions.

- There is a VAV terminal unit, or "box," with a thermostat and supply diffusers for each independently controlled space.
- VAV terminal unit controls are either pressure dependent or pressure independent.
- A VAV unit is considered pressure dependent when the flow rate passing through it varies with the pressure in the supply duct. Pressure independent VAV units use a flow controller to maintain air supply. Pressure independent VAV units are more common and provide more comfort for occupants.

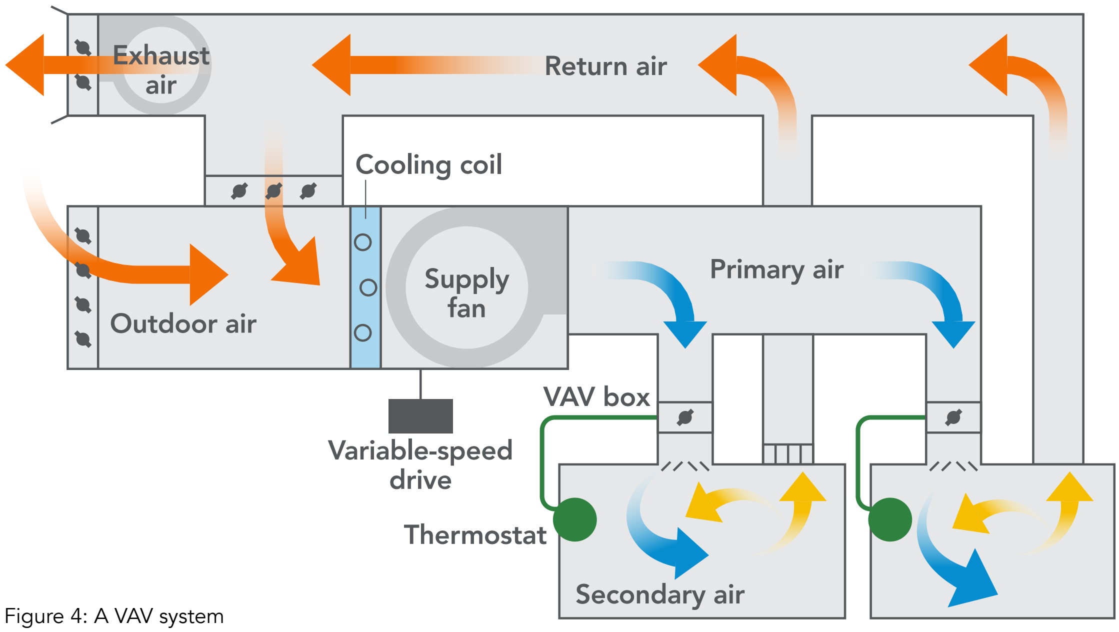


Figure 4: A VAV system

COMPARING DESIGN OPTIONS

CV single zone system	CV terminal reheat system	Most efficient VAV system
Constant fan energy	Constant fan energy	Fan energy savings
Refrigeration energy savings at part load	Nearly constant refrigeration energy	Refrigeration energy savings at part load
Delivers comfort to only one thermal zone	Delivers comfort to many spaces inefficiently	Delivers comfort to many spaces efficiently
	Reheat energy increase at part load	

ENERGY-EFFICIENT DESIGN OPTIONS FOR PUBLIC SECTOR HVAC CONTROL

For efficient HVAC control options in public buildings, consider implementing systems like smart thermostats, occupancy sensors and building automation systems that can adjust heating and cooling based on real-time occupancy and environmental conditions, leading to significant energy savings.

- A **cascade control system** uses multiple heating and cooling equipment units (e.g., boilers, modular chillers) as required to meet fluctuating heating/cooling demands.
  - It always maintains maximum efficiency by precisely matching the load and, if applicable, using the most efficient equipment first.
  - The controller will modulate, stage and rotate the equipment, and regulate the supply temperature of the system (e.g., air or water temperature).
  - Advantages include:
    - Greater energy efficiency
    - Greater life expectancy of equipment (increased modulation ratios)
    - Beneficial redundancy (multiple units available as back up)
    - Flexible installation
  - This is the most appropriate approach for the efficient operation of hybrid heat pump systems.

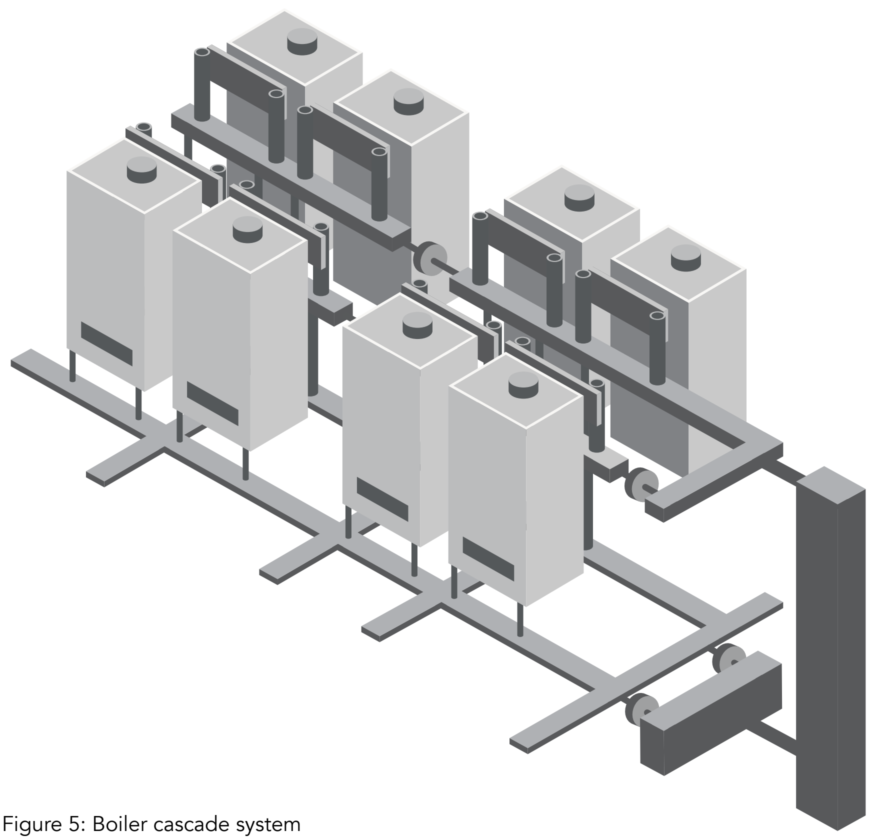


Figure 5: Boiler cascade system

ENERGY-EFFICIENT DESIGN OPTIONS FOR PUBLIC SECTOR HVAC EQUIPMENT

- A **heat pump** is an electrically driven device that extracts heat from a lower temperature place (a source) and delivers it to a higher temperature place (a sink). A heat pump is fully reversible, providing year-round comfort by providing both heating and cooling energy.
  - The two principal modes of heat pump operation are heating and cooling. A third mode, the defrost cycle, is used to protect the coils from excessive frost buildup.
  - The two common types found in Canada are:
    - Air source: The heat pump draws heat from the outside air during the winter heating season and moves heat outside during the summer cooling season.
    - Ground source: The heat pump uses the earth, ground water or both as the source of heat in the winter and as a reservoir to remove heat from the building in the summer.

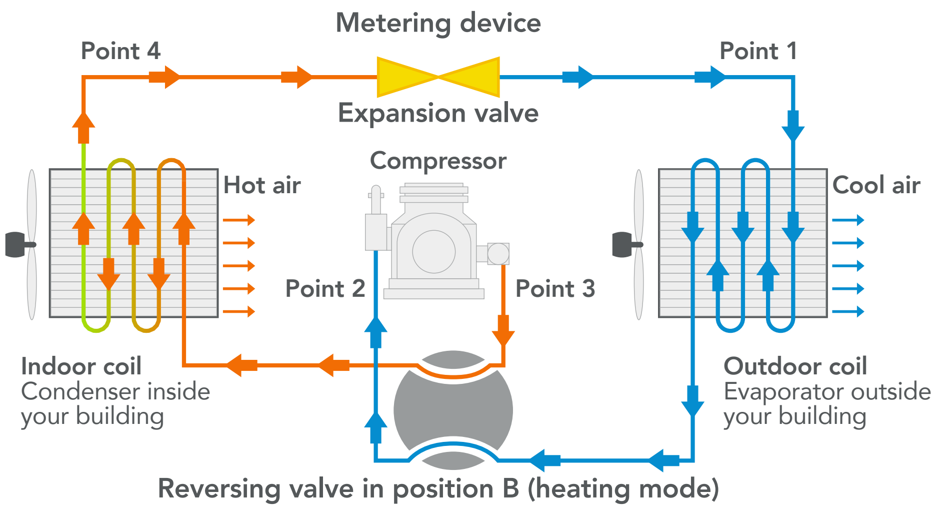


Figure 6: A heat pump in heating mode

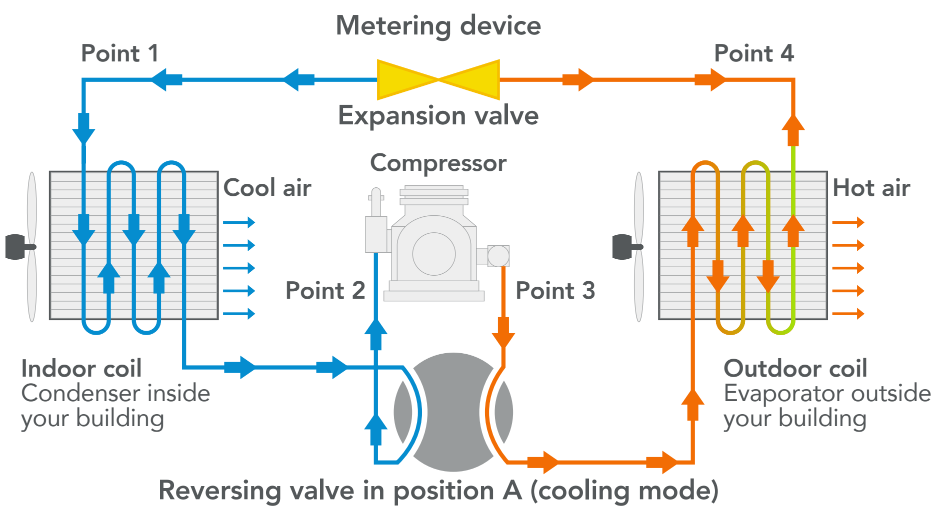


Figure 7: A heat pump in cooling mode

ENERGY-EFFICIENT DESIGN OPTIONS FOR PUBLIC SECTOR HVAC EQUIPMENT

For efficient HVAC control options in public buildings, consider implementing systems like smart variable air volume (VAV) systems, demand-controlled ventilation, heat recovery ventilators, variable frequency drives and energy-efficient heating and cooling equipment that can optimize whole facility efficiency leading to significant energy savings.

- Efficient centralized systems use the following equipment or components:
  - **Heat recovery ventilation:** Recovers the heat from the exhaust air and, using a heat exchanger, transfers it back into the supply air without mixing the air flows.
    - Modern ventilation technology allows a heat recovery rate of between 75 and 95 percent.
  - **Demand-controlled ventilation:** Adjusts airflow based on the demand of the space. This could be based on occupancy, carbon monoxide levels in parking garages or other loads such as cooking loads in large kitchens.
  - **Hot water heat recovery**
  - **Heat pumps**
  - **Condensing boilers:** When operated in the correct circumstances, a hydronic heating system can achieve high efficiency (greater than 90 percent) by condensing water vapour found in the exhaust gases in a heat exchanger to preheat the circulating water. This recovers the latent heat of vaporization, that would otherwise be wasted.
  - **Electronically commutated fan motors:** Better than conventional motors in terms of efficiency, maintenance and life cycle.
  - **Variable frequency drives:** An electronic device that controls the voltage and frequency supplied to a motor resulting variability of the speed of the motor and the system it serves. By meeting only the required process demands, the efficiency of the system can be improved.
  - **Optimized fan cycling (staging)**

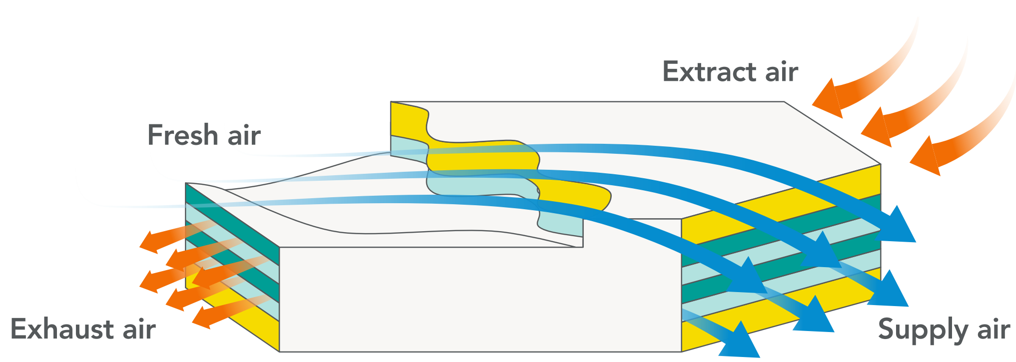


Figure 8: Heat recovery ventilation air flows

BUILDING AUTOMATION SYSTEMS (BAS)

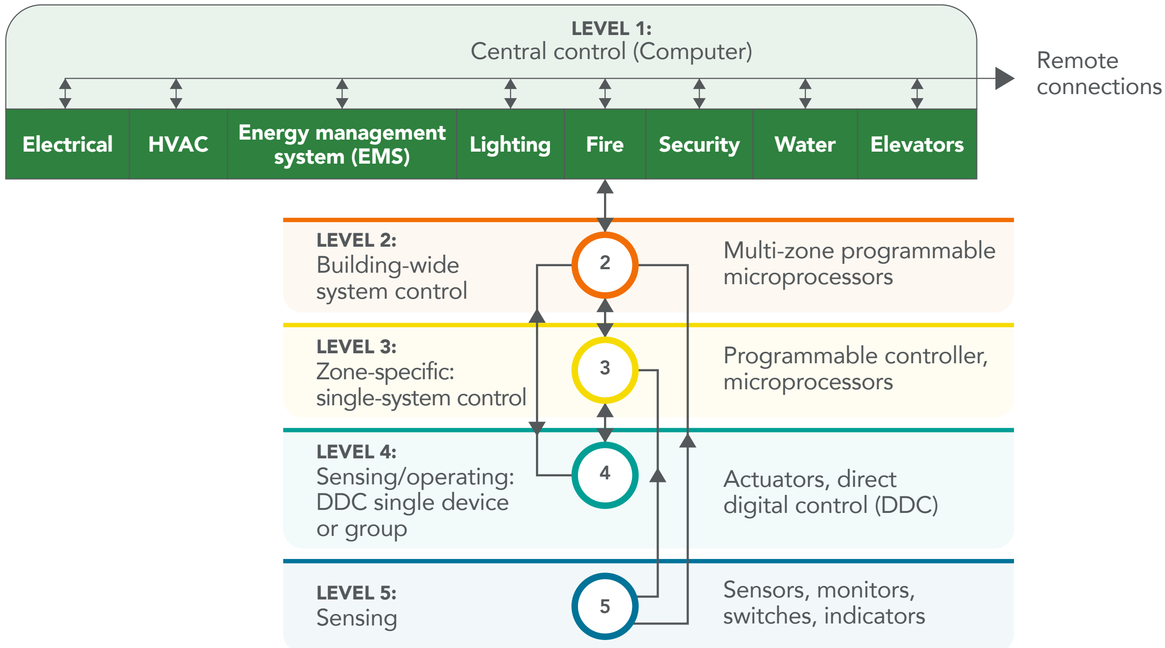


Figure 9: BAS hierarchy

Remote connections refer to the ability to access and control the system from a location other than the building where the systems are installed.

- Sensors in BAS generally include, but are not limited to:
  - Pressure sensors
  - Flow sensors
  - Heat sensors
  - Humidity, CO_2 and other contaminant probes
  - Occupancy and motion detectors
  - Light sensors
  - Water flow detectors
  - Electrical current sensors
  - Contact sensors
- In **occupied control modes,** the building must be ventilated and the temperature set points must be maintained in all occupied zones. The main supply fan operates continuously. The primary air temperature is controlled to a constant set point. The supply fan is controlled to maintain the static-pressure set point of the system. The outdoor air damper is controlled to deliver the proper amount of ventilation air. All terminal units are controlled to maintain their respective occupied space temperature set points.
- In **unoccupied control modes**, the building does not require ventilation because it is not occupied, and the temperature in the perimeter spaces must only be prevented from getting too cold (below 16°C) or too hot (above 29°C). The main supply fan cycles on only when a perimeter space demands heating or cooling relative to the unoccupied set point.

  If separate perimeter heat is installed and heat is demanded, that system will operate and the main supply fan remains off. The supply fan is controlled to maintain the static pressure set point of the system. The outdoor air damper remains closed. All terminal units with demand for central heating or cooling maintain their respective unoccupied temperature set points. All other terminal units remain off.

- The **morning warm-up/cool-down mode** typically occurs as a transition from the unoccupied mode to the occupied mode. In this mode, the building does not initially require ventilation because it is not occupied, but ventilation may eventually be provided for a preoccupancy purge (diluting the contaminants that accumulated during the unoccupied mode). The AHU fan operates continuously to provide primary air to the spaces for cooling or heating. If separate perimeter heat is installed and heat is demanded, the perimeter heat source operates and the AHU fan remains off. The supply fan is controlled to maintain the static pressure set point for the system. The outdoor air damper is closed unless ventilation is needed for the preoccupancy purge. Terminal units may be fully open, allowing "wild" (uncontrolled) warm-up or cool-down, or they may modulate to achieve the occupied temperature set points for a "controlled" warm up or cool down.
- **Economizer cycles** compare outdoor conditions to inside conditions and vary the proportion of outdoor air to return air inside to provide "free" cooling.

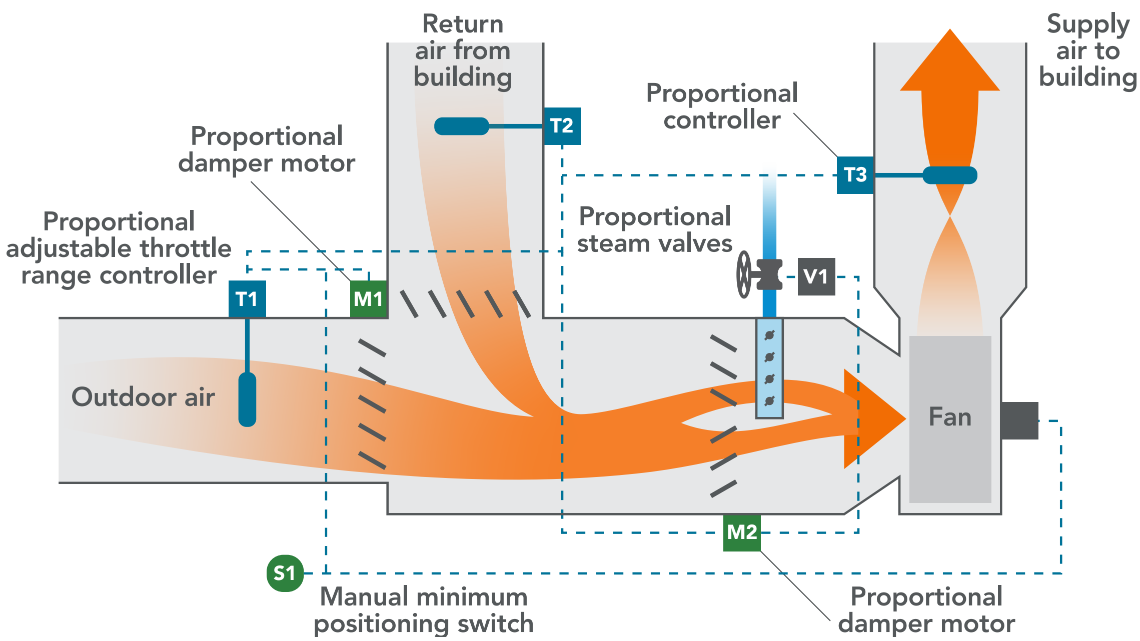


Figure 10: Economizer control cycle

EXISTING BUILDING COMMISSIONING

Commissioning activities are an important aspect of efficient HVAC operations in existing buildings, especially when existing systems are being retrofitted or modified. Different types of commissioning will be important at different times.

- Building Commissioning (BCx) is a quality-focused process for enhancing the delivery of a project. The process focuses on verifying and documenting that the facility and all its systems and assemblies are planned, designed, installed, tested, operated and maintained to meet the owner's project requirements.
- Recommissioning (RCx) is required over time, as changing building use patterns along with unintended consequences of "quick fixes" alter the building's operations from how it was initially designed, decreasing energy performance.
- New technologies allow for Smart and Ongoing Commissioning (SOCx) with the aid of artificial intelligence. SOCx can assist the building operators in diagnosing problems, while constantly monitoring building system performance and identifying areas of potential energy savings. SOCx systems have two key functions:
  - Fault detection and diagnosis (and resolution, where possible)
  - Energy optimization

TECHNICAL CONSIDERATIONS FOR PLANNING HVAC RETROFITS

There are many technical considerations for each technology for building HVAC retrofits. In order to identify the most appropriate technology for any given building, project developers need to determine the following:

- Appropriateness of the technology for the building type and type of system it is replacing.
- Cost-effectiveness of the technology (product and installation) compared to other options.
- Benefits of the technology (energy and non-energy benefits such as occupant comfort, improved air quality and/or alignment with organizational objectives) compared to other options.
- Building modelling enables professionals to rapidly identify and assess the viability of potential energy efficiency, renewable energy and/or cogeneration projects through activities such as:
  - Energy benchmarking
  - Feasibility analysis (energy models, cost, emission, financial, risk)
- Building analytics software easily measures and verifies the actual and ongoing energy performance of buildings for utility bill management. These include:
  - Regression analysis
  - Cumulative sum
  - Measurement and verification