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Efficient HVAC System Operations for Public-Sector Facilities

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Agenda

1. Introduction to Save on Energy
2. Review common HVAC systems found in public sector facilities
3. Overview of the role of ventilation
4. Discuss the implications of heat flow, building envelope and design principles
5. Understand the role of control theory and building automation systems
6. Discuss the importance of building commissioning and re-commissioning

Save on Energy Program Updates

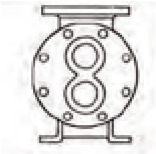
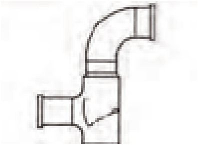
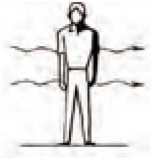
- **Retrofit program** prescriptive incentives for most **non-lighting measures** increased as of October 30, 2023. Many **doubled**, including for air source heat pumps. Visit the Retrofit program website for the updated measures and incentives.
- The **Instant Discounts program** for lighting launched **December 18, 2023.** Program incentives are directly to distributors, enabling them to offer instant point-of-sale discounts on energy-efficiency lighting to customers.
- **Strategic Energy Management program** offers a two-year, cohort-based learning model to organizations with at least 3,000,000 kWh annual energy consumption.
- The **Existing Building Commissioning program** provides financial incentives for businesses to hire qualified commissioning providers and to receive pay-for-performance incentives for savings achieved.

Save on Energy Training and Support

- **Save on Energy's Training and Support program** delivers webinars, coaching workshops and information resources to energy professionals across Ontario on a range of topics, including energy data, efficient electrification and heat pumps, all at no cost to participants.
- We also offer **incentives of up to 50% for 18 energy-efficiency training courses** and of up to 75% to Enbridge customers for several courses.
- All our training and support resources, including webinar recordings, information sheets, guides and case studies, can be found on the **Training and Support page** of the Save on Energy website. For more information, please contact us at trainingandsupport@ieso.ca.

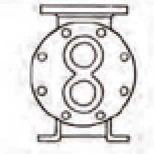
HVAC systems in public-sector facilities

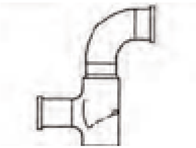
Basic HVAC system tasks and components

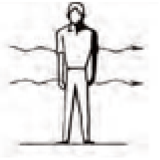




Intake Exhaust	**Production/motion** **Movers, converters, processors**	**Distribution** **Supply and return trees, delivery and control components**	**Results**
Heat Fuel combustion air Heat CO_2	Boilers Furnaces Pumps Fans Filters Heat Pumps	Pipes, ducts Electricity conduits Diffusers, grills Radiators Thermostats Valves, dampers	Warm air or surfaces Air motion often controlled Humidity control sometimes needed

Basic HVAC system tasks and components







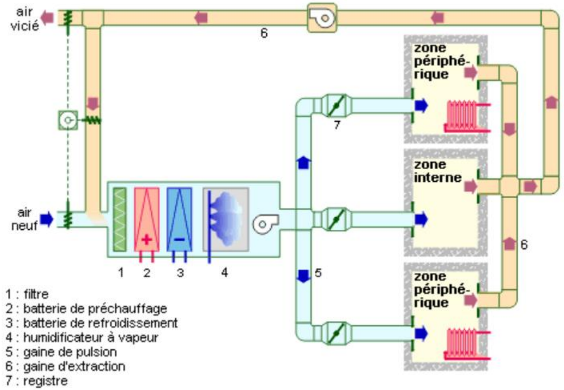
	Production/motion	Distribution	Results
Cool Air, water, fuel Air, vapor, water, heat CO_2	Evaporative coolers Heat pumps Chillers, cooling towers Coils Pumps Fans Filters	Pipes Ducts Diffusers, grills Radiators Thermostats Valves, dampers	Cool air or surfaces Air motion usually controlled Humidity control usually provided
Vent Air Air	Fans Filters	Ducts Diffusers Grilles Switches Dampers	Fresh air Air motion usually controlled Air quality control often needed

Decentralized system characteristics

- One or more individual HVAC units, each with an integral refrigeration cycle, heating source, and direct or indirect outdoor air ventilation.
- Components are factory designed and assembled into a package that includes fans, filters, heating source, cooling coil, refrigerant compressor(s), controls, and condenser.
- Equipment is manufactured in various configurations to meet a wide range of applications.

Examples of decentralized HVAC equipment

- Window air conditioners
- Through-the-wall room HVAC units
- Air-cooled heat pump systems
- Water-cooled heat pump systems
- Multiple-unit systems
- Light commercial split systems
- Self-contained (floor-by-floor) systems
- Outdoor package systems
- Packaged, special-procedure units (e.g., for computer rooms)
- Single-zone variable-air-volume systems
- Variable-refrigerant-flow systems



Centralized system characteristics

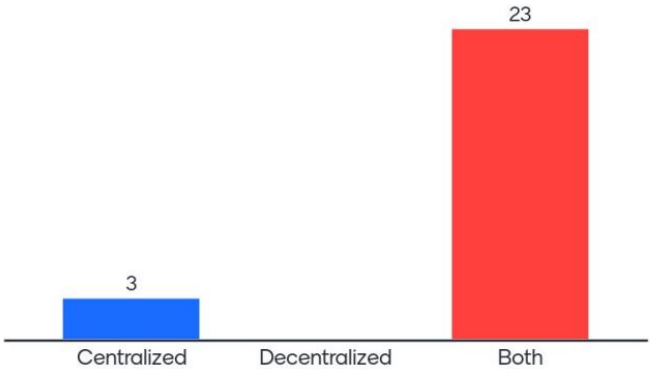
- Central systems are characterized by large chilling and heating equipment located in one facility or multiple installations interconnected to operate as one.
- Equipment configuration and ancillary equipment vary significantly, depending on the facility’s use.
- The plant and equipment can be located as part of the facility, or in remote stand-alone plants.
- Also, different combinations of centralized and decentralized systems (e.g., a central cooling plant and decentralized heating and ventilating systems) can be used.

Examples of centralized HVAC equipment

- Central refrigeration equipment/systems with chilled-water distribution
  - Water-chilling equipment, cooling towers, pumps, and water system specialty items
- Central boiler equipment/system with hot-water distribution
- Low-, medium-, and high-pressure steam plants
- Cogeneration central equipment/systems
- Condenser water systems used with water-source heat pumps

Poll Question 1: What type of systems are used in your facility?

What type of systems are used in your facility?



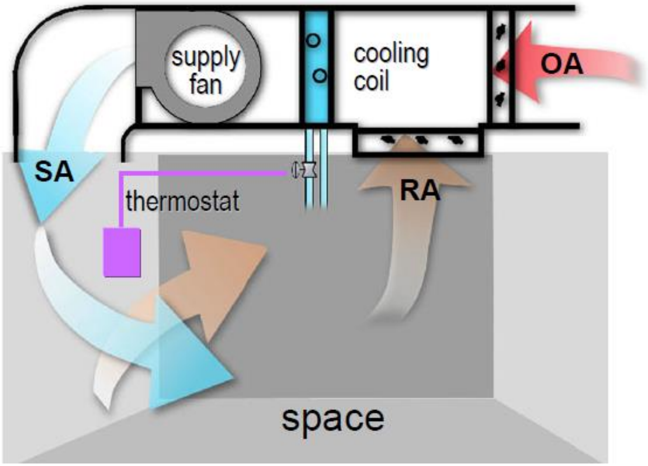
Air distribution system

Consists of two major subsystems:

1. Air-handling units (AHUs) that generate 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 air-handling unit to the space being conditioned. The air distribution subsystem often includes means to control the amount or temperature of air delivered to each space.

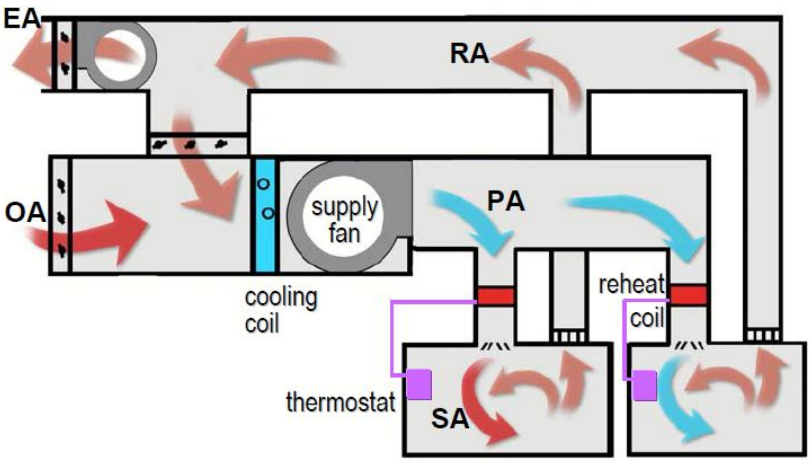
Constant volume (CV) variable temperature system

- This system delivers a constant volume of air to the space and, to maintain the required temperature at all load conditions, varies the temperature of this air.
- In this system, air temperature is varied by controlling the capacity of the central cooling coil.
- Buildings with multiple zones having diverse cooling needs require multiple systems because this type of system can respond to the demands of only one thermostat.



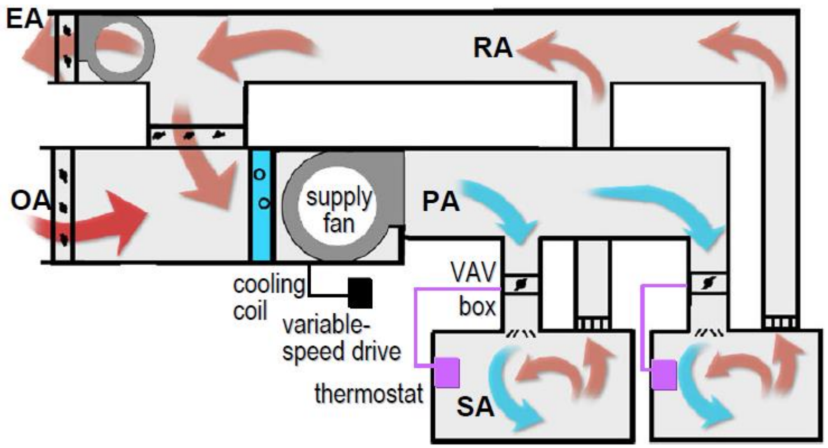
Terminal reheat system

- Each space has its own heating coil to temper the air to satisfy the space load.
- Reheating cooled air to achieve part-load supply air temperature control is not energy efficient and is used only in special constant-volume applications, or when there is a "free" source of heat (i.e., heat recovery).



Variable-air-volume (VAV) system

- VAV systems deliver the primary air at a constant temperature and varies the airflow to maintain the required space temperature at all load conditions.
- Central air handler with a variable-volume supply fan, a cooling coil, possibly a heating coil, controls, filters, a mixing box, and a return or relief fan
- Supply duct
- VAV terminal unit, or “box,” with a thermostat and supply diffusers for each independently controlled space



- Thermostat and unit controller for each terminal unit
- Return plenum or duct

VAV system savings

- The system does not overheat nor overcool spaces; reheat is eliminated.
- Attention to fan static pressure settings and static pressure reset with VAV air terminal unit (ATU) unloading is needed to minimize energy use.
- Potential for part-load energy savings:
  - Air volume reduction creates an opportunity to reduce the fan energy required to move this air (energy saved depends on the method used to modulate the capacity of the fan)
  - Reduced airflow across the cooling coil causes the refrigeration system to throttle back in order to stabilize the primary air temperature. In turn, this results in a reduction in refrigeration energy compared to full load.

System comparison

CV, single zone

- Constant fan energy
- Refrigeration energy savings at part load
- Deliver comfort to only one thermal zone

CV, terminal reheat

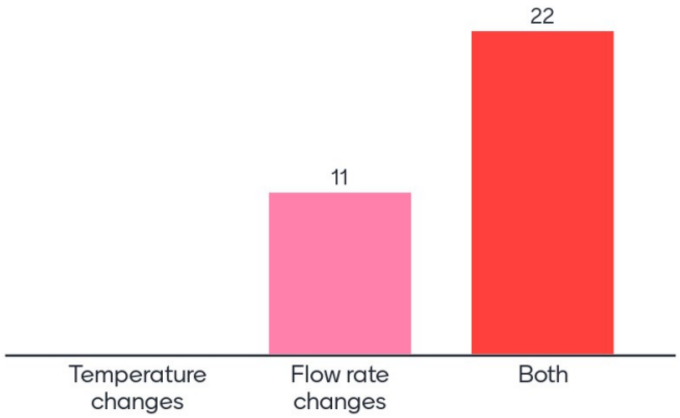
- Constant fan energy
- Nearly constant refrigeration energy
- Delivers comfort to many spaces inefficiently
- Reheat energy increase at part load

VAV

- Fan energy savings
- Refrigeration energy savings at part load
- Delivers comfort to many space efficiently

Poll Question 2: What is the best control sequence for a terminal air distribution box?

What is the best control sequence for a terminal air distribution box?



VAV terminal unit controls

Pressure-dependent control

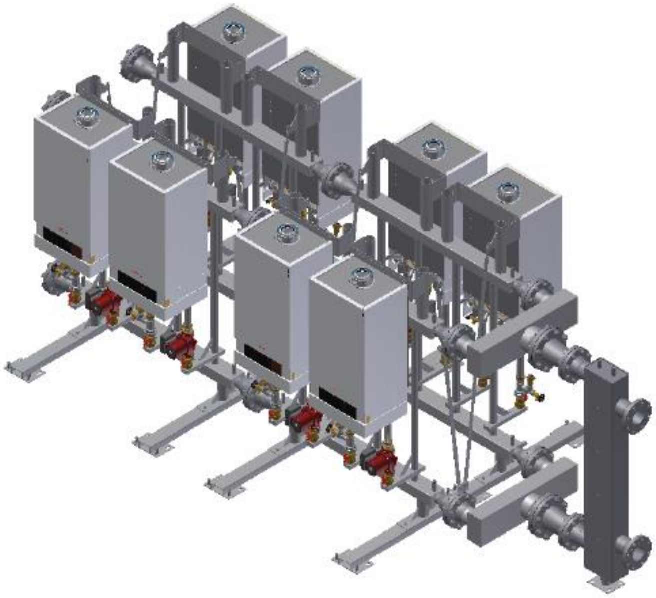
- Space sensor controls position of the modulating device
- Airflow to space depends on SP in upstream duct system

Pressure-independent control

- Space sensor controls desired airflow
- Airflow to space is controlled directly, independent of SP in upstream duct system
- Accurate measurement of primary airflow is required

Cascade control systems

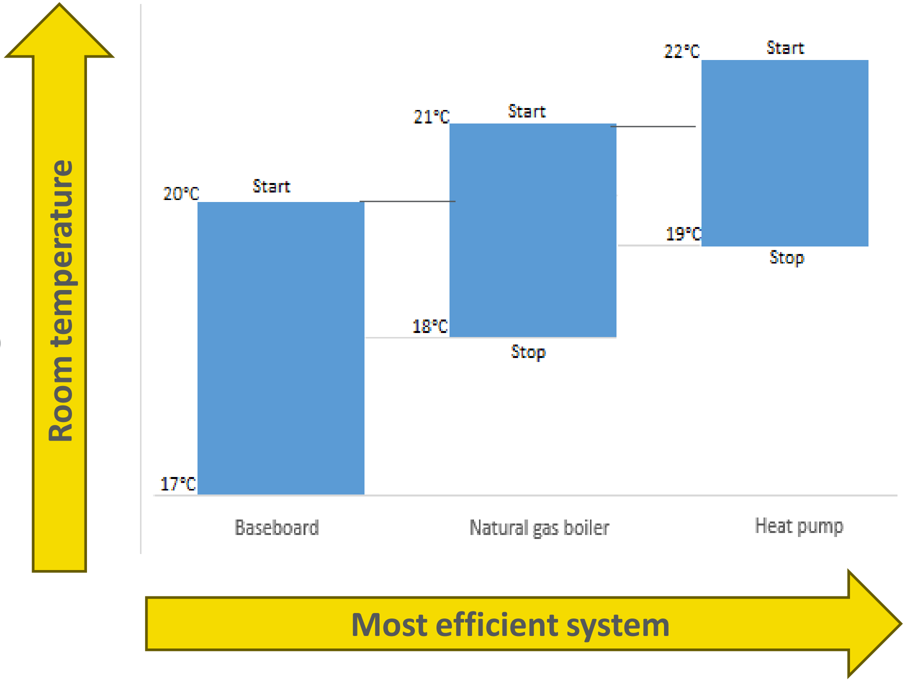
- A cascade system uses multiple units (for ex. boilers, modular chillers) as required to meet fluctuating heating/cooling demands.
- It maintains maximum efficiency at all times by precisely matching the load and, if applicable, using most efficient equipment first.
- Controller will modulate, stage and rotate equipment, regulate equipment water and common supply temperature.



8-boiler cascade system in back-to-back configuration

Advantages of cascaded systems

- Greater energy efficiency
- Greater life expectancy of equipment
    - Increased modulation ratios
- Beneficial redundancy
    - Multiple units available as back up
- Flexible installation
- Appropriate approach for efficient operation of hybrid heat pump systems



Heat pumps

- 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:

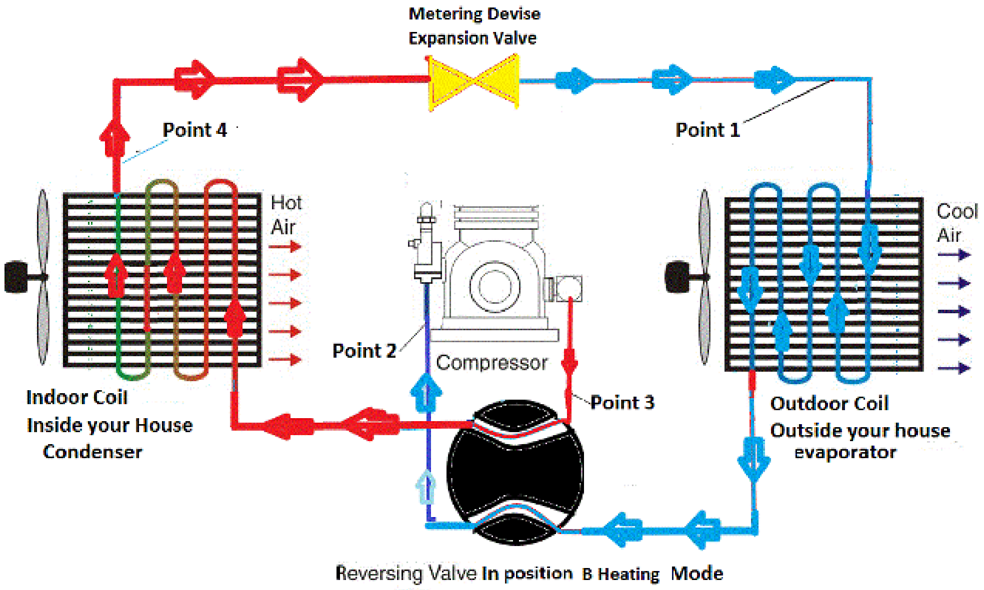
Air-source:

- The heat pump draws heat from the outside air during the heating season and rejects heat outside during the summer cooling season.

Ground-source:

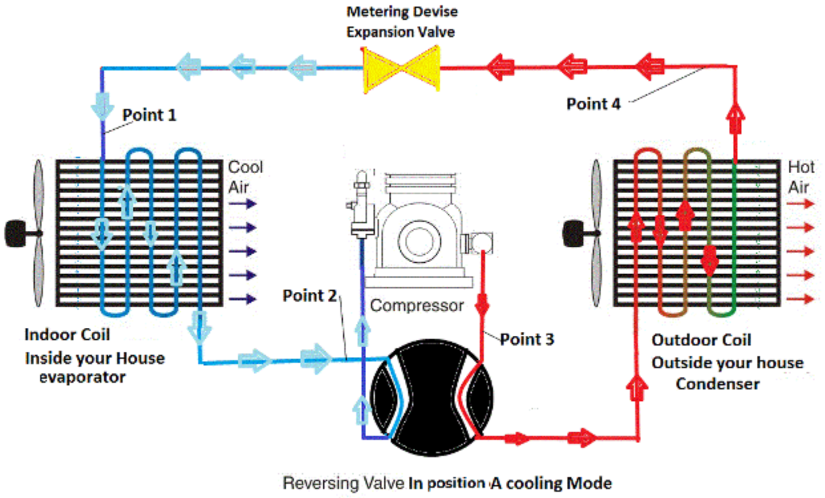
- A ground-source heat pump uses the earth, ground water, or both as the source of heat in the winter, and as a reservoir to reject heat removed from the home in the summer.

Heat pump modes



Heating mode

Cooling mode



Typical efficiencies in HVAC systems

Heating system type	Typical annual heating system seasonal efficiency
Standard boiler/furnace (with pilot light)	55 to 65%
Mid efficiency boiler/furnace (spark ignition)	65 to 75%
High efficiency or condensing boiler/furnace	75 to 85%
Electric resistance	100%
Heat pump - air-source	130 to 200%
Heat pump - ground source	250 to 350%

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Cooling system type	Typical annual cooling system seasonal COP
Compressor - centrifugal	5 to 6.7
Compressor - reciprocating	3.8 to 4.6
Compressor - screw	4.1 to 5.6
Compressor - scroll	4.6 to 7
Heat pump - gas	1.1
Heat pump - air-source	1.3 to 2
Heat pump - ground-source	3 to 3.5
Absorption - single stage	0.5
Absorption - two stage	0.7
Steam jet refrigeration	0.2 to 0.3

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Efficient centralized systems

- Heat recovery ventilation
- Condensing boilers
- Fluid coolers
- Hot water heat reclaim
- EC (electronically commutated) fan motors
- Optimized fan cycling (staging)
- Heat pumps

Role of ventilation

Evolution of ventilation

- Passive convective heating systems represented the gold standard until large spaces became the norm in the building industry.
- For heating large spaces, forced air circulation is needed because heat diffusion in air is very slow (air is quite a good insulator and is hard to heat).
- Moving treated air requires a blower. Another point of failure, another investment and running cost. There is no free lunch!
- The next question is why do we have to remove air from the building and add fresh air into buildings?

Indoor air quality (IAQ)

- Refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.
- Indoor air pollution can be described both in terms of the types of contaminants (gaseous, organic or particulate) and the types of effects (odours, irritants, toxic substances) involved.
- Common air pollutants include: excess moisture, carbon dioxide, carbon monoxide, VOCs, fungus particles, dust mites, hazardous bacteria and viruses, radon gas, methane and other soil gases.

Poll Question 3: How do buildings provide acceptable IAQ?

How do buildings provide acceptable IAQ?

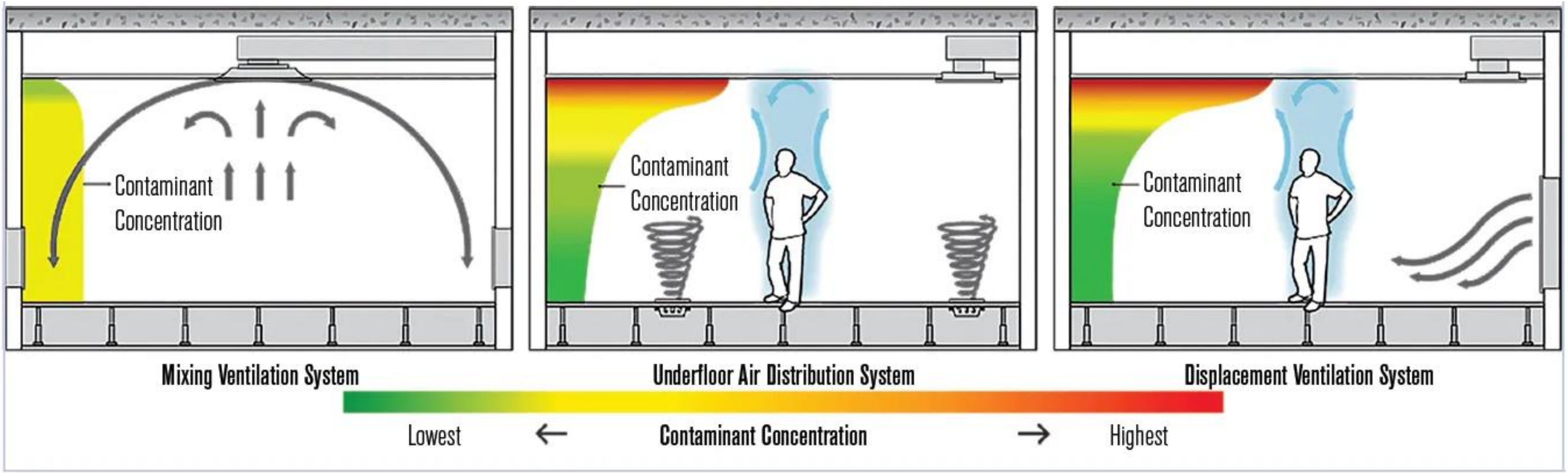
20 responses

Providing acceptable IAQ

1. Limiting pollution at the source
2. Isolating unavoidable sources of pollution
3. Providing for an adequate supply and filtering of fresh air (and recirculated air)
4. Maintaining a building and its equipment in a clean condition

- Standards and codes exist for minimum allowable ventilation and exhaust rates.
  - ASHRAE 62.1
- Simple measurement of CO_2 concentration is typically used as a proxy of potential IAQ problems related to occupancy.

IAQ with mechanical ventilation systems



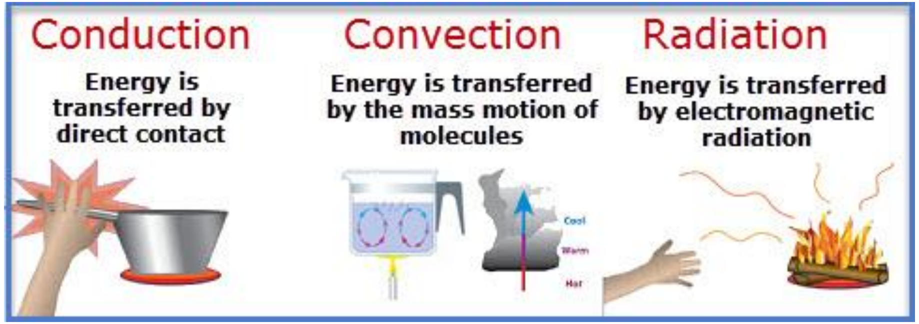
Demand controlled ventilation (DCV)

- An energy-saving strategy that controls the air change rate according to the 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.
- Multimode ventilation (MMV) was developed to address different scenarios (i.e. when different pollutants are produced at different rates) to improve indoor thermal comfort.

Heat flow and building envelope

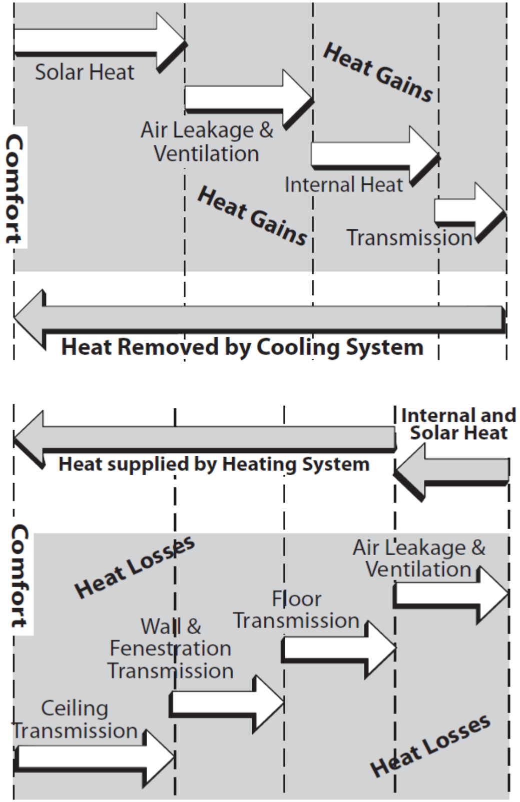
Types of heat flow

- Energy is neither created nor destroyed, it merely flows from place to place and changes form.
  - More common to say that energy is used.
- Heat travels from areas of high temperature to areas of lower temperature in three ways:



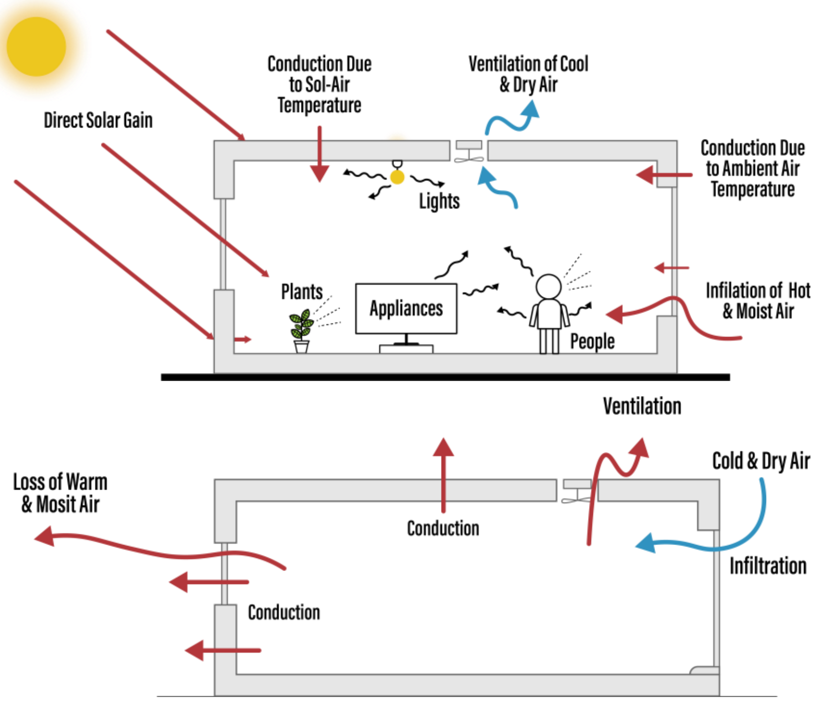
Building envelope heat loads

- Heat loss and gain through the building envelope are large energy demands on buildings.
- To maintain comfort, heating and cooling systems supply or remove heat at a rate roughly equaling heat's flow rate through the building envelope.



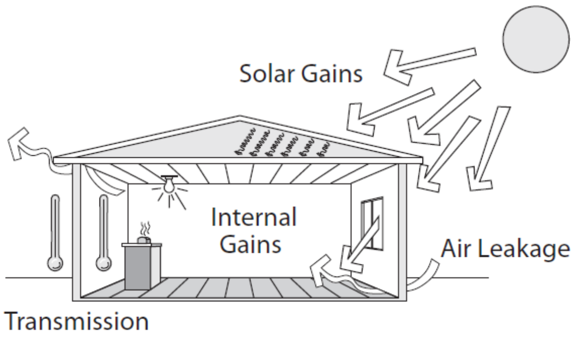
Building envelope heat flow

- Heat flows through the building envelope in two ways: heat transmission and air leakage.
- Transmission and air leakage occur through **four independent pathways**: floors and foundations; walls; roofs and ceilings; and fenestration (windows and doors).
- **Heat transmission** depends on two factors: thermal resistance and surface area.
- **Air leakage** depends on the surface area of the envelope's holes and the pressure differences between indoors and outdoors.



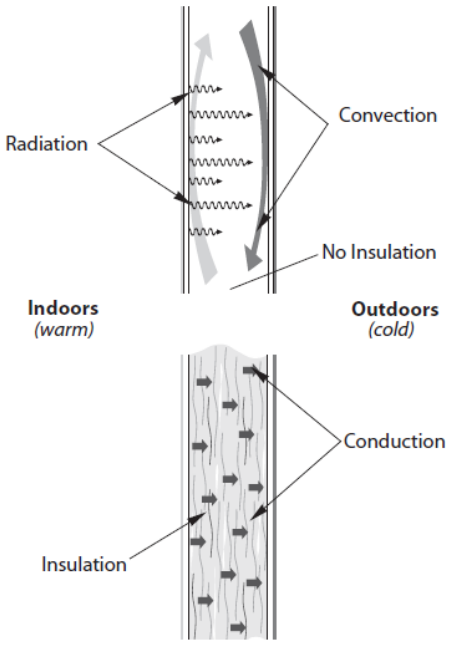
Heat gains and insulation effects

Four Types of Heat Gains



When heat accumulates in a home, the home can become uncomfortably hot. Heat accumulates inside in four ways: solar gains, internal gains, air leakage from outdoors, and the transmission heat gain due to temperature difference.

Effect of Insulation



The uninsulated wall transmits heat through its air space by convection and radiation. In the insulated wall, heat must conduct through the tiny air pockets trapped by the insulation — a slower process.

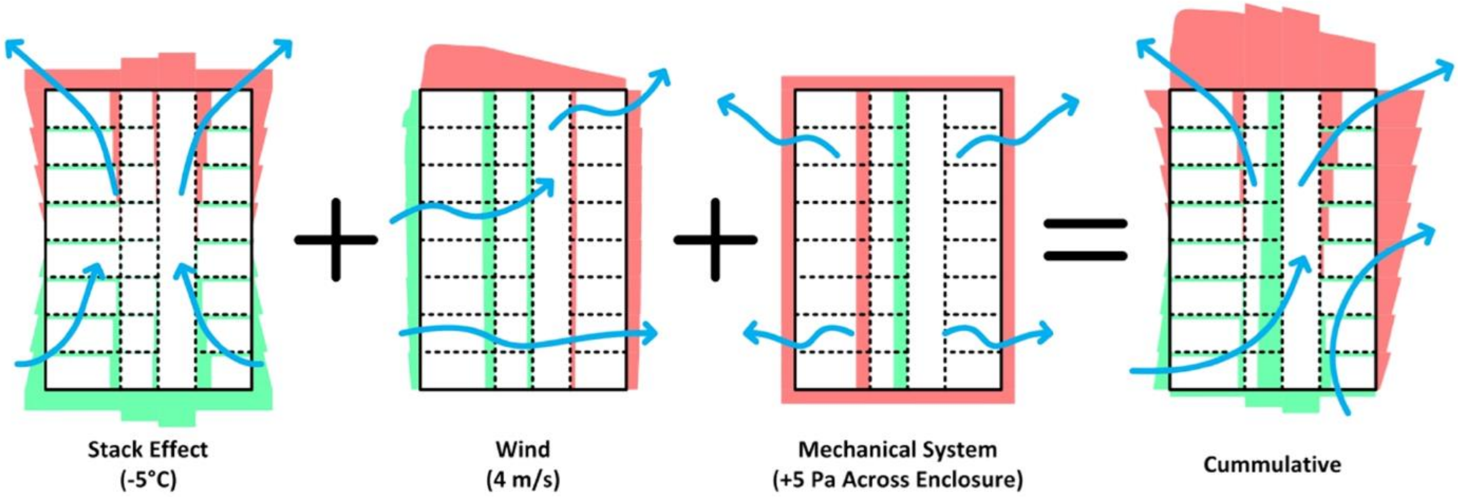
Poll Question 4: What drives air leakage in buildings?

What drives air leakage in buildings?

16 responses

Pressures driving air leakage

Pressure difference is created by three forces that drive airflow:



Passive house institute (PHI) design

PHI Standard

- Core philosophy is that efficiency improves comfort
- Heating/cooling load is limited to a maximum of 10 W/m^2
- Conventional primary energy use may not exceed 120 $kWh/(m^2a)$
  - With renewable energy supply no more than 60 $kWh/(m^2a)$
- Air change rates limited to n50 = 0.6/h

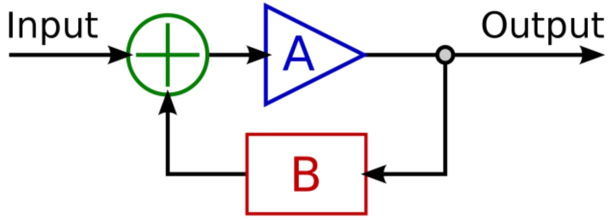
Five basic principles

- Thermal insulation
- Energy efficient windows
- Ventilation with heat recovery
- Air tightness
- Thermal bridge free design

Building automation systems (BAS)

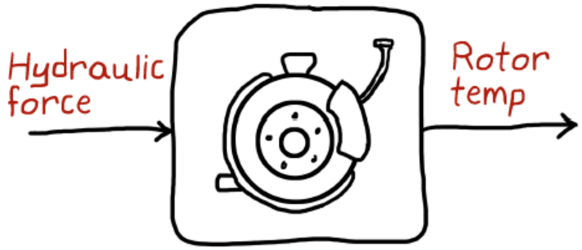
Control theory

- Develop a model or algorithm governing the application of system inputs to drive the system to a desired state.
    - Minimizing any delay, overshoot, or steady-state error and ensuring a level of control stability and optimality.
- To do this, a controller with the requisite corrective behavior is required.
- This controller monitors the controlled process variable (PV) and compares it with the set point (SP).
- The difference between actual and desired value of the process variable, called the error signal, or SP-PV error, is applied as feedback to generate a control action to bring the controlled process variable to the same value as the set point.

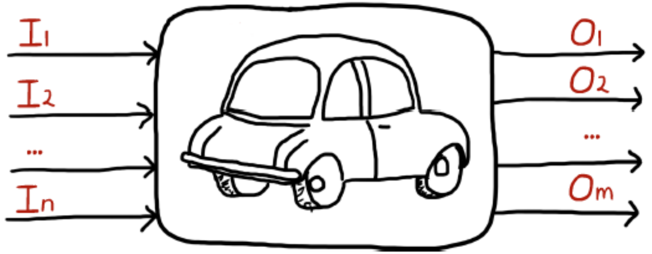


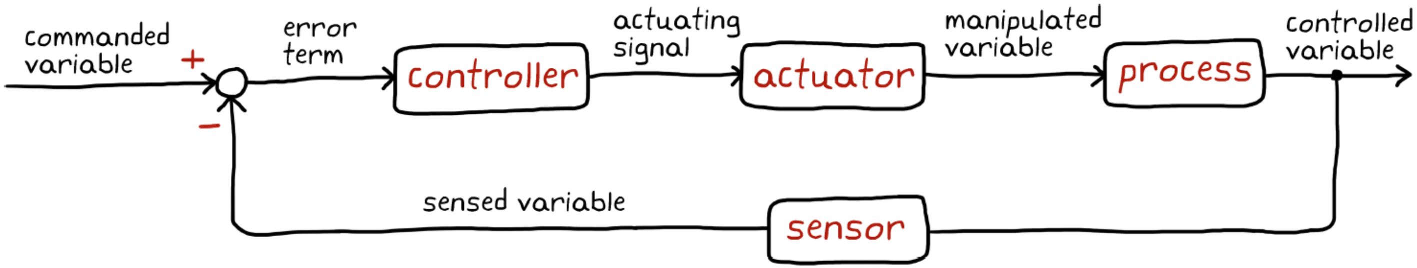
System interface and feedback control

- Single input single output (SISO)



- Multiple input multiple output (MIMO)





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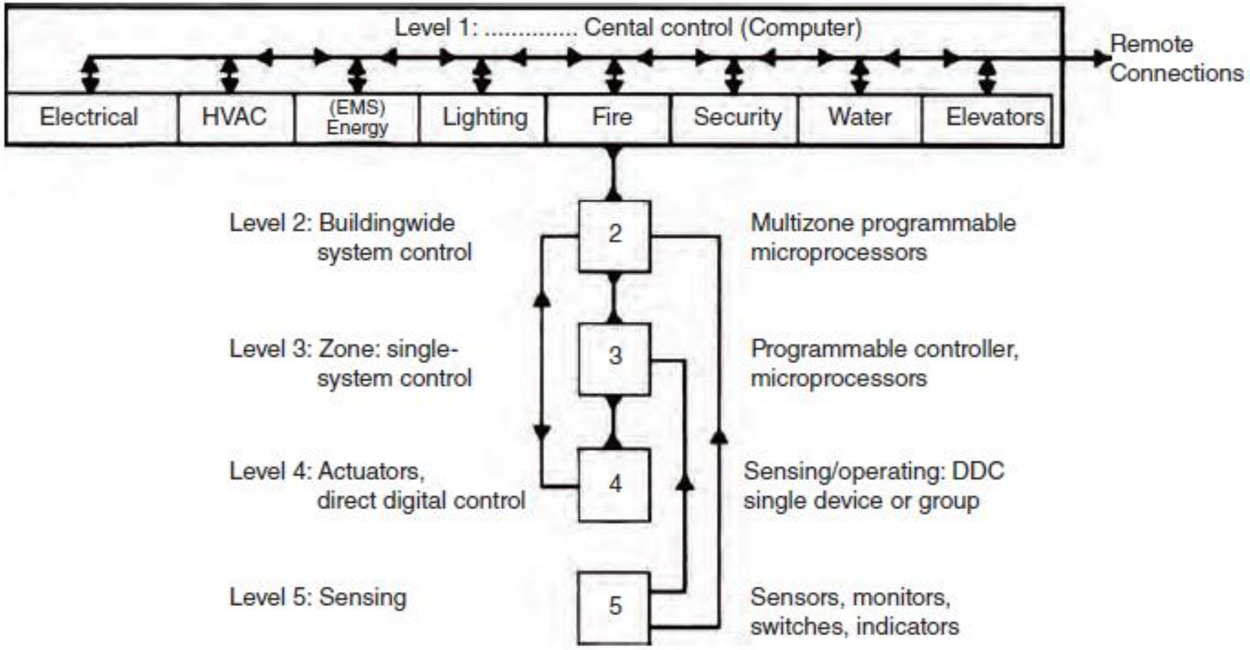
Active climate controls

- Most HVAC systems are actuated and regulated by automatic controls.
- Most control systems in larger buildings are computerized (BAS).
- The most obvious HVAC control function is to maintain desired thermal comfort conditions.
- HVAC controls are just now starting to focus on independently maintaining desired indoor air quality.
- Controls regularly increase energy efficiency by promoting optimum operation.
- They act as safety devices, limiting or overriding mechanical and electrical equipment.
- Automatic controls can also serve to eliminate human forgetfulness and bias.
- Controls can usually maintain only a range of conditions, not a specific setpoint.

Building automation system (BAS)



Sensors in buildings

- Pressure sensors
- Flow sensors
- Heat sensors
- Humidity, CO_2, other contaminant probes
- Occupancy and motion detectors
- Light sensors
- Water-flow detectors
- Electrical current sensors
- Contact sensors

Occupied control mode

- 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.

Unoccupied control mode

- The building does not require ventilation when unoccupied, temperature in the perimeter spaces must be prevented from getting too cold (~60°F [15.6°C]) or too hot (~85°F [29.4°C]).
- The main supply fan cycles on whenever any perimeter space or centrally located nighttime thermostat demands heating or cooling.
- If separate perimeter heat is installed and heat is demanded, it 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 is closed.
- All terminal units with demand for central heating or cooling maintain their respective unoccupied temperature set points.
- All other terminal units remain off.

Warm-up/cool-down mode

- The morning warm-up/cool-down mode typically occurs as a transition from unoccupied mode to occupied mode.
- In this mode, 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.
- 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 preoccupancy purge.
- The terminal units may be fully open, allowing "wild" (uncontrolled) warmup or cool-down, or they may modulate to achieve the occupied temperature set points for a "controlled" warm-up or cool-down.

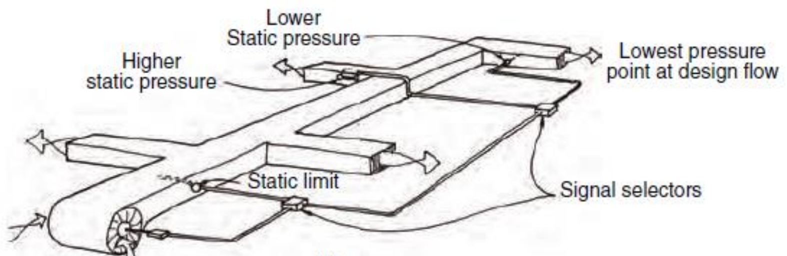
Poll Question 5: Fill in the blanks: Economizer cycles compare __________ conditions to __________ conditions, and vary the proportion of __________ __________ to __________ __________ in order to provide "free" cooling.

Economizer cycles compare __ conditions to __ conditions, and vary the proportion of__ __to __ __ in order to provide "free" cooling

indoor to outdoor	1. outdoor air2. return air/space air3. outdoor air qty to return air qty	indoor outdoor dampers	indoor, ambient, fresh air to recycled air.
outside, inside, outside air, return air	Outdoor Air. Return Air. Fresh Air. Return Air.	indoor, outdoor, economizer modulate	Indoor temperature to outdoor temperature outside air volume to temp control

8

Single-duct VAV and economizer control example



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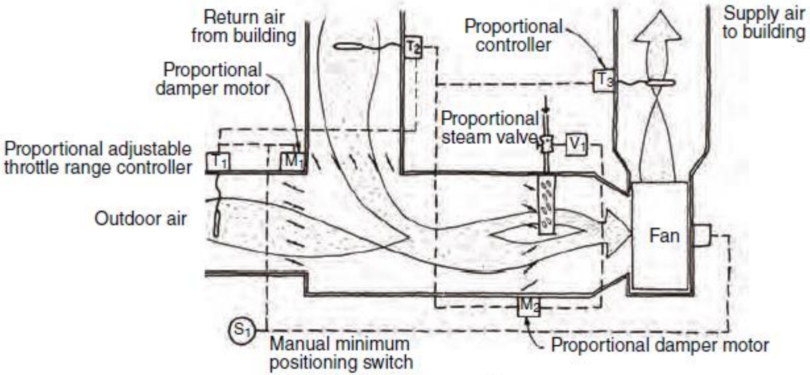


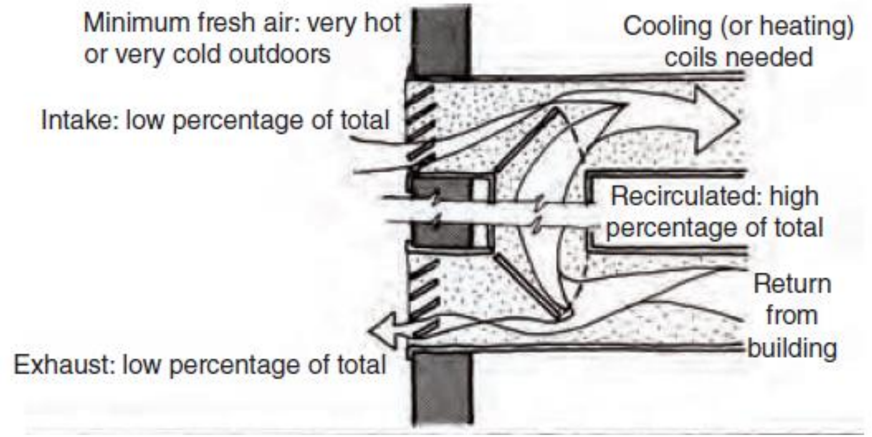
(b)

- Fan must be regulated to maintain the minimum pressure (and therefore, flow) needed at the most demanding outlet
- Outlet may be either the one most remote from the fan or the one needing the greatest flow

- Economizer cycles compare outdoor conditions to inside conditions and vary the proportion of OA to RA in order to provide "free" cooling.

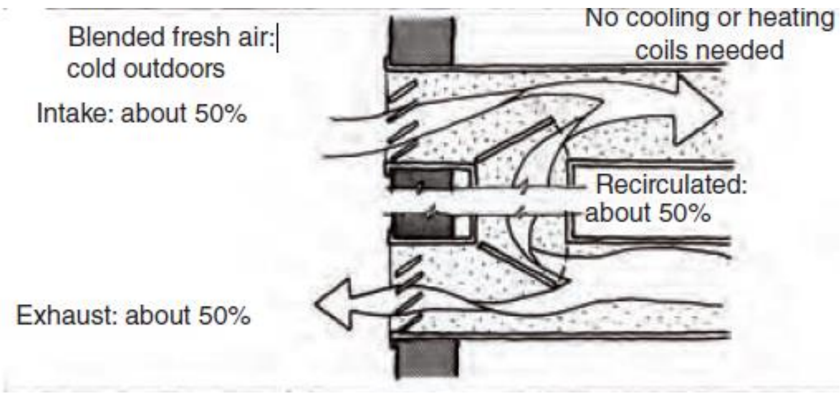
Economizer cycle

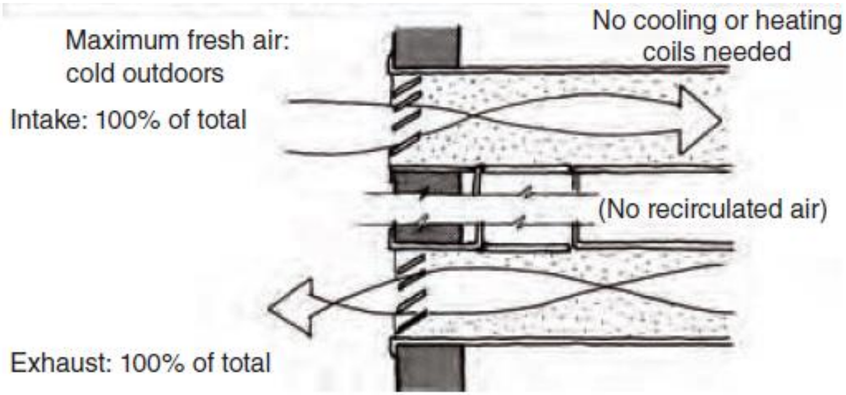
- An economizer cycle uses cool outdoor air, as available, as supply air.
- The economizer cycle can be thought of as a central mechanical substitute for an open window; when it is cool enough, 100% outdoor air can be provided as supply air, and no refrigeration is needed.



- When outdoor air is too hot or too cold, the economizer cycle is inactive, and IAQ-minimum outdoor air is introduced.

Economizer cycle continued





- As very cold outdoor air gets warmer, it can be blended with recirculated air, and neither heating nor cooling coils are needed.
- When outdoor air is cool, it can completely displace the need for mechanical cooling.

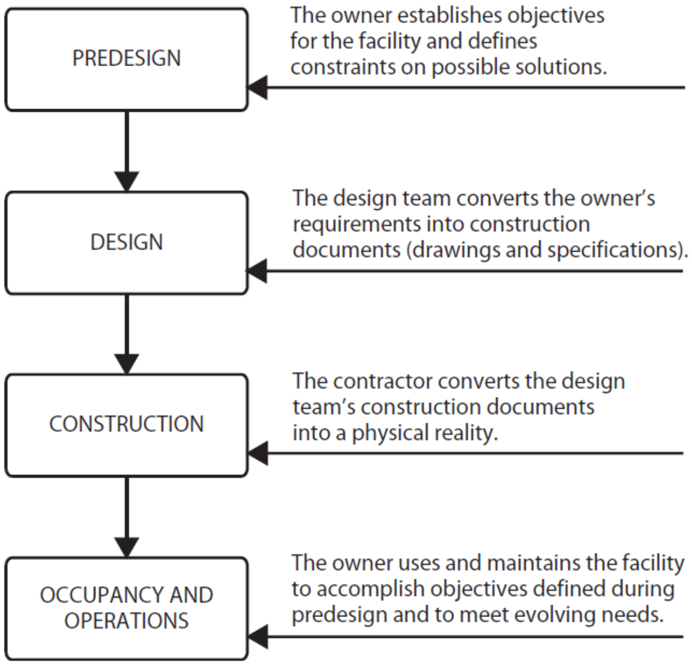
Modelling and analytics

- Energy benchmarking
- Feasibility analysis (energy models, cost, emission, financial, risk)
- Energy performance (utility bill management)
  - Regression analysis
  - Cumulative sum
  - Measurement & verification

Commissioning Process

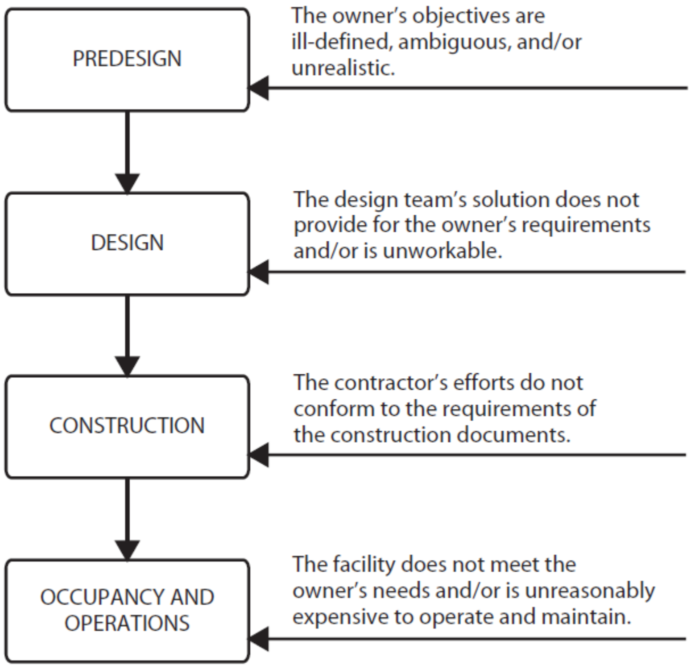
Building commissioning (BCx)

- A quality-focused process for enhancing the delivery of a project.
- The process focuses on verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements.
- Commissioning is a process that parallels and integrates with the conventional design-construct-occupy process for buildings.



What is building commissioning?

- It is an ongoing **process**
  - Spanning from pre-design into occupancy
- It is **not** an "event"
- It is **not** a short-term "task"
- It is **not** just "problem" clearance
- Each phase of the design-construct-occupy process can lead to problems for a building owner.



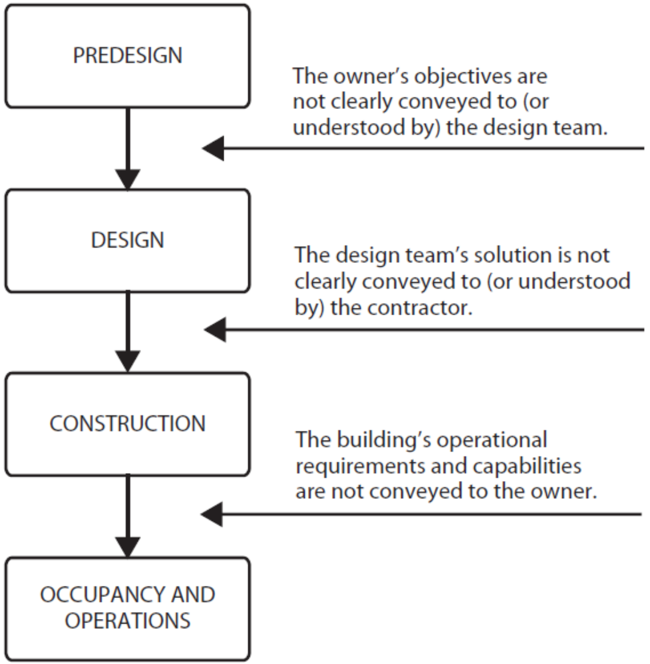
Poll Question 6: What can be commissioned?

What can be commissioned

- Whole buildings
- Building systems
    - Active systems (dynamic)
    - Passive systems (static)
- Building sub-systems

Why is commissioning needed?

- Poor coordination between phases of the design-construct-occupy process can lead to problems for a building owner.
- Issues detrimental to the owner's best interests will arise, it may involve:
- Poorly identified owner needs/wants
- Poorly executed work
    - Design, construction and/or operations/maintenance
- Poor communication



Recommissioning (RCx)

- Over time, changing building use patterns along with unintended consequences of the 'quick fixes' alter the building's operations from how it was initially designed, decreasing the energy performance.
- RCx is required and can lead to:
  - Reducing building energy use
  - Improving equipment performance and overall asset value
  - Lowering operating and tenancy costs
  - Improving IAQ

New trends that enhance commissioning

- New technologies allow for Smart & Ongoing Commissioning (SOCx) with the aid of artificial intelligence (AI).
- 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 & diagnosis (and resolution, where possible)
    - Energy optimization
- There are a few key barriers:
    - Need for standardized approaches for data collection and analysis
    - Cost to deploy, maintain, and (re)calibrate sensors
    - High cost of developing models to predict building performance and estimate energy use
    - Challenges to scale these solutions from local demonstrations to full-scale implementation.

Question and Answer session
Ask questions via the chat or raise your hand please!

Post-webinar Support

One-on-one coaching: tailored support for managing energy resources effectively

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Coaching sessions conducted virtually: phone, video calls and email

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