Ventilation

Dr. Benjamin P.L. Ho
Department of Mechanical Engineering
The University of Hong Kong
E-mail: benjamin.ho@hku.hk

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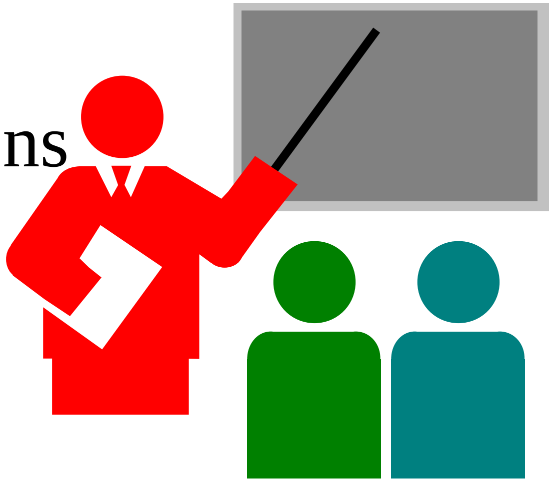


Purpose of Ventilation

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

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

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 (0.016g/s)
- At ambient condition with humidity ratio = 1g/kg dry air = 1.02g/m^3 This is equivalent to about 16 L/s/person

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).

Sources other than occupants - Unwanted moisture

- A swimming pool hall: moisture from vaporizing 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

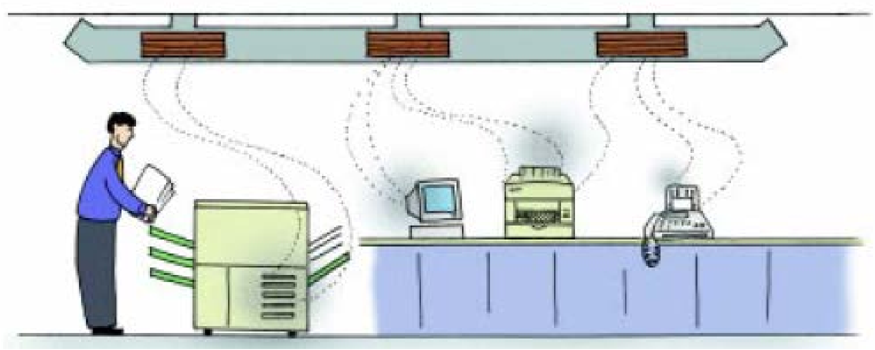
Purpose of Ventilation

Sources other than occupants - Contaminants

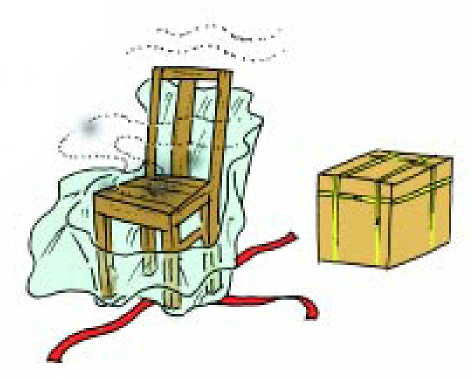
- Exhaust from Medical buildings, laboratories, animal rooms are examples other than offices.
- Removal of vapor generated in the process of spraying paint and welding for factory.
- Room at slightly negative pressure to minimize migration of pollutants (such as kitchen, canteen, toilet, bath, printing 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

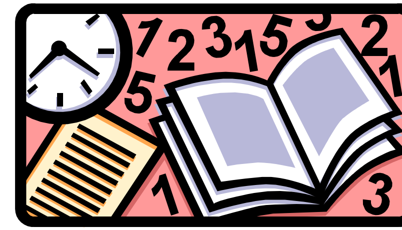


Ozone, heat, etc



Furniture

Determining Ventilation rates



There are a number of ways to determine the ventilation rate

- 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.

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

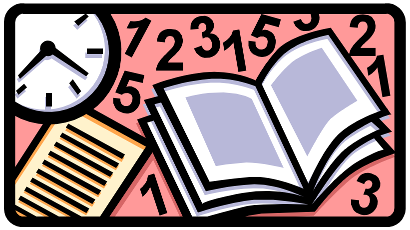
where Q = ventilation rate (l/s)

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

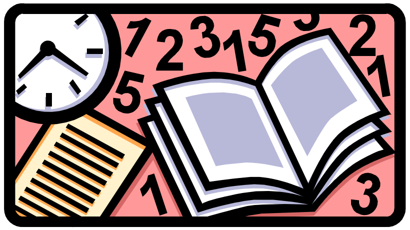
Determining Ventilation rates



- **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

- <u>Flow rate per floor area.</u>
- <u>Maintaining temperature</u> (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)

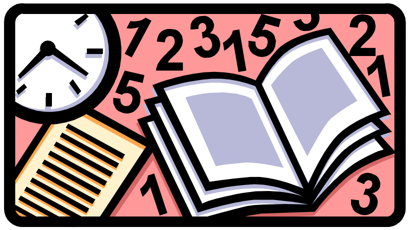
c_p = specific heat capacity of air (J/kg.K)

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)

Table 3-2: IAQ Objectives for Office Buildings and Public Places

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]

Table 3-3: IAQ Objectives for Individual VOCs (for Good Class TVOC Objective Only)

Compound	Good Class
Benzene	5 ppbv [a] (16.1 µg/m^3)
Carbon tetrachloride	16 ppbv [b] (103 µg/m^3)
Chloroform	33 ppbv [b] (163 µg/m^3)
1,2-Dichlorobenzene	83 ppbv [c] (500 µg/m^3)
1,4-Dichlorobenzene	33 ppbv [c] (200 µg/m^3)
Ethylbenzene	333 ppbv [c] (1,447 µg/m^3)
Tetrachloroethylene	37 ppbv [a,c] (250 µg/m^3)
Toluene	290 ppbv [a] (1,092 µg/m^3)
Trichloroethylene	143 ppbv [a,d] (770 µg/m^3)
Xylene (*o*-, *m*-, *p*-isomers)	333 ppbv [c] (1,447 µg/m^3)

IAQ Control Measures

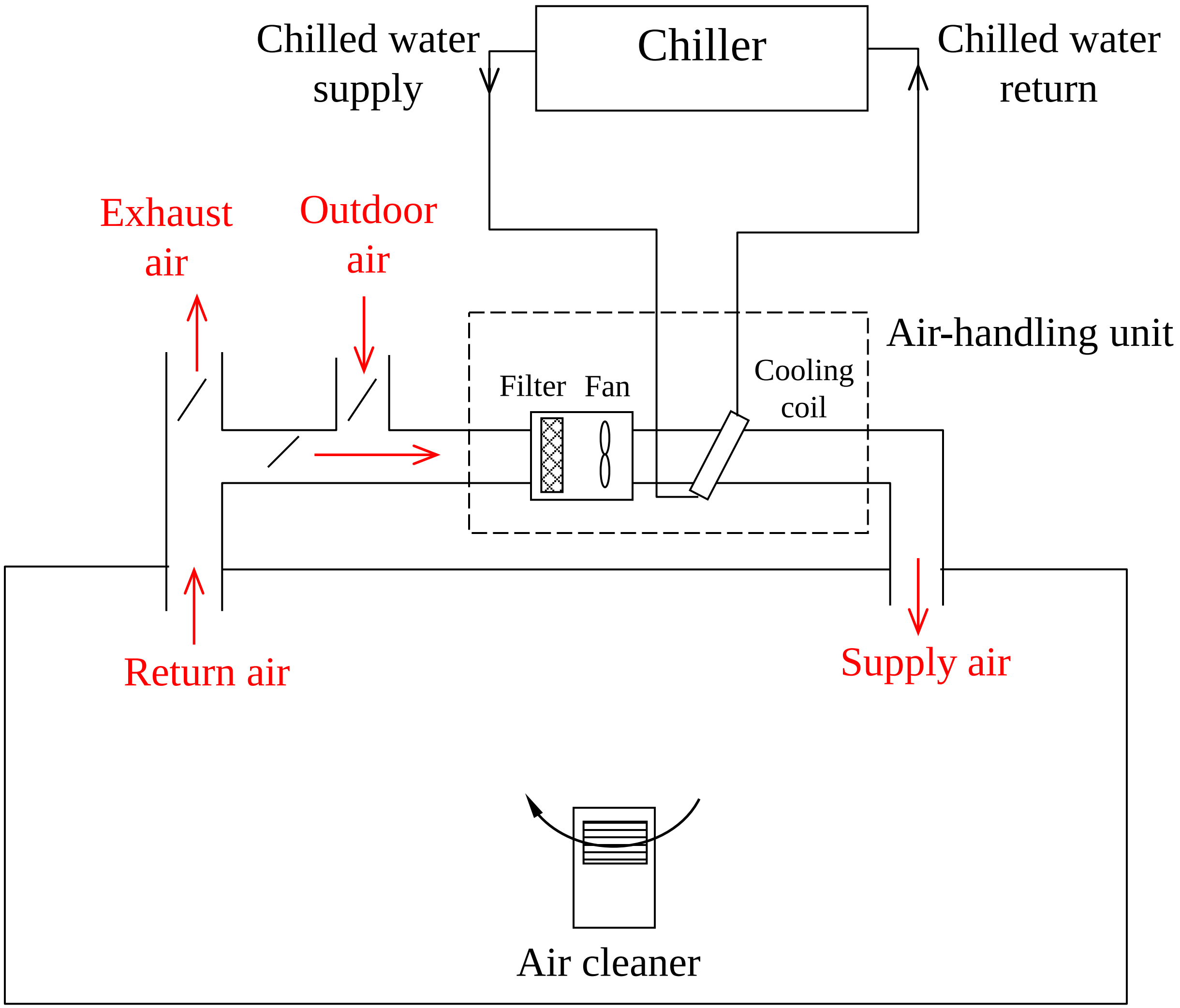
- **Source control**
- **Ventilation**
- **Filtration**
- **Other air cleaners**
  - **Absorption**
  - **Adsorption**
  - **Ultraviolet germicidal radiation**
  - **etc.**

From an engineering perspective, <u>ventilation</u> & <u>filtration</u> are essential. <u>Air cleaners</u> offer additional help.

Ventilation

- **Dilution of contaminants by combination of supply of outdoor air and removal of indoor air in a building.**
- **Processes typically include:**
  - **Exhausting portion of the return air**
    (by exhaust air fan).
  - **Bringing in outdoor air**
    (by fresh air fan).
  - **Mixing and conditioning the outdoor air and remaining return air**
    (mixing plenum and air handling unit).
  - **Distributing the mixed air throughout the indoor environment**
    (air ductwork and distribution through diffusers).

Mechanical Ventilation and Air-Conditioning (MVAC)



Ventilation Standard

- **In 1981, ASHRAE published "Standard 62-1981: Ventilation for Acceptable Indoor Air Quality."**
- **Latest version: ASHRAE Standard 62.1-2010**
- **"The purpose of this standard is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects."**

To Achieve Acceptable Air Quality

I. **<u>Ventilation rate procedure</u>: Acceptable air quality is achieved by providing ventilation air of the specified quality and quantity to the space.**

II. **<u>Indoor air quality procedure</u>: Acceptable air quality is achieved within the space by controlling known and specifiable contaminants.**

Ventilation Rate Procedure

1. Acceptable outdoor air

TABLE 4-1
National Primary Ambient-Air Quality Standards for Outdoor Air as Set by the U.S. Environmental Protection Agency

	Long Term			Short Term		
	Concentration		Averaging	Concentration		Averaging
Contaminant	μg/m^3	ppm		μg/m^3	ppm	
Sulfur dioxide	80	0.03	1 year	365[a]	0.14[a]	24 hours
Particles (PM 10)	50[b]	—	1 year	150[a]	—	24 hours
Carbon monoxide				40,000[a]	35[a]	1hour
Carbon monoxide				10,000[a]	9[a]	8 hours
Oxidants (ozone)				235[c]	0.12[c]	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	—	3 months[d]			

a Not to be exceeded more than once per year.
b Arithmetic mean.
c Standard is attained when expected number of days per calendar year with maximal hourly average concentrations above 0.12 ppm (235 μg/m^3) is equal to or less than 1, as determined by Appendix H to subchapter C, 40 CFR 50.
d Three-month period is a calendar quarter.

2. Outdoor air treatment

- **Air should be treated if the outdoor air contaminant levels exceed the standards in Table 4-1.**
- **Appropriate air-cleaning systems should be used.**
- **Outdoor air intake may be reduced during periods of high contaminant levels.**

3. Zone calculation

6.2.2.1 Breathing Zone Outdoor Airflow. The design outdoor airflow required in the *breathing zone* of the occupiable space or spaces in a *zone, i.e., the breathing zone outdoor airflow* (V_{bz}), shall be determined in accordance with Equation 6-1.

$$V_{bz} = R_p P_z + R_a A_z \qquad (6\text{-}1)$$

where:

A_z = *zone floor area*: the net occupiable floor area of the *zone* m², (ft²).

P_z = *zone population*: the largest number of people expected to occupy the zone during typical usage. If the number of people expected to occupy the zone fluctuates, P_z may be estimated based on averaging approaches described in Section 6.2.6.2. **Note**: If P_z cannot be accurately predicted during design, it shall be an estimated value based on the zone floor area and the default occupant density listed in Table 6-1.

R_p = outdoor airflow rate required per person as determined from Table 6-1. **Note**: These values are based on adapted occupants.

R_a = outdoor airflow rate required per unit area as determined from Table 6-1.

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s•person	cfm/ft^2	L/s•m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s•person	
Office Buildings									
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Hotels, Motels, Resorts, Dormitories									
Bedroom/living Room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multi-purpose assembly	5	2.5	0.06	0.3		120	6	2.8	1

Air Change

Air change rate

The replacement of a quantity of air in a space within a given period of time, typically expressed as number of air changes per hour (ACH). If a building has one ACH, this is equivalent to all of the air in the building being replaced in a one-hour period.

Total air change rate

$$\text{No. of total air changes per hour} = \frac{\text{Volume of total supply air per hour}}{\text{Volume of indoor environment}}$$

Outdoor air change rate

$$\text{No. of outdoor air changes per hour} = \frac{\text{Volume of outdoor air intake per hour}}{\text{Volume of indoor environment}}$$

6.2.2.2 Zone Air Distribution Effectiveness. The *zone air distribution effectiveness* (E_z) shall be determined using Table 6-2.

6.2.2.3 Zone Outdoor Airflow. The design *zone outdoor airflow* (V_{oz}), i.e., the outdoor airflow that must be provided to the zone by the supply air distribution system, shall be determined in accordance with Equation 6-2.

$$V_{oz} = V_{bz}/E_z \qquad (6\text{-}2)$$

6.2.3 Single-Zone Systems. When one air handler supplies a mixture of outdoor air and recirculated air to only one zone, the *outdoor air intake flow* (V_{ot}) shall be determined in accordance with Equation 6-3.

$$V_{ot} = V_{oz} \qquad (6\text{-}3)$$

6.2.4 100% Outdoor Air Systems. When one air handler supplies only outdoor air to one or more zones, the *outdoor air intake flow* (V_{ot}) shall be determined in accordance with Equation 6-4.

$$V_{ot} = \Sigma_{all\ zones} V_{oz} \qquad (6\text{-}4)$$

TABLE 6-2
Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. **Note**: For lower velocity supply air, E_z = 0.8.	1.0
Floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 ft (1.4 m) or more above the floor. **Note**: Most underfloor air distribution systems comply with this proviso.	1.0
Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification	1.2
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup supply drawn in near to the exhaust and/or return location	0.5

1. "Cool air" is air cooler than space temperature.
2. "Warm air" is air warmer than space temperature.
3. "Ceiling" includes any point above the *breathing zone*.
4. "Floor" includes any point below the *breathing zone*.
5. As an alternative to using the above values, E_z may be regarded as equal to air change effectiveness determined in accordance with ASHRAE Standard 129[16] for all air distribution configurations except unidirectional flow.

Ventilation effectiveness

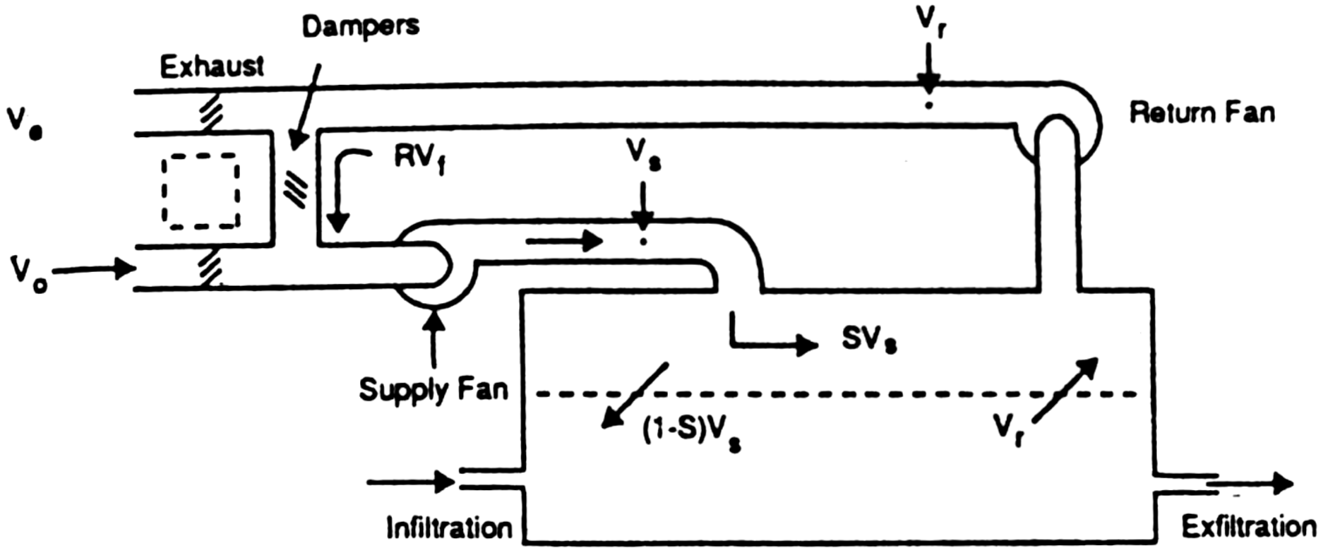


Figure E-1 Typical air distribution system.

$$E_v = [1 - S] / [1 - RS]$$

Multiple zones

$Y = X / [1 + X – Z]$

$Y = V_{ot}/V_{st}$

$X = V_{on}/V_{st}$

$Z = V_{oc}/V_{sc}$

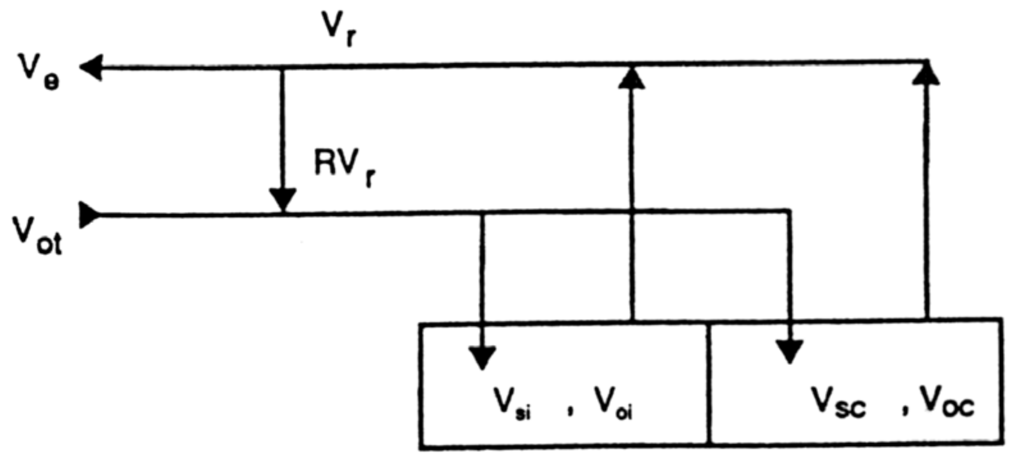


Figure G-1 Multi-zone model.

V_{ot} = corrected total outdoor air flow rate
V_{st} = total supply flow rate (sum of all supply for all branches)
V_{on} = sum of outdoor air flow rates for all branches
V_{oc} = outdoor air flow rate required in critical spaces
V_{sc} = supply flow rate in critical space
* Critical space = space with the greatest required fraction of outdoor air in the supply to this space

Example: Multiple zones

(4) $Y=0.429/(1+0.429-0.667)=0.563$

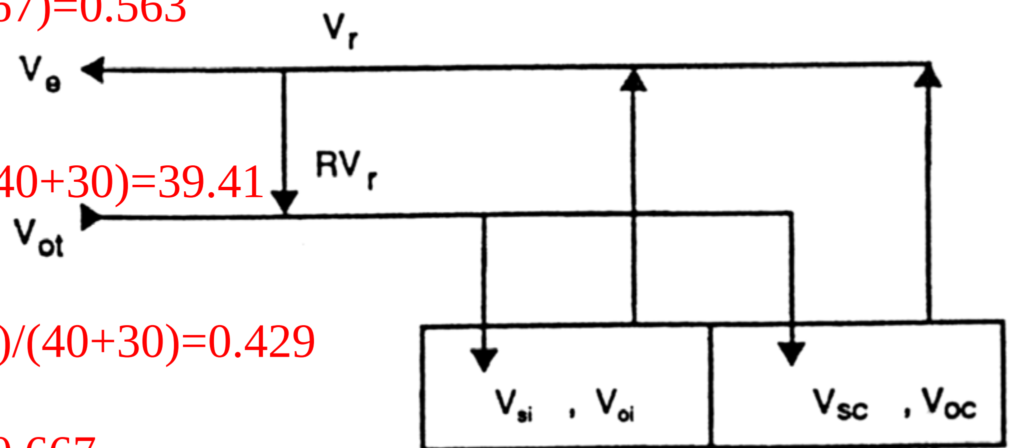
$$Y = X / [1 + X - Z]$$

(5) $V_{ot}=0.563x(40+30)=39.41$

$$Y = V_{ot}/V_{st}$$

$$X = V_{on}/V_{st}$$ (2) $X=(10+20)/(40+30)=0.429$

$$Z=V_{oc}/V_{sc}$$ (3) $Z=20/30=0.667$



Given: 40 10 30 20 L/s

Figure G-1 Multi-zone model.

(Step 1) Outdoor/Supply = 10/40=0.25 =20/30=0.667

∴Critical zone

The corrected total outdoor air = 39.4 L/s

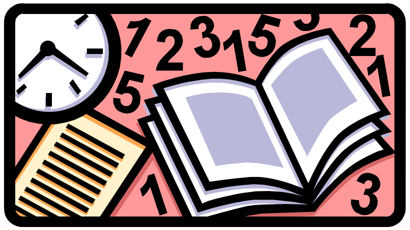
Indoor Air Quality Procedure

TABLE B-1 Comparison of Regulations and Guidelines Pertinent to Indoor Environments[a]

(The user of any value in this table should take into account the purpose for which it was adopted and the means by which it was developed.)

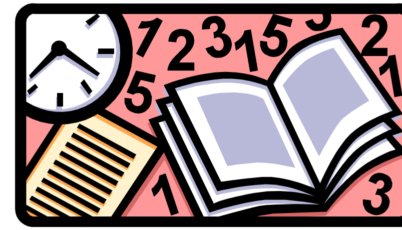
	Enforceable and/or Regulatory Levels			Non-Enforced Guidelines and Reference Levels			
	NAAQS/EPA (Ref. B-4)	OSHA (Ref. B-5)	MAK (Ref. B-2)	Canadian (Ref. B-8)	WHO/Europe (Ref. B-11)	NIOSH (Ref. B-13)	ACGIH (Ref. B-1)
Carbon dioxide		5,000 ppm	5,000 ppm 10,000 ppm [1 h]	3,500 ppm [L]		5,000 ppm 30,000 ppm [15 min]	5,000 ppm 30,000 ppm [15 min]
Carbon monoxide[c]	9 ppm[g] 35 ppm [1 h][g]	50 ppm	30 ppm 60 ppm [30 min]	11 ppm [8 h] 25 ppm [1 h]	90 ppm [15 min] 50 ppm [30 min] 25 ppm [1 h] 10 ppm [8 h]	35 ppm 200 ppm [C]	25 ppm
Formaldehyde[h]		0.75 ppm 2 ppm [15 min]	0.3 ppm 1 ppm[i]	0.1 ppm [L] 0.05 ppm [L][b]	0.1 mg/m^3 (0.081 ppm) [30 min][p]	0.016 ppm 0.1 ppm [15 min]	0.3 ppm [C]
Lead	1.5 µg/m^3 [3 months]	0.05 mg/m^3	0.1 mg/m^3 1 mg/m^3 [30 min]	Minimize exposure	0.5 µg/m^3 [1 yr]	0.1 mg/m^3 [10 h]	0.05 mg/m^3
Nitrogen dioxide	0.05 ppm [1 yr]	5 ppm [C]	5 ppm 10 ppm [5 min]	0.05 ppm 0.25 ppm [1 h]	0.1 ppm[1 h] 0.004 ppm [1 yr]	1 ppm [15 min]	3 ppm 5 ppm [15 min]
Ozone	0.12 ppm [1 h][g] 0.08 ppm	0.1 ppm	j	0.12 ppm [1 h]	0.064 ppm (120 µg/m^3) [8 h]	0.1 ppm [C]	0.05 ppm[k] 0.08 ppm[l] 0.1 ppm[m] 0.2 ppm[n]
Particles[e] <2.5 µm MMAD[d]	15 µg/m^3[1 yr][o] 65 µg/m^3 [24 h][o]	5 mg/m^3	1.5 mg/m^3 for <4 µm	0.1 mg/m^3 [1 h] 0.040 mg/m^3 [L]			3 mg/m^3
Particles[e]<10 µm MMAD[d]	50 µg/m^3[1 yr][o] 150 µg/m^3 [24 h][o]		4 mg/m^3				10 mg/m^3
Radon	See Table B-2[f]				2.7 pCi/L [1yr]		
Sulfur dioxide	0.03 ppm [1 yr] 0.14 ppm [24 h][g]	5 ppm	0.5 ppm 1 ppm[i]	0.38 ppm [5 min] 0.019 ppm	0.048 ppm [24 h] 0.012 ppm [1 yr]	2 ppm 5 ppm [15 min]	2 ppm 5 ppm [15 min]
Total Particles[e]		15mg/m^3					

Methods of Ventilation



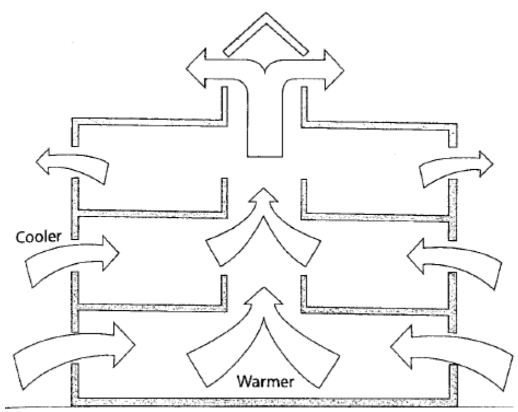
- **Natural Ventilation**
- **Mechanical Ventilation**
- **Displacement Ventilation**

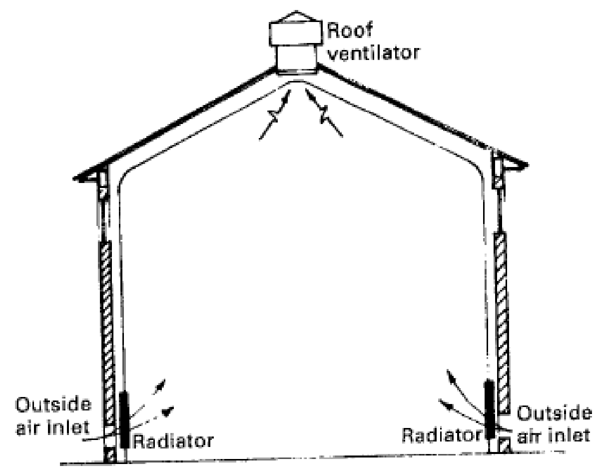
Methods of Ventilation



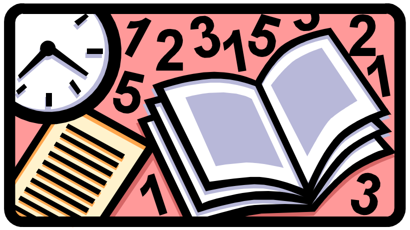
Natural Ventilation

- 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.





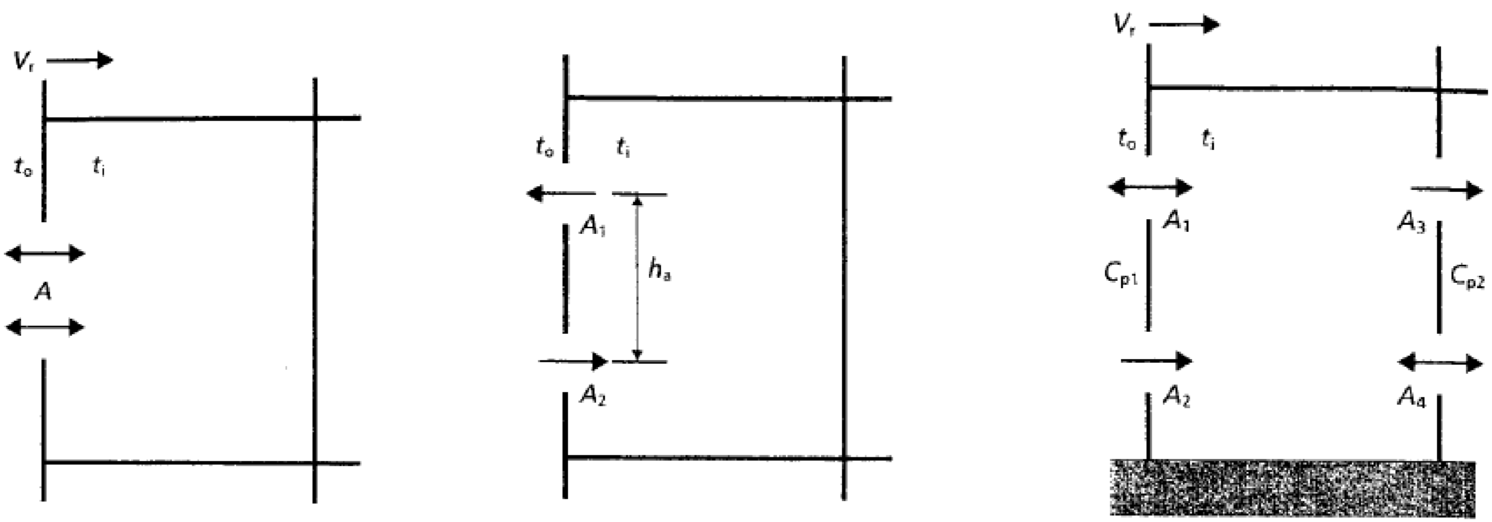
Methods of Ventilation



Wind effect

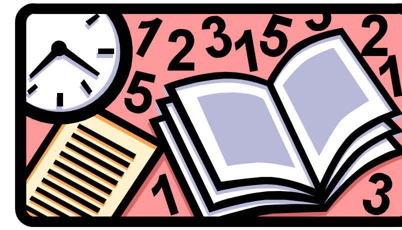
- Air entering through openings in the windward walls, and leaving through openings in the leeward walls

- Establishing a pressure difference across the building.



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

Methods of Ventilation



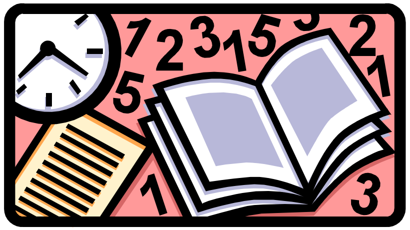
Flow caused by wind

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

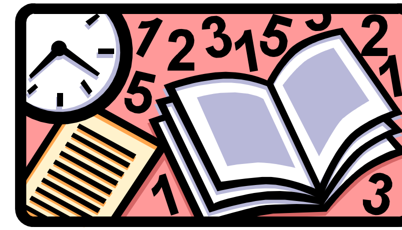


- The following equation shows the air flow rate through ventilation inlet opening forced by wind:

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

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

$$u = u_m K h^a$$

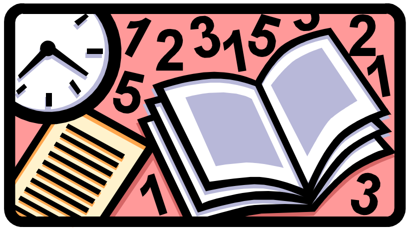
where u = mean wind speed at height h

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

<u>Case one: Inside temperature > outside temperature</u>

Difference in air density =>

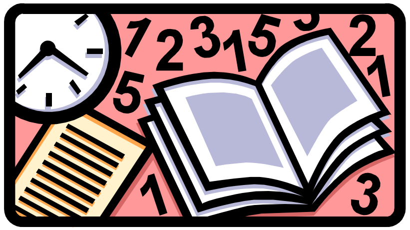
1) Higher density thus higher pressure outside at low level
   Inward air flow at low levels

2) Thus creating an upward air flow inside the space
   Outward flow at high levels.

<u>Case two: Inside temperature< outside temperature</u>

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)

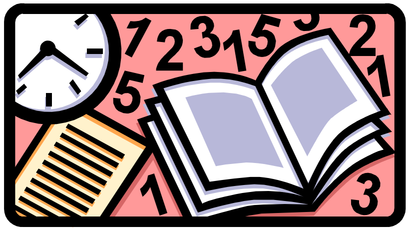
A = free area of inlet openings (m^2)

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

T_i = indoor air temperature (K)

T_o = outdoor air temperature (K)

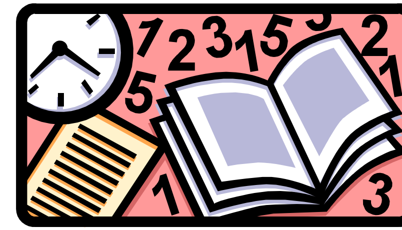
Methods of Ventilation



Points to 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.

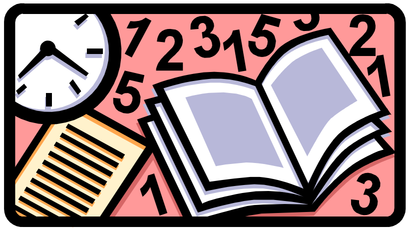
Methods of Ventilation



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 treatment
- Devices for shading, privacy & daylighting may hamper the free flow of air
- Problems with automatic controls in openings

Methods of Ventilation



Mechanical ventilation strategies

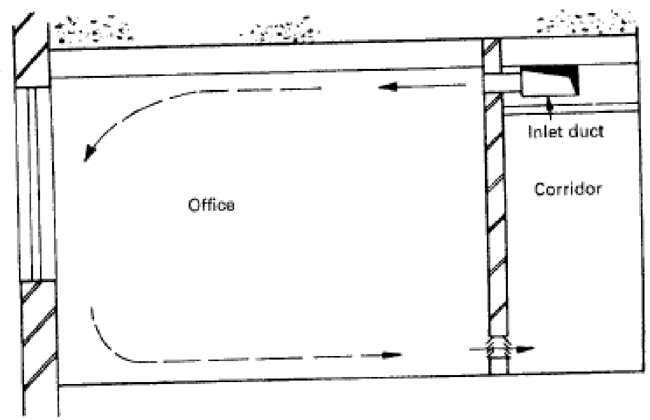
Balanced supply and extract

- 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 (e.g. heat wheels).
- It is also weather independent.
- Effective building sealing is required as the system is designed to be pressure neutral. (Usually a positive pressure is intentionally designed against infiltration, as it is quite impossible to completely seal the building)
- Capital costs are high due to the expense of two separate ductwork systems and increased fan energy requirements.

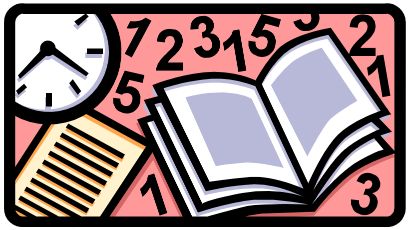
Methods of Ventilation

Mechanical supply & natural exhaust

- 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).

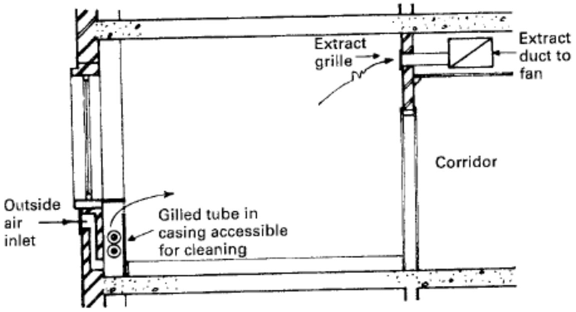


Methods of Ventilation

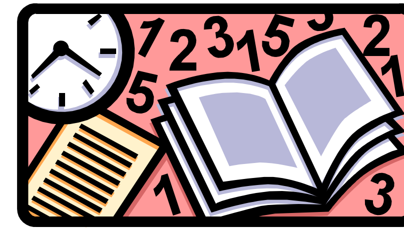


Mechanical exhaust & natural supply

- 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.

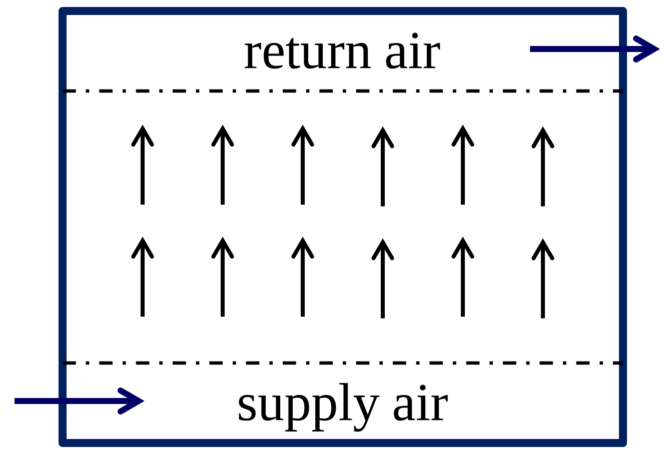


Methods of Ventilation

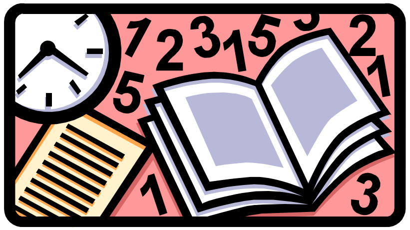


Displacement Ventilation

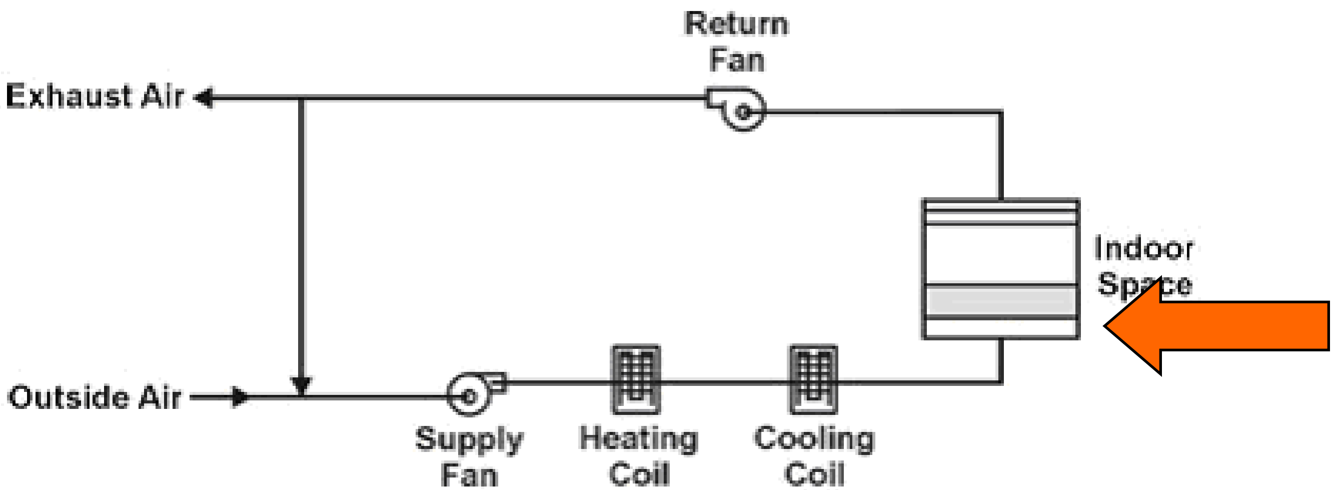
- Displacement ventilation uses a low-velocity stream of fresh cold air supplied near the floor to slowly "displace" the stale air up toward the ceiling from where it leaves the room.
- This stratifies the air in the room, with warm stale air concentrated above the occupied zone and cool fresher air in the occupied zone.



Methods of Ventilation

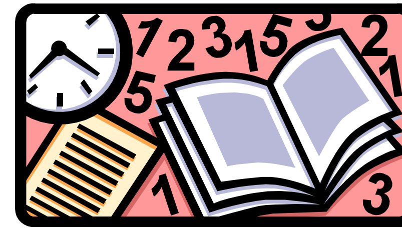


Displacement Ventilation



Schematic diagram of displacement ventilation

Methods of Ventilation



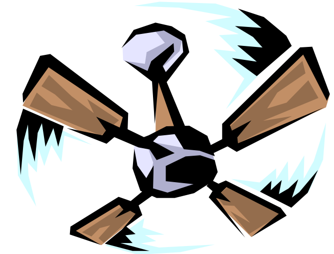
Displacement ventilation reduces the energy consumption in several ways:-

- 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

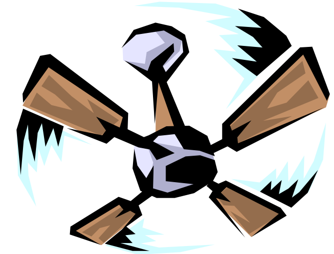


Control of Air Pollution in Car Parks

Air Quality Guidelines

- 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
  - Carbon monoxide blocks the absorption of oxygen by the blood and this can lead to dizziness, unconsciousness, or death depending on the concentration.
- diesel engine vehicles are the source of most but not all nitrogen dioxide.
  - 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

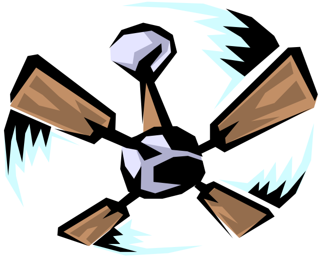
<u>Air Quality Guidelines</u>

Air Pollutants	Averaging Time	Maximum Concentration: Microgrammes Per Cubic Metre ($\mu g/m^3$)	Maximum Concentration: 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.

- **All limits are expressed as at reference conditions of 298 K and 01.325 kPa.**

Ventilation - Applications

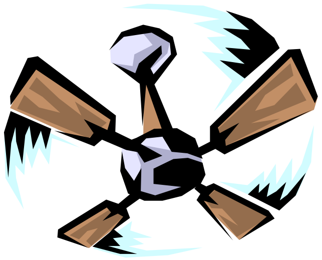


Control of Air Pollution in Car Parks

Design Considerations

- 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

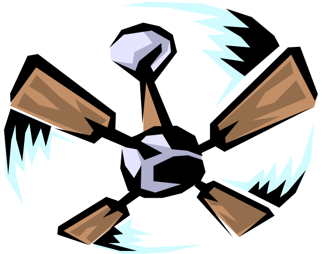
- Sufficient standby units should be provided to meet the air quality guidelines during maintenance periods or in the event of the break down of the normal units.

- 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

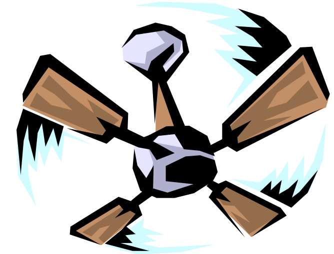


Kitchen Exhaust

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

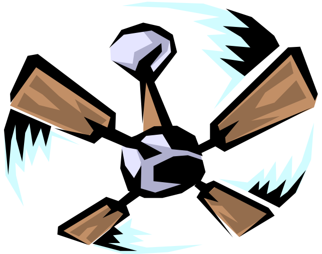
Oily Fume and Cooking Odour Control

- 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

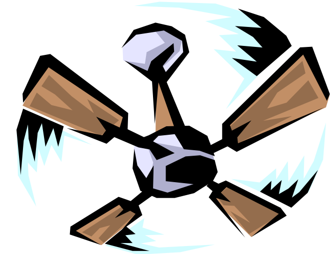
Grease Filters

- 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



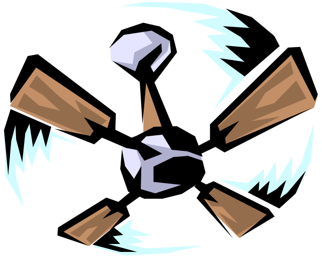
Available Techniques for the Control of Oily Fume & Odour emissions
Hydrovent /Air Washer

- 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

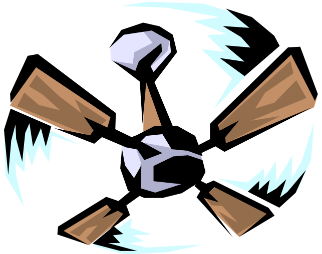


Available Techniques for the Control of Oily Fume & Odour emissions

Electrostatic Precipitators (ESPs)

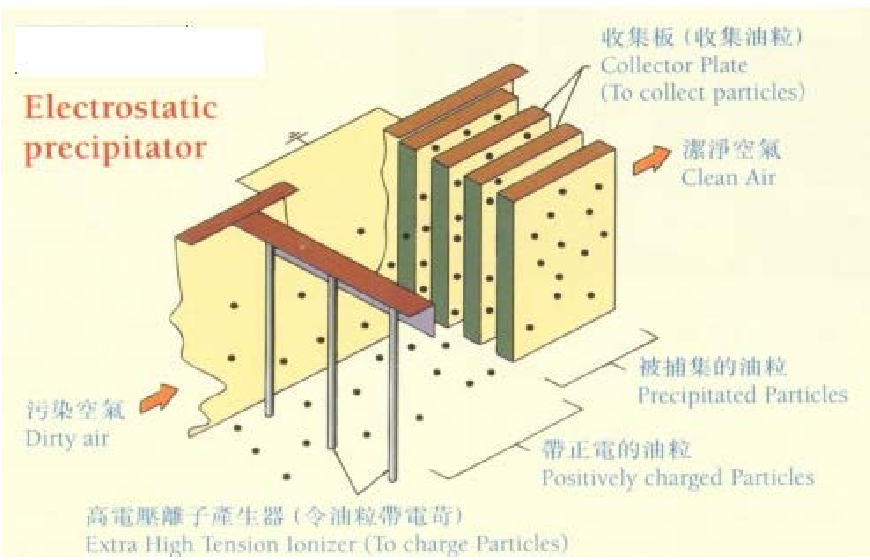
- If properly designed and maintained, ESPs can achieve a high collection efficiency for oily fume.
- Since oily fume is sticky and easily coated on the collector plates and render the equipment inoperative, ESPs should be cleaned/serviced regularly and properly.
- A weekly servicing should be the minimum 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.

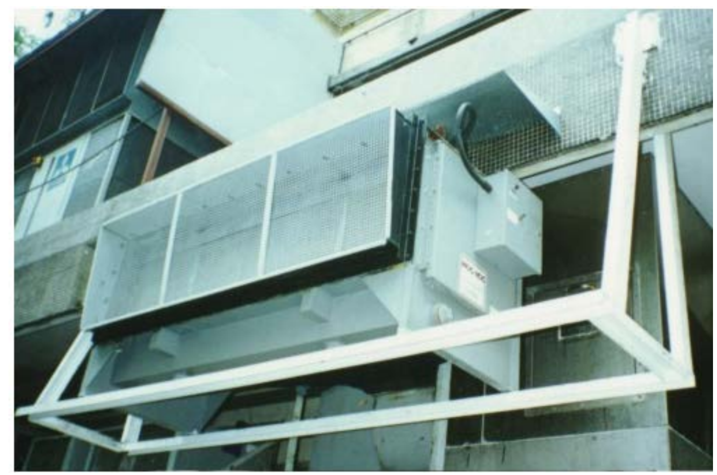
Ventilation - Applications



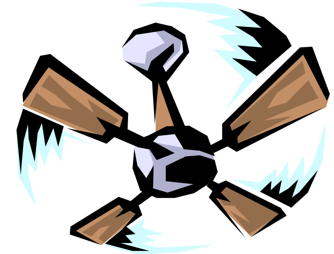
Available Techniques for the Control of Oily Fume & Odour emissions

Electrostatic Precipitators (ESPs)





Ventilation - Applications



Available Techniques for the Control of Oily Fume & Odour emissions

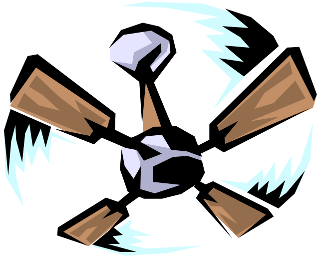
Venturi Scrubbers

- 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

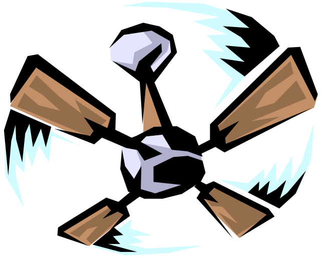


Ventilation for Food Premises

- 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

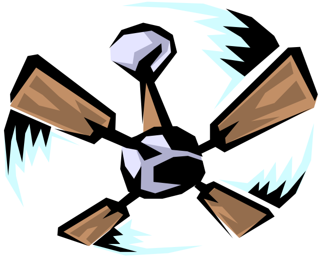


Ventilating Systems for Seating Accommodation inside Restaurants and Factory Canteens

- 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

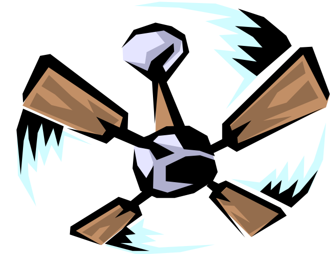
Some degree of access

- 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

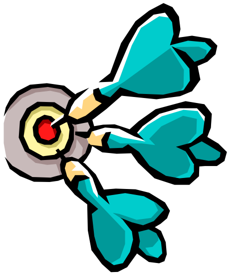
The velocity at a given distance from an opening of exhaust hood (decreased with increase of distance from openings) can be predicted from: -

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

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



<u>Mechanical Ventilation</u>

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.

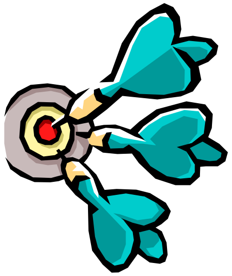
During Δt, Δq air enters the room that is free of carbon dioxide.

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

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

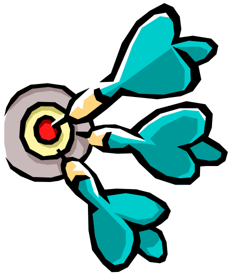
Taking Q is rate of influx of ventilating air with

$Q = \dfrac{\Delta q}{\Delta t}$ 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: -

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

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

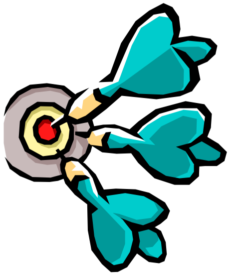
$$\log_e c = -\frac{Qt}{V} + \log_e k$$

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

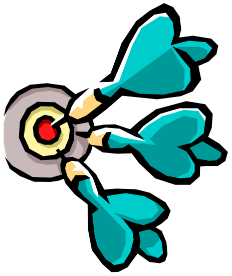


<u>Case 2 – The fresh air contained carbon dioxide</u>

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



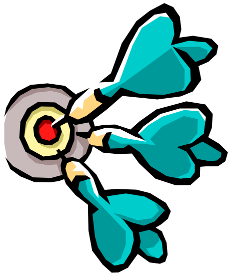
Consider the change in carbon dioxide level: -

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 = $\frac{Q' \Delta t c}{10^6}$ --------(3)

Simple Models for Ventilation



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

Change in concentration of carbon dioxide/person

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

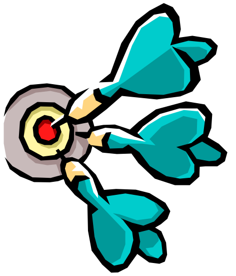
That is,

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

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

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

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.

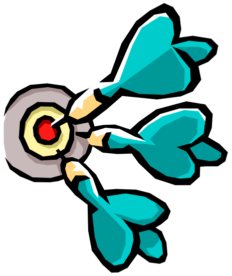
With t = 0, c = c_0, we have

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

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 $t \rightarrow \infty$

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

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

This is the steady state equation.

Pollutant Concentration Equation

c = pollutant concentration in the room

c_o = pollutant concentration of outdoor air

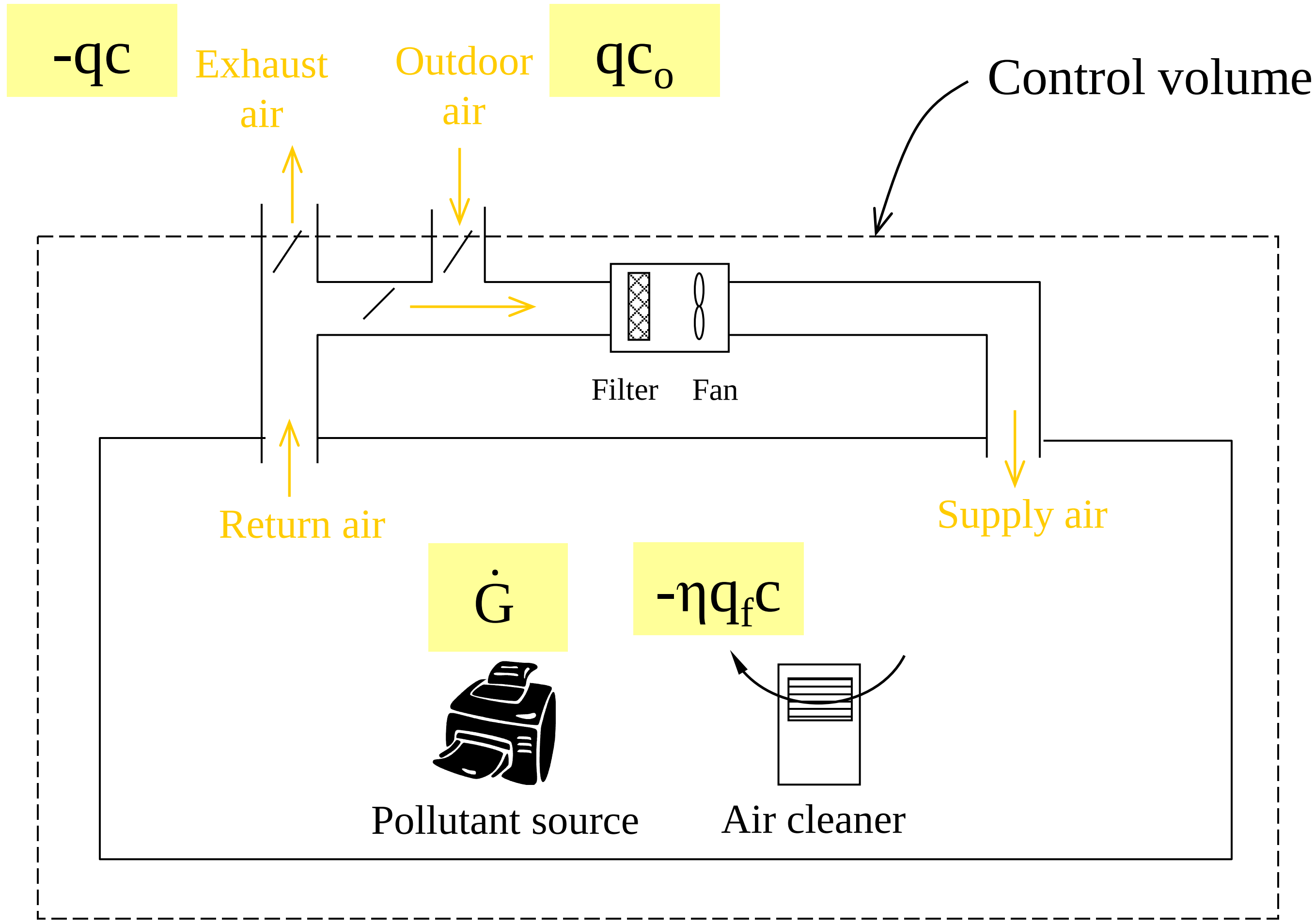
q = volumetric flow rate of outdoor air intake

q_f = volumetric flow rate of air passing through air cleaner

$\dot{G}$ = generation rate of indoor pollutant

η = air cleaner efficiency (e.g. dust removal)

t = time



$$V\frac{dc}{dt} = q(c_o - c) + \dot{G} - \eta q_f c$$

Pollutant Concentration Equation

Governing equation,

$$V\frac{dc}{dt} = q\left(c_o - c\right) + \dot{G} - \eta q_f c$$

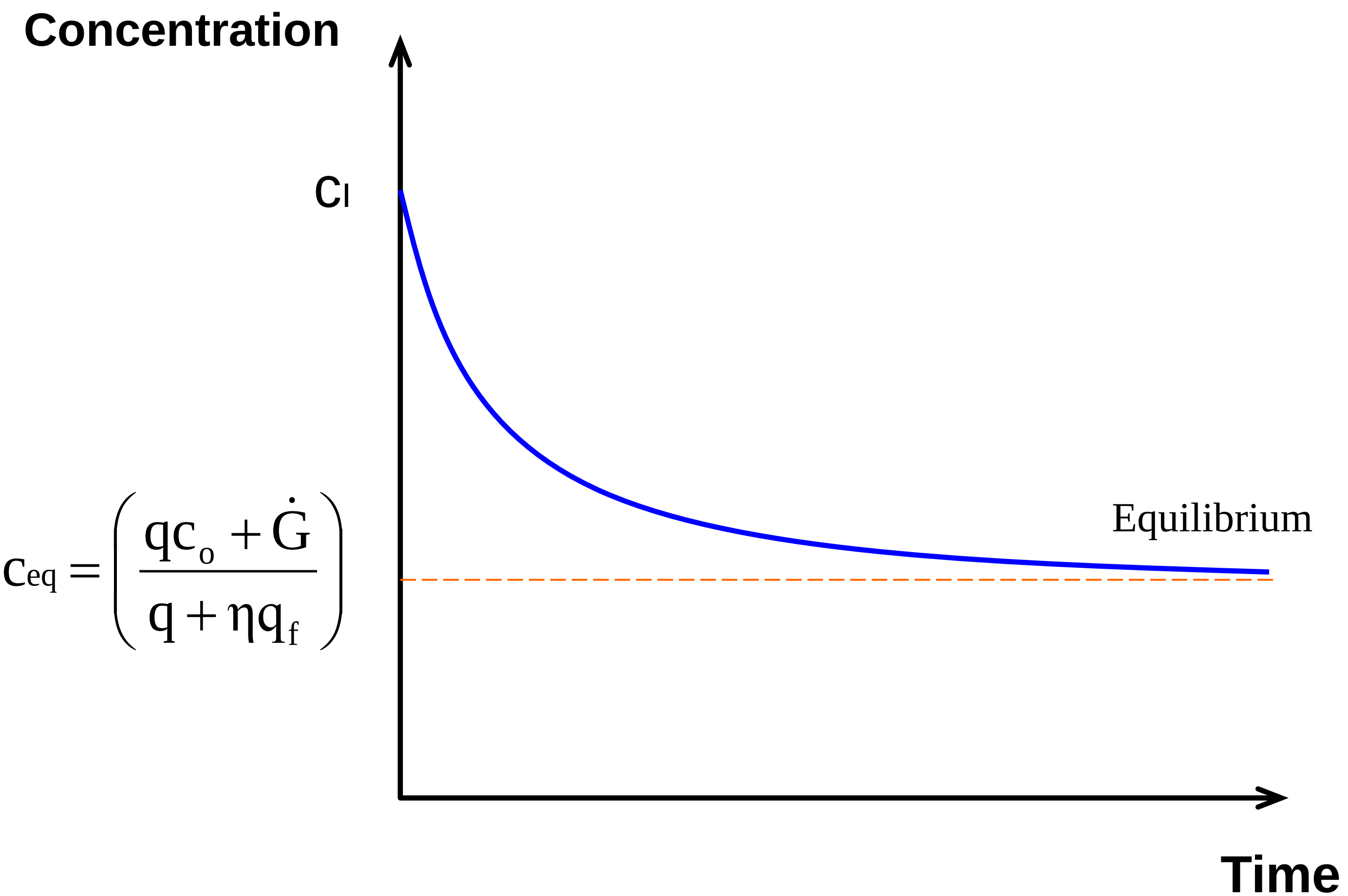
Initial condition (t = 0 sec)**,**

$$c = c_I$$

Solution,

$$c = \left(\frac{qc_o + \dot{G}}{q + \eta q_f}\right)\left[1 - e^{-\left(\frac{q+\eta q_f}{V}\right)t}\right] + c_I e^{-\left(\frac{q+\eta q_f}{V}\right)t}$$

Concentration Profile



$$c_{eq} = \left(\frac{q c_o + \dot{G}}{q + \eta q_f} \right)$$