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Efficient HVAC System Operations for Small Industrial Facilities

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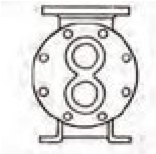
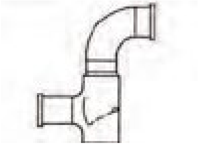
Agenda

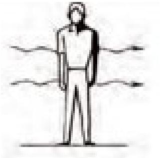
1. Review common HVAC systems found in small industrial facilities
2. Overview of the role of ventilation
3. Discuss contaminants and management of them
4. Understand the concept of thermal comfort
5. Discuss the heat effect on equipment and instruments
6. Discuss the importance of control mechanisms and heat recovery

HVAC Systems in Small Industrial Facilities

Basic HVAC system tasks and components

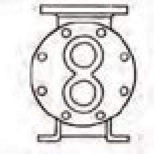


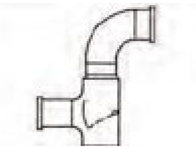


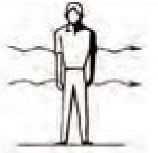


Intake Exhaust	**Production/motion** **Movers, converters, processors**	**Distribution** **Supply and return trees, delivery and control components**	**Results**
Heat Fuel combustion air Heat CO_2	Boilers Furnaces Pumps Fans Filters Heat Pumps	Pipes, ducts Electricity conduits Diffusers, grills Radiators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

Basic HVAC system tasks and components



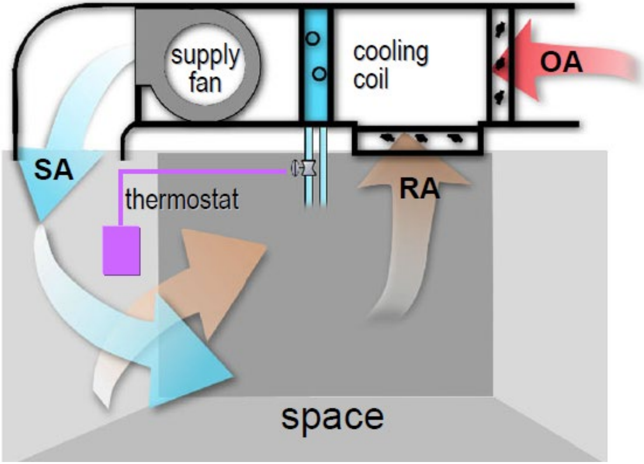




	Production/motion	Distribution	Results
Cool Air, water, fuel Air, vapor, water, heat CO_2	Evaporative coolers Heat pumps Chillers, cooling towers Coils Pumps Fans Filters	Pipes Ducts Diffusers, grills Radiators Thermostats Valves, dampers	Cool air or surfaces Air motion usually controlled Humidity control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

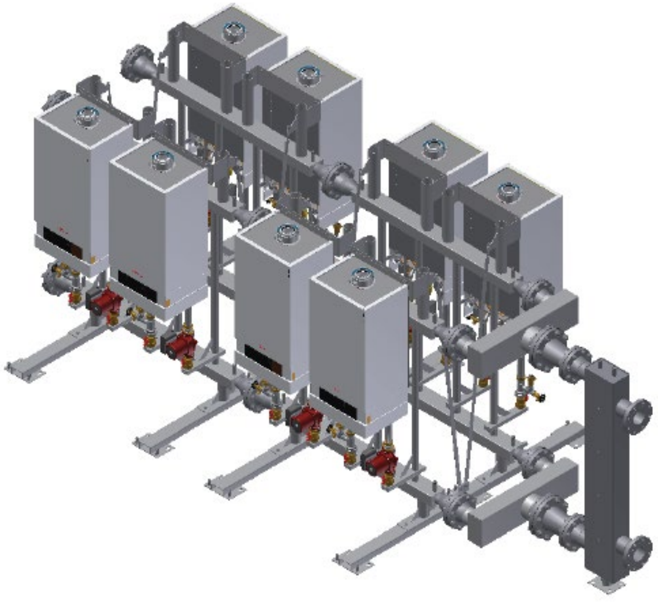
Constant volume (CV) variable temperature system

- This 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.
- In this example, the temperature of the air is varied by controlling the capacity of the central cooling coil.
- If a building has many spaces with diverse cooling needs, each must be served by its own system because this type of system can respond to the demands of only one thermostat.



Cascade control systems

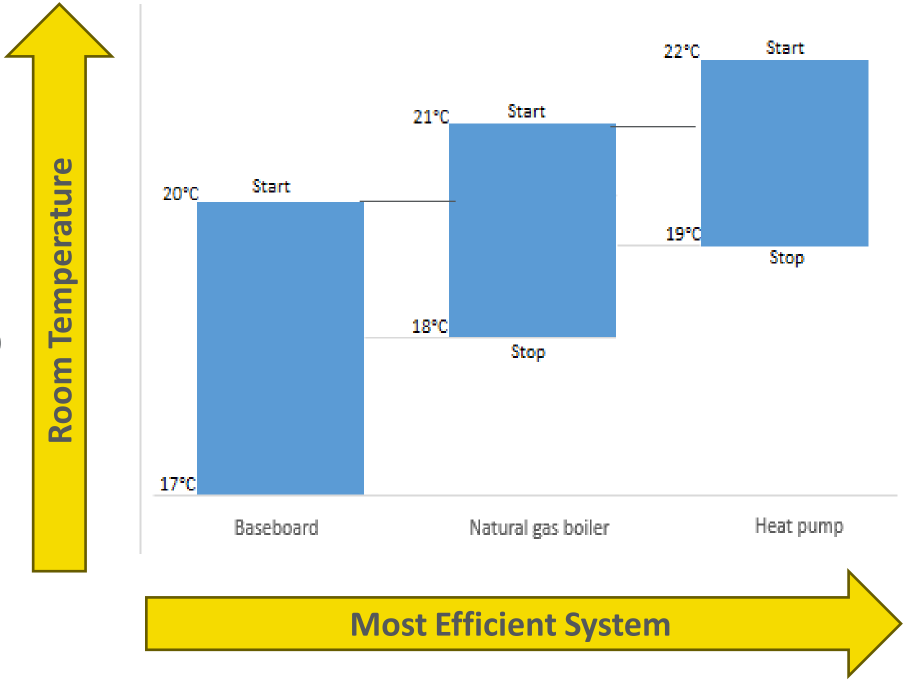
- A cascade system uses multiple units (for ex. boilers, modular chillers) as required to meet fluctuating heating/cooling demands.
- It maintains maximum efficiency at all times by precisely matching the load and, if applicable, using most efficient equipment first.
- Controller will modulate, stage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



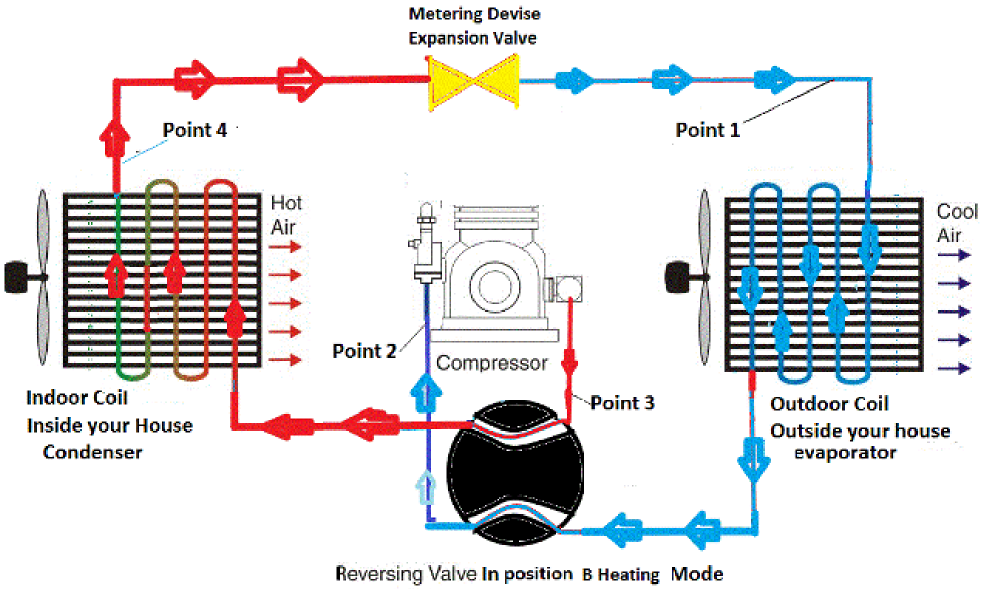
Heat pumps

- 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.

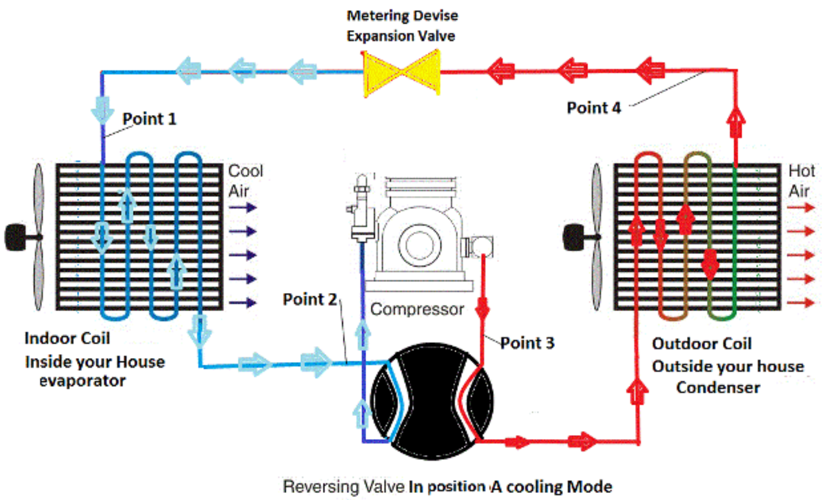
Ground-Source:
- A ground-source heat pump uses the earth, ground water, or both as the source of heat in the winter, and as a reservoir to reject heat removed from the home in the summer.

Heat pump modes



Heating Mode

Cooling Mode



Role of Ventilation

Principles of ventilation design

- Locate the exhaust openings near the sources of contamination, if possible, in order to obtain the benefit of "spot ventilation."
- Locate the air supply and exhaust outlets to make sure that the air passes through the contaminated zone. People should remain between the air supply and the source of the contaminant.
- Replace exhausted air with treated supply air system (correct pressure balancing).
- Avoid re-entry of the exhausted air.

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.

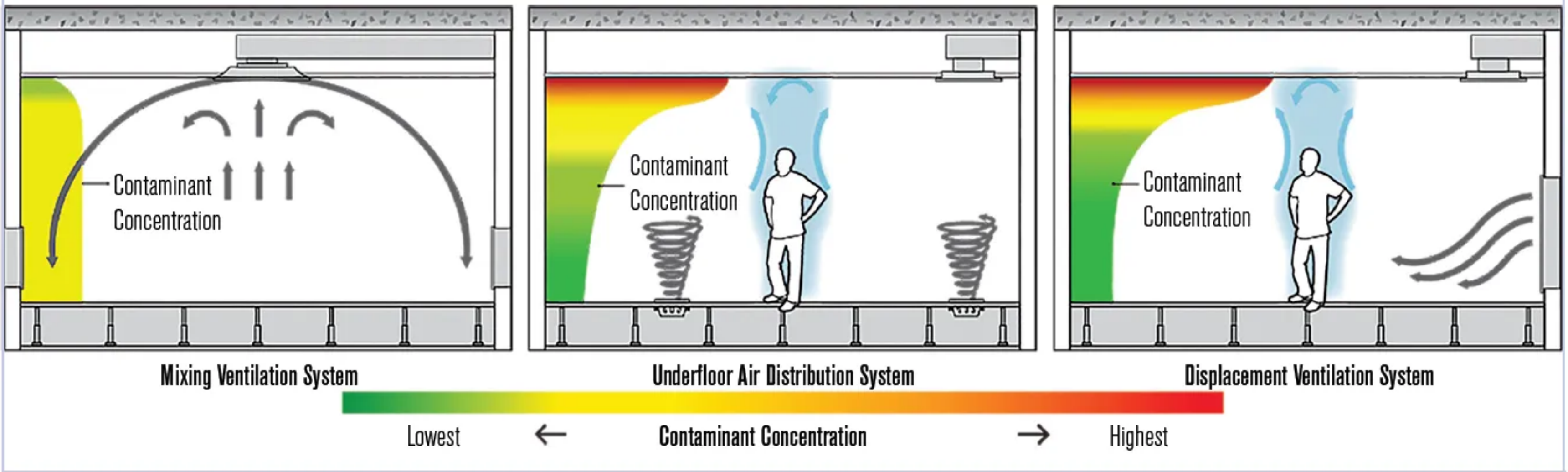
Poll

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.
- If it is a hazardous contaminant consult a specialized firm in health and safety.

IAQ with mechanical ventilation systems



Industrial ventilation systems

Can be classified into the following four types:

- Industrial air-conditioning
- General ventilation systems
- Local ventilation systems
- Process ventilation systems

Zones

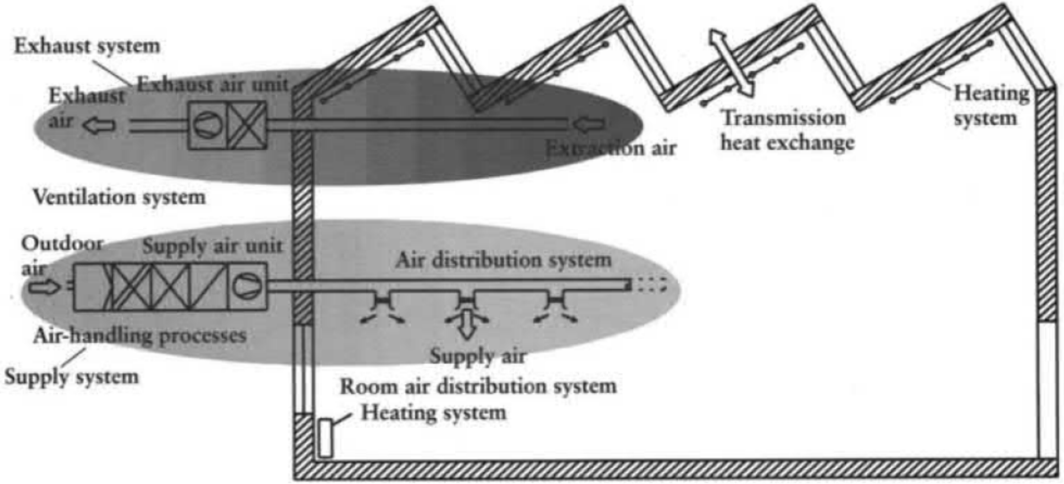
- In industrial premises the target levels of IAQ as well as other targets (e.g., emissions), shall be specified zone by zone.
- A *controlled zone* is a zone in which the thermal and air purity (quality) conditions are controlled to their specified levels.
    - *Main controlled zone* is normally a large area, which is often the same as the occupied zone.
    - *Local controlled zone* is an area where the air is controlled locally; the control requirements may be for worker protection and comfort, for process control, or for production protection.

Zones continued

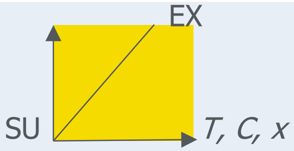
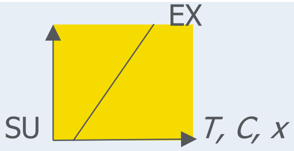
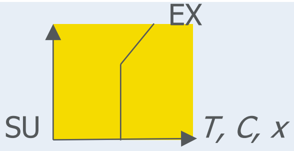
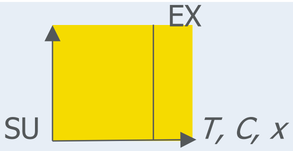
- An *uncontrolled zone* is a zone in which the thermal and air purity (quality) conditions are not specified or controlled.
    - There may also be uncontrolled zones near the processes inside the main controlled zone.
- *Capture zones* are zones in which source emissions will be captured by a source-capturing system (local exhaust ventilation), and where the capture efficiency is determined and shall be maintained over the working period.

Industrial air-conditioning systems

- Room air-conditioning systems are used to control the main controlled zone.
- Discharge systems are used to discharge exhaust air to the outdoors in such a way that harmful spreading of pollutants to the environmen and back indoors is avoided.



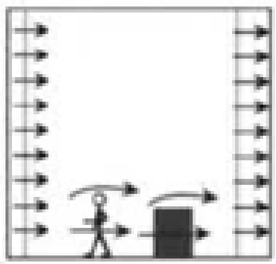
Ideal room air-conditioning strategies

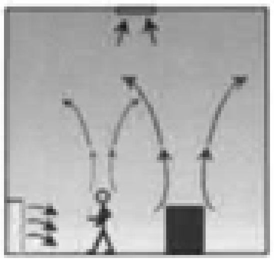
Strategy	Piston	Stratification	Zoning	Mixing
Description	Create unidirectional airflow field over the room by supply air	Support flow field created by differences in density; replace airflow removed with supply air	Control air conditions within the zone by supply air; allow stratification of heat and contaminants in other areas	Provide uniform conditions throughout the ventilated space
Heat, humidity and contaminant distribution				
Main characteristics	Room airflow patterns controlled by low-momentum unidirectional supply airflow; overcome disturbances	Room airflow patterns controlled mainly by buoyancy; supply air distribution with low momentum	Room airflow patterns controlled partly by supply, partly by buoyancy	Room airflow patterns controlled typically by high-momentum supply airflow

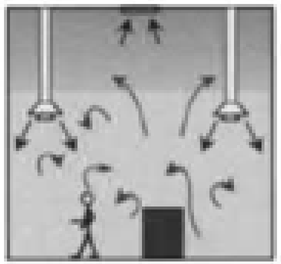
SU, supply; EX = Exhaust, x = Axis: C mg/m3, g/kg; y-Axis: room dimension

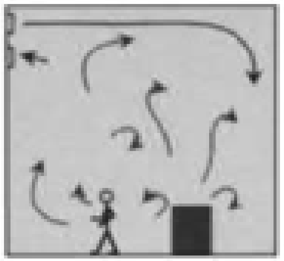
Ideal contaminant and heat removal efficiency

Typical application (example of a general room air distribution method)



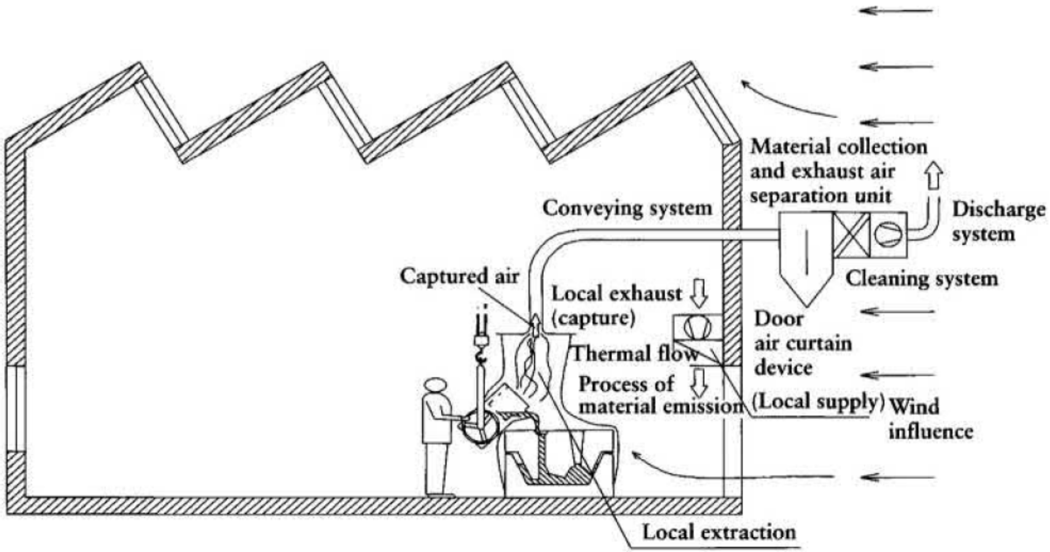






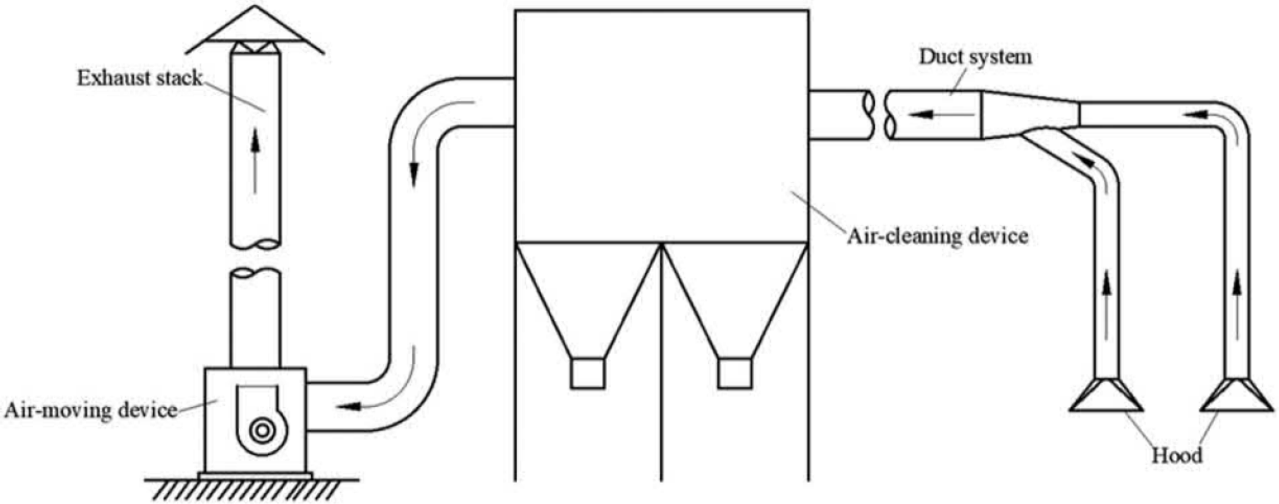
Local exhaust ventilation systems

- These systems are used for local controlled zones and are based on engineering design methods for local protection.
- Local protection should be made using process methods such as encapsulation or process modification.
- Also used for source capturing.



Composition of local exhaust systems

- Hood
- Duct system
- Air-cleaning dev
- Air-moving devic
- Exhaust stack



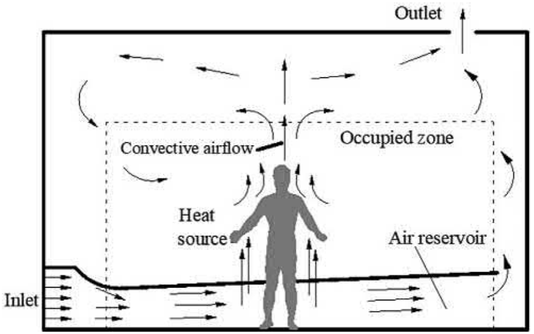
Gas-cleaning systems

There are many types of cleaning systems and equipment, for example:

- Dynamic separators (cyclones)
- Fabric filters
- Wet separators (scrubbers)
- Electrostatic precipitators
- Desulfurization equipment (SOx control)
- Denitrification equipment (NOx control)

Design of industrial ventilation systems

- **Mixing ventilation**: combines both mechanical and natural ventilation aiming to dilute polluted and warm or cool room air with cleaner and cooler or warmer supply air.
- **Displacement ventilation**: cold air with higher density is directly supplied into the occupied zone and sinks to floor forming an air reservoir; the indoor thermal pollutant source generates plume and constantly entrains the surrounding air, making the pollutant air flow to the outlet upward under the combination of the air supply exhaust systems.



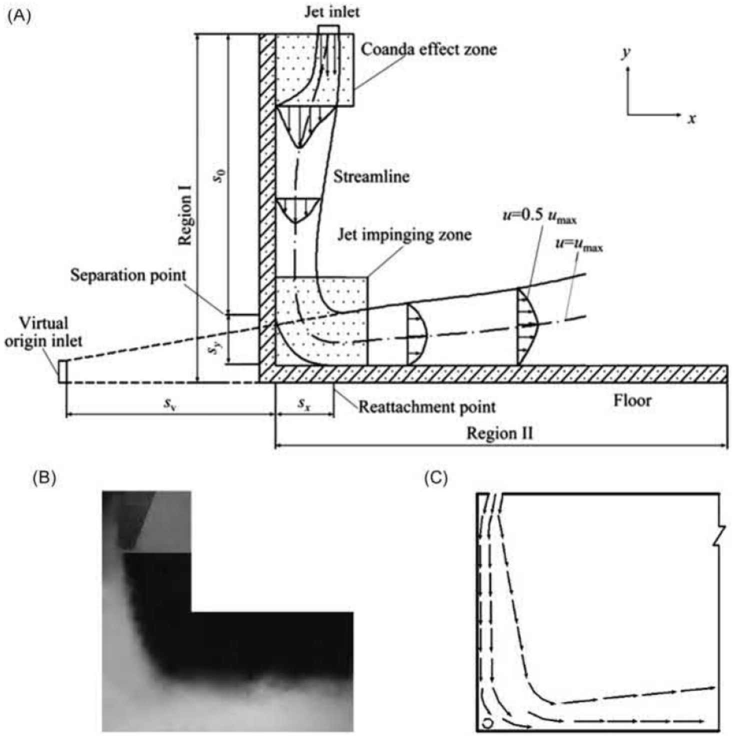
Design of industrial ventilation systems continued

- Attachment ventilation: based on Coanda Effect and Extended Coanda Effect; air diffuser is set at the upper space of the room and is on or very close to the vertical sidewall.

(A) An airflow structure of attachment ventilation by Extended Coanda Effect

(B) Visualization of attachment ventilation

(C) Airflow pattern of attachment ventilation



Demand controlled ventilation (DCV)

- An energy-saving strategy that controls the air change rate according to the occupancy and indoor pollutant load.
- The contaminant 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.

Contaminants

Poll

Introduction

- Any unwanted liquid, solid, or gaseous product, resulting from the activity of man.
  - Primary: a pollutant that is discharged into the ambient air.
  - Secondary: a pollutant formed in the air as a result of reactions of primary pollutants.
- “Contaminant” is the same as pollutant but is usually used to describe indoor conditions.
- The US is averaging one chemical accident every two days!
- The top five chemicals associated with injury are:
  1. Carbon monoxide
  2. Ammonia
  3. Chlorine
  4. Hydrochloric acid
  5. Sulfuric acid

Exposure, types of harm and WHMIS

- There are 3 ways to be exposed to chemicals and pollutants:
  - Inhaling (breathing in)
  - Absorption (skin and eye contact)
  - Ingesting (eating or drinking)
- Different types of harm:
  - Acute harm
  - Chronic harm
  - Nuisance
  - Corrosive
- The Workplace Hazardous Materials Information System (WHMIS) is Canada's hazard communication standard. The key elements of the system are:
  - Hazard classification
  - Cautionary labelling of containers
  - Provision of safety data sheets (SDSs)
  - Worker education programs

Major factors affecting ventilated spaces

- Contaminant sources.
- Transport mechanism of contaminant in ventilated spaces.
- Forced convection or supply air jets introduced into the room by mechanical or natural ventilation systems or their combination.
- Free convection flows along heated and cooled vertical surfaces and above heat sources.
- Airflow created in the vicinity of local and general exhausts.
- Aerodynamic means of the large opening protection.
- Airflow through intended and unintended openings and cracks in the building envelope.

Classification of contaminant sources

- Knowledge of the process or operation and contaminant sources is essential before ventilation systems can be selected and designed.
  - External sources
  - HVAC system
  - Internal sources

External sources

- Outdoor air is generally less polluted than the system return air.
- Problems with re-entry of previously exhausted air occur as a result of improperly located exhaust and intake vents or periodic changes in wind conditions.
- Other outdoor contamination problems include contaminants from other industrial sources, power plants, motor vehicle exhaust, dust, asphalt vapors, and solvents from construction or renovation.
- Also heat gains and losses through the building envelope due to heat conduction through exterior walls, floor, and roof and due to solar radiation and infiltration.

HVAC system

- The HVAC system also acts as a pollutant source when it is not maintained properly.
- Micro-organisms breed in various environments present within components (e.g., cooling coils, ducts, humidifier, filter, etc.) of the system and may be distributed throughout the building.
- Improper maintenance of filters leads to loss of efficiency and re-emission of contaminants.

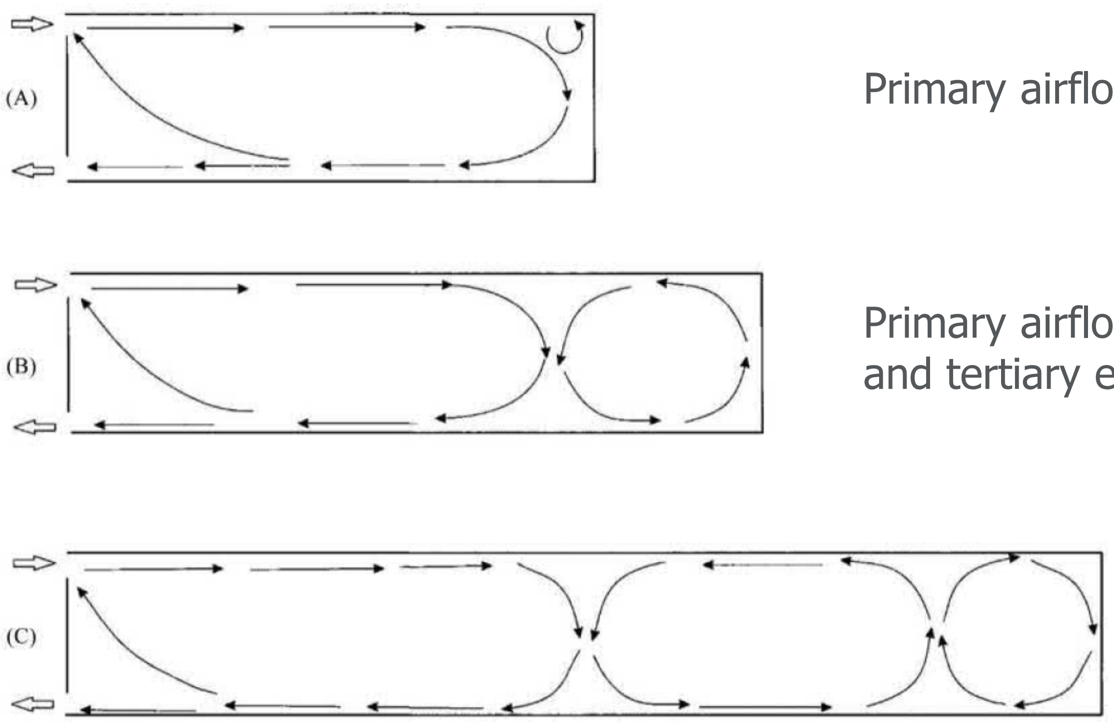
Internal sources

- Air contaminants: dusts, fumes, fibers, gases, vapours, mist, aerosols, fogs, smog.
    - Buoyant (e.g., heat) sources
    - Non-buoyant (diffusion) sources
    - Dynamic sources
- Biological hazards: bacteria, viruses, fungi, and other living organisms.
- Physical hazards: thermal parameters (temperature, relative humidity, and velocity) beyond the comfort range, excessive levels of ionizing and nonionizing electromagnetic radiation, noise, vibration, and illumination.

Identification of contaminant sources

- Sensors can only indicate the concentration locally.
- Where, when, and how the contaminants have been released are still required to be known, inference of the contaminant sources based on the limited available concentrations constitutes inverse modeling.
  - Directly reversing transport equations to track a source.
  - Solving forward transport equations to match a source.
- The monitored concentration at a sensor is the superposition of concentrations from each source, so the inverse modeling must decouple the combined concentration response into that from each source to determine the pollutant sources.

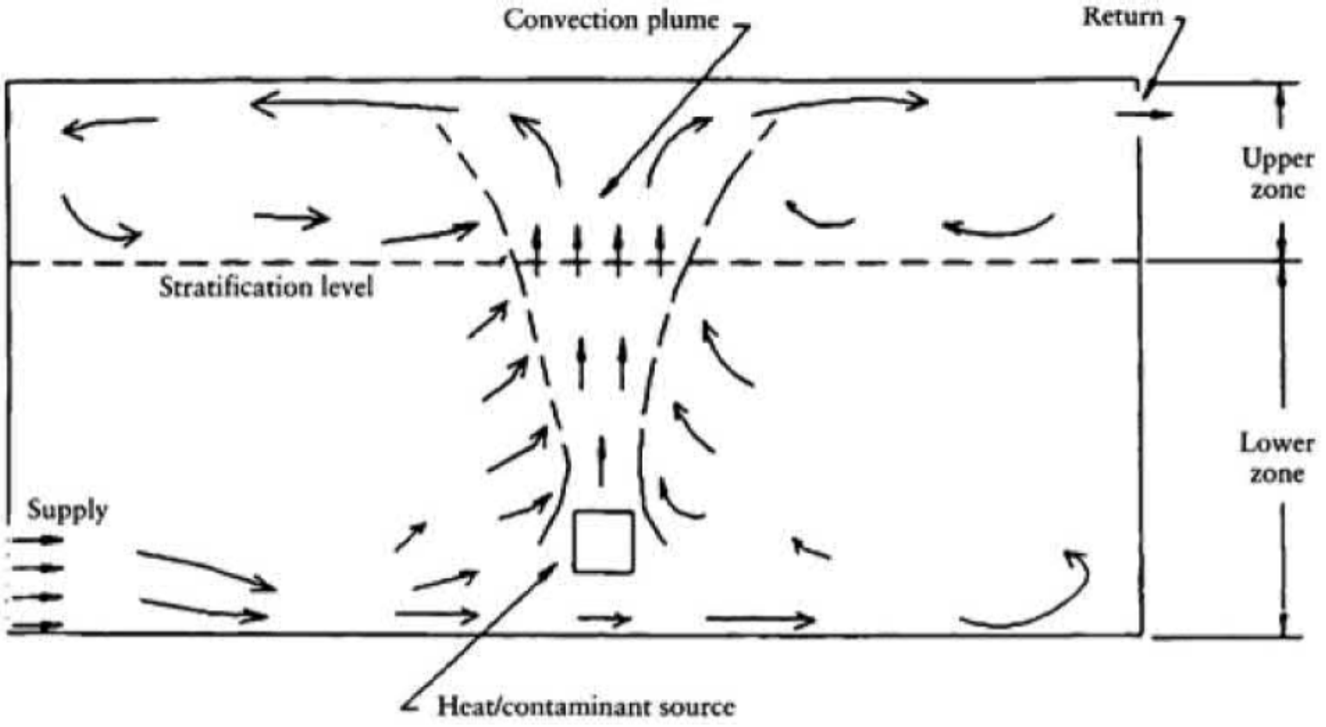
Mixing-type air distribution



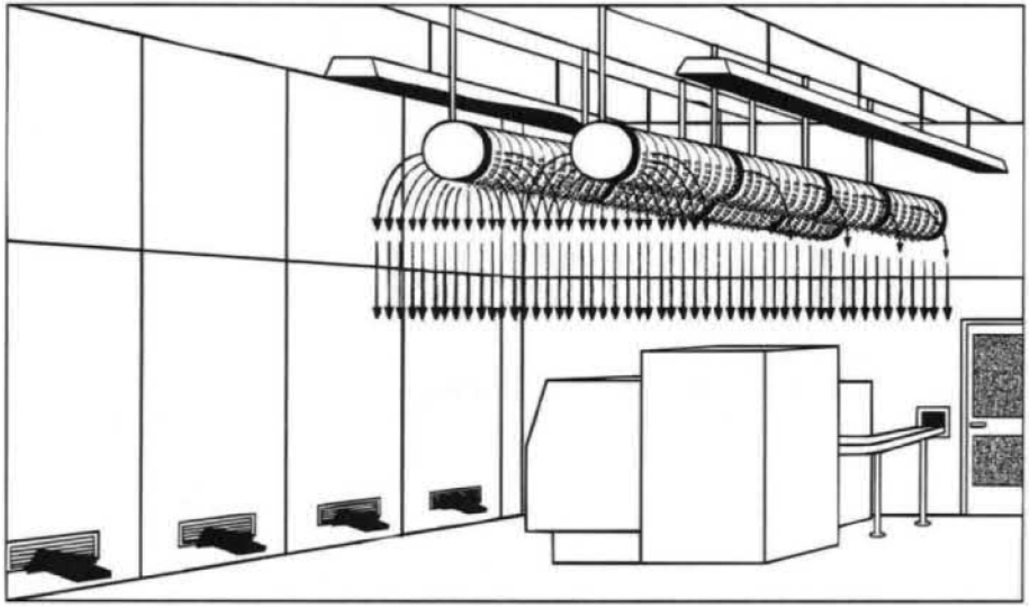
Primary airflow in a short room

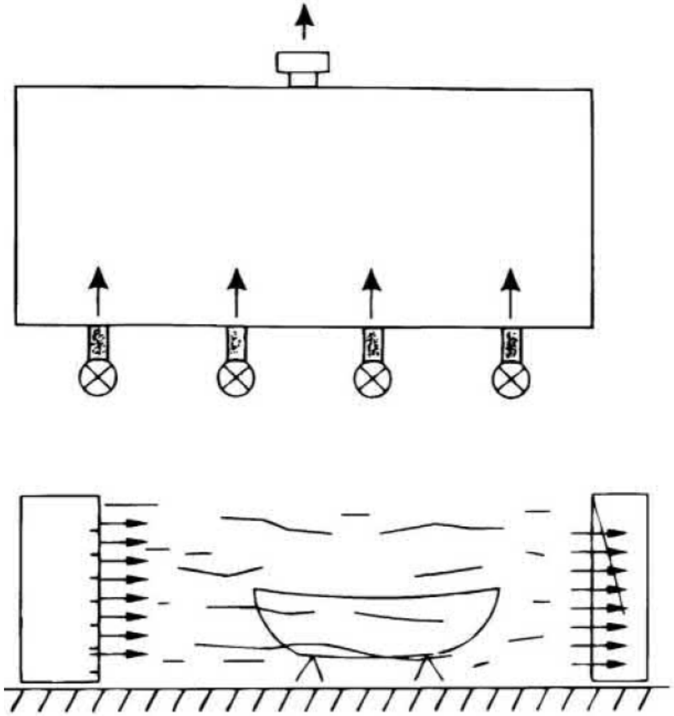
Primary airflow and secondary and tertiary eddies in long rooms

Displacement ventilation airflow

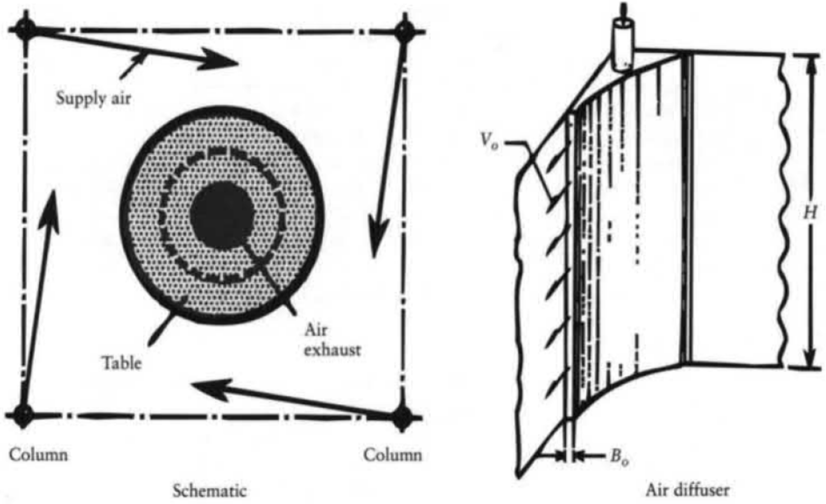


Unidirectional airflow





Spiral vortex air distribution



- Used to localize air contaminants in certain room areas and to evacuate the polluted air from those areas.
- A spiral vortex in a space can be formed by supplying air through the vertical supply ducts located along a closed contour (preferably along the walls), thus generating a vertical vortex.
- An exhaust outlet can be located in the ceiling near the center of the rotational flow.

Thermal Comfort

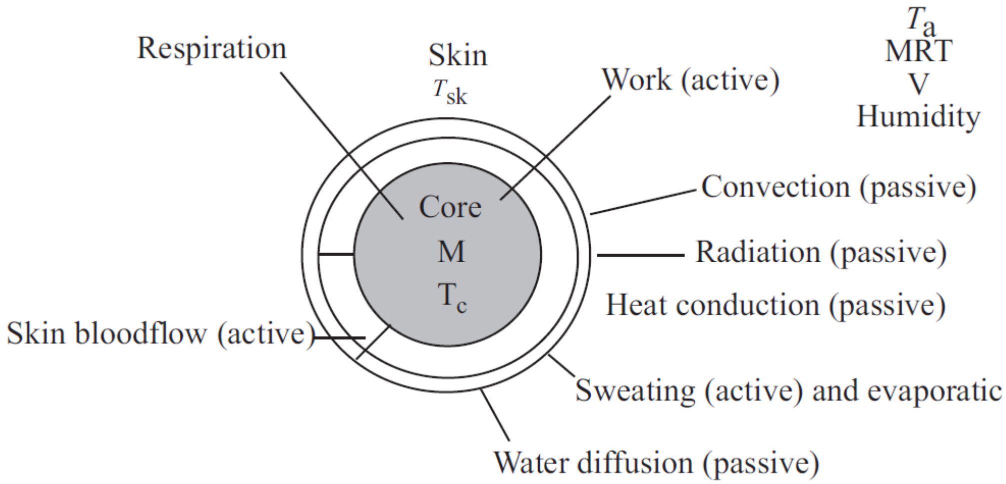
Poll

Introduction

- Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment.
- Thermal discomfort results from the physiological strain of thermoregulation. Discomfort can contribute to mistakes, productivity decreases, and industrial accidents.
- Both primary factors and lesser secondary factors affect our sense of satisfaction with the thermal environment.
- ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy
- ISO 7730:2005 Ergonomics of the thermal environment

Primary factors

- The primary factors have significant reproducible effects and directly affect heat transfer and the occupant's thermal state.
  - Body temperature
  - Metabolism
  - Physiological temperature regulation



Secondary factors

- Secondary factors such as gender and age may affect one's sense of thermal satisfaction.
- It is reported that females and the elderly are more critical of indoor thermal environment and more sensitive to deviations of temperatures than males and the young.
- Other secondary factors such as circadian rhythm, physical disabilities, fitness, color and ambiance, local climate, sound, and food have been found to have impact on thermal comfort.

Clothing

- Clothing hinders heat and moisture transfer between a body and environment.
- Thermal and moisture transfer occurs due to dry heat transportation by convection, conduction, and radiation and due to moisture transportation.
- Higher thickness or number of layers of clothing increases insulating capability of the clothing and reduces body heat loss.
- Heat and moisture transfer occurs through pores of textiles, fiber interior and surface, capillaries and air between fibers and yarns.

Indoor humidity

- In general, a Relative Humidity (RH) level between 30% and 60% is ideal for human thermal comfort.
- Low indoor humidity level affects comfort and health (dry nose, throat, eyes, and skin).
- Dusty environments can further exacerbate low-humidity dry skin conditions.
- Comfort is reduced by elevated humidity levels. It is recommended that on the warm side of the comfort zone the RH should not exceed 60% to prevent warm discomfort.

Air velocity

Air velocity	Possible lower-temperature comfort sensation (26-32 °C; larger numbers correspond to high humidity areas	Probable impact
Up to 50 fpm (0.25 m/s)	No change in comfort sensation	Unnoticed
50-100 fpm (0.25-0.51 m/s)	1.1-1.7 °C lower	Pleasant
100-200 fpm (0.51-1.02 m/s)	2.2-2.8 °C lower	Generally pleasant, causing a constant awareness of air movement.
200-300 fpm (1.02-1.52 m/s)	2.8-3.9 °C lower	From slightly annoying to drafty.
Above 300 fpm (1.52 m/s)	More than 3.9 °C lower	Requires corrective measures to ensure work is efficient and health secured.

Heat stroke

- Heat stroke is caused by the breakdown of your body's cooling system and has a high risk of irreversible damage to body organs and organ systems.
- Some people lose the ability to sweat and are not very physically active when ill (classic heat stroke), while others experience heat stroke while still sweating and active (exertional heat stroke).
- Symptoms include: high body temperature (above 40ºC), a fast pulse, headache or dizziness, passing out, weakness, confusion or acting strangely, hot dry red skin (classic) or profusely sweating (exertional)

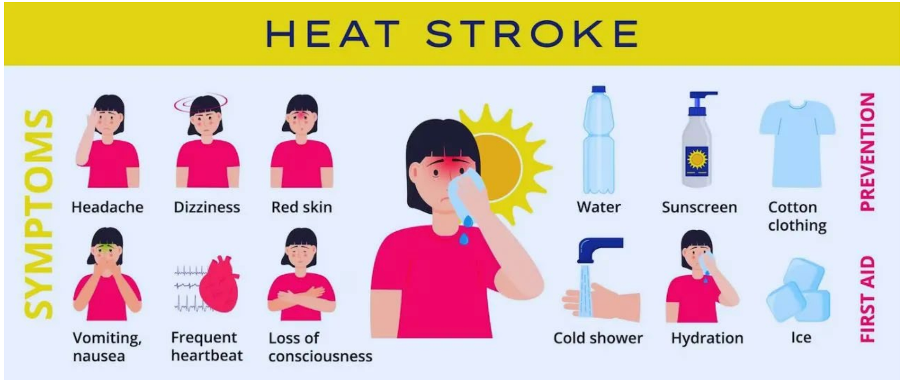
Heat stroke prevention and treatment

Prevention

- Reduce activity levels
- Reduce heat exposure
- Drink fluids regularly
- Check on your coworker(s) for any irregular behaviour

Treatment

- Call an ambulance
- Remove excess clothing
- Drink and spray cool water

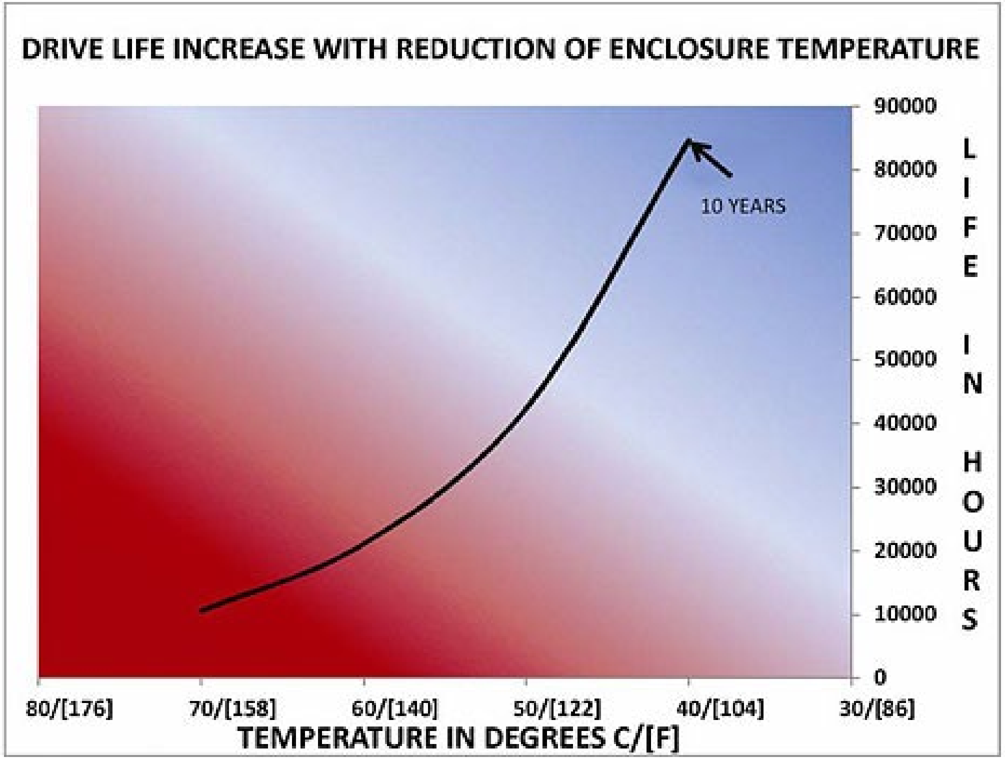


Effect of Heat on Equipment and Instruments

Introduction

- Heat is both a by-product and one of the greatest enemies of electrical and electronic components.
  - Heat increases the corrosion and failure rate.
- If an enclosure is properly cooled, the components within can have a long and useful life.
- Without proper cooling, the components in these enclosures can be subject to damaging heat, shortening their longevity and reliability.

Examples


DRIVE LIFE INCREASE WITH REDUCTION OF ENCLOSURE TEMPERATURE
10 YEARS
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
LIFE IN HOURS
80/[176]
70/[158]
60/[140]
50/[122]
40/[104]
30/[86]
TEMPERATURE IN DEGREES C/[F]

Examples

Device	Maximum recommended air temperature for operation	Cautionary notes
Variable frequency drives (VFDs)	40 °C	Operation above this temperature typically requires de-rating a larger drive or risking premature failure.
VFDs with external heat sinks	50 °C	Operation above this temperature typically requires de-rating a larger drive or risking premature failure.
Human machine interface (HMI), touchscreens and flatscreen displays	50-60 °C	Manufacturers of HMIs specify a maximum temperature for their products. A few can operate to 70 °C.
HD televisions	40-50 °C	32 °C is recommended for normal life expectancy.
Programmable logic controls (PLC)	50-80 °C	Most devices are not certified to function properly beyond their maximum operating temperatures.
Computers and server racks	Internal air temperature of 40 °C With cooling fans 55 °C	Exceeding PC operating temperatures can result in memory errors, read-write errors, faulty video and other problems. Nearly all server racks require cooling.

Heat sources of electrical components

- Devices that transmit motive power have voltage drop or efficiency losses that are converted into heat.
  - In the case of electronics or microprocessors, nearly all of their power is converted into heat.
- Other sources include ambient air, solar load, humidity and air infiltration.

Removing the heat

- Often natural convection is used in conjunction with a heat sink to keep electronics cool.
- Blowers, fans, motorized impellers and fan trays are open loop cooling systems that can be used when the surrounding air can be passed over the heat producing components and exhausted from the enclosure.
- Air to air heat exchangers utilize closed loop cooling. Water to air heat exchangers provide cooling in a closed loop system where a reliable source of clean, cool or chilled water is available.
- Air conditioners.

System design and economic considerations

- Avoiding condensation and dust.
- National Electrical Manufacturers Association (NEMA) enclosure ratings.
- Investment in enclosure cooling yields high returns.

Controls and Heat Recovery

Control mechanisms in achieving energy savings

- Thermostats: regulate the thermal environment (heat/cool).
- Timers/movement detectors: heat/cool space when needed.
- Differential pressure sensors: change filters at the right time (predictive maintenance).
- Light sensors:
  - Photocells: illuminate fixtures when it is dark outside.
  - Occupancy sensors: illuminate space when occupied.

Ventilation on demand (VoD)

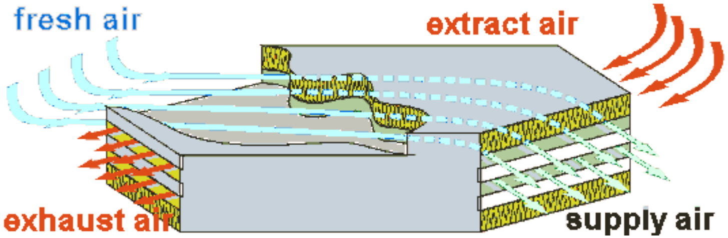
- Ventilation on demand (VoD) systems employ sensors that transmit real-time data on key parameters such as vehicle use, personnel, and information from gas, flow, and temperature sensors to a central control system, enabling control of fans and air regulators.
- VoD systems learn and adapt over time with more data available, intelligently adjusting and optimizing air flow to maximize air quality and minimize consumption.
- Potential problems are identified more quickly and blast gases are evacuated faster, decreasing downtime.

Alternative methods

- Infrared heaters: heat the surface not the air.
- Clothing: it often costs less to buy a (nice) jacket for employees than to heat a warehouse.
- Destratification fans: mixing the stratified air to create a comfortable environment.
- Adiabatic cooling: cooling system using closed circuit ambient air, water consumption only if required

Heat recovery

- Typically used to transfer heat from an exiting air stream to an incoming air stream.
- Heat recovery ventilators (HRV): denotes a sensible heat exchange device.
- Energy recovery ventilators (ERV): can exchange both sensible and latent heat (through use of a desiccant-coated exchange medium).
- Modern ventilation technology allows a heat-recovery rate of between 75% and 95%



Poll

Heat reclaim

- Boiler flue economizers: passing the hot gases in a boiler’s stack through a heat exchanger; the collected heat is used to preheat incoming boiler water.
- Common waste heat producers: exothermic processes, thermal oxidizers, equipment
  - Equipment: compressors, hydraulics, engines, hot drain water etc. generate a lot of heat; heat can be captured and sent to other spaces or processes.

Additional considerations for heat recovery

- The contaminants' level in the extract air from the industrial process and the industrial building may be much higher; heat exchanger fouling resulting from the particulate matters and gaseous contaminants should be considered.
- The extract air may contain corrosive substances or water-soluble chemicals that will damage or destroy the heat exchanger; should be filtered.
- The heat-recovery units may change the indoor moisture level when the condensation and evaporation occur inside the ERV.
- Icing and frosting may occur inside the heat recovery units in cold climates; frost control and defrost strategies should be added.

Emerging technologies

- Membrane energy exchangers
- Run-around heat and energy exchangers
- Heat pipe-based waste heat recovery systems
- Heat recovery with heat pumps

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

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