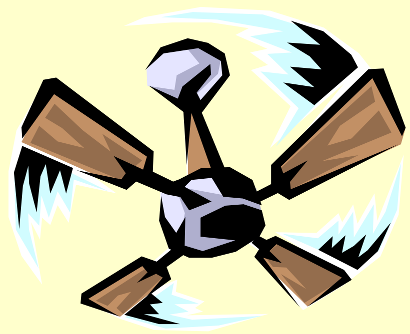

Ventilation

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Content

- **Ventilation**
  - Purpose of Ventilation
  - Determination of Ventilation Rates
  - Methods of Ventilation
  - Ventilation - Different Situations
  - Simple Models for Ventilation
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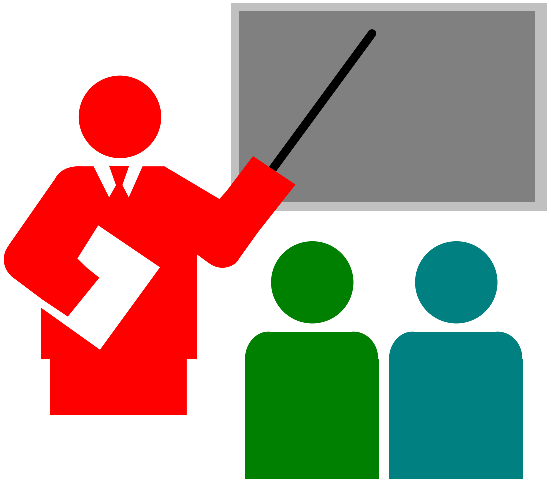


Purpose of Ventilation

Respiration, Exhalation and Comfort

- At rest, the normal adult inhales between 0.10 and 0.12L/s of air
- Only about 5% is absorbed as oxygen by the lungs
- The exhaled breath contains about 4% of carbon dioxide (CO_2) (about 0.004 L/s).
- The outside air requirement is a very low rate of 0.847 L/s per person.
- Provision of sufficient air movement is need for feelings of freshness and comfort

Purpose of Ventilation

Parameter	Unit	8-hour average [a]	
		Excellent Class	Good Class
Room Temperature	°C	20 to < 25.5 [b]	< 25.5 [b]
Relative Humidity	%	40 to < 70 [c]	< 70
Air movement	m/s	< 0.2	< 0.3
Carbon Dioxide (CO_2)	ppmv	< 800 [d]	< 1,000 [e]
Carbon Monoxide (CO)	$\mu g/m^3$	< 2,000 [f]	< 10,000 [g]
	ppmv	< 1.7	< 8.7
Respirable Suspended Particulates (PM_{10})	$\mu g/m^3$	< 20 [f]	< 180 [h]
Nitrogen Dioxide (NO_2)	$\mu g/m^3$	< 40 [g]	< 150 [h]
	ppbv	< 21	< 80
Ozone (O_3)	$\mu g/m^3$	< 50 [f]	< 120 [g]
	ppbv	< 25	< 61
Formaldehyde (HCHO)	$\mu g/m^3$	< 30 [f]	< 100 [f, g]
	ppbv	< 24	< 81
Total Volatile Organic Compounds (TVOC)	$\mu g/m^3$	< 200 [f]	< 600 [f]
	ppbv	< 87	< 261
Radon (Rn)	Bq/m^3	< 150 [i]	< 200 [f]
Airborne Bacteria	cfu/m^3	< 500 [j, k]	< 1,000 [j, k]

Purpose of Ventilation

Removing Body Odour

- Fresh air at 5 L/s/person is sufficient for this purpose
- 8 L/s is preferred.
- If venue is densely populated, i.e. factory canteens, 10-15 L/s/person is suggested

Purpose of Ventilation

Removal of Unwanted Heat

- A sedentary worker emits sensible heat at 0.1 kW.

- Assume ventilation air is provided at 16L/s/person (which is double the minimum quantity required to remove body odour) the air temperature rise = (0.1 x 1000)/(16 x 1.205 x 1.012) = 5.1 K, assuming no further heat gain/loss from room.

- If no air conditioning provided, the ventilation air is used to remove the heat accumulated

Purpose of Ventilation

Removing Unwanted Moisture

- Sedentary worker produce latent heat at 0.04 kW.
- This represents a moisture output of (0.04 x 3600 x 1000)/2450
= 59 g of water vapour per hour
- At ambient condition with humidity ratio = 1g/kg dry air = 1.02g/m^3
This is equivalent to about 16 L/s/person
- The moisture produced by unflued direct heating appliances should also be considered.

Purpose of Ventilation

Removing Contaminants

- Assessment of the ventilation rate → pollution in offices from tobacco smoke (when smoke is still not yet prohibited by the law)
- In a large open office→ a quarter of the occupants will smoke
- In a small private office → the ratio of smokers to abstainers much higher.
- Fresh air supply of 8 L/s/person with no smoking
- Fresh air supply of 12 L/s/person in light smoking place
- Fresh air supply of 16 to 32 L/s/person for heavily concentrated smoking.

Purpose of Ventilation

Sources other than occupants - Unwanted heat

- Temperature rise from heating sources (solar, lighting and equipment)
- Removal of solar heat during the summer months by a simple ventilation system may not effective (magnitude of such a gain is such that a very large air volume would be needed).

Purpose of Ventilation

Sources other than occupants - Unwanted moisture

- A swimming pool hall: moisture from vaporising water, condensation.
- Fresh air supply rate > 15 L/s/m^2 of the water and wetted surround surface, i.e. about 18 L/s/m^2 of water surface.
- Domestic kitchens, the ventilation requirement to avoid condensation is about l00 L/s for electric cooking and half as much again for gas cooking.
- Prevention of condensation will prevent growth of molds and bacteria

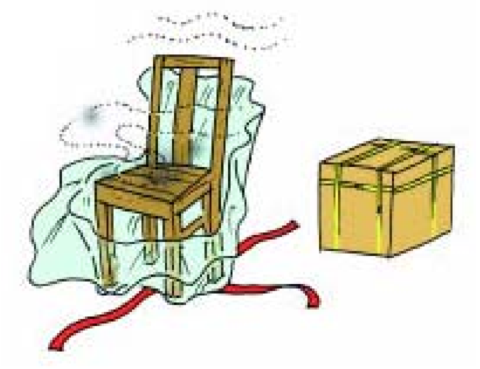
Purpose of Ventilation

Sources other than occupants - Contaminants

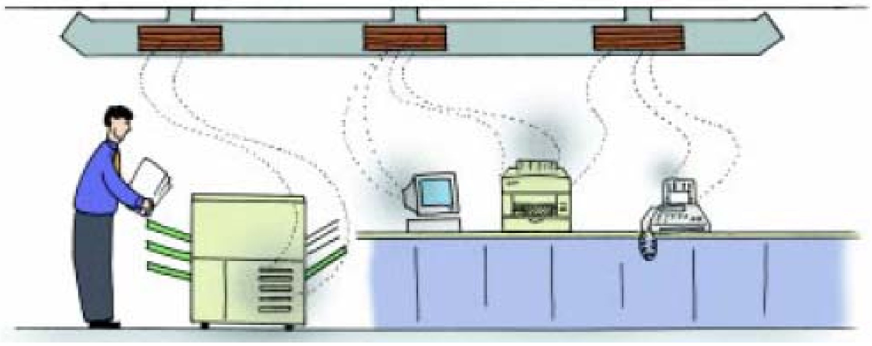
- Exhaust from Medical buildings, laboratories, animal rooms are examples other than offices.
- Removal of vapor generated in the process of spraying paint and welding for factory.
- Room at slightly negative pressure to minimize migration of pollutants (such as kitchen, canteen, toilet, bath, printing room, photocopying room)
- Running the MVAC system at least 48 hours before occupation to purge the room air of gaseous contaminants, e.g. solvents.
- Maintaining a higher rate of ventilation during the first few months of occupation to reduce emission levels of new, renovated or newly refurbished buildings.

Purpose of Ventilation

By Isolation



Furniture



Ozone, heat, etc

Purpose of Ventilation

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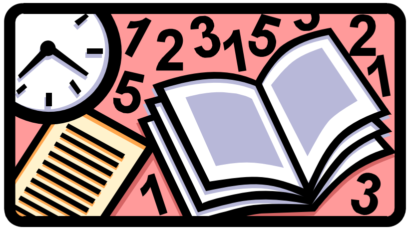
Determining Ventilation rates



- Head count of number of occupants
  (e.g. ventilation rate in L/s/person x total number of occupants)
- Air change rate per hour (ACH) The number of times in an hour the content of the room replaced by outdoor air.

$$Q = \frac{V \cdot ACH}{3600} \cdot 1000$$

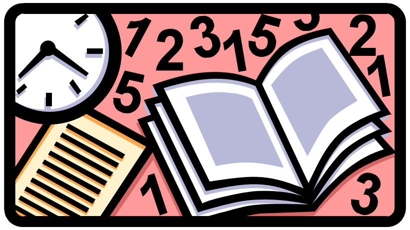
where Q = ventilation rate (l/s)

V = concentration of contaminants in outdoor air

ACH = air change per hour

Space	Air change rates per hour
Carparks	6
Kitchen	20 - 60
Lavatory	15
Bathrooms	6
Boiler rooms	15 - 30

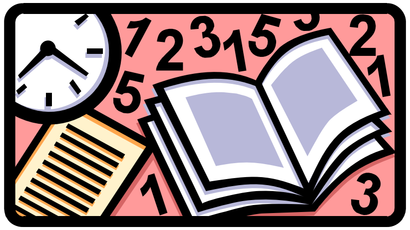
Determining Ventilation rates



- **Outdoor air requirements for ventilation**

Application	*Estimated maximum occupancy (persons per 100 m^2 floor area)*	*Outdoor air requirements (l/s/person)*
Offices		
- office space	7	10
- conference room	50	10
Retail's Stores		
- street level	30	5
- upper floors/arcades	20	5
Education		
- classroom	50	8
- auditorium	150	8
- library	20	8
Hospitals		
- patient rooms	10	13
- operating rooms	20	15

Determining Ventilation rates



Determination of ventilation rates

- Flow rate per floor area.
- Maintaining temperature (Air flow required to carry away the sensible heat released at heat source to maintained air temperature)

$$Q = \frac{H}{c_p \cdot \rho \cdot (T_i - T_o)}$$

where H = heat generation inside the space (W)

Q = ventilation rate (l/s)

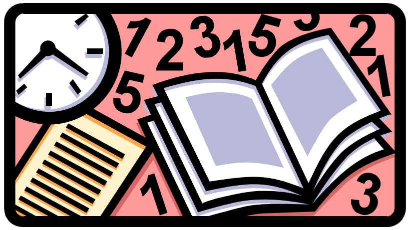
c_p = specific heat capacity of air (J/kg.K)

ρ = density of air (kg/m^3)

T_i = indoor air temperature (K)

T_o = outdoor air temperature (K)

Determining Ventilation rates



Determination of ventilation rates

- Required dilution level of air contaminants (Amount of air required to remove exhaled air and to control interior moisture, carbon dioxide and odor)

$$C_i = C_o + F/Q$$

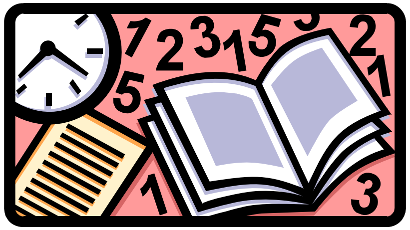
where C_i = maximum allowable concentration of contaminants

C_o = concentration of contaminants in outdoor air

F = rate of generation of contaminants inside the occupied space (l/s)

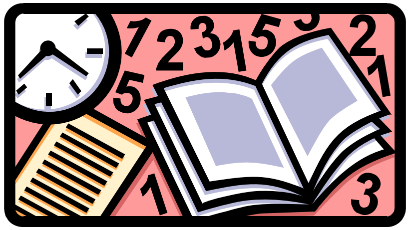
Q = ventilation rate (l/s)

Methods of Ventilation



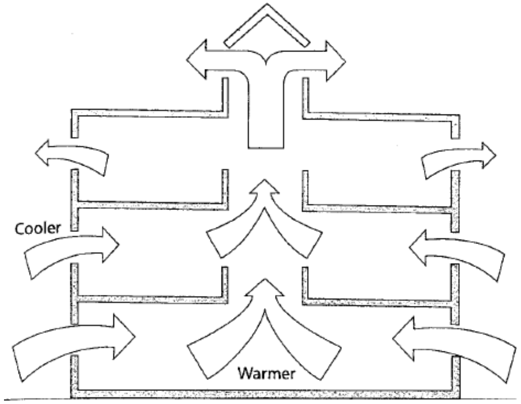
- **Natural Ventilation**
- **Mechanical ventilation**
- **Displacement Ventilation**

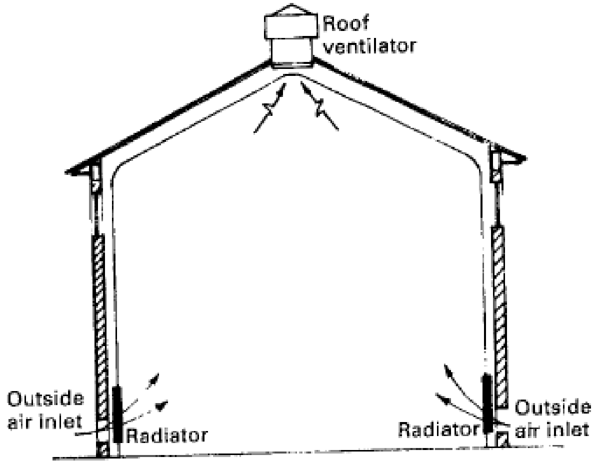
Methods of Ventilation



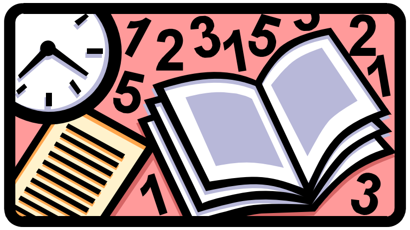
Natural Ventilation

- The design of controlled natural ventilation systems requires identification the prevailing wind direction,
- the strategic orientations and positions of openings (windows, doors, roof ventilators, skylights, vent shafts) on the building envelope.



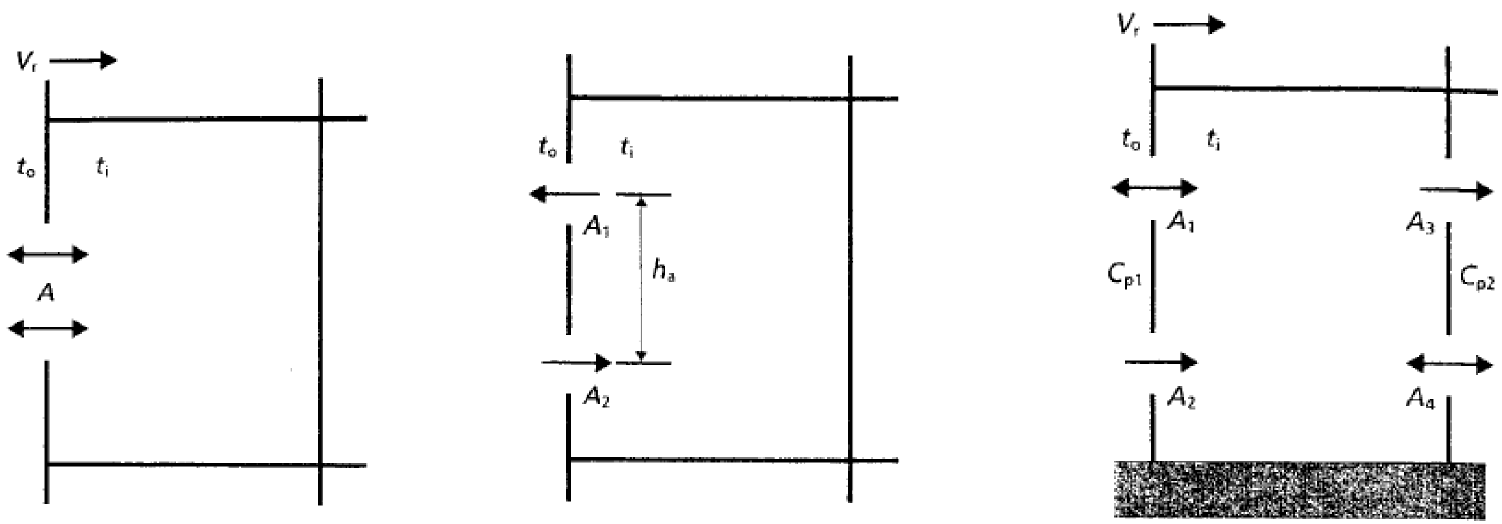


Methods of Ventilation



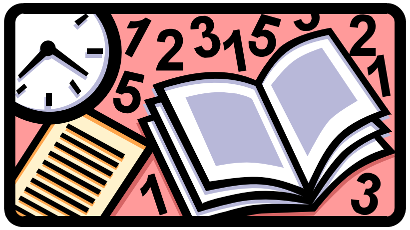
Wind effect

- Air entering through openings in the windward walls, and leaving through openings in the leeward walls
- Establishing a pressure difference across the building.



(a) Single sided single opening (b) Single sided double opening (c) Cross ventilation

Methods of Ventilation



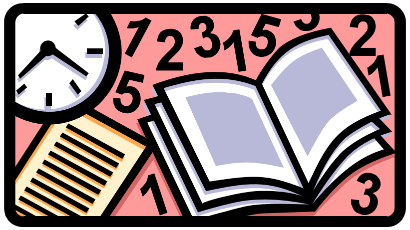
Flow caused by wind

Major factors affecting ventilation wind forces include:

- average wind speed;
- prevailing wind direction;
- seasonal and daily variation in wind speed and direction;
- local obstructing objects, such as nearby buildings and trees;
- position and characteristics of openings through which air flows; and
- distribution of surface pressure coefficients for the wind.

Natural ventilation systems are often designed for wind speeds of half the average seasonal velocity (climatic analysis → very few places where wind speed falls below half the average velocity)

Methods of Ventilation

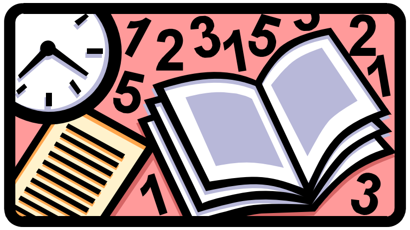


- The following equation shows the air flow rate through ventilation inlet opening forced by wind:

$$Q = C_v \cdot A \cdot v$$

where	Q	= air flow rate (m^3/s)
	A	= free area of inlet openings (m^2)
	v	= wind velocity (m/s)
	C_v	= effectiveness of the openings (assumed to be 0.5 to 0.6 for perpendicular winds and 0.25 to 0.36 for diagonal winds)

Methods of Ventilation



Wind Effect - the theory

$$u = u_m K h^a$$

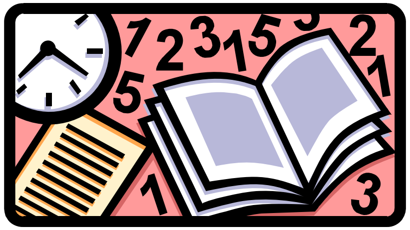
where u = mean wind speed at height h

u_m = mean wind speed at a height of 10m in open country

K, a = parameters depend on its locations

such as city, urban, country with scattered windbreaks, open flat country

Methods of Ventilation



Stack effect (Chimney effect)

- Air flow due to indoor-outdoor temperature difference
- The flow of air is in the vertical direction
- The flow follows the path of least resistance

Case one: Inside temperature > outside temperature

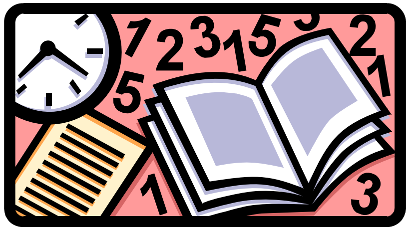
Difference in air density =>

1) Negative pressure outside and inward air flow at low levels
2) Positive pressure inside and outward flow at high levels.

Case two: Inside temperature< outside temperature

The reverse of case one

Methods of Ventilation



Flow caused by thermal forces

- If the building's internal resistance is not significant, the flow caused by stack effect may be estimated by:

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_o - T_i}{T_o}} \quad \text{if } T_o > T_i$$

where Q = air flow rate (m^3/s)

K = discharge coefficient for the opening (usually assumed to be 0.65)

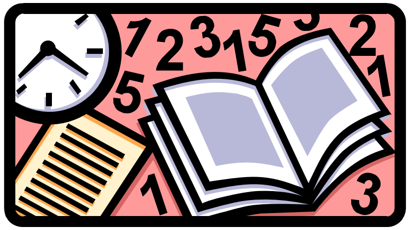
A = free area of inlet openings (m^2)

Δh = height from lower opening (mid-point) to neutral pressure level (m)

T_i = indoor air temperature (K)

T_o = outdoor air temperature (K)

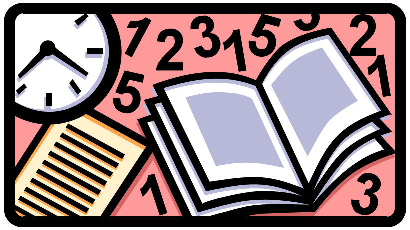
Methods of Ventilation



Points note in designing natural ventilation systems:

- Windows should be located in opposing pressure zones since this usually will increase ventilation rate;
- A certain vertical distance should be kept between openings for temperature to produce stack effect;
- Architectural elements like wingwalls, parapets and overhangs may be used to promote air flow into the building;
- To admit wind air flow, the long façade of the building and the door and window openings should be oriented with respect to the prevailing wind direction;
- Vertical shafts and open staircases may be used to increase and generate stack effect.

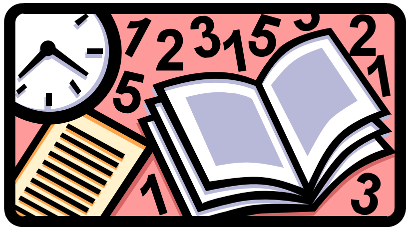
Methods of Ventilation



Barriers to the application of natural ventilation

- Safety concerns
- Noise from outdoor
- Dust and air pollution
- Solar shading covering the openings
- Draught prevention Building and fire regulations
- Need for acoustic protection
- Devices for shading, privacy & daylighting may hamper the free flow of air
- Problems with automatic controls in openings

Methods of Ventilation



Mechanical ventilation strategies

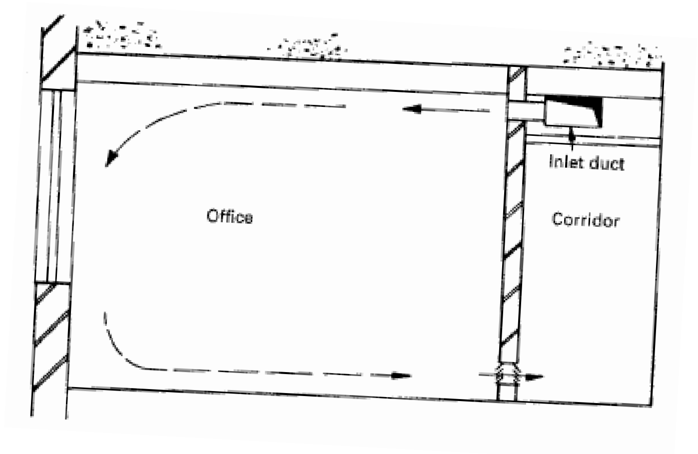
Balanced supply and extract

- Extract and supply systems are installed as two separately ducted networks.
- This offers the maximum flexibility by permitting contaminants to be removed at source and allowing for heat recovery.
- It is also weather independent.
- Effective building sealing is required as the system is designed to be pressure neutral.
- Capital costs are high due to the expense of two separate ductwork systems and increased fan energy requirements.

Methods of Ventilation

Mechanical supply & natural extract

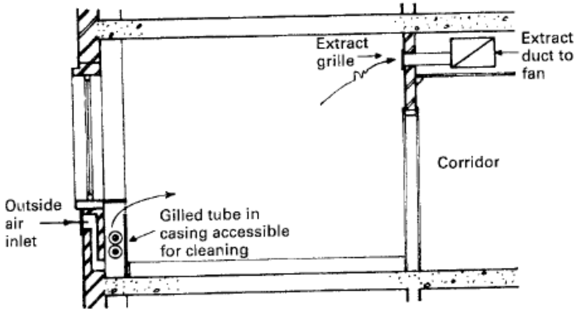
- Supply air is mechanically introduced into the building, displacing indoor air through purpose provided openings and/or infiltration.
- A proportion of the air can be re-circulated.
- Use where positive pressure is required to prevent the inward leakage of air, e.g. clean rooms.
- Also to provide uniform ventilation, or can be set to provide individual airflow rates.
- The supply air can be treated as required, e.g. heated or filtered (suitable for allergy control).



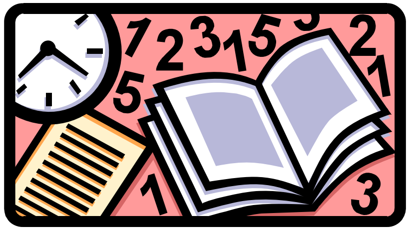
Methods of Ventilation

Mechanical extract & natural supply

- A fan is used to extract air from the space and create a negative pressure that draws in an equal mass of fresh air from outside.
- Mechanical extract can be provided on a local basis, either from industrial processes or sources of moisture e.g. bathrooms.
- Non-domestic environment where a suction pressure is desirable to prevent the egress of contaminants, e.g. chemical laboratories.
- Excessive under-pressure must be avoided as it may give rise, to back-draught of combustion products, the ingress of radon or other soil gases, and noise problems.



Methods of Ventilation



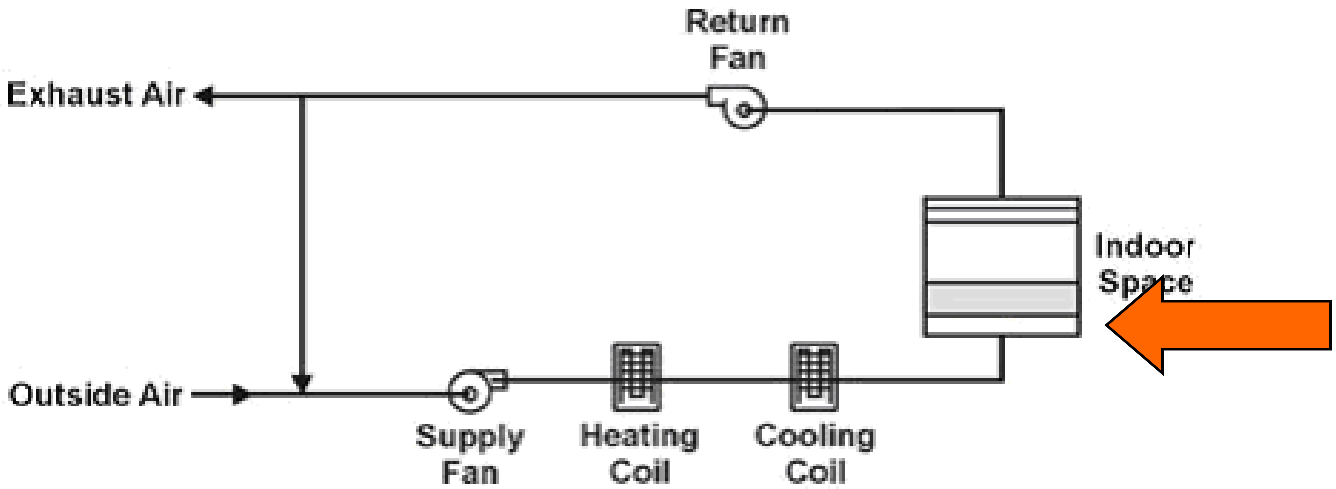
Displacement Ventilation

- Displacement ventilation uses a low-velocity stream of fresh cold air supplied near the floor to slowly "displace" the stale air up toward the ceiling from where it leaves the room.

- This stratifies the air in the room, with warm stale air concentrated above the occupied zone and cool fresher air in the occupied zone.

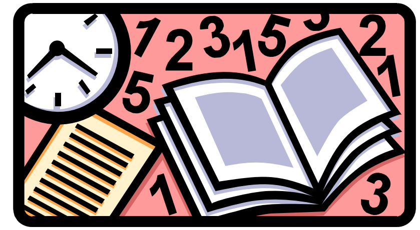
Methods of Ventilation

Displacement Ventilation



Schematic diagram of displacement ventilation

Methods of Ventilation



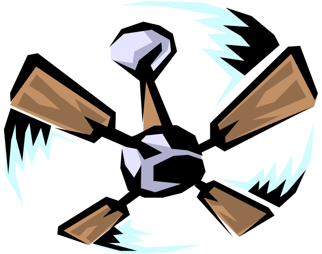
Displacement ventilation reduces the energy consumption in several ways:-

- The supply air temperature for displacement ventilation is usually 5°C - 8°C higher than that of conventional mixing ventilation. This allows higher refrigerant evaporator temperatures in the air-conditioning equipment and increases the coefficient of performance (COP) of the cycle.

- The stratified air in a space using displacement ventilation results in a higher average room air temperature than mixing ventilation resulting in reduced heat transfer through walls and roof of a building.

- For a system incorporating demand-controlled ventilation, the required fresh-air for a displacement ventilation system could be lower than that of mixing ventilation because light-weight pollutants (e.g. dusts) are trapped near the ceiling in the stratified air and can be removed easily through the ceiling exhaust air ducts.

Ventilation - Applications

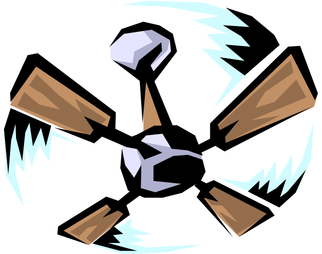


Control of Air Pollution in Car Parks

<u>Air Quality Guidelines</u>

- Carbon monoxide and nitrogen dioxide are the most relevant air pollutants inside car parks in Hong Kong.
- Petrol engine vehicles (mainly cars) are the source of most but not all carbon monoxide in car parks and diesel engine vehicles are the source of most but not all nitrogen dioxide.
- Carbon monoxide blocks the absorption of oxygen by the blood and this can lead to dizziness, unconsciousness, or death depending on the concentration.
- Nitrogen dioxide affects the lungs and can cause breathing difficulties, prompts asthma attacks and causes long term damage to the lungs.

Ventilation - Applications



Control of Air Pollution in Car Parks

<u>Air Quality Guidelines</u>

		Maximum Concentration	
Air Pollutants	**Averaging Time**	**Microgrammes Per Cubic Metre ($\mu g/m^3$)**	**Parts Per Million (ppm)**
Carbon monoxide (CO)	5 minutes	115,000	100
Nitrogen dioxide (NO_2)	5 minutes	1,800	1

All limits are expressed as at reference conditions of 298 K and 101.325 kPa.

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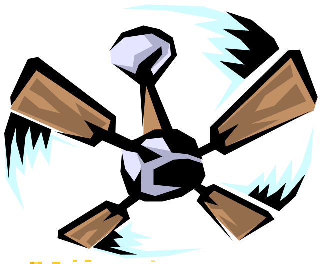
Ventilation - Applications

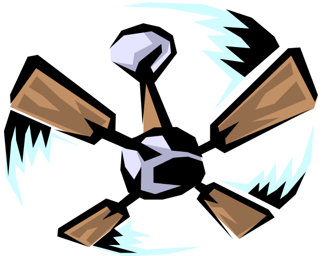


Control of Air Pollution in Car Parks

<u>Design Considerations</u>

- NO_2 concentration in a car park is within the guideline limit as long as the CO guideline is satisfied.
- For car parks used by a high proportion of goods and other diesel-fuelled vehicles, NO_2 concentration becomes a more important consideration.
- The ventilation provide sufficient dilution of the CO and NO_2 emitted from vehicles during peak hours and queuing of vehicles within the car park.
- For car parks, carbon monoxide (CO) and temperature sensors can be used to monitor the quality of car park air and control the supply and exhaust fans.
- In car park ventilation systems that have many supply and exhaust fans serving specific areas of the car park, sensors installed in various parts of the car park can be used to switch on/off the sets of supply and exhaust fans serving specific areas when the CO level and temperature in a particular part of the car park reaches a set value.

Ventilation - Applications



Control of Air Pollution in Car Parks

Design Considerations

- Sufficient standby units should be provided to meet the air quality guidelines during maintenance periods or in the event of the break down of the normal units.

- Separate fresh air supply should be provided to areas that are occupied regularly such as lift lobbies, pay booths and car cleaning services bay.

- The levels of CO in a car park should be monitored continuously and the measurement results linked up automatically through a tamper-proof device with the control of the ventilation system.

- The car park management to ensure no vehicle will be allowed to enter the car park once it is full or when the air quality guidelines have been exceeded.

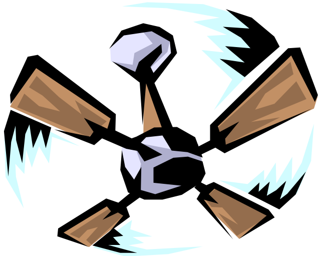
Ventilation - Applications

Kitchen Exhaust

Positioning of Exhaust Outlets

- Provide sufficient separate distance from any sensitive receptor in the vicinity so that the emissions will not cause, or contribute to, an odour nuisance or other type of air pollution to the public;
- Ensure the emission from the exhaust system will be directed vertically upwards.
- Ensure the emission from the exhaust system will not be restricted or deflected by the use of plates or caps.
- Extend the exhaust to at least 3 metres above the highest point of the restaurant's own building and of any adjacent or attached buildings that fall within a 20-metre radius.

Ventilation - Applications



Kitchen Exhaust

Oily Fume and Cooking Odour Control

- The complete exhaust system serving the cooking stoves or other cooking appliances, including the air pollution control equipment, should be designed, commissioned and maintained by competent professionals, and be operated by competent staff.

- For those exhaust systems serving stoves for frying, charbroiling, roasting and similar operations that will give out excessive oily fume emissions, they should be equipped with high efficiency air pollution control equipment.

- If the exhaust contains a strong odour or the exhaust outlet is in close proximity to any sensitive receptor in the vicinity such that an air pollution exists or is imminent, high efficiency odour control equipment will also be required.

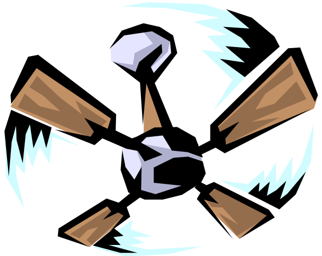
Ventilation - Applications

Available Techniques for the Control of Oily Fume & Odour emissions

Grease Filters

- Metallic grease filters, which are commonly found in the market, can screen out large droplets and are therefore suitable for preliminary treatment of oily fume.
- Grease filters that are made of densely packed synthetic fibres, would be more effective than metallic filters.
- Used together with a hydrovent (which serves as a fire break as well as cooling and condensing the oily fume) to give a reasonable preliminary treatment in oily fume control.

Ventilation - Applications



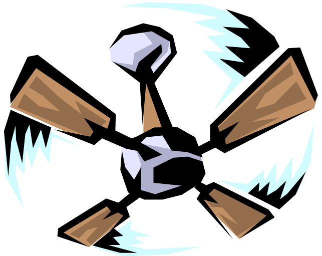
Available Techniques for the Control of Oily Fume & Odour emissions

Hydrovent /Air Washer

- Hydrovent/ air washer have a better performance in oily fume control than grease filters but neither one of them alone can effectively reduce oily fume to an acceptable level.
- Air washers should be filled with specially designed baffles to enhance their performance

- In the design of a hydrovent and air washer system:
  - Sufficient residence time;
  - Adequate air-to-water-ratio;
  - Choices of scrubbing liquid; and
  - Easy maintenance and cleaning.

Ventilation - Applications



Available Techniques for the Control of Oily Fume & Odour emissions

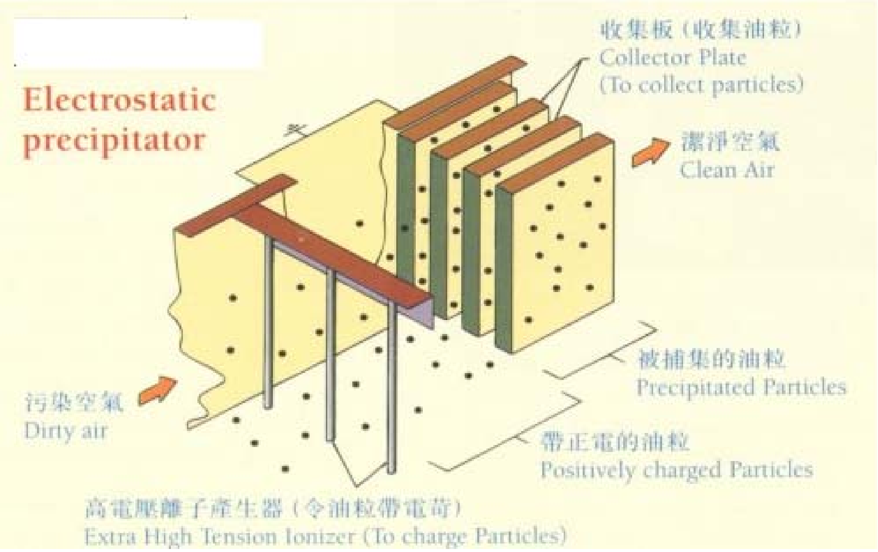
Electrostatic Precipitators (ESPs)

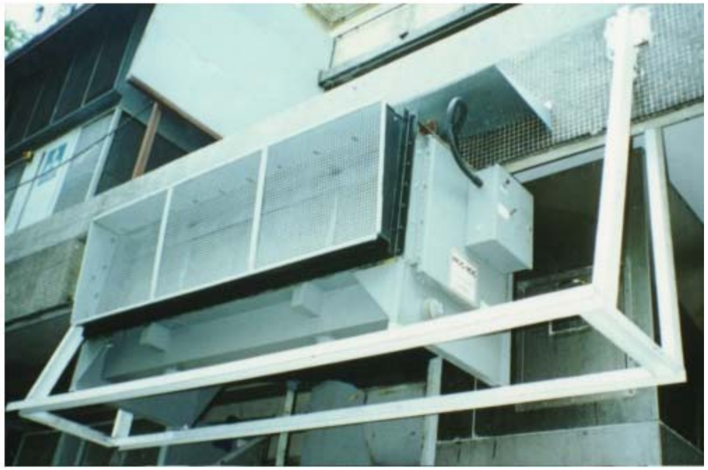
- If properly designed and maintained, ESPs can achieve a high collection efficiency for oily fume.
- Since oily fume is sticky and easily coated on the collector plates and render the equipment inoperative, ESPs should be cleaned/serviced regularly and properly.
- A weekly servicing should be the minimum and they should be cleaned immediately as soon as there is any sign of deterioration in fume control.
- Some manufacturers have incorporated automatic self-cleaning mechanism into their equipment to facilitate automatic daily cleaning.

Ventilation - Applications

Available Techniques for the Control of Oily Fume & Odour emissions

Electrostatic Precipitators (ESPs)





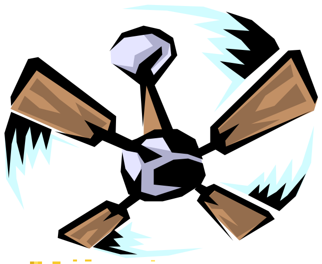
Ventilation - Applications

Available Techniques for the Control of Oily Fume & Odour emissions

Venturi Scrubbers

- Venturi scrubbers are sometimes employed to control oily fume.
- Exhaust gas stream is forced through the venturi throat where they are intercepted by an atomized scrubbing liquid stream.
- Removal efficiency depends on the pressure drop across the venturi throat and particle size.

Ventilation - Applications

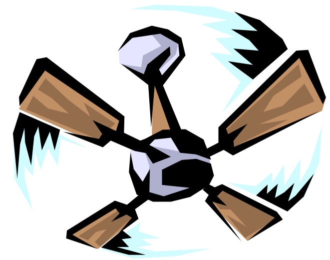


Ventilation for Food Premises

- Food premises should have sufficient natural or mechanical ventilation to effectively remove fumes, smoke, steam, heat and condensation arising from the food premises, and supply fresh air.

- Adequate propulsion fans and extraction fans should be provided, with the point of intake or discharge being in the open air (a space that is vertically uncovered and unobstructed) at a height of not less than 2.5m from the ground level and in such a manner as not to cause a nuisance.
- Ventilating systems housed inside restaurants and factory canteens should comply with section 4(1) of the Ventilation of Scheduled Premises Regulation (Cap. 132 subsidiary legislation). A Letter of Compliance for installation of ventilating system shall be obtained from the Director of Fire Services.

Ventilation - Applications

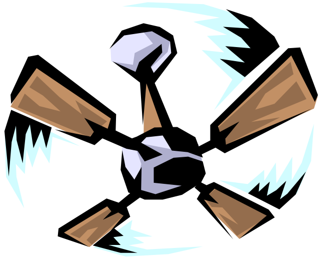


Ventilating Systems for Seating Accommodation inside Restaurants and Factory Canteens

- Where natural ventilation is insufficient for the seating accommodation inside restaurants and factory canteens (i.e. where openings or windows which can be opened to the open air are less than 1/10 of the floor area), a mechanical ventilating system should be provided to give not less than 17m3 of outside air per hour for each person that the premises are designed to accommodate.

- Seating areas, kitchens / food rooms and toilets should have their own independent ventilating system.

Ventilation - Applications



Industrial Ventilation

Total Enclosure

- It prevents contaminant from entering the breathing zone of the worker

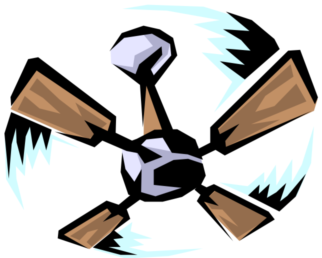
Some degree of access

- Access to a low emission chemical process within a fume cupboard via a sliding door such as welding of components and spray painting to a surface.

Momentum of air exhausted to the opening should be sufficient to overcome:-

- Frictional force (drag on the mixture due to neighbouring bulk of room air)
- Dynamic force (initial momentum of contaminant)

Ventilation - Applications



Exhaust Hood Dynamic

The velocity at a given distance from an opening of exhaust hood (decreased with increase of distance from openings) can be predicted from: -

$$V_d = \frac{Q}{Bd^n + A}$$

where :

V_d	=	Air velocity at distance d from the opening
Q	=	Volume flow rate of air
d	=	Distance from the opening
A,B	=	Constants determined by flow characteristic and geometry of opening, determined from experiments

Simple Models for Ventilation

Mechanical Ventilation

Case 1- Incoming air free of carbon dioxide

Considering that a room with concentration of carbon dioxide c where c is in part per million (i.e. ppm)

The volume of the room is V m^3.

During Δt, Δq air enters the room that is free of carbon dioxide.

In this connection, concentration of carbon dioxide inside the room decreased by $\frac{\Delta q}{V} c$

that is $\Delta c = -\frac{\Delta q}{V} c$ --(1)

Rate of change of concentration is equal to $\frac{\Delta c}{\Delta t}$ ---(2)

Simple Models for Ventilation

Putting (1) to (2), we have:

Rate of change of concentration of carbon dioxide

$$= \frac{\Delta c}{\Delta t} = -\left(\frac{\Delta q}{V}\right)\left(\frac{c}{\Delta t}\right) \text{--- (3)}$$

Taking Q is rate of influx of ventilating air with

$Q = \dfrac{\Delta q}{\Delta t}$ where Q is a constant.

(3) becomes :-

$$\frac{\Delta c}{\Delta t} = -\frac{cQ}{V}$$

Simple Models for Ventilation

Rate of change of concentration in respect with the time becomes: -

$$\frac{dc}{dt} = -\frac{Qc}{V}$$

$$\int \frac{dc}{c} = -\int \frac{Q}{V} dt$$

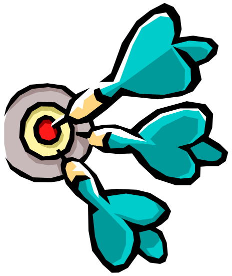
$$\log_e c = -\frac{Qt}{V} + \log_e k$$

where k is a constant

Hence the solution of the equation is:

$$ke^{-n} = c \quad \text{where} \quad n = \frac{Qt}{V}$$

Simple Models for Ventilation



Case 2 – The fresh air contained carbon dioxide

Considering that

c	=	Concentration of carbon dioxide in the room at any instant
Q'	=	Fresh air supply rate per occupant
V'	=	Occupied volume of a room by one occupant
t	=	Time after beginning of occupancy and ventilation
c_a	=	Concentration of carbon dioxide in the ventilating air
V_c	=	Volume of carbon dioxide produced per breathing occupant
c_0	=	Concentration of carbon dioxide at time t = 0

Simple Models for Ventilation

Consider the change in carbon dioxide level: -

Carbon dioxide entering the room = $Q'\Delta t\left[\frac{c_a}{10^6}\right]$ ---------(1)

Carbon dioxide produced = $V_c\Delta t$ --------------------------(2)

Carbon dioxide exhausted out the room = $\frac{Q'\Delta tc}{10^6}$ --------(3)

Simple Models for Ventilation

Net change = (2)+(1)-(3)

Change in concentration of carbon dioxide/person

$$= \frac{\text{Net change in } CO_2 \text{ per person}}{\text{Volume of the room per person}}$$

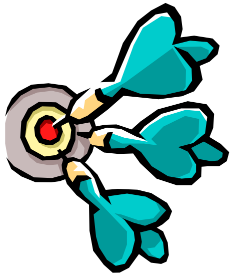
That is,

$$\Delta c = \frac{\left[V_c \Delta t + (Q' \Delta t c_a / 10^6) - (Q' \Delta t c / 10^6)\right]}{V'}$$

$$\frac{\Delta c}{\Delta t} = \frac{\left[V_c + (Q' c_a / 10^6) - (Q' c / 10^6)\right]}{V'}$$

$$\frac{dc}{dt} + \frac{Q'c}{V'} = \frac{10^6 V_c + Q' c_a}{V'} \quad \text{-----------------------------------(4)}$$

Simple Models for Ventilation



By multiplying an integrating factor $e^{\frac{Q't}{V'}}$ to both sides of (4), we get

$$x + ce^{\frac{Q't}{V'}} = \left[\frac{10^6 V_c + Q'c_a}{V'}\right]\left[\frac{V'}{Q'}e^{\frac{Q't}{V'}}\right]$$

where x is a constant.

With t = 0, c = c_0, we have

$$c = \left(\frac{10^6 V_c}{Q'} + c_a\right)(1 - e^{-\frac{Q't}{V'}}) + c_o e^{-\frac{Q't}{V'}}$$

With $N = \frac{Q't}{V'}$, where N is the number of air changes after the passage of time t.

$$c = \left(\frac{10^6 V_c}{Q'} + c_a\right)(1 - e^{-N}) + c_o e^{-N}$$

Simple Models for Ventilation

With $n = -\frac{Q' t}{V'}$, where n is the number of air changes after the passage of time t.

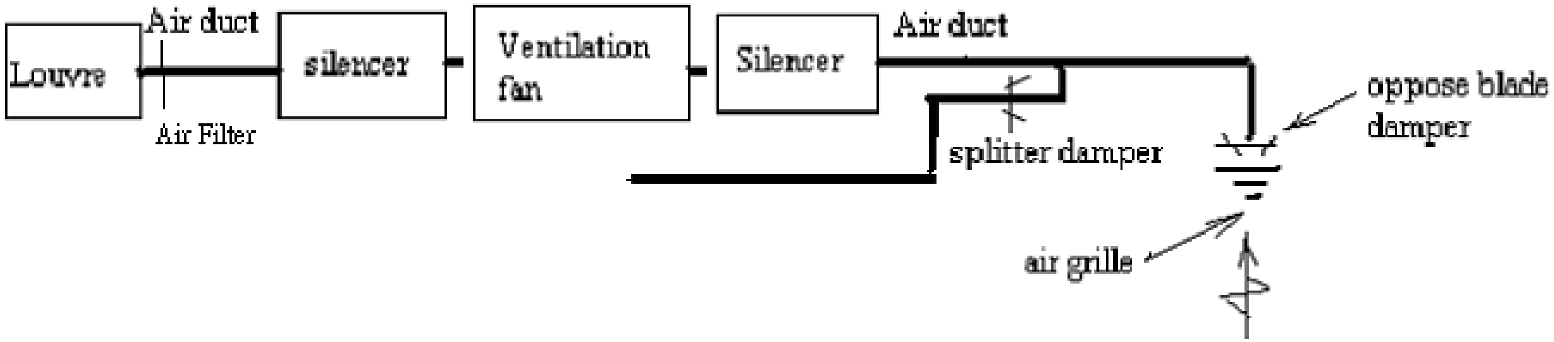
After elapsing for a long period with $t \to \infty$

$$c = \frac{10^6 V_c}{Q'} + c_o$$

$$Q' = \frac{10^6 V_c}{(c - c_{out})}$$

This is the steady state equation.

Mechanical Ventilation System Component



1) Louvre

2) Duct work – rectangular, round, flat oval and flexible

3) Ventilation fan

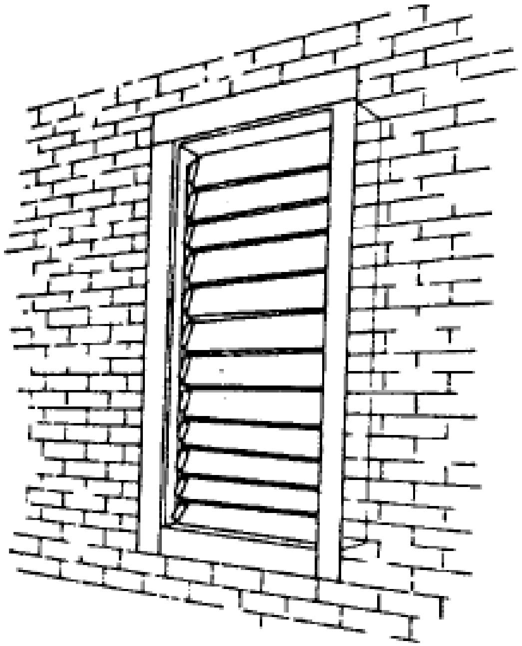
5) Damper – splitter damper, oppose blade damper

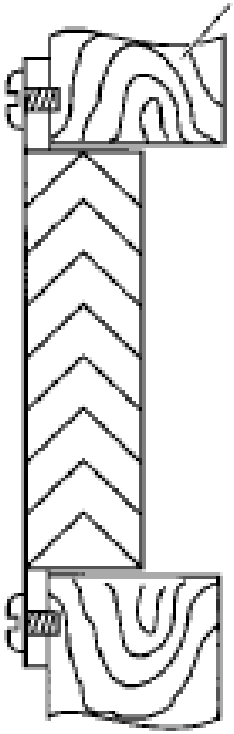
6) Silencer

7) Grilles & Register, slot diffusers, ceiling diffuser

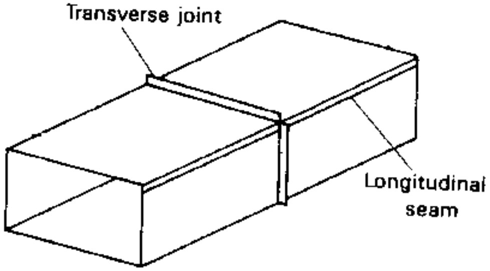
8) Air filter

Louvre fixed at wall





Rectangular Ducts



Rectangular duct

They could be **fabricated** on-site.

The joints of rectangular ducts have a comparatively greater % of **air leakage** than factory-fabricated spiral-seamed round ducts and flat oval ducts

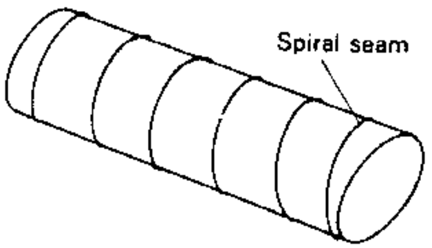
Unsealed rectangular duct : **air leakage** from 15 to 20 %.

The ratio of the long side (length or width) to the short side (length or width) in a rectangular duct - **aspect ratio**.

To prevent **vibration of the duct** wall due to pulsating airflow by transverse joints and longitudinal seam reinforcements

Round Ducts

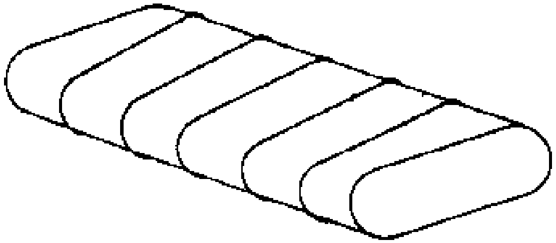
- A round duct has **less fluid resistance** against airflow than rectangular or flat oval ducts.
- Round ducts also have **better rigidity and strength**.
- The **spiral- and longitude-seamed** round ducts used in commercial buildings are usually **factory-fabricated** to improve the quality and sealing of the ductwork.
- **Air leakage** at about 3 percent (well-sealed seams and joints).
- Round ducts have much **smaller radiated noise** breakout from duct than rectangular or flat oval ducts.
- The main disadvantage of round ducts is the **greater space** required under the beam for installation.



Spiral round duct

Flat Oval Ducts

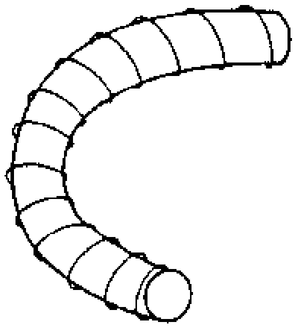
- Flat oval ducts have a **cross-sectional shape** between rectangular and round.
- They share the advantages of both the round and the rectangular duct with **less large-scale air turbulence** and **a small depth of space** required during installation.
- Flat oval ducts are **quicker to install** and have **lower air leakage** because of the factory fabrication.



Flat oval duct

Flexible Ducts

- Flexible ducts are often **used** to connect the main duct or the diffusers to the terminal box.
- Their **flexibility and ease of removal** allow allocation and relocation of the terminal devices.
- Flexible ducts are usually **made of** multiple-ply polyester film reinforced by a helical steel wire core or corrugated aluminum spiral strips.
- The flexible duct should be **as short as possible**, and its length should be fully extended to minimize flow resistance.



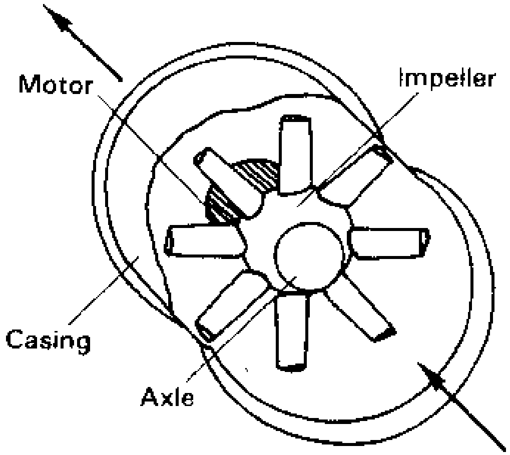
Flexible duct.

Mechanical Ventilation System Component

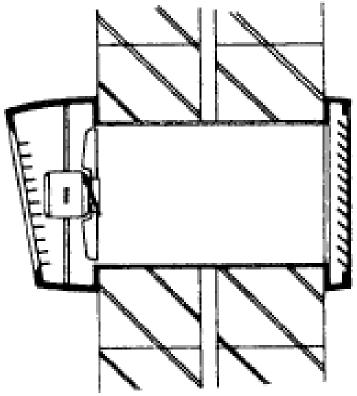
Axial / wall mounted Fan

- Increase of air static pressure is created by the conversion of velocity pressure to static pressure

- Direction of airflow is parallel to the axle of the fan.



Axial fan

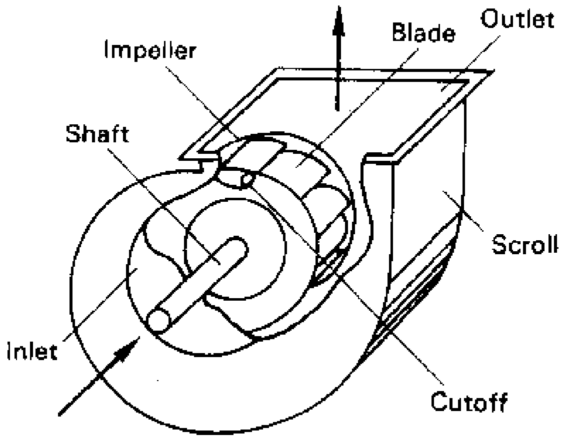


Mounted in wall

Mechanical Ventilation System Component

Centrifugal fan

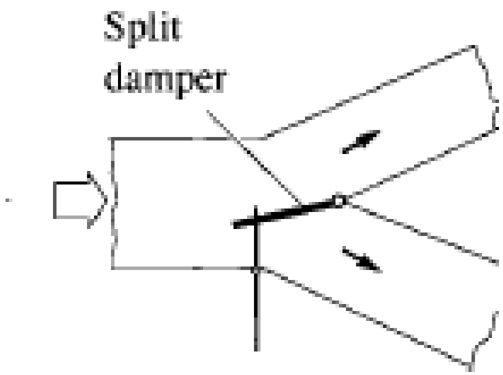
- Increase of air static pressure is created by the conversion of **velocity pressure to static pressure**.
- Air is **radially** discharged from the impeller and turns 90° from its inlet to its outlet.



Centrifugal fan

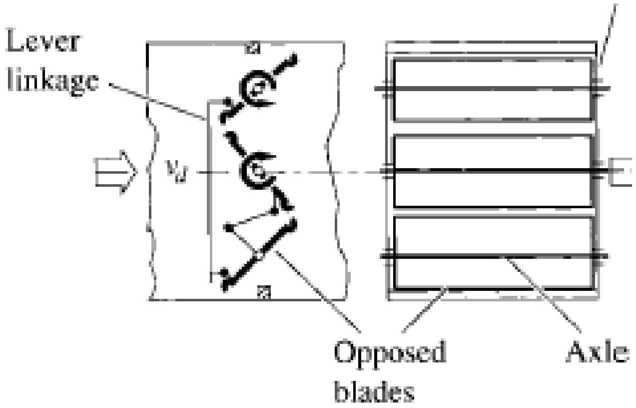
Split Dampers.

- A split damper is also a single-blade damper.
- It is a piece of movable sheet metal
- It is usually installed at the Y connection of a rectangular duct system



Opposed-Blade Dampers

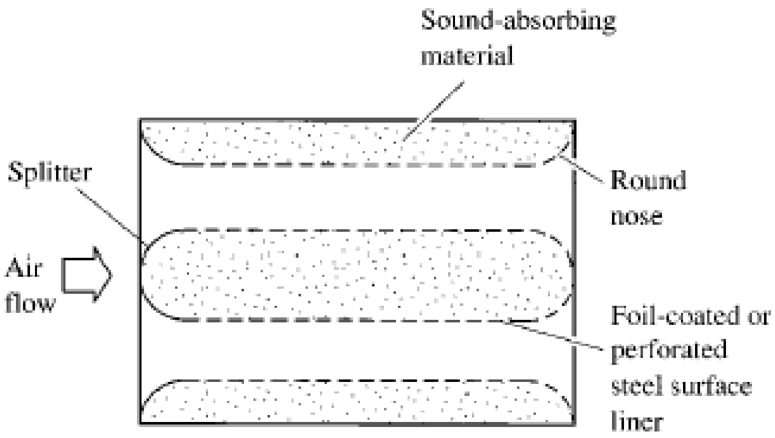
- It is a type of **multi-blades** damper that is often rectangular.
- The damper blades may be **made of** galvanized steel, aluminum alloy, or stainless-steel sheets.
- Rubber or spring **seals** at the fully closed position to control the air leakage rating
- The **bearing** used for supporting the blade axle should be made of a corrosion-resistant material such as copper alloy.
- Lever **linkages** are used to open and close the damper blades.



Mechanical Ventilation System Component

Silencers

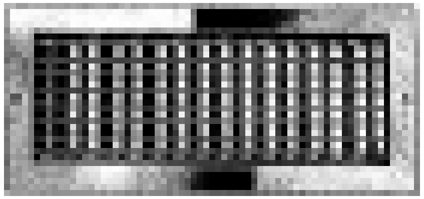
- Silencer **reduces the sound power level** of a fan to a required level.
- Inside the rectangular casing are a number of **flat splitters**, depending on the width of the silencer.
- These **splitters** direct the airflow into small sound-attenuating passages.
- The splitter is made from an envelope containing **sound-attenuating material**, such as fiberglass or mineral wool, with protected non eroding facing.
- Splitters often have around instead of a **flat nose**, to reduce their airflow resistance.

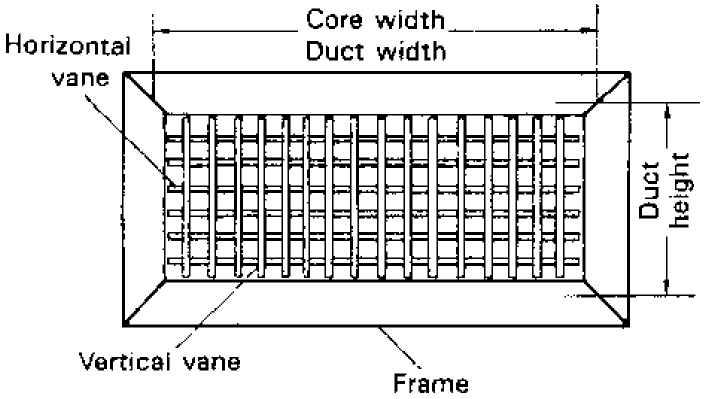


Mechanical Ventilation System Component

Grilles and Registers

- A grille or grill is an outlet for supply air or an inlet for return air or exhaust air.
- A register is a grille with a volume control damper (to adjust the volume flow).
- A single-deflection grille consists of a frame and one set of adjustable vanes (either vertical or horizontal vanes) to deflect the airstream.
- A double-deflection register is able to deflect the airstream both horizontally and vertically.
- Extruded aluminum vanes, steel frames, steel dampers with a baked enamel finish.



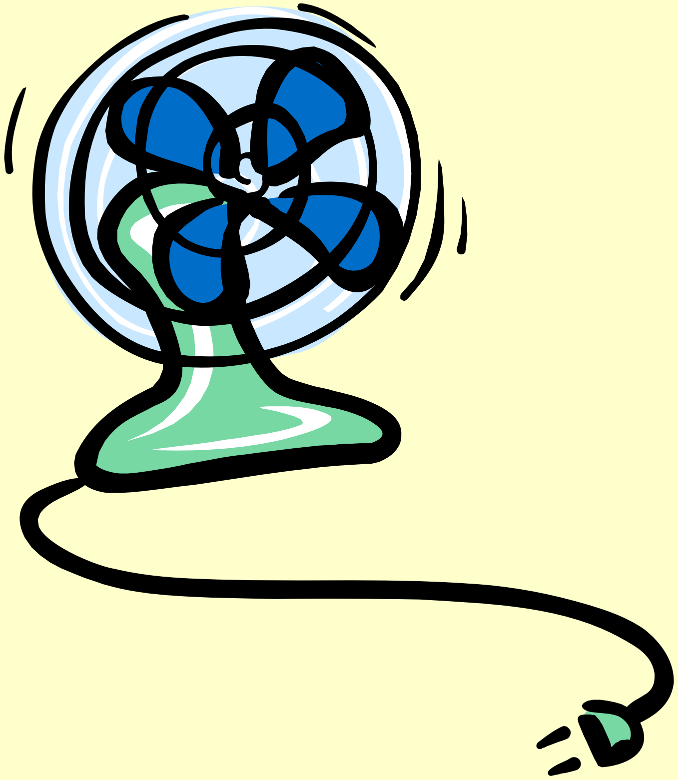


Grill

Mechanical Ventilation System Component

Air Duct Cleaning

- Conduct an air duct cleaning operation after occupation for a long period of time.
- Duct cleaning is a delicate process which sometimes involves the use of powerful chemicals to loosen particles.
- Should duct work cleaning be deemed necessary, e.g. ductwork is water damaged or shows signs of biological growth, debris in ductwork restricting airflow or dust coming out of supply diffusers



Thank You