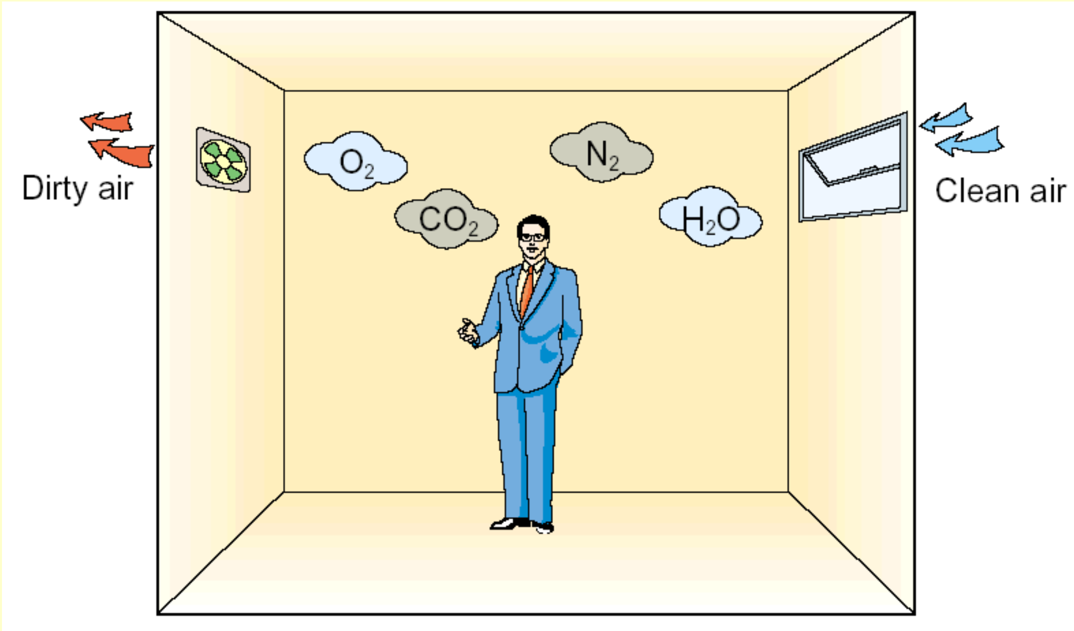

Mechanical and Natural Ventilation

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- Ventilation Requirements
- Natural Ventilation
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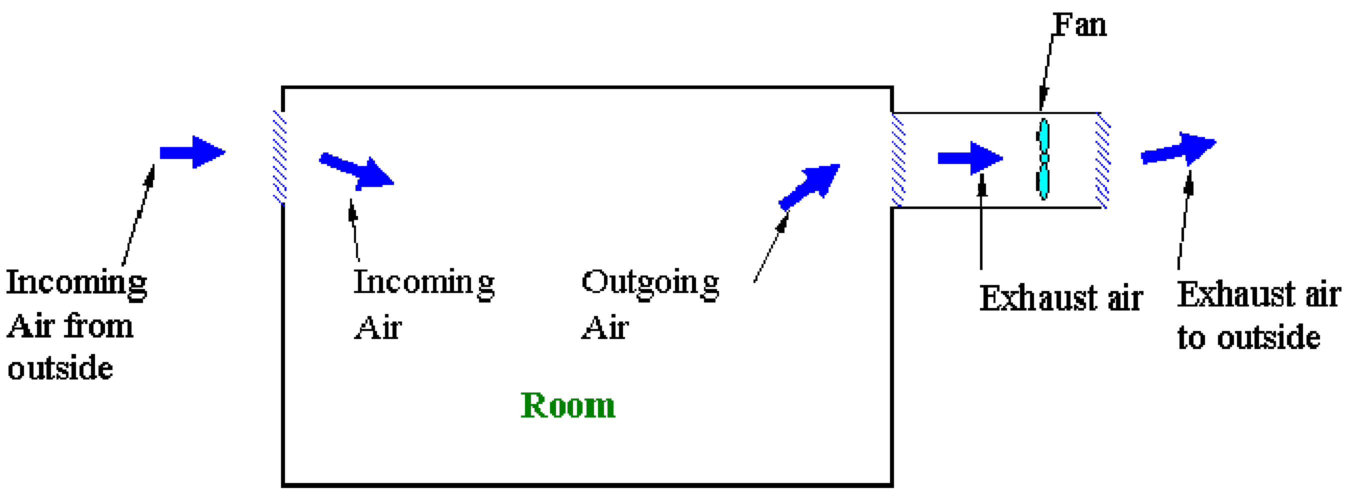
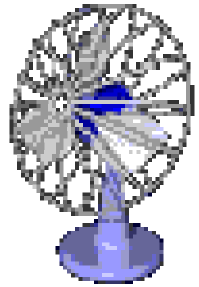
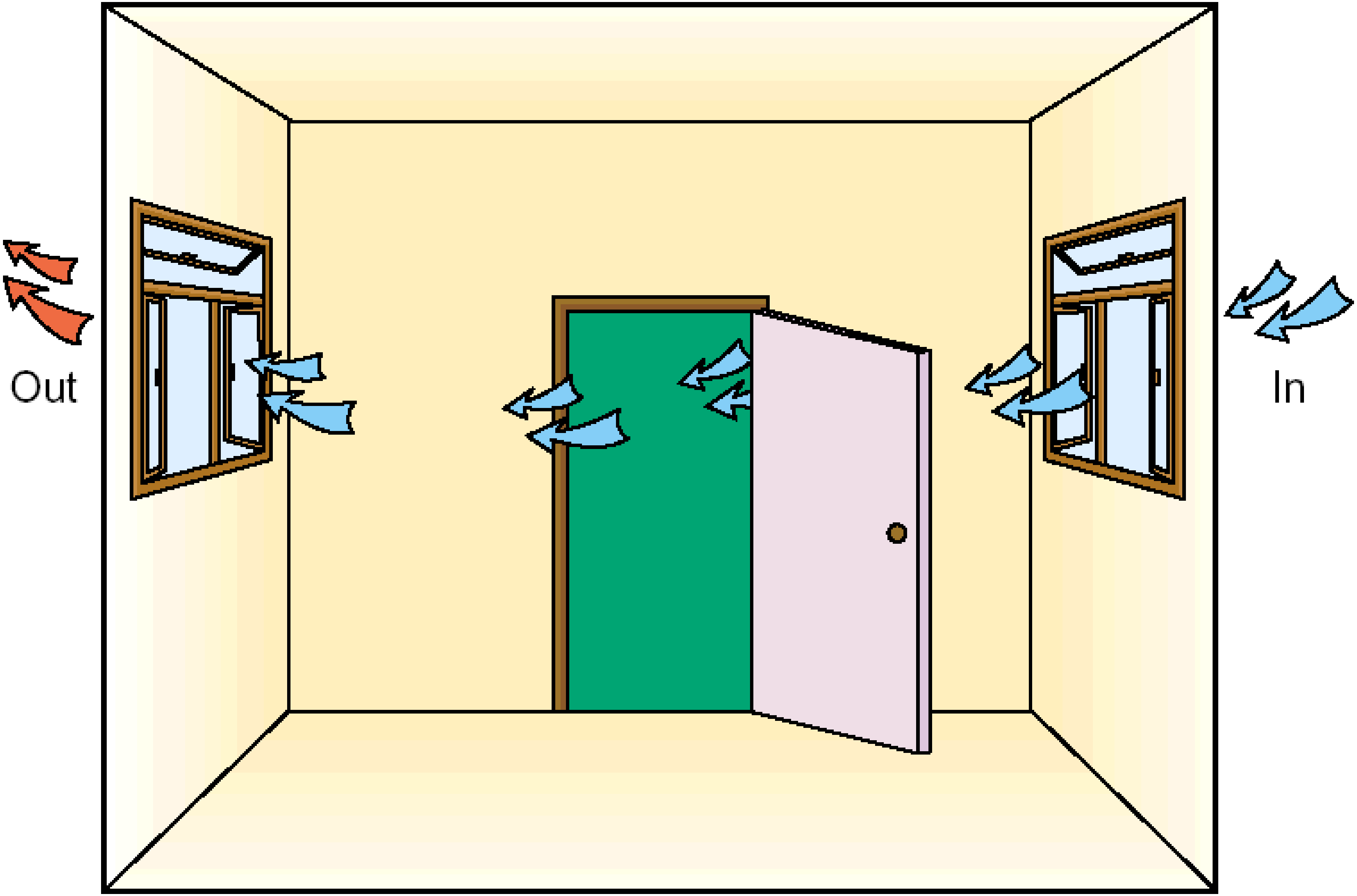


Basic Concepts



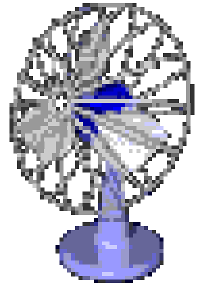
- What is Ventilation (通風)?
  - The process by which fresh air is introduced and ventilated air is removed
  - Primary aim: to preserve the qualities of air
    - May also be used to lower temperature & humidity
- Natural ventilation
  - By means of purpose-provided aperture (such as openable windows, ventilators and shafts) and the natural forces of wind and temperature-difference pressures

Natural ventilation (e.g. cross ventilation 穿堂風)



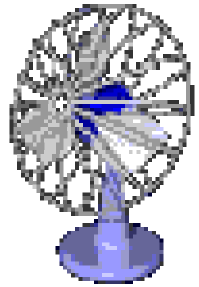
(Source: Environmental Protection Department)

Basic Concepts



- Two categories of natural ventilation:
  - Controlled natural ventilation
    - Intentional displacement of air through specified openings such as windows, doors, and ventilators by using natural forces
    - Usually controlled to some extent by the occupant
  - Infiltration (air leakage into a building)
    - Uncontrolled random flow of air through unintentional openings driven by wind, temperature-difference pressures and/or appliance-induced pressures across the building envelope

Basic Concepts



- Mechanical (or forced) ventilation
  - By means of mechanical devices, such as fans
  - May be arranged to provide either supply, extract or balanced ventilation for an occupied space
- Exfiltration
  - Leakage of indoor air out of a building through openings (similar to infiltration)
  - When indoor space is at higher (+ve) pressure than outdoor

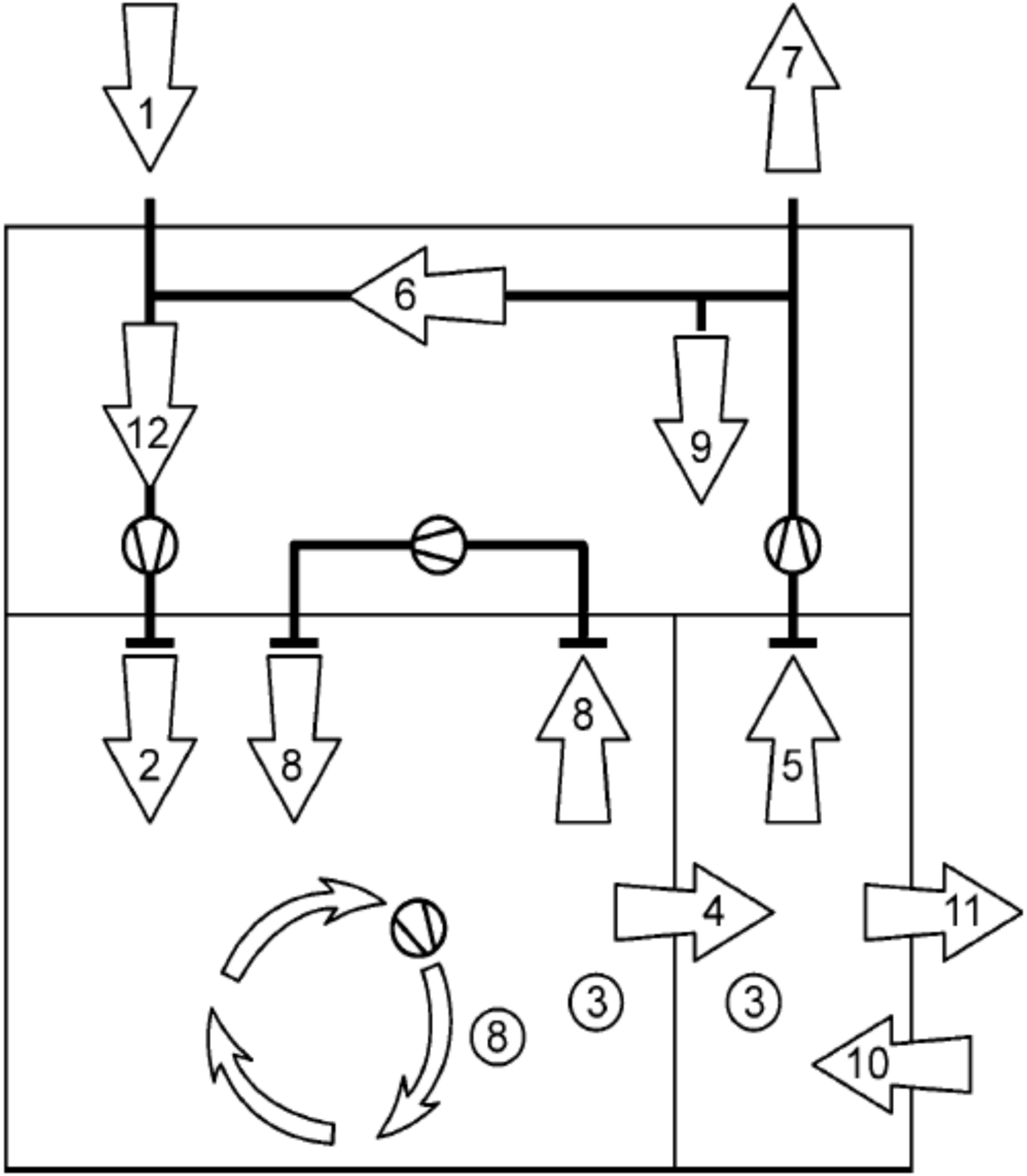
Mechanical ventilation (extract ventilation)

What will happen if the windows are closed?

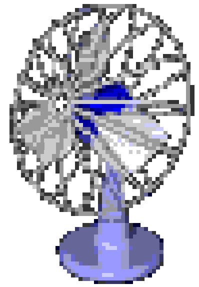
(Source: Environmental Protection Department)

Analysis of air flow

1. Outdoor air
2. Supply air
3. Indoor air
4. Transferred air
5. Extract air
6. Recirculation air
7. Exhaust air
8. Secondary air
9. Leakage
10. Infiltration
11. Exfiltration
12. Mixed air

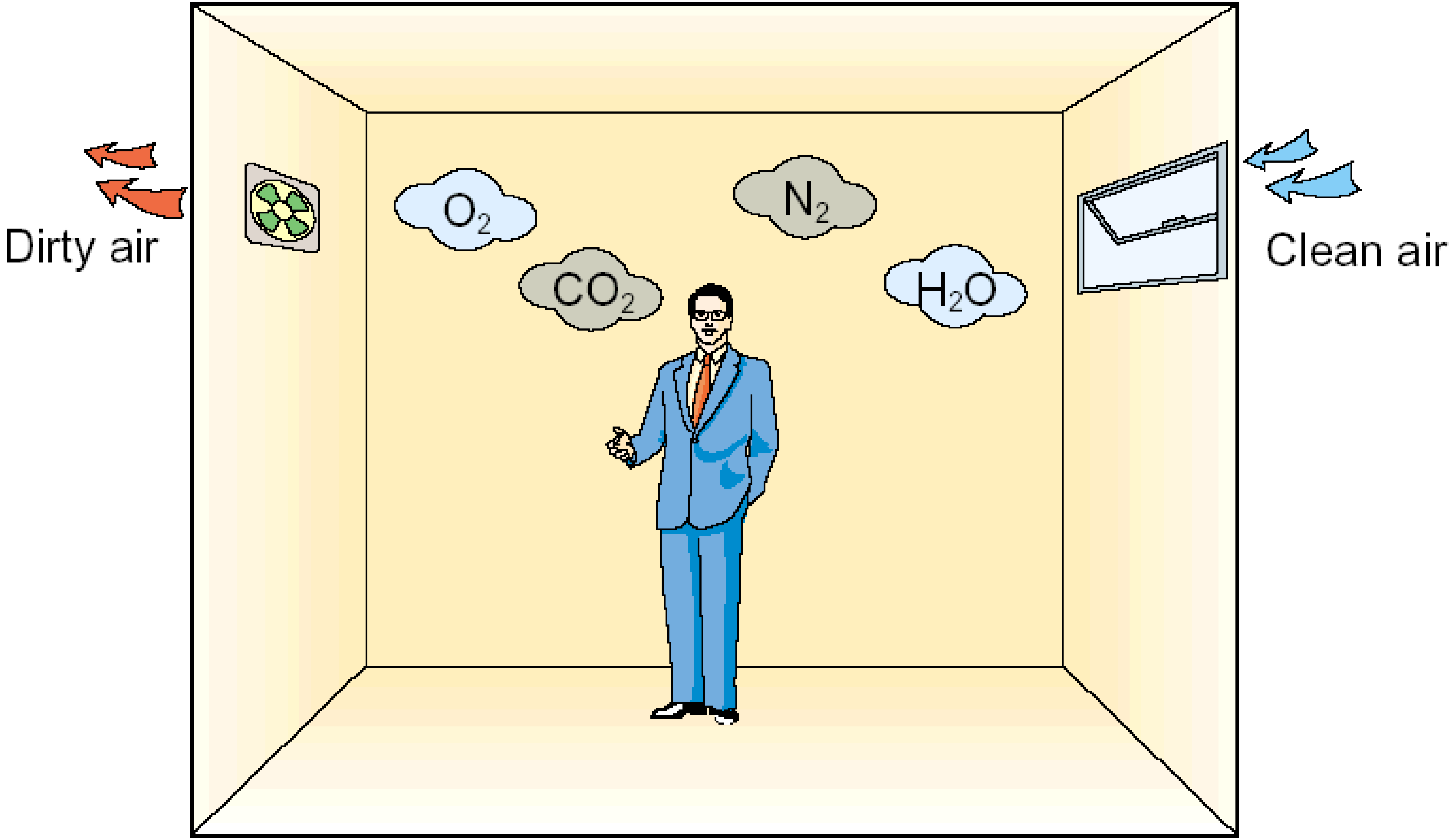


Ventilation Requirements



- Ventilation for supporting life
  - Maintain sufficient oxygen in the air
  - Prevent high concentration of carbon dioxide
  - Remove odour, moisture & pollutants
- Poor ventilation and indoor air quality
  - Impact on human health & productivity
- CO_2 as an index of air quality
  - < 1,000 ppm, corresponds to fresh air 7 l/s/person
  - < 800 ppm, corresponds to fresh air 10 l/s/person

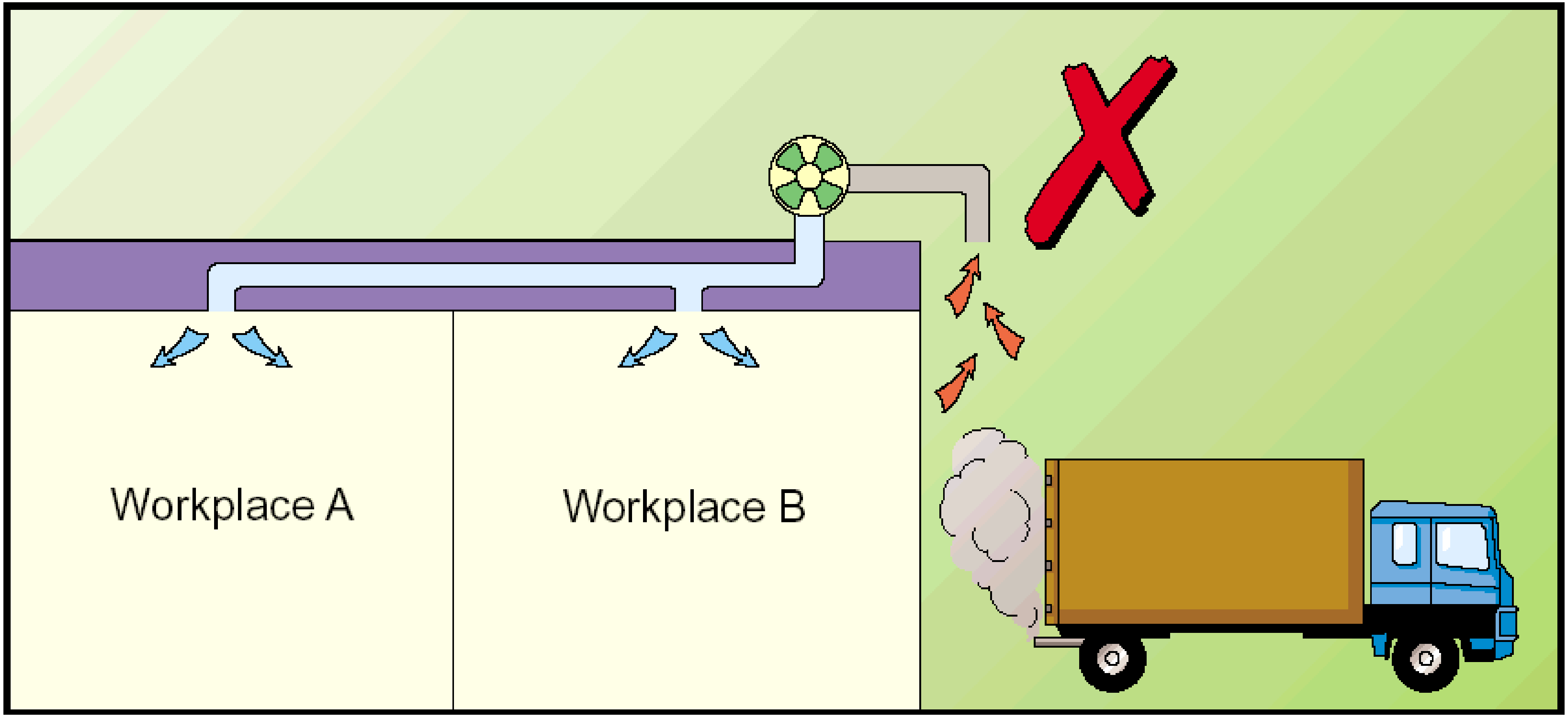
Ventilation to remove pollutants and moisture



* Remember, source control is usually more effective than ventilation

(Source: Environmental Protection Department)

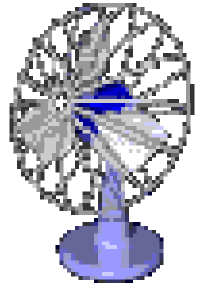
Ventilation system design should avoid intake of vehicle exhaust



* Also ensure outdoor air intake is of adequate quality

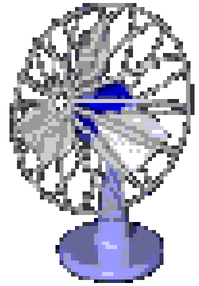
(Source: Environmental Protection Department)

Ventilation Requirements



- Purposes of ventilation
  - Maintain human comfort and health
  - Provide sufficient air/oxygen for human/livestock
  - Provide sufficient air/oxygen for processes
  - Remove products of respiration and bodily odour
  - Remove contaminants or harmful chemicals
  - Remove heat generated indoor
  - Create air movement (feeling of freshness/comfort)

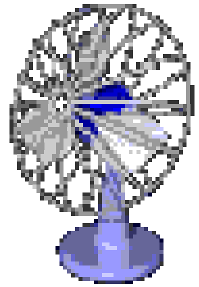
Ventilation Requirements



- For removal of indoor pollution
  - Estimate production rates of all known pollutants
  - Select the largest ventilation rate for design
- Standards & guides, e.g. ASHRAE Standard 62.1 and CIBSE Guide B2
  - Prescriptive procedure and analytical procedure
- In Hong Kong, the related building regulation
  - e.g. Building (Ventilating Systems) Regulations -- Chapter 123J

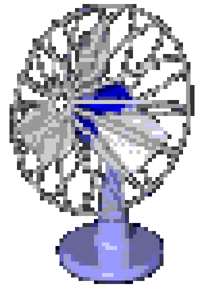
(See also: Ventilation Design http://www.arca53.dsl.pipex.com/index_files/vent7.htm)

Ventilation Requirements



- Ventilation calculations
  - For general mechanical ventilation:
    - Ventilation Rate (m^3/h) = Air Change Rate (/h) x Room Volume (m^3)
      - Ventilation Rate (m^3/s) = Ventilation Rate (m^3/h) / 3600
  - For calculating fresh air ventilation rates
    - Fresh air rate (m^3/s) = Fresh air rate per person (l/s/p) x number of occupants
- Ventilation effectiveness
  - Depend on ventilation strategy, air distribution method, room load & air filtration

Ventilation Requirements

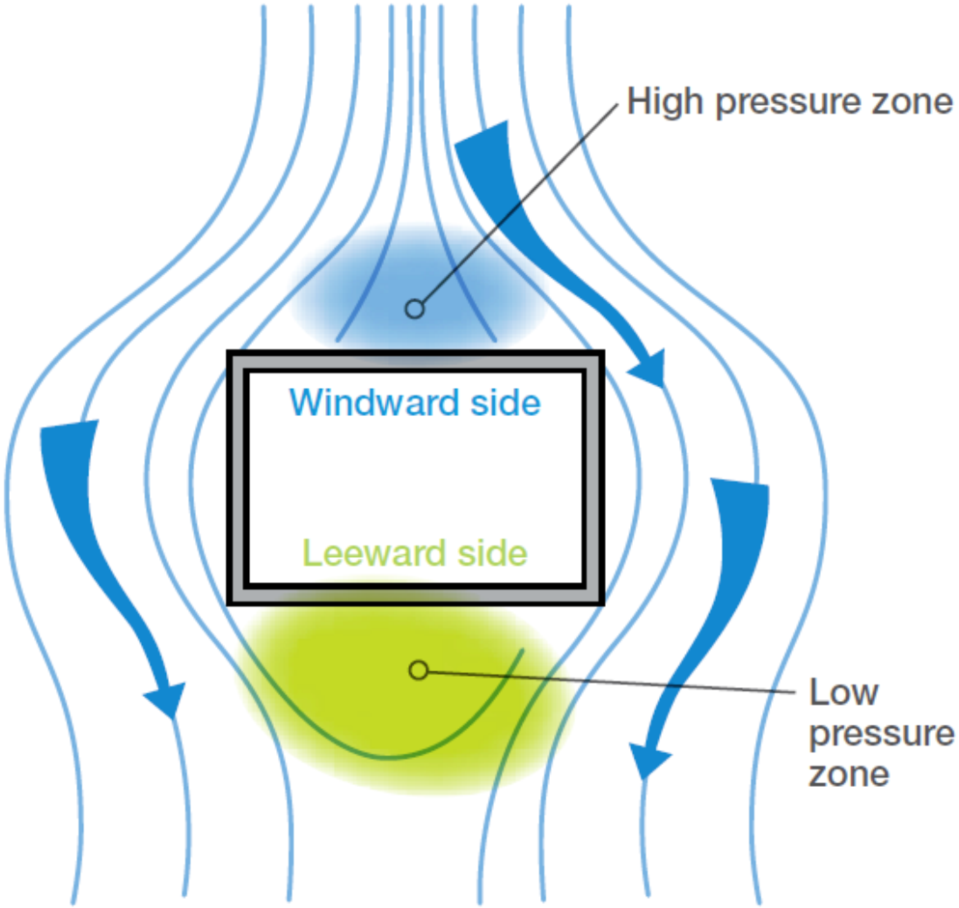


- Determine the required ventilation rate (*Q*):
  - (a) Maximum allowable concentration of contaminants (C_i)
    - $C_i = C_o + F / Q$
  - (b) Heat generation inside the space (*H*)
    - $Q = H / [c_p \times \rho \times (T_i - T_o)]$
  - (c) Air change rates (*ACH*)
    - $Q = V \times ACH / 3.6$

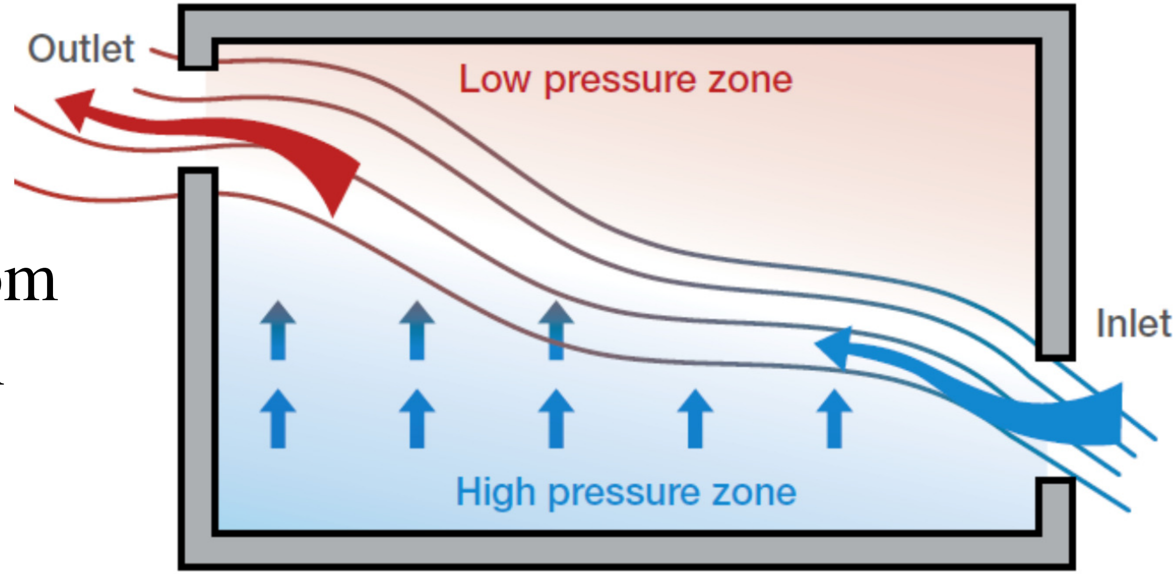
Natural Ventilation

- For air to move into and out of a building, a pressure difference is required
- Resistance to air flow through the building will affect the actual air flow rate
- The pressure difference is caused by:
  - 1. Wind effect
  - 2. Stack or chimney effect
  - 3. Combination of both wind and stack effects

(See also: Natural Ventilation -- HK Green Building Technology Net http://gbtech.emsd.gov.hk/english/utilize/natural.html)



Pressure effect from wind

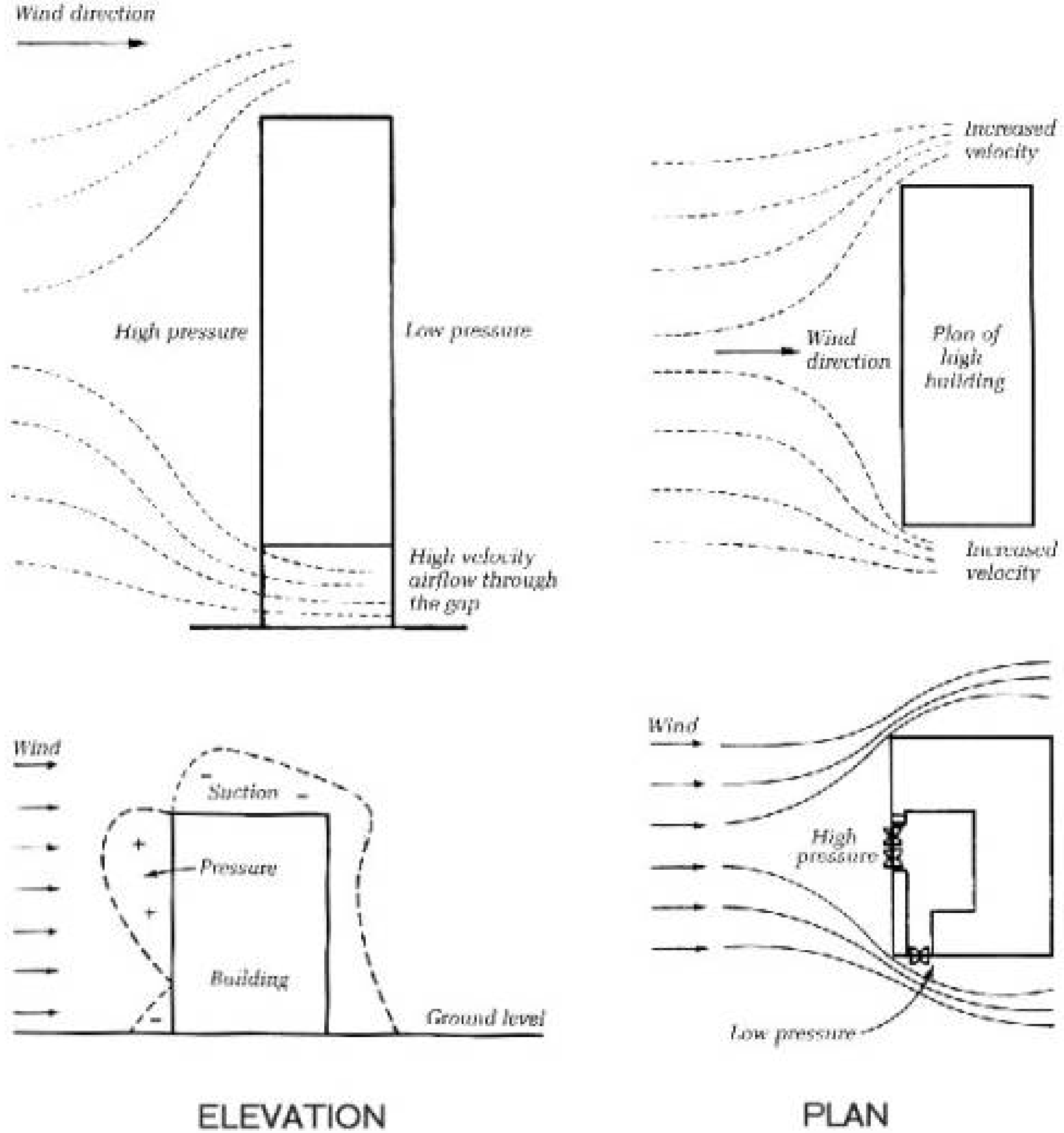


Pressure effect from stack ventilation

Natural Ventilation

- Wind effect
  - Air flow around a building
    - Wind pressure +ve windward side, -ve leeward side
  - Wind pressure depends on:
    - Wind speed and direction
    - Location and surrounding environment
    - Shape of the building
  - Wind pressure on building surfaces

$$P_w - P_o = C_p \cdot \frac{1}{2} \cdot \rho \cdot v_w^2$$



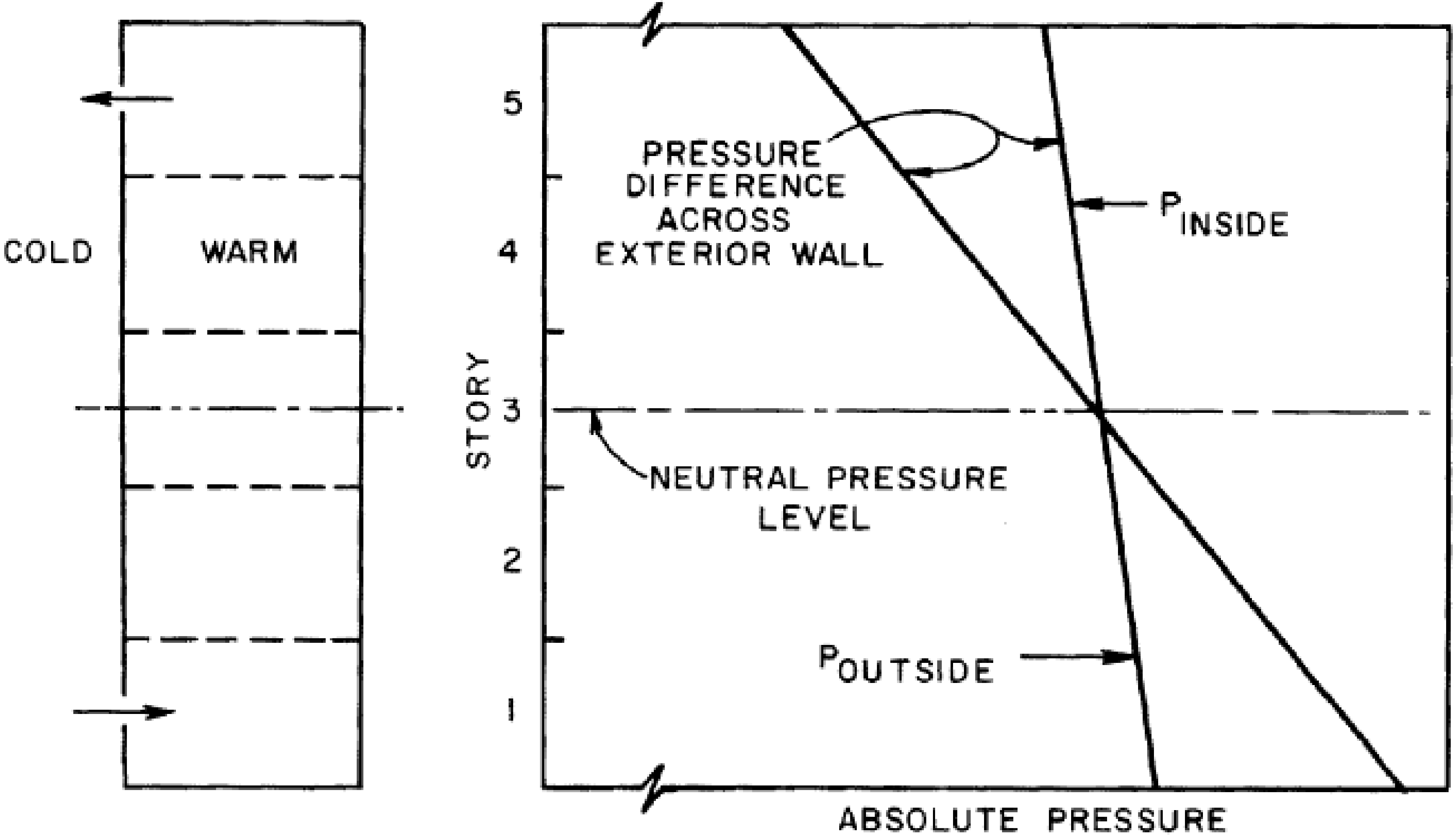
(Source: ASHRAE Handbook Fundamentals 2005)

Natural Ventilation

- Stack effect: air movement due to temp. difference between indoor and outdoor
  - Flow of air in vertical direction and along the path of least resistance
    - Winter: air flowing up; Summer: air flowing down
  - A neutral pressure level (NPL) exists where the interior and exterior pressures are equal
  - Pressure difference due to stack effect is given by:

$$\Delta P_s = (\rho_o - \rho_i) \cdot g \cdot (h - h_{neutral}) = \rho_i \cdot g \cdot (h - h_{neutral}) \cdot \frac{T_i - T_o}{T_o}$$

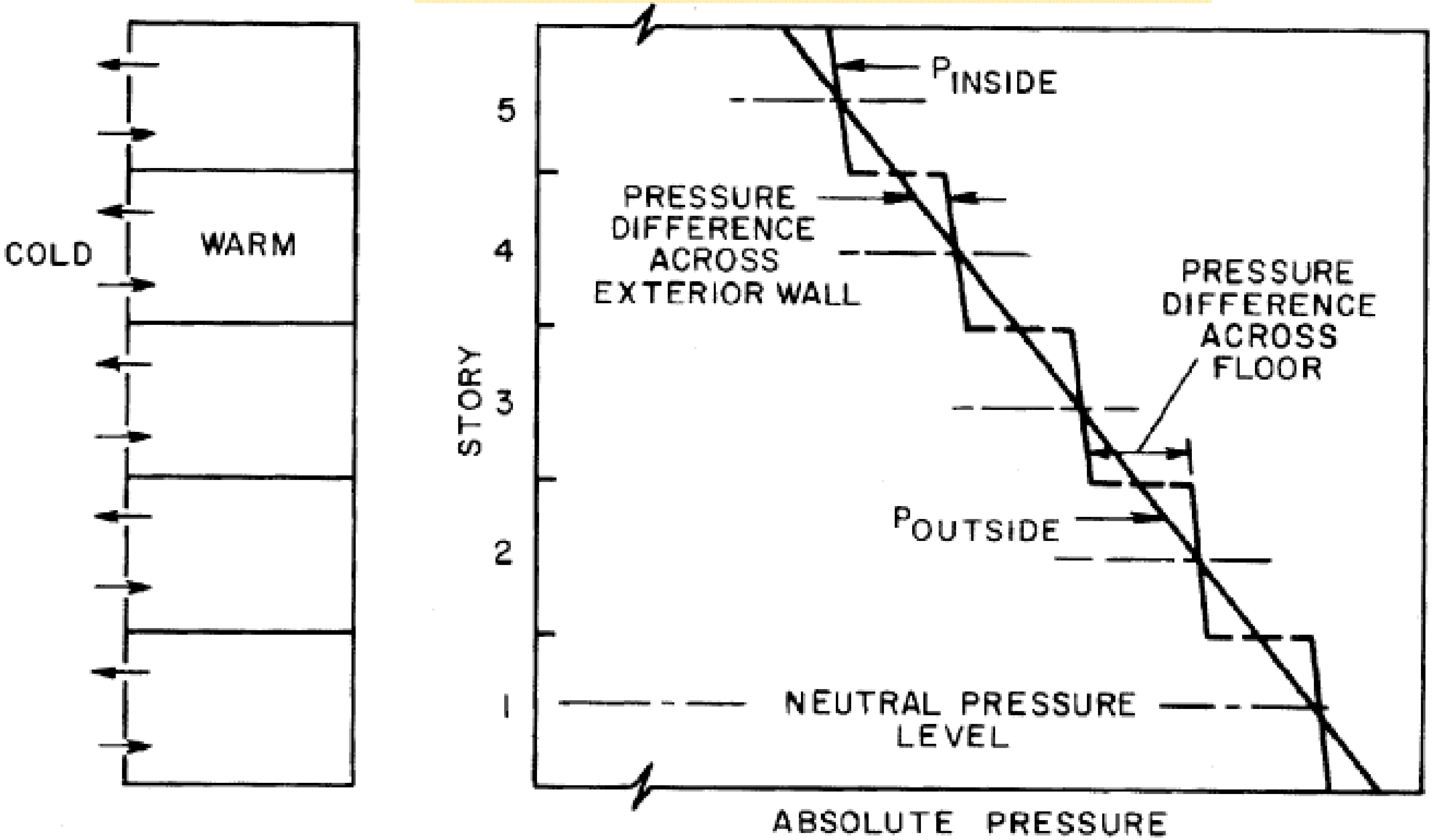
Neutral pressure level is not necessarily at the middle height



A. BUILDING WITH NO INTERNAL PARTITION

(Source: ASHRAE Handbook Fundamentals 2005)

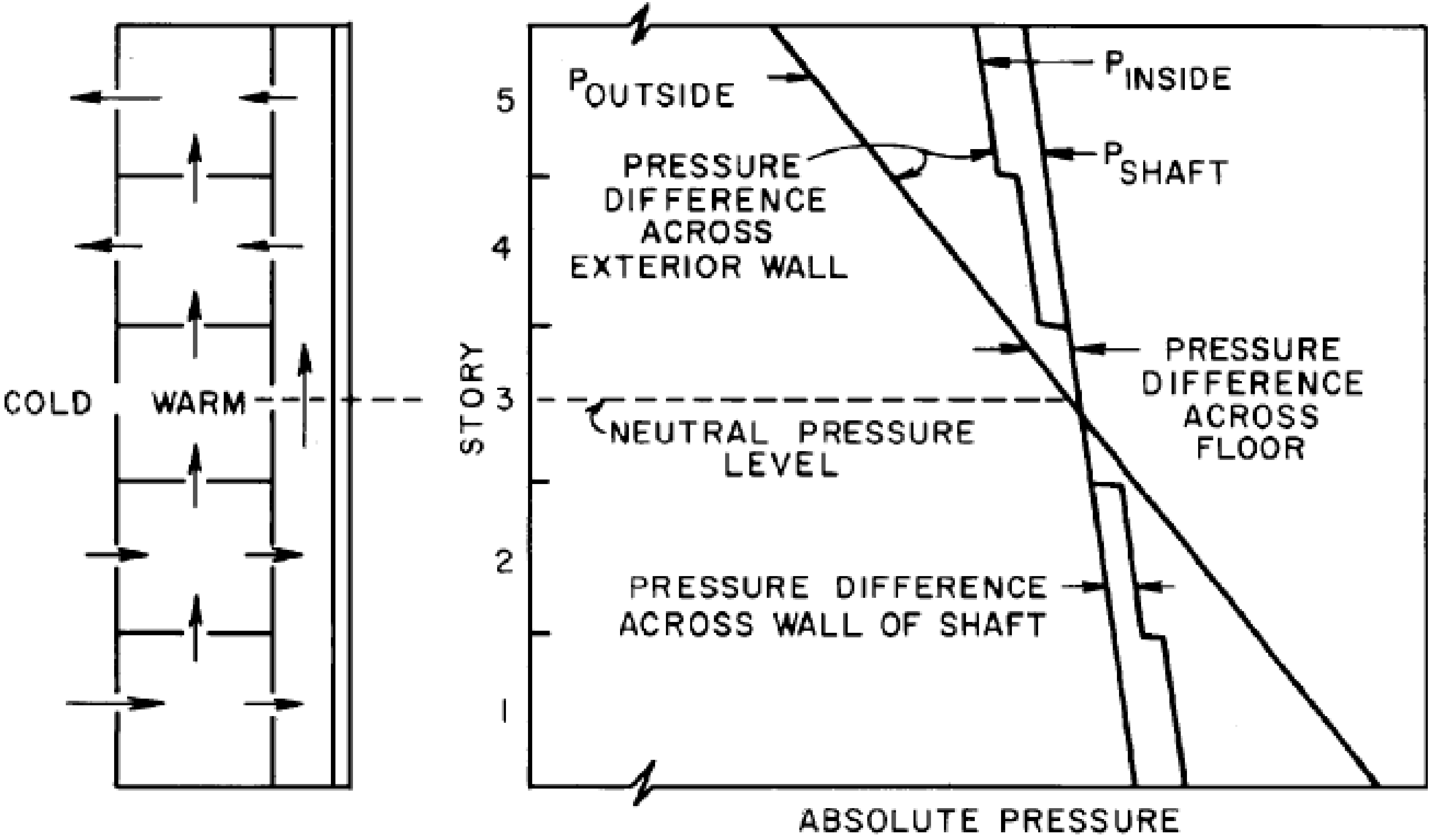
Each floor is separate and independent



B. BUILDING WITH AIRTIGHT SEPARATION OF EACH STORY

(Source: ASHRAE Handbook Fundamentals 2005)

Floors are connected by a shaft and openings



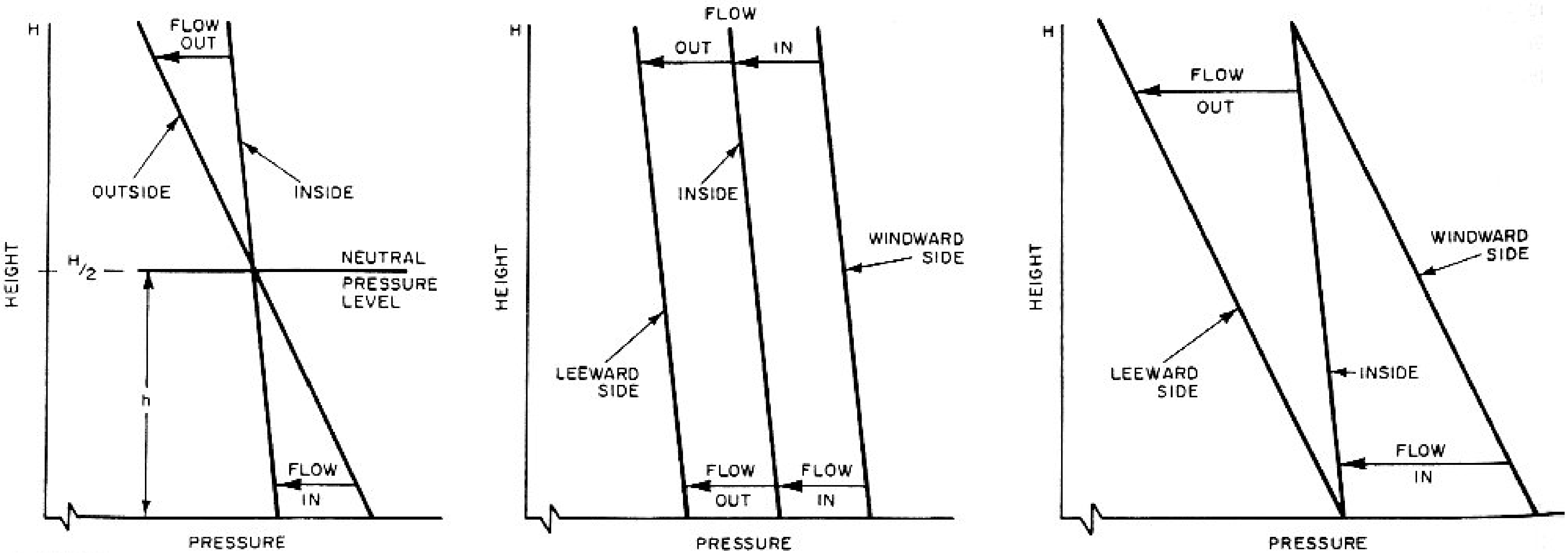
C. IDEAL BUILDING

(Source: ASHRAE Handbook Fundamentals 2005)

Natural Ventilation

- Combined effect of wind and temp. difference
  - Most commonly found
  - Pressures due to each effect are added together
  - The relative importance of wind and stack pressures depends on:
    - Building height
    - Internal resistance to vertical air flow
    - Location and flow resistance of openings
    - Local terrain and immediate shielding

Combined effect of wind and thermal forces



A. STACK ACTION ONLY WITH NEUTRAL PRESSURE LEVEL AT MID-HEIGHT

B. WIND ACTION ONLY WITH PRESSURES OF EQUAL MAGNITUDE ON WINDWARD AND LEEWARD SIDES

C. WIND AND STACK ACTION COMBINED

(Source: ASHRAE Handbook Fundamentals 2005)

Natural Ventilation

- Infiltration – uncontrolled air flow through building envelope driven by pressures from:
  - Wind
  - Temp. difference between indoor and outdoor
  - Operation of mechanical exhaust
- Characteristics determined by:
  - Measuring air leakage of building envelope
  - Typical leakage rates (residential) = 6 to 10 ACH at 50 Pa pressure difference

Natural Ventilation

- Building air leakage (e.g. at cracks)
  - A measure of air tightness of building envelope
    - Expressed as (effective) air leakage area
    - Varies with design, construction, season and age
    - No simple relationship with air exchange rate
- Air leakage may be determined by:
  - Pressurisation testing
  - Tracer gas measurement

(See also: Natural Ventilation Systems http://www.arca53.dsl.pipex.com/index_files/natvent.htm)

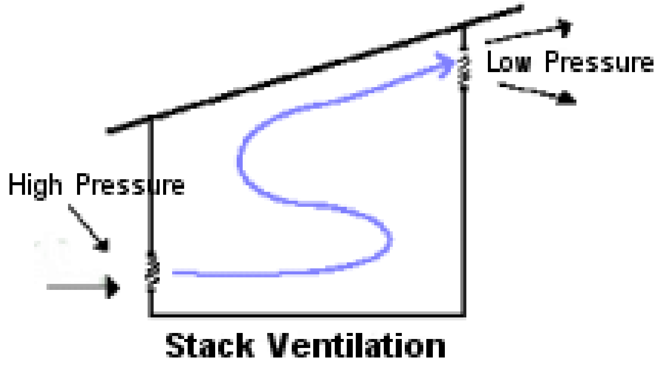
Natural Ventilation

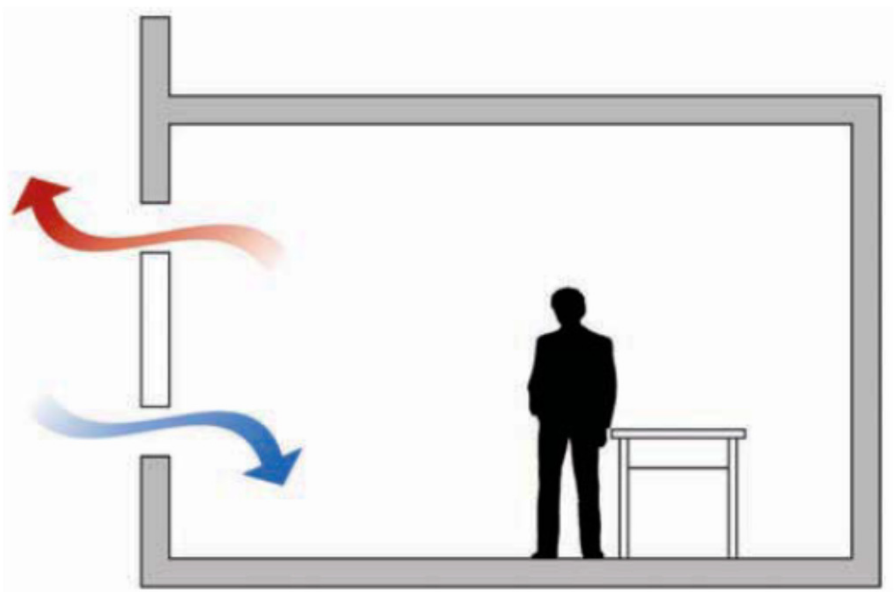
- Ratings for air tightness may be found for whole building (e.g. leakage class A, B, C, D)
- Exterior walls and windows usually important
  - Air leakage area per component, per unit surface area, or per unit length of crack or sash
- Infiltration rate may be calculated by:

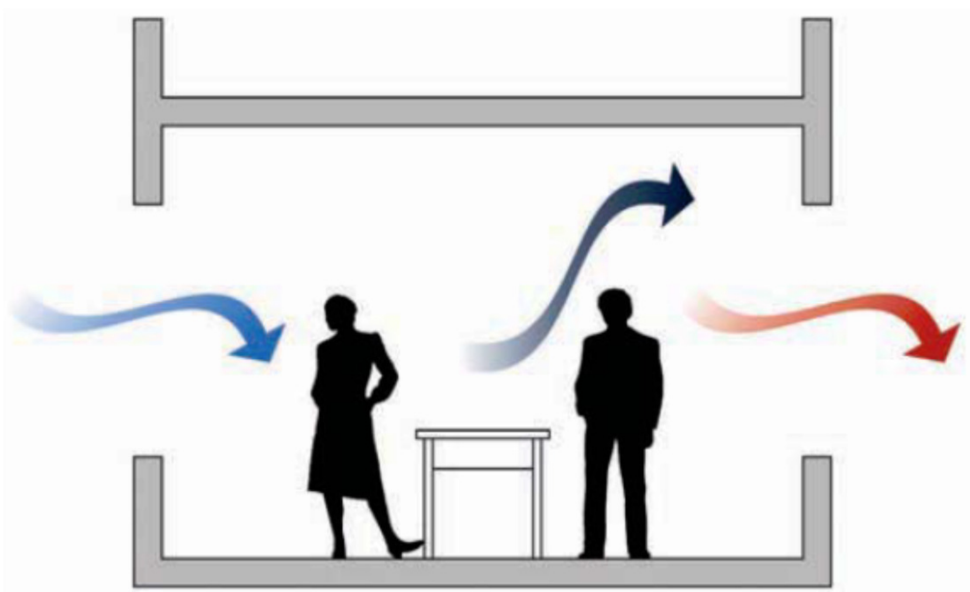
$$\frac{Q}{A_e} = \sqrt{A \cdot \Delta T + B \cdot V_W^2}$$

Natural Ventilation

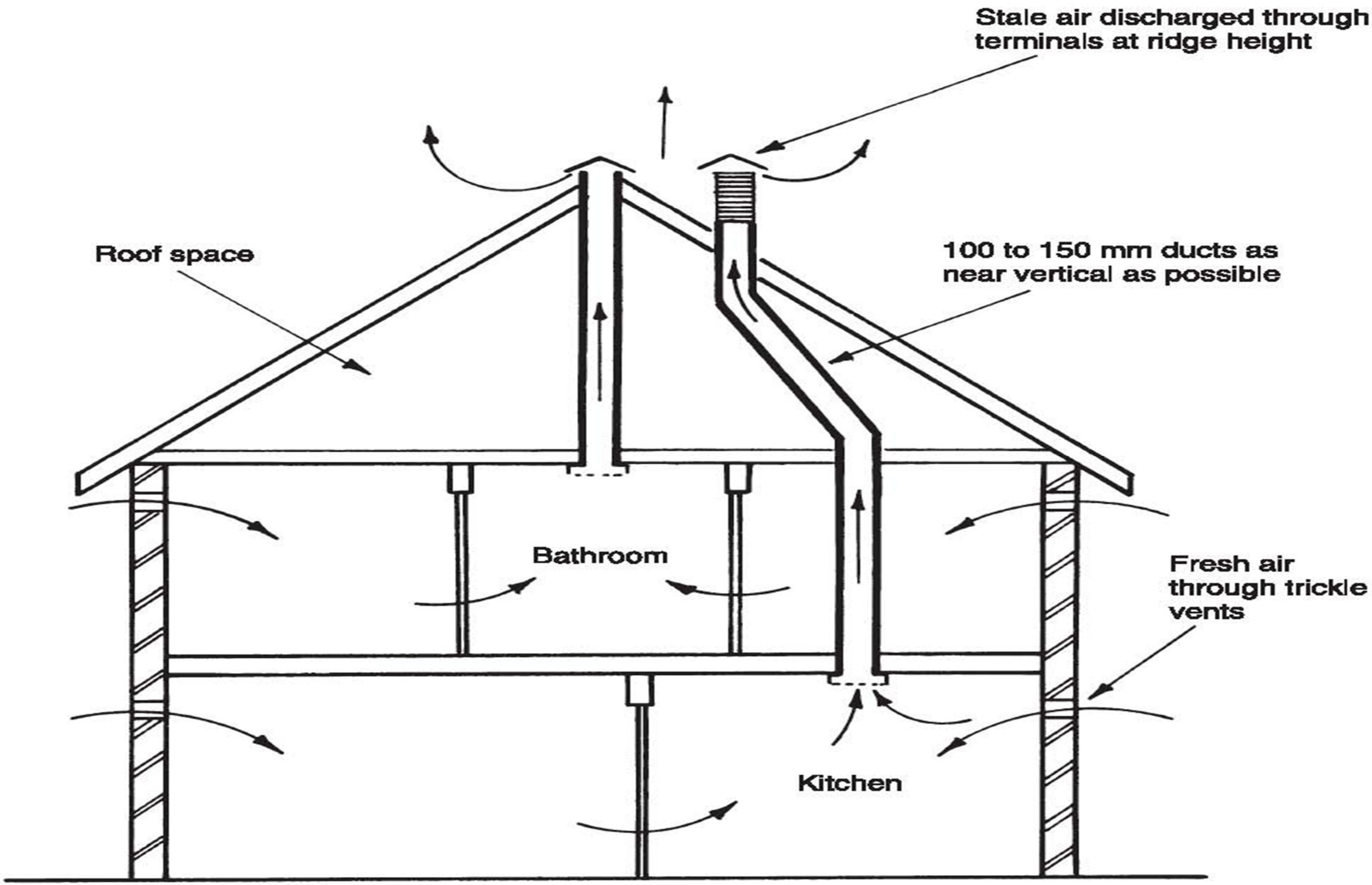
- Three main types of natural ventilation
  - Single-sided ventilation
  - Cross ventilation
  - Passive stack ventilation







Passive stack ventilation (PSV)



PSV to a dwelling house

(Source: Building Services Handbook)

Stack Ventilation Analysis

Stack ventilation rate q_B through two openings is:

$$q_B = c_d A^* \sqrt{2\left(\frac{T_i - T_o}{T_o}\right) g H}$$

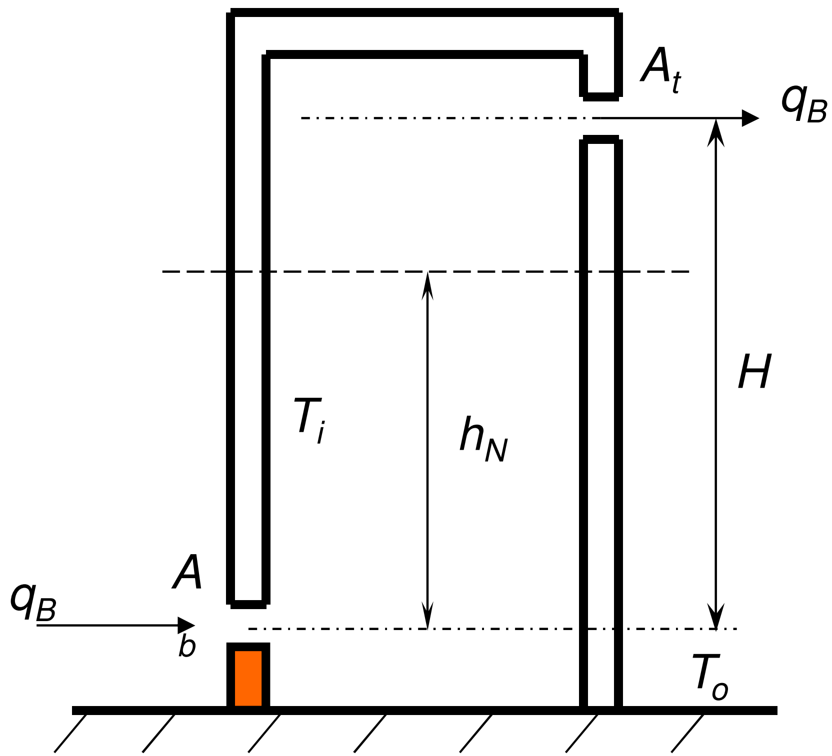
where

$$1/A^{*2} = 1/A_b{}^2 + 1/A_t{}^2$$

the Neutral Plane Level h_N is:

$$h_N = \frac{A_t^2}{A_b^2 + A_t^2} H$$

and C_d = discharge coefficient for opening, $C_d = 0.61$ for sharp-edge orifice.



Natural Ventilation

- Solar-induced ventilation
  - Relied upon the heating of part of the building fabric by solar irradiation resulting into a greater temp. difference, hence larger air flow
  - Three devices are often used:
    - Trombe wall
    - Solar chimney
    - Solar roof

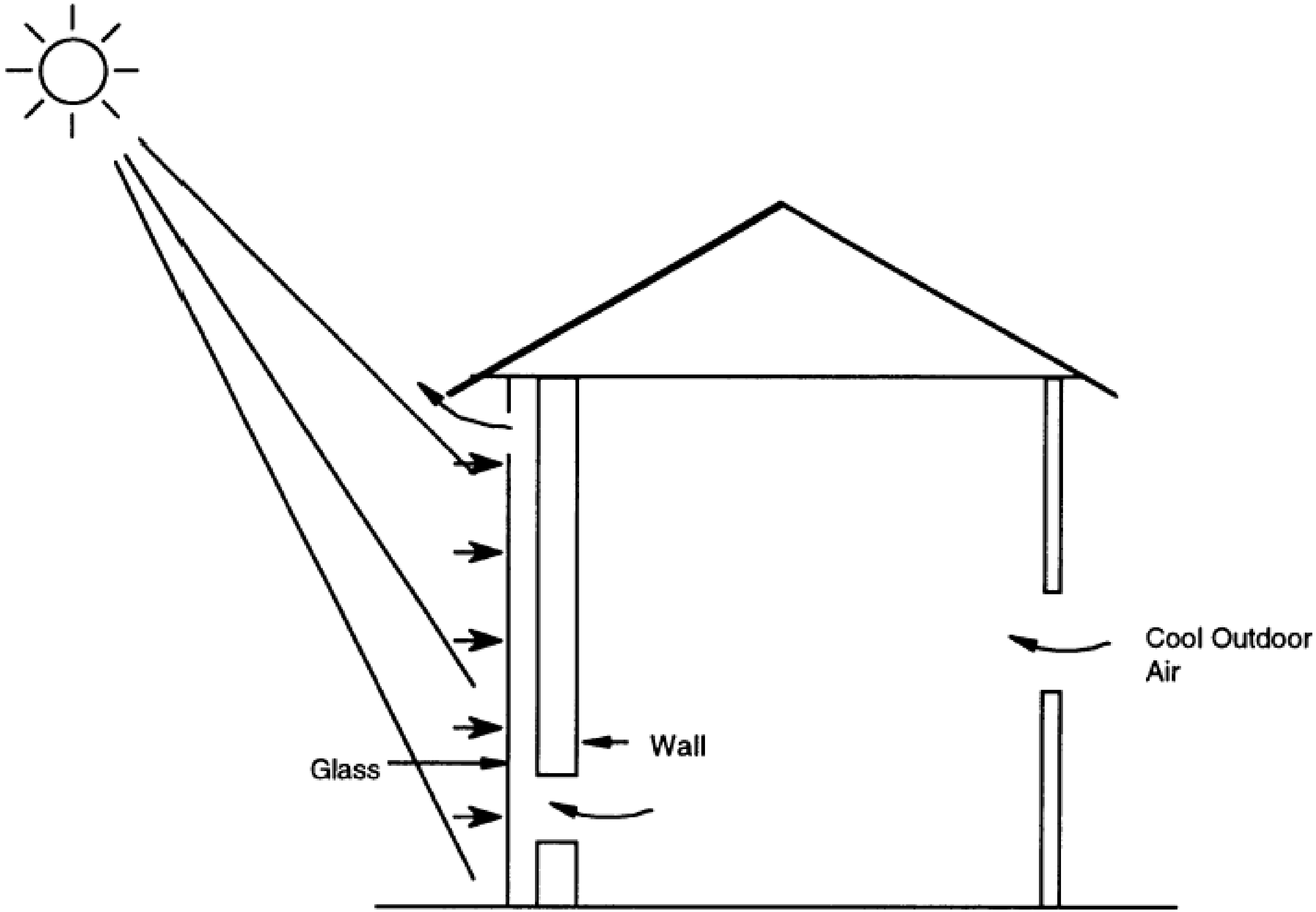


Fig. 5. Trombe wall ventilator.

(Source: Awbi (1998))

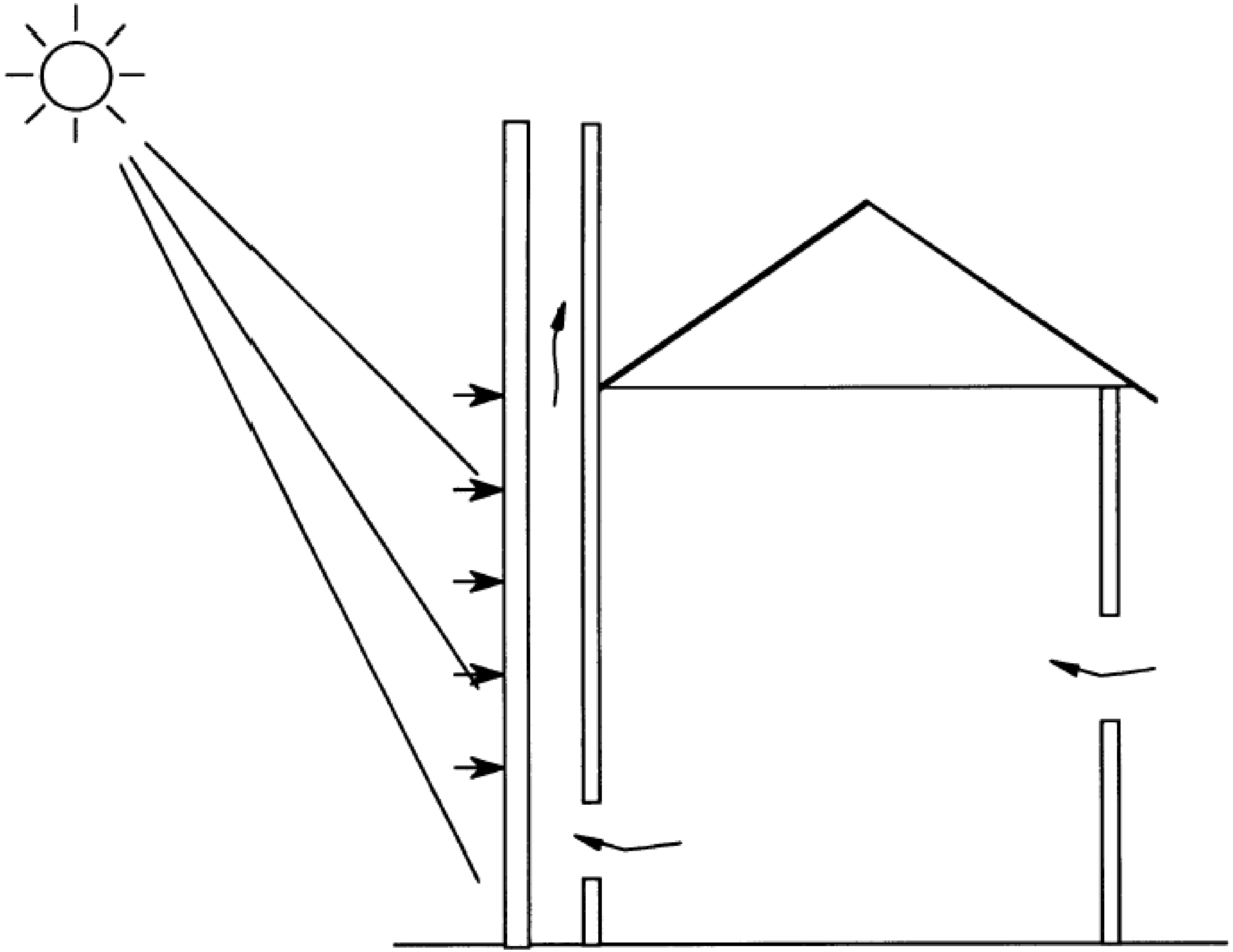


Fig. 6. Solar chimney.

(Source: Awbi (1998))

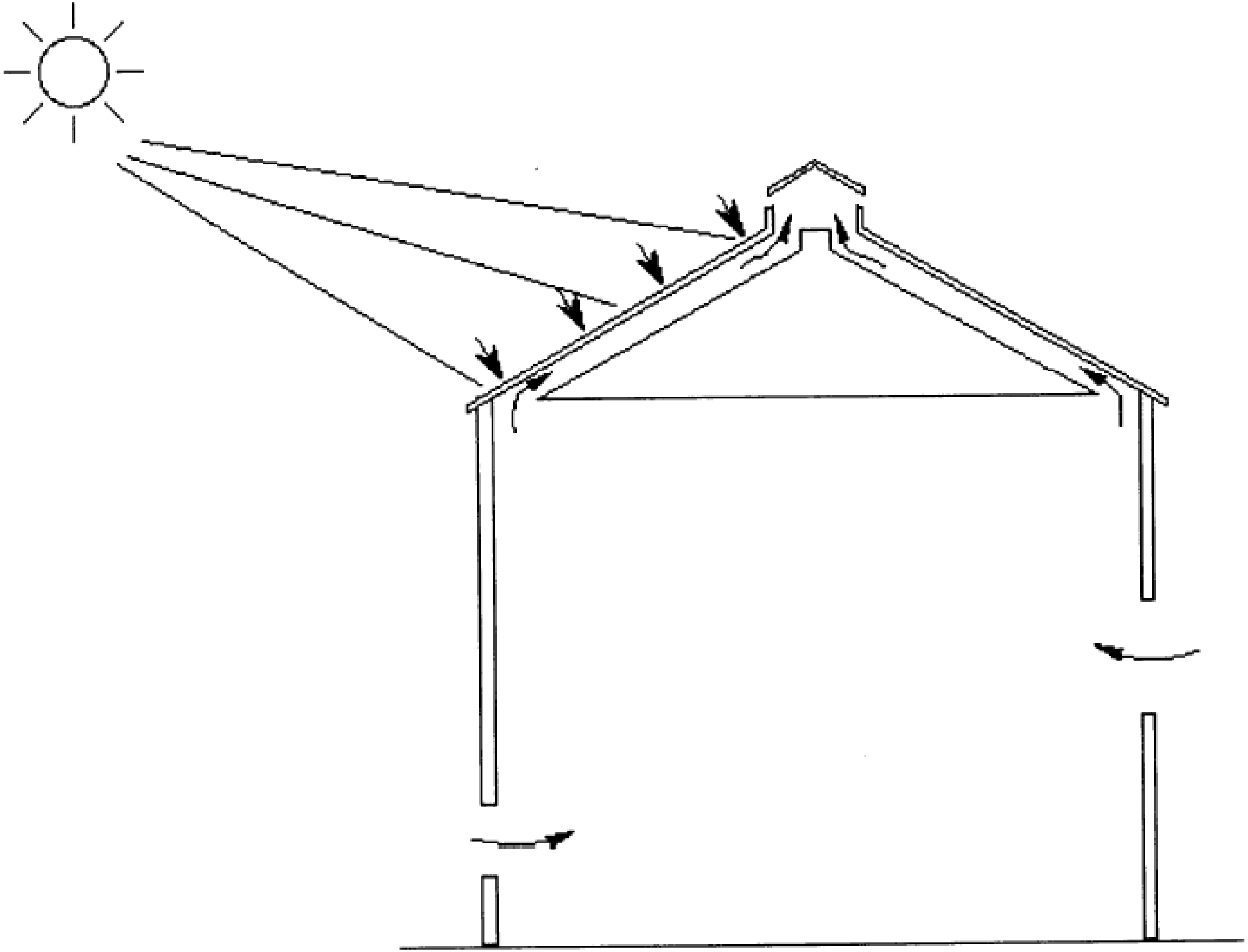
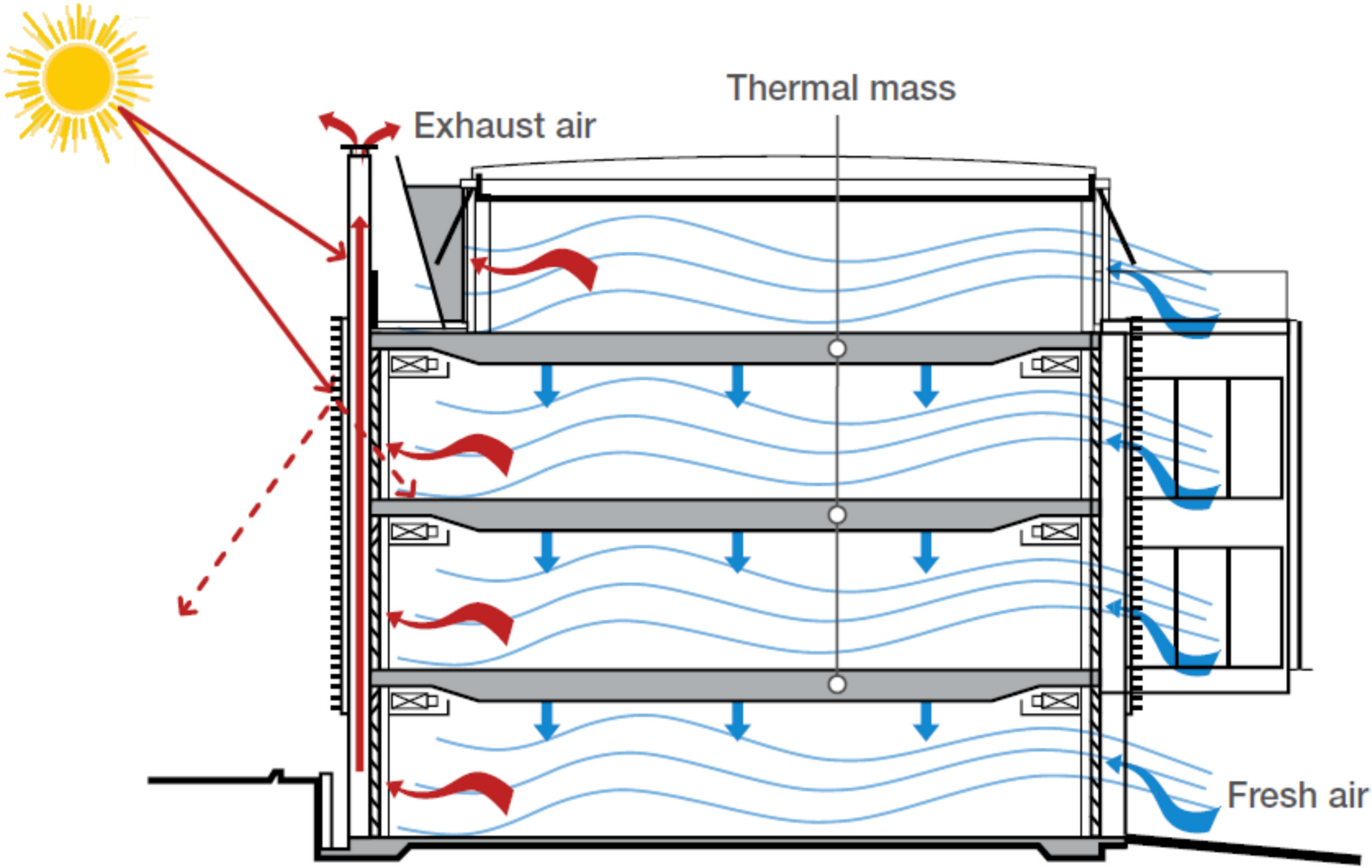


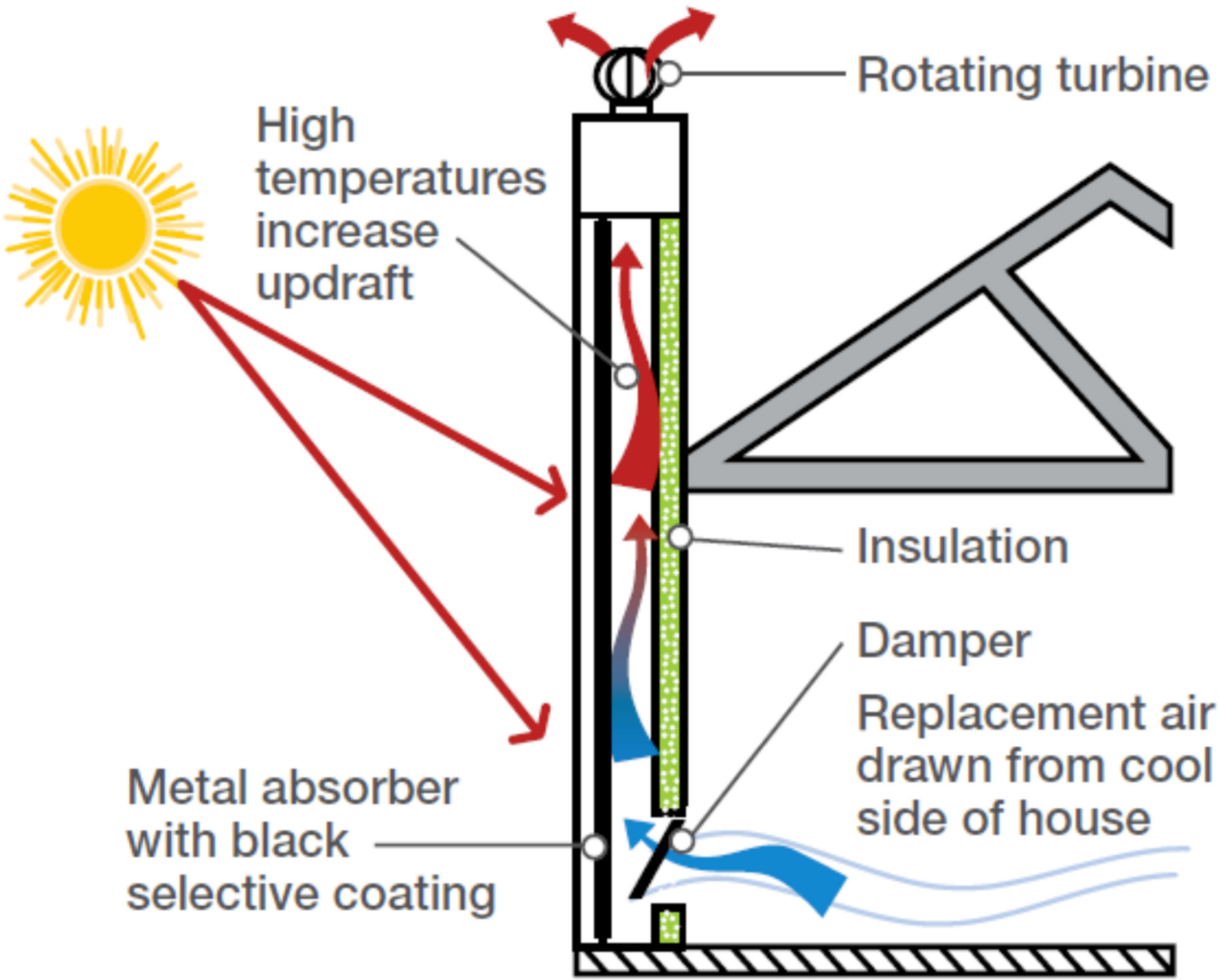
Fig. 7. Solar roof ventilator.

(Source: Awbi (1998))

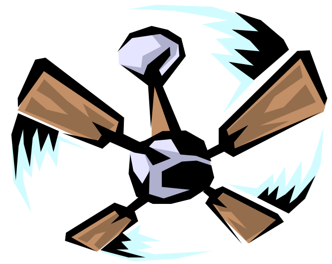
Cross flow natural ventilation with a solar chimney



Solar chimney with thermal insulation



Mechanical Ventilation

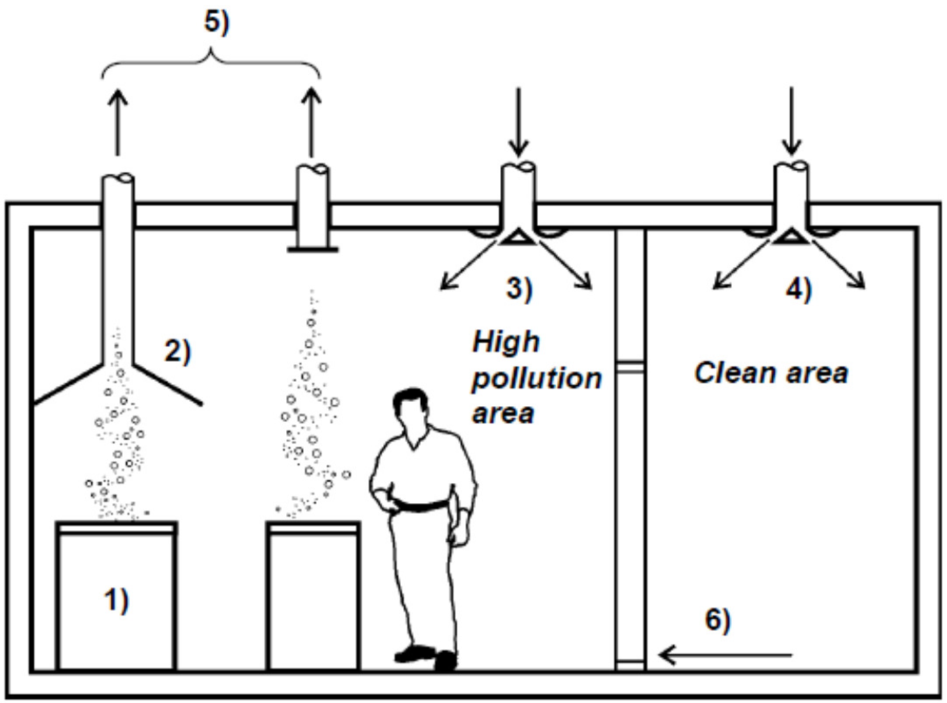


- Mechanical ventilation
  - Movement of air through a building using fan power
  - Ability to control the air flows
- Two types:
  - Unbalanced systems
    - Air is either supplied or extracted
  - Balanced systems
    - Air is supplied and extracted simultaneously

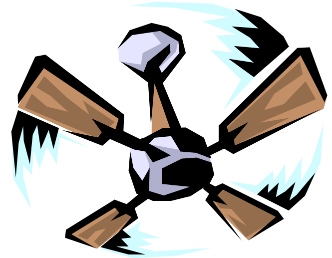
(See also: Basic Mechanical Ventilation Systems http://www.arca53.dsl.pipex.com/index_files/vent3.htm)

Mechanical Ventilation

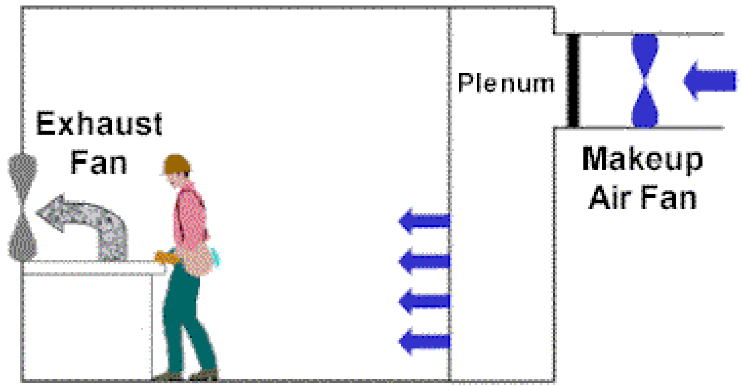
- Design principles:
  1. Exhaust close to pollutant generation
  2. Effective local extracts
  3. Supply to the breathing zone
  4. Supply air to clean areas
  5. More extract from "dirty" areas
  6. Transfer air from "clean" to "dirty" areas



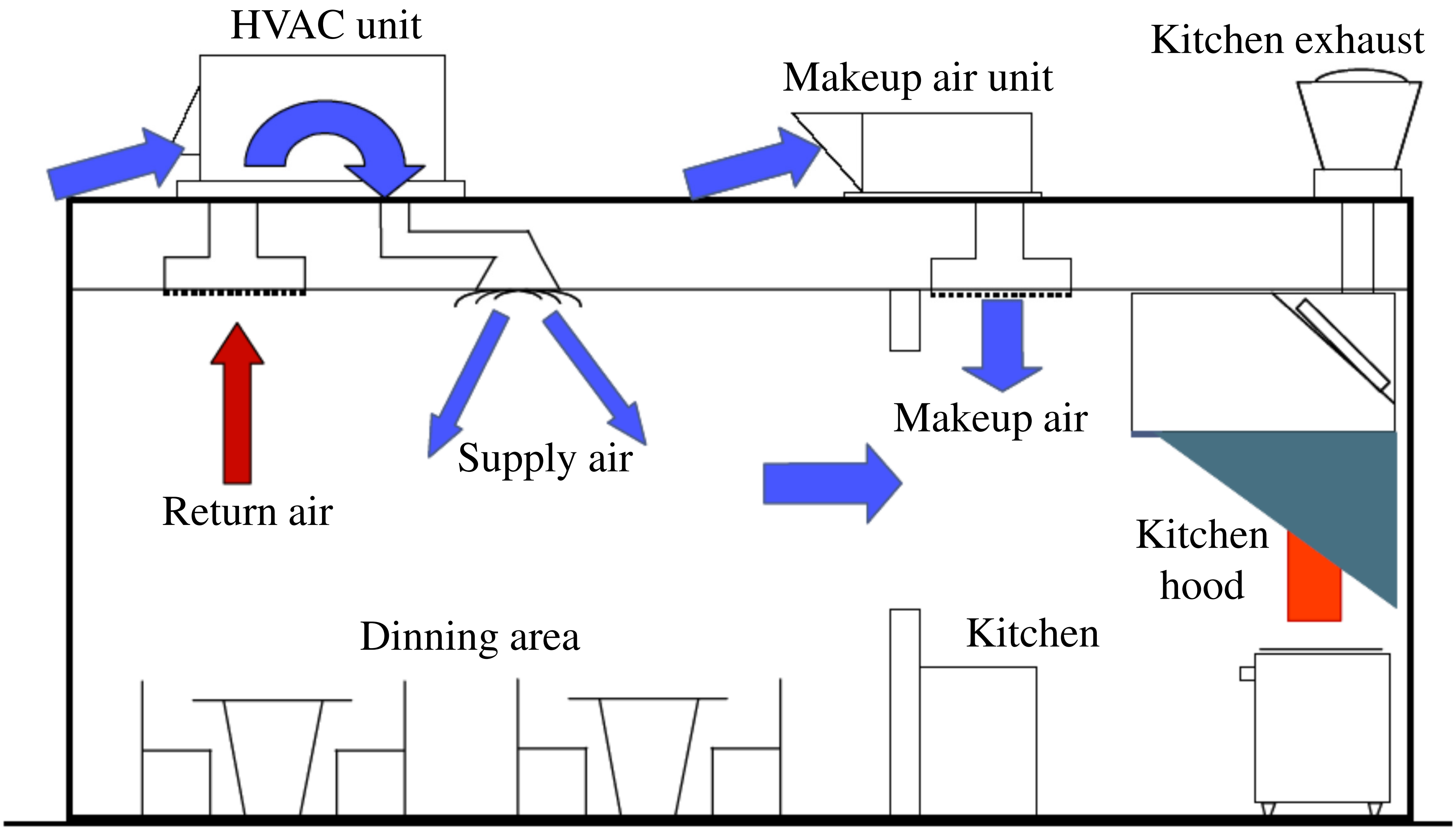
Mechanical Ventilation



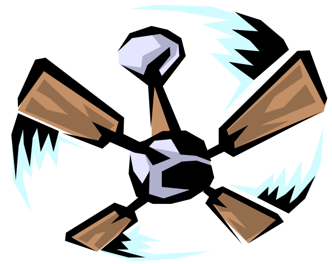
- Extract ventilation, e.g.
  - Commercial kitchens
  - Toilets and bathrooms
  - Underground carparks
  - Factories or industrial buildings
  - Localised industrial extraction
- Supply ventilation
  - Can be used to ensure adequate supply of outside air, e.g. in boiler house ventilation



Example of kitchen ventilation system

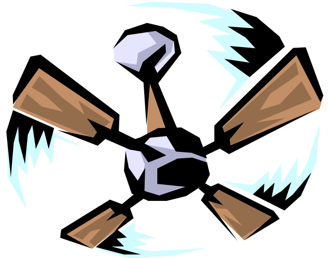


Mechanical Ventilation



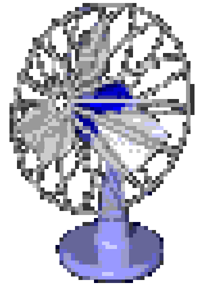
- Industrial ventilation
  - An important method for reducing employee exposures to airborne contaminants
  - Dilution systems:
    - Reduce the concentrations of contaminants released in a work room by mixing with air flowing through the room
  - Local exhaust ventilation (LEV):
    - Capture or contain contaminates at their source before they escape into the workplace environment

Mechanical Ventilation



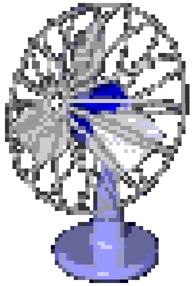
- Supply and extract (balanced) systems
  - Central air handling unit (AHU) with separate supply and extract fans
  - A heat recovery device can also be incorporated
- Energy implications & efficient ventilation
  - Heat recovery
  - Demand controlled ventilation (DCV)
  - User control ventilation
  - Ventilation system balancing

Design Factors



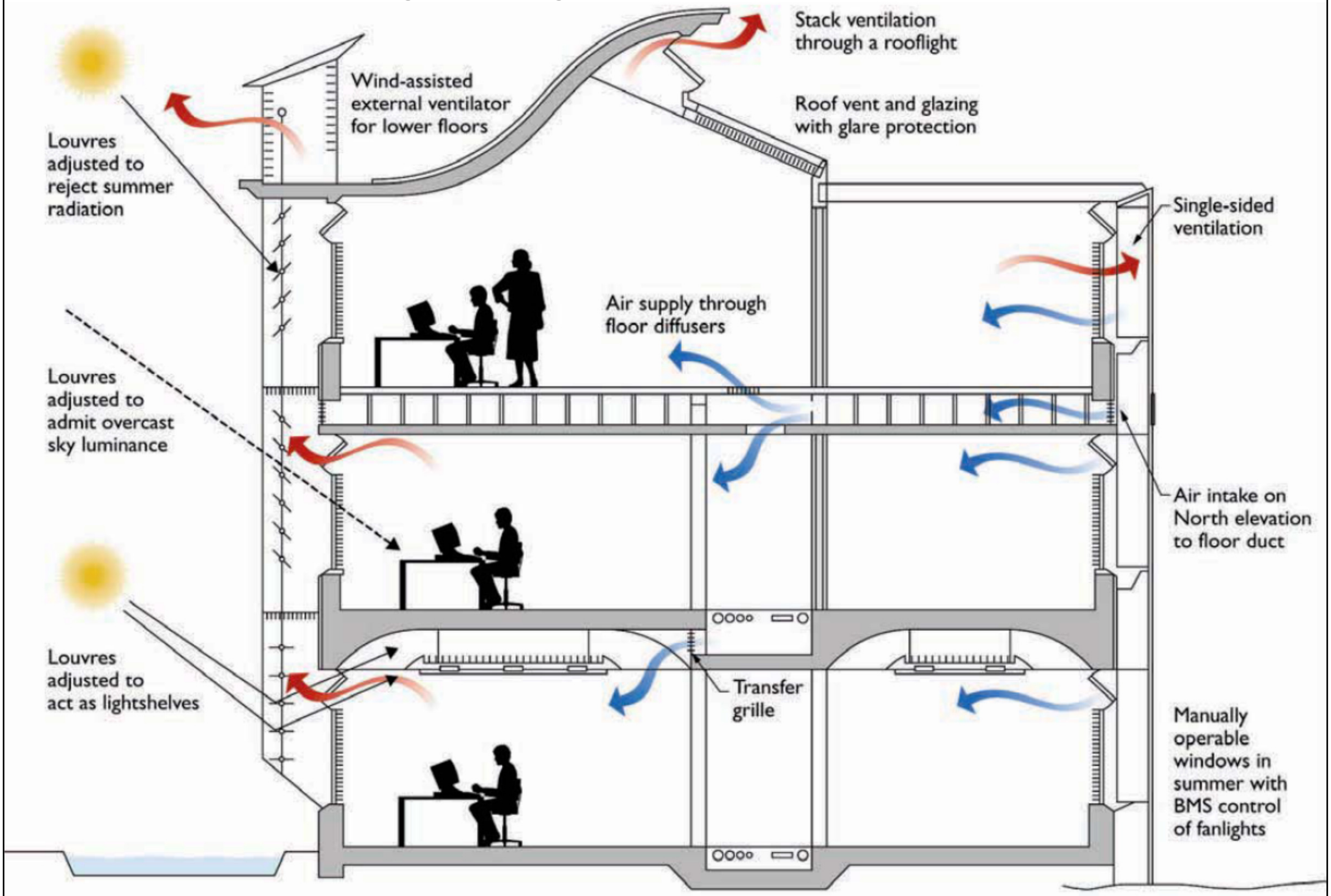
- Benefits of natural ventilation
  - Can save substantial energy by decreasing or eliminating the need for HVAC
  - May improve indoor air quality if outdoor air quality is good and air exchange rate is high
  - Buildings with well-designed natural ventilation systems often provide very comfortable and pleasant environments for the occupants
  - People may increase their work productivity when they can open and close windows and vary the natural ventilation rate in their workspace

Design Factors



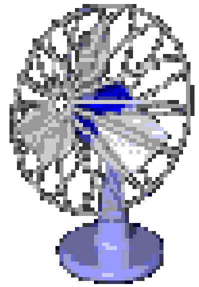
- Key factors affecting natural ventilation:
  - Depth of space with respect to ventilation openings
  - Ceiling height
  - Thermal mass exposed to the air
  - Location of building and possible air pollutants
  - Heat gain
  - Climate, e.g. outdoor temperature or wind velocity
- Passive cooling
  - Technologies or design features used to cool buildings without power consumption

Design strategies of natural ventilation



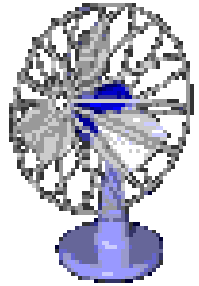
(Source: Pennycook, K., 2009. *The Illustrated Guide to Ventilation*)

Design Factors



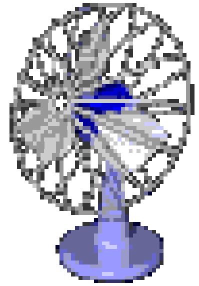
- Suitability of natural ventilation
  - Most suited to:
    - Buildings with a narrow plan or atria with floor plate width of 15 m or less
    - Sites with minimal external air and noise pollution
    - Open plan layouts
  - Not suited to:
    - Buildings with a deep floor plan
    - Buildings that require precise temp. & humidity control
    - Buildings with individual offices or small spaces
    - Buildings with continual heat loads above 35–40 W/m^2
    - Locations with poor air quality

Design Factors



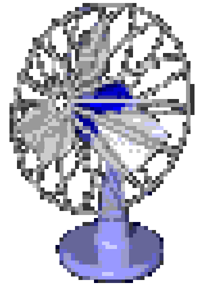
- Natural ventilation -- basic principles for sizing and placing openings:
  - The area of the opening at intake must be equal to or 25% smaller than the area of opening for exhaust
  - Air flow will take the line of least resistance so follow the flow line to check for dead spots (areas where fresh air does not go)
  - Consider security, privacy and noise transfer

Design Factors



- Design for natural ventilation (cont'd)
  - Flow caused by wind is affected by:
    - Average wind speed
    - Prevailing wind direction
    - Seasonal & daily variation in wind speed and direction
    - Local obstructing objects, e.g. nearby buildings & trees
    - Position and characteristics of openings
    - Distribution of surface pressure coefficients for the wind

Design Factors



- Design for natural ventilation (cont'd)
  - Flow caused by thermal forces

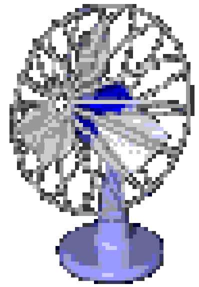
$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$

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

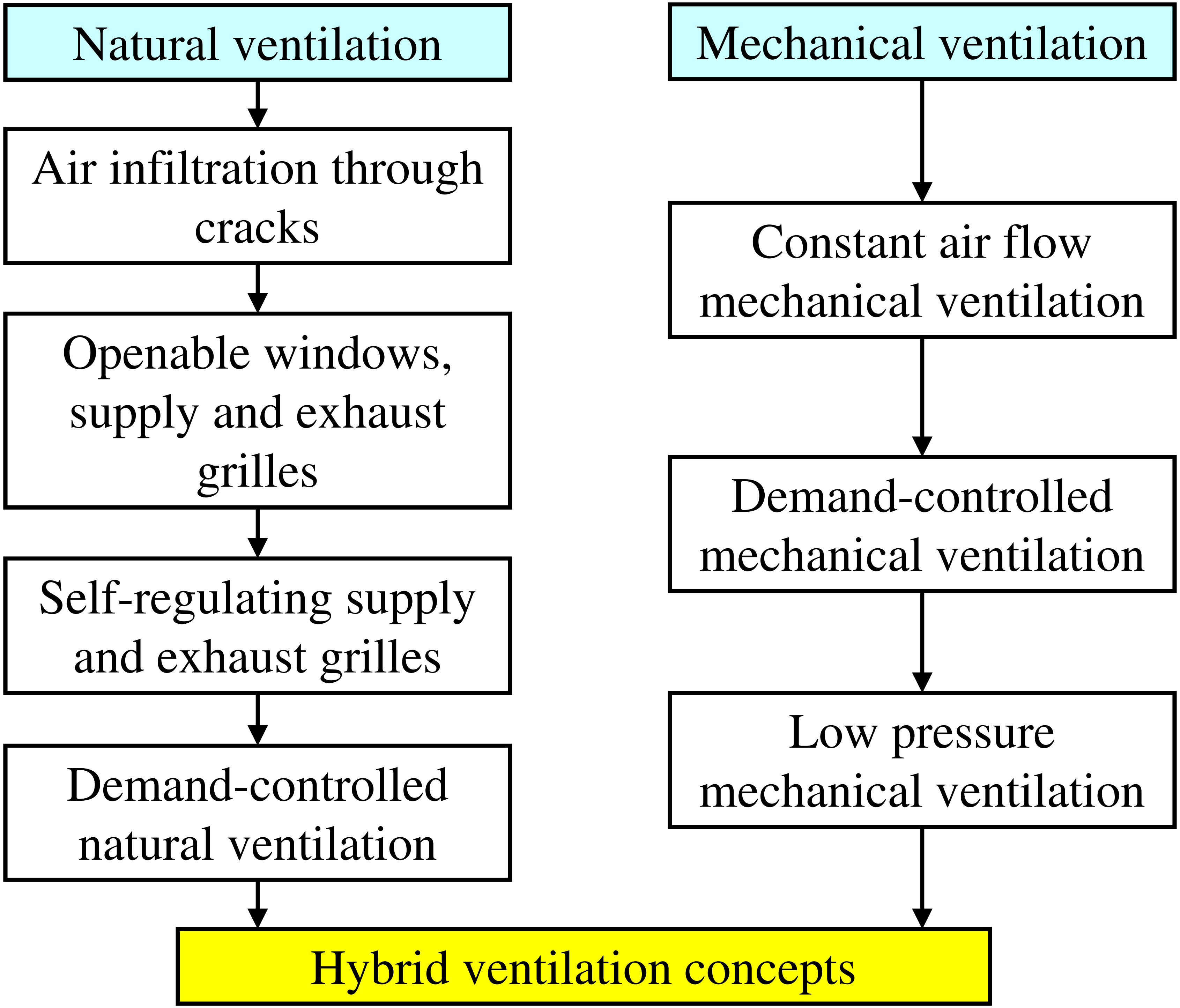
where

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)
h = height from lower opening (mid-point) to neutral pressure level (m)
T_i = indoor air temperature (K)
T_o = outdoor air temperature (K)

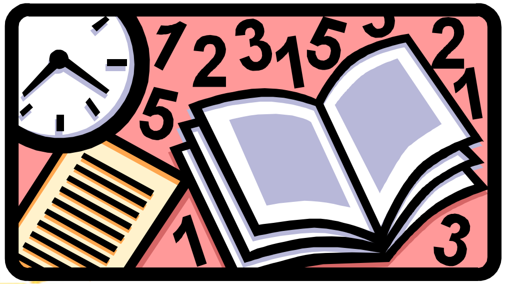
Design Factors



- Hybrid ventilation (or mixed mode ventilation)
  - = Natural ventilation + Mechanical ventilation
  - Use them at different time of the day or season of the year
  - Usually have a control system to switch between natural and mechanical modes
  - Combine the advantages of both to satisfy the actual ventilation needs and minimise energy consumption


Natural ventilation
Air infiltration through cracks
Openable windows, supply and exhaust grilles
Self-regulating supply and exhaust grilles
Demand-controlled natural ventilation
Mechanical ventilation
Constant air flow mechanical ventilation
Demand-controlled mechanical ventilation
Low pressure mechanical ventilation
Hybrid ventilation concepts

Further Reading



- Air Movement and Natural Ventilation [Web-based lecture by Dr. Sam C. M. Hui]
  - http://arch.hku.hk/teaching/lectures/airvent/
- Ventilation [BSE notes]
  - http://www.arca53.dsl.pipex.com/index_files/venta.htm
  - Design guidelines
  - Design examples
  - Ventilation drawings
- Lesson 40 Ventilation For Cooling http://nptel.ac.in/courses/112105129/40