Educational Package Ventilation

Lecture 1: Typical ventilation design concepts and strategies

Zoltán MAGYAR, PhD
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Summary

- Ventilation background
- Why ventilate?
- Two ways of building ventilation
- Ventilation and Air Quality
- Insulation, Air tightness and Ventilation
- The two natural mechanisms of ventilation
- Three-pronged recommended strategy for ventilation
- Energy impact of ventilation
- Evaluation of required ventilation rate
Ventilation background

Before 1973

1973
Petroleum crisis

1985
Thermal Regulations

1996
Reinforced thermal regulations

Insulated
Airtight housing
Ventilation system

JUST insulated roof

Double glazing

“Man is a funny creature
When it’s hot he wants it cold
When it’s cold he wants it hot
Always wanting what is not
Man is a funny creature”
ASHRAE Journal, unknown author

Tomorrow

NOT insulated
NEITHER airtight

INSULATED AIRTIGHT
Housing

INSULATED
Ventralation system
Why ventilate?

To provide fresh air to occupants

To dilute and remove pollutants

To provide natural ‘passive’ cooling

To distribute heating or cooling

Heating and Air-Conditioning

Air Quality

Why Ventilation?
TWO ways of building ventilation

**Natural ventilation**

- **Single sided ventilation**
  - supply and extraction through the same openings
  - openings ~4% of floor area
  - less efficient
  - internal door remain closed

- **Cross ventilation**
  - supply and extraction at the same level in the building
  - good result when wind exists
  - internal doors opened or equipped with ventilation grilles

- **Stack ventilation**
  - air supply through louvers and extracted through chimneys
  - wind not needed

**Mechanical ventilation**

- **Mechanical supply ventilation**
  - a fan supplies air to spaces
  - ventilation openings in building’s envelope are used for extraction
  - usually used where high ventilation rates are needed and air has to be heated before entering the room

- **Mechanical extract ventilation**
  - a fan draws air from spaces
  - fresh outdoor air enters into rooms either through the leakage routes of building envelope or through ventilation openings in the building envelope

- **Mechanical extract & supply ventilation**
  - a balanced ventilation system
  - it must always include a supply and a return air fan
  - an air heater is almost always installed in the supply air side
Ventilation and Air Quality

Required:
- AIR QUALITY
- COMFORT
- HEALTH

STUFFY
ODOUR
TOXIC
SICK BUILDING
HOT
COLD
DRAUGHTY

A Solution:
VENTILATION

CAN REMOVE POLLUTANTS
CAN REMOVE HEAT

A Problem:
LOSS OF CONDITIONED AIR
FAN ENERGY

risk of compromising health and comfort
To achieve high performance in terms of thermal comfort, energy savings and air quality, it becomes necessary to control the ventilation.

To reduce heat loss through the walls, in addition to the installation of insulation, delete air leakage through the building envelope. The airtightness solves this problem.

The realization of an airtight envelope -> no longer a sufficient air renewal.

Ventilation solves this problem.
The two natural mechanisms of ventilation

In other words:
- Minimize the amount of air leakage through the building envelope
- Install a controlled ventilation system to provide the necessary level of ventilation where and when necessary.

Objectif

The objective of a good ventilation strategy is to ensure a balance between energy efficiency and indoor air quality. “build tight – ventilate right”
The two natural mechanisms of ventilation

1. Wind Driven Ventilation

Wind driven flow

Wind tower

\[ p_w = C_p \rho v^2 / 2 \]

Fig.1 (a,b,c)

Cross Flow Wind

Fig.2

Fig.3

IUT building La Réunion Island

Yazd, Iran

Badgir (WindCatcher)

Fig.4

Fig.5

Natural ventilation cross tropical climate

Natural ventilation system single sided type tropical climate

F. ALLARD- CHAMPS Seminar Nanjing 20-22/03/2011
The two natural mechanisms of ventilation

2. Stack Driven Ventilation

Pressure of air increases closer to the ground due to the extra amount of air above.

The pressure gradient of air increases indoors because warmer air is less dense.

(Stack) pressure between openings is given by \( A + B \)

(Courtesy M. Liddament)

Fig. 6
Three-pronged recommended strategy for ventilation

1. Extract ventilation in 'wet' rooms
   - Remove these pollutants directly to outside
   - Minimize their spread into the rest of the building

2. Whole building ventilation
   - Provide a continuous supply of fresh air from outside
   - Dilute and disperse water vapor and pollutants that are either not removed by extract ventilation or are generated in other rooms from the building

3. Purge ventilation throughout the building
   - Aid removal of high concentrations of pollutants and water vapor released from occasional activities such as painting and decorating
   - Opened windows
Energy impact of ventilation

Dissipation through Air:
- Ventilation
- Infiltration
- Venting

Huge demand to reduce the energy impact of ventilation!
Energy impact of ventilation

1. Under-floor ventilator grilles.
2. Gaps in and around suspended timber floors.
3. Leaky windows or doors.
4. Pathways through floor/ceiling voids into cavity walls and then to the outside.
5. Gaps around windows.
6. Gaps at the ceiling-to-wall joint at the eaves.
7. Open chimneys.
8. Gaps around loft hatches.
9. Service penetrations through ceilings.
10. Vents penetrating the ceiling/roof.
11. Bathroom wall vent or extract fan.
13. Kitchen wall vent or extractor fan.
15. Gaps around floor-to-wall joints (particularly with timber frame).
Evaluation of required ventilation rate

1 cfm = 1.7 m³/h

Brief Ventilation Rate History
References

F. ALLARD - “Natural Ventilation in Buildings”, James & James London NW1 3ER UK

C. Ghiaus, F. Allard, Y. Mansouri, J. Axley, Natural ventilation in urban context

HEALTHVENT HEALTH-BASED VENTILATION GUIDELINES FOR EUROPE, WORK PACKAGE 5, EXISTING BUILDINGS, BUILDING CODES, VENTILATION STANDARDS AND VENTILATION IN EUROPE FINAL DRAFT REPORT, Coordination of work: Olli Seppänen, Secretary General of REHVA, Project group: Nejc Brelih, Guillaume Goeders, Andrei Litiu

lecture F. Allard, “AERAULIQUE DES BATIMENTS”

F. ALLARD- CHAMPS Seminar Nanjing 20-22/03/2011

F. ALLARD- CLIMA 2010-Antalya

F. ALLARD-HealthVent WP5 Seminar, Brussels 7-8/09/2010

History And Background of Ventilation Rates, Kansas City Seminar 4, June 29, 2003; Fred Kohloss Consulting Engineer, Honolulu, Hawaii
Lecture 2: Natural Ventilation

Educational Package Ventilation

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Summary

Natural ventilation principles

Natural Ventilation strategies

Technical solutions for natural ventilation

Case study:

BRE Office Building, Watford, UK;

Conclusion
Role of ventilation

- to maintain acceptable levels of oxygen in air and to remove odours, moisture, and internal pollutants;
- it may also remove excess heat by direct cooling or by using the building thermal mass;

Performance criteria: a) minimum ventilation rates used in USA for indoor air quality (Awbi 1998); b) thermal comfort in natural ventilation (Brager 1998) and air conditioning (ASHRAE 1993).

Source: Natural ventilation: principles, solutions and tools; Cristian Ghiaus, Francis Allard, James Axley, Claude-Alain Roulet
Natural ventilation principles

- attractive because it is seen as a cost effective alternative to conventional mechanical ventilation with air conditioning;
- steady improvements in design, material and control methods means that the range of buildings in which this approach is applicable continues to grow;
- in practice natural ventilation is most suited to buildings located in mild to moderate climates away from inner city locations;

natural ventilation is the use of wind and temperature differences to create airflows in and through buildings;

these airflows may be used both for ventilation air and for passive cooling strategies;

natural ventilation is often strongly preferred by building occupants, especially if they have some control over it, as with operable windows.
Subject to climate and outside noise and pollution constraints, typical building types include:

- Dwellings (individual and apartments);
- Small to medium sized offices;
- Schools;
- Small to medium retail premises;
- Recreational buildings;
- Warehouses;
- Industrial premises.

Specialised natural ventilation may be applicable to a wider range of climatic conditions and buildings examples are included in the accompanying resource module.
In a mild summer, natural ventilation can reduce the apparent temperature (e.g. up to 6°C at an airflow of 1.5 m/s or so).

Source: Natural Ventilation in Buildings, Tony Rofail, NEERG seminar, 31 Aug 2006, Windtech Consultants
## Effect of Air Movement on Occupants

<table>
<thead>
<tr>
<th>Air Velocity</th>
<th>Probable Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 0.25 m/s</td>
<td>Unnoticed</td>
</tr>
<tr>
<td>0.25 to 0.5 m/s</td>
<td>Pleasant</td>
</tr>
<tr>
<td>0.5 to 1 m/s</td>
<td>Generally pleasant, but causes a constant awareness of air movement</td>
</tr>
<tr>
<td>1 to 1.5 m/s</td>
<td>From slightly drafty to annoyingly drafty</td>
</tr>
<tr>
<td>Above 1.5 m/s</td>
<td>Requires corrective measures if work and health are to be kept in high</td>
</tr>
</tbody>
</table>

Source: Victor Olgyay, Design with Climate, Princeton University Press, 1963
Summer Example

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature (deg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6am</td>
<td>30</td>
</tr>
<tr>
<td>6pm</td>
<td>20</td>
</tr>
<tr>
<td>12noon</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: Natural Ventilation – capabilities and limitations (comfort and energy efficiency in domestic dwellings), ATA Melbourne Branch presentation, April 2008, Jim Lambert
Natural ventilation principles

Summer Example

Source: Natural Ventilation – capabilities and limitations (comfort and energy efficiency in domestic dwellings), ATA Melbourne Branch presentation, April 2008, Jim Lambert
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<table>
<thead>
<tr>
<th>Time</th>
<th>Outside Temperature (deg C)</th>
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<tbody>
<tr>
<td>6am</td>
<td>30</td>
</tr>
<tr>
<td>12noon</td>
<td>20</td>
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<td>10</td>
</tr>
<tr>
<td>midnight</td>
<td>6am</td>
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</tbody>
</table>

Normal comfort range with moving air

Source: Natural Ventilation – capabilities and limitations (comfort and energy efficiency in domestic dwellings), ATA Melbourne Branch presentation, April 2008, Jim Lambert
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Outside temperature

Source: Natural Ventilation – capabilities and limitations (comfort and energy efficiency in domestic dwellings), ATA Melbourne Branch presentation, April 2008, Jim Lambert
Summer Example

<table>
<thead>
<tr>
<th>Time</th>
<th>Outside Temperature</th>
<th>Inside Temperature</th>
<th>Normal Comfort Range</th>
<th>Comfort Range with Moving Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>6am</td>
<td>30</td>
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**Source:** Natural Ventilation – capabilities and limitations (comfort and energy efficiency in domestic dwellings), ATA Melbourne Branch presentation, April 2008, Jim Lambert
Summer Example

Temperature (deg C)

6pm 6am 6am midnight 12noon
day night

Outside temperature

Normal comfort range

Comfort range with moving air

Gentle forced ventilation overnight

Start internal fan

Open all windows

Close all windows

Open all windows

Gentle forced ventilation overnight

Inside temperature

Open all windows

Close all windows

Start internal fan

Source: Natural Ventilation – capabilities and limitations (comfort and energy efficiency in domestic dwellings), ATA Melbourne Branch presentation, April 2008, Jim Lambert
Natural Ventilation Driving Forces

- Air moves through an opening (e.g. window) when there is a pressure difference across the opening:
  - greater pressure difference = higher airflow
  - larger opening area = higher airflow

- Natural ventilation pressure differences driven by two mechanisms:
  - air density difference (stack effect)
    - warm air is less dense than cool air (more buoyant)
    - works when indoor air is warmer than outdoor air
    - harder to achieve stack airflow in summer
  - wind
    - creates varying surface pressures around the building

Source: Erik Kolderup, Saving Energy with Natural Ventilation Strategies, September 2008
**Stack effect**

Outdoor air is cooler and more dense. Pressure gradient is larger than for warmer indoor air.

Indoor air is warmer and less dense. Pressure gradient from low to high is smaller than for cooler outdoor air.

\[ dP(z) = - \rho g \, dz \]

then:

\[ P(z) = P_0 - \rho g z \] (hydrostatic pressure)

Source: Erik Kolderup, Saving Energy with Natural Ventilation Strategies, September 2008
Stack effect

At higher elevation, indoor pressure is greater than outdoors. Air flows from inside to outside.

Neutral pressure level occurs somewhere between lower and upper openings.

At low height, pressure outdoors is higher than indoors. Airflow flows from outside to inside.

Outdoors (cooler)  Indoors (warmer)

Source: Erik Kolderup, Saving Energy with Natural Ventilation Strategies, September 2008
**Stack effect**

Height of neutral pressure level (NPL) depends on relative size of lower and upper openings. NPL is closer to the larger opening; less pressure needed to move air through a larger opening.

**Airflow through an opening**

with $P_1 > P_2$,

**Theoretical airflow** ($m^3/s$) will be:

$$Q_{th} = V \times A$$

$V$ is calculated using Bernoulli’s equation

$$P_1 - P_2 = \frac{1}{2} \rho_1 V^2$$

then: $$Q_{th} = A \left( 2 \left( P_1 - P_2 \right)/\rho_1 \right)^{0.5}$$

**Real airflow < theoretical airflow**

$$Q_v = Cd \times Q_{th}$$

with $Cd < 1$ (surface pressure coefficient)

Source: Erik Kolderup, Saving Energy with Natural Ventilation Strategies, September 2008
Source: F. Allard, Aeraulique des batiments et ventilation naturelle
Flow Through Gaps and Cracks – Air Infiltration

Flow rate through less well defined openings such as infiltration openings is represented by the Power Law Equation:

\[ Q_v = C_d (\Delta p)^n \]

\[ C_d \] = flow coefficient;
\[ n \] = flow exponent;
\[ \Delta p \] = pressure difference across the opening.

“\[ C_d \]” is related to the size of the opening (i.e. it increases with opening size).

“\[ n \]” characterises the flow regime and varies in value between 0.5 (fully turbulent flow) to 1.0 (fully laminar flow).

A quadratic equation is recommended in which the laminar and turbulent terms are separated. This form of the equation is given by:

\[ \Delta p = \alpha Q + \beta Q^2 \]
Stack effect

Very large opening required top of stack to ensure that neutral pressure level is higher than the upper floor. If neutral pressure level is too low, can get recirculation into upper floor.

Neutral pressure level

Larger openings required at upper floors to achieve equal airflow, due to smaller pressure difference

Lower floor openings can be smaller

Source: Erik Kolderup, Saving Energy with Natural Ventilation Strategies, September 2008
Wind Driven Ventilation

Wind flowing around a building creates areas of positive and negative pressure.

Wind velocity is typically lower near the ground and increases with height above ground.

On the windward (upwind) side, air velocity slows and pressure rises.

On the roof and sides, air velocity accelerates and pressure drops.

On the leeward (downwind) side, flow separates from the roof and sides creating a low pressure recirculation zone.

Wind Pressure Distribution

Wind Pressure

\[ p_w = 0.5 \rho C_p v_r^2 \]  (Pa)

\( \rho \) = Air Density (Kg/m³)
\( C_p \) = Wind Pressure Coefficient
\( v_r \) = Wind Velocity (m/s) (at Building Height)

Evaluation:
- Tabulated Data
- Wind Tunnel Tests
- CFD

Wind Driven Ventilation

Wind pressure distribution for various building shapes and orientations

Source: VENT Dis. Course, Distant learning vocational training material for the promotion of best practice ventilation energy performance in buildings, Module 1: Natural and Hybrid Ventilation
Combining Wind and Stack Driven Ventilation

The total pressure, $p_{ti}$, acting at an opening, i, due to the combined impact of wind and stack effect, is given by:

$$p_{ti} = p_{wi} + p_{si}$$

Summing the pressures due to stack and wind effect at each opening is not the same as summing the flow rates determined by calculating the flow rates due to wind and stack pressure separately.

Summing the flow rates would lead to an erroneous result.

Calculating Natural Ventilation Rate Using the Flow Equations, Wind Pressure and Stack Pressure Equations

This involves:

- identifying the ventilation openings;
- determining the pressures acting on each opening;
- applying the flow equations at each opening;
- obtaining a flow balance so that the air entering the building (and individual zones in a building) is balanced by the outgoing air.

Source: VENT Dis. Course, Distant learning vocational training material for the promotion of best practice ventilation energy performance in buildings, Module 1: Natural and Hybrid Ventilation
Advantages of Natural Ventilation

- Suitable for many types of buildings located in mild or moderate climates;
- The 'open window' environment associated with natural ventilation is often popular, especially in pleasant locations and mild climates;
- Natural ventilation is usually inexpensive when compared to the capital, operational and maintenance costs of mechanical systems;
- High air flow rates for cooling and purging are possible if there are plenty of openings;
- Short periods of discomfort during periods of warm weather can usually be tolerated;
- No plant room space is needed;
- Minimum maintenance;
- Can be less expensive to install and operate than HVAC but this need not always be true;
- No fan or system noise.
Disadvantages of Natural Ventilation

- Inadequate control over ventilation rate could lead to indoor air quality problems and excessive heat loss;
- Air flow rates and the pattern of air flow are not constant;
- Fresh air delivery and air distribution in large, deep plan and multi-roomed buildings may not be possible;
- High heat gains may mean that the need for mechanical cooling and air handling will prevent the use of natural ventilation;
- Natural ventilation is unsuited to noisy and polluted locations;
- Some designs may present a security risk;
- Heat recovery from exhaust air is technically feasible (Shultz, 1993) but not generally practicable;
- Natural ventilation may not be suitable in severe climatic regions;
- Occupants must normally adjust openings to suit prevailing demand;
- Filtration or cleaning of incoming air is not usually practicable;
- Ducted systems require large diameter ducts and restrictions on routing.
Natural Ventilation Approaches

**Advantages:**
- Single sided ventilation is popular because openings are located on one face only.

**Disadvantages:**
- No defined exit route for air;
- Net driving forces may be small resulting in poor ventilation;
- Depth of penetration of air restricted to approximately 2.5 x ceiling height.

Single sided natural ventilation should be avoided!

**Advantages:**
- ‘Open’ air flow path presents minimum resistance to air flow and hence provides good ventilation to a space;
- For equivalent size of openings, cross flow will provide more reliable ventilation than single sided.

**Disadvantages:**
- Cross flow of ‘used’ air into further occupied spaces should be avoided;
- Design of interior layout etc. can be more complex than for single sided solutions.

Cross flow designs form the basis of best practice in natural and mixed mode ventilation systems. The majority of designs are based on cross flow.

Source: VENT Dis. Course, Distant learning vocational training material for the promotion of best practice ventilation energy performance in buildings, Module 1: Natural and Hybrid Ventilation
Natural ventilation strategies

Advantages:
- Air is drawn in at high level where pollutant concentration is usually lower than at street level;
- Can be integrated with a mixed mode fan to ensure reliable operation under low wind speed conditions;
- Possible to supply air into deep plan spaces.

Disadvantages:
- Reliable wind force is required unless combined with mixed mode;
- Can usually only provide fresh air to single or two storey buildings;
- Possible conflict with stack driven ventilation;
- Cold draughts are possible in winter periods.

Wind Tower or Wind Catcher

Advantages:
- Provides good winter driving force in cold climates;
- Can relieve the problem of single sided ventilation by providing stacks in the interior of the building;
- Can be used in conjunction with wind induced ventilation by locating the roof termination in the negative pressure region generated by the wind (See Section 5).

Disadvantages:
- Each room should be individually ducted since Shared ducts may result in cross contamination between zones;
- Potential for reverse flow (downdraught) if the column of air in the stack becomes cold;
- Requires a temperature differential between inside and outside.

Stack Ventilation

Advantages:
- Provides an extract driving force on the core of the building to drive cross flow ventilation through surrounding offices.
- The zone above the occupied area can trap waste heat which can be further used to add to the stack driving force.

Disadvantages: Flow can be upset by wind forces.

Source: VENT Dis. Course, Distant learning vocational training material for the promotion of best practice ventilation energy performance in buildings, Module 1: Natural and Hybrid Ventilation
BRE Office Building, Watford, UK

- Year of completion: 1996
- Type of building: Office
- Site: Urban
- Project Manager: Bernard Williams and Associates
- Architect: Feilden Clegg Bradley Architects
- Services Engineers: Max Fordham and Partners

**Key Features:**

- Single sided, cross flow and stack ventilation for air quality and cooling;
- Optional occupant controlled openable windows;
- Solar heated fan assisted stack and wind driven design for first two floors;
- Good internal air contact with thermal mass through hollow sinusoidal concrete ceiling elements;
- BEMs controlled openings of stack vents to control cooling and air quality;
- Cellular and open plan offices;
- Daylighting and low energy lighting;
- Active external solar shading;
- Some groundwater cooling;
- BEMS system controls air quality and night cooling ventilation;
- Air change rates as high as 30 h⁻¹ could be achieved to meet cooling needs;
- The top floor of the building was separately ventilated by cross flow, wind and stack action.

Source: [http://www.feildenclegg.com](http://www.feildenclegg.com)
Source: The Environmental Building, Case Study by Clayton Harrison, Spring 2006
BRE Office Building, Watford, UK

Ventilation & Cooling

- five cooling stacks towering over the south side of the building which hint at the building's complex ventilation system that takes advantage of the building's narrow layout for cross-ventilation purposes;
- the curved, hollow, concrete floor slabs also aid in the building's ventilation by drawing air in through the passages in the floor/ceiling on hot, windy days;
- cooling can be managed also by circulating water through the passages in the curving slab;
- this cold water is supplied by a 70-meter-deep bore hole where the temperature is a constant 10° Celsius.
- this cold water is used in heat exchangers to chill circulatory water;
- the floor can also then use the water to store "coolness" from the night for the next day. In the winter time, the water is heated by condensing gas boilers that are 30% more efficient than traditional boilers by recovering heat lost in flue gases. All heating and cooling systems are managed by the Trend building management system (BMS).

Source: The Environmental Building, Case Study by Clayton Harrison, Spring 2006
BRE Office Building, Watford, UK

Solar Control and Daylighting

- The building’s glazing is optimized by a louvered exterior shading system that is designed to allow maximum daylighting while minimizing glare;
- The louvers in the shading system have a translucent ceramic coating on their underside to filter direct sunlight as it reflects off it;
- The louvers change position corresponding to the time of day and season; they are controlled by the automated functions of the BMS, but can be overridden by occupants via a remote control;
- The louvers are oriented so the views of the occupants are not obstructed while either seated at desks or standing in circulation spaces.

Fig. 19 a,b

Source: The Environmental Building, Case Study by Clayton Harrison, Spring 2006
Monitoring in winter and summer showed that design conditions were fully satisfied; 

During hot weather the inside air temperature remained at between approximately 3-5 K below the outdoor peak temperature;

The inside peak design temperature of 28°C was not exceeded.

Source: The Environmental Building, Case Study by Clayton Harrison, Spring 2006
Lecture 3: Mechanical (forced) ventilation

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Summary

Supply-Only ventilation system (SOV)

Extract-Only ventilation system
- A- Mechanical extract ventilation (MEV)
- B- Intermittent extract fans and background ventilators

Balanced ventilation system
- A- Single room heat recovery ventilators (SRHRVs)
- B- Whole house mechanical ventilation with heat recovery (MVHR)

Fans

Design criteria

Air filters
4 basic types of ventilation systems

<table>
<thead>
<tr>
<th>No. in fig</th>
<th>Type of air</th>
<th>Definition</th>
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<tbody>
<tr>
<td>1</td>
<td>outdoor air</td>
<td>air taken into the air handling system or opening from outdoors before any air treatment</td>
</tr>
<tr>
<td>2</td>
<td>supply air</td>
<td>airflow entering the treated room, or air entering the system after any treatment</td>
</tr>
<tr>
<td>3</td>
<td>indoor air</td>
<td>air in the treated room or zone</td>
</tr>
<tr>
<td>4</td>
<td>transferred air</td>
<td>indoor air which passes from the treated room to another treated room usually adjacent rooms</td>
</tr>
<tr>
<td>5</td>
<td>extract air</td>
<td>the airflow leaving the treated room</td>
</tr>
<tr>
<td>6</td>
<td>recirculation air</td>
<td>extract air that is returned to the air treatment system</td>
</tr>
<tr>
<td>7</td>
<td>exhaust air</td>
<td>airflow discharged to the atmosphere</td>
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<tr>
<td>8</td>
<td>secondary air</td>
<td>airflow taken from a room and returned to the same room after any treatment (example: fancoil unit)</td>
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<tr>
<td>9</td>
<td>leakage</td>
<td>unintended airflow through leakage paths in the system</td>
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<tr>
<td>10</td>
<td>infiltration</td>
<td>leakage of air into the building through leakage paths in the elements of structure separating it from the outdoor air</td>
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<tr>
<td>11</td>
<td>exfiltration</td>
<td>leakage of air out of the building through leakage paths in the elements of structure separating it from the outdoor air</td>
</tr>
<tr>
<td>12</td>
<td>mixed air</td>
<td>air which contains two or more streams of air</td>
</tr>
</tbody>
</table>

Source: VENT Dis.Course, Distant learning vocational training material for the promotion of best practice ventilation energy performance in buildings
Module 3: Energy Efficient Mechanical Ventilation

Various air flows in a mechanical ventilation system (EN 13779).
SOV or
Positive input ventilation (PIV)

- Particularities:
  - PIV consists of a fan to supply air to spaces and ventilation openings in building envelope to allow air to flow out of the building;
  - Filtration of the incoming air;
  - Can be used in a polluted and noisy environment
  - Adequate when the occupants are sensible of exterior contaminates

Source: Guide pratique “La ventilation mécanique des habitations”
**Description**

- A fan, typically mounted in the roof space, supplies air into the dwelling via central hallway or landing.
- This creates a slight positive pressure in the dwelling.

**Control**

- The systems deliver a continuous flow of air to the dwelling;
- Fan speed can be increased by occupant, or automatic switching;

**Installation**

- If the fan draws air directly from the roof space, it will depressurize the roof space relative to the rest of the house upstairs ceiling has to be airtight;
- the roof space needs to be adequately ventilated from outside

**Maintenance**

- occasional cleaning is necessary;
- intake filters (fitted to most units) will need occasional cleaning/replacement.

A - Mechanical extract ventilation (MEV)

(MEV) continually extracts air
- single-point exhaust systems
- multi-point exhaust systems

**Advantages**
- easy to install;
- provides continuous 'low-level'
  background ventilation;
- small negative pressure in
  building prevents moisture
  mitigation into the constructions
  of external walls and prevents
  condensation and consequently
  the mould growth;

**Disadvantages**
- requires ducting from wet rooms;
- air infiltration through the building envelope creates easily
  draught in winter in cold climate;
- heat recovery from the exhaust air is not easy to implement;
- as the exhaust is usually from kitchens, bathrooms, and
  toilets ventilation supply air flow is not evenly distributed in the
  bed rooms and living rooms.

Source: Dr. Sam C. M. Hui, Department of Mechanical Engineering, The University of Hong Kong, lecture
“Mechanical and Natural Ventilation”, 2011
A - Mechanical extract ventilation (MEV)

**SINGLE-POINT EXHAUST SYSTEMS**

System Components:
1) quiet, efficient exhaust ventilation fan  
2) several passive wall or window vents  
3) programmable timer with speed switch

System Operation:
1) exhaust ventilation fan operates continuously  
2) spot fans exhaust air from kitchen and bathrooms  
3) residents can temporarily boost the ventilation rate.


Source: Marion Russell, Max Sherman and Armin Rudd, Review of Residential Ventilation Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, 2005
A - Mechanical extract ventilation (MEV)

**MULTI-POINT EXHAUST SYSTEMS**

System Components:
1) quiet, efficient multi-port exhaust fan
2) several passive wall or window vents
3) 3-4" diameter ventilation ductwork, grilles
4) programmable timer with speed switch

System Operation:
1) exhaust fan operates continuously on low.
2) bathrooms have exhaust ports instead of spot fans
3) residents can temporarily boost the ventilation rate.

Example of the short circuiting ventilation in an apartment with mechanical exhaust ventilation

Fig. 6 a, b, c

Source: Marion Russell, Max Sherman and Armin Rudd, Review of Residential Ventilation Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, 2005
Balanced ventilation uses a supply fan and an exhaust fan to regularly exchange indoor air; both fans move similar volumes of air, so indoor pressure fluctuates near neutral or "balanced."

From a safety and health perspective, balanced pressure is better than negative indoor pressure, but not as beneficial as positive indoor pressure, which helps keep outdoor pollutants outdoors!

**Particularities:**
- controlled air flow rates (inlet and outlet)
- filtration of the inlet air
- possibility of heat recovery
- used in a polluted and noisy environment

**Types:**
- With heat recovery
- Without heat recovery

**Both can be:**
- Centralized
- Decentralized

Source: Marion Russell, Max Sherman and Armin Rudd, Review of Residential Ventilation Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, 2005

Balanced Ventilation with Heat Recovery

Ventilation System Components:
1) HRV unit containing exhaust and supply fans, and air-to-air heat exchanger
2) exhaust and supply ducts and grilles
3) programmable timer with speed switch

Ventilation System Operation:
1) air is supplied to bedrooms, exhausted from bathrooms;
2) sensible heat is recovered from exhausted indoor air;
3) residents can temporarily boost the ventilation rate.

Centralized mechanical supply and exhaust system with heat recovery in an apartment building

Decentralized mechanical supply and exhaust ventilation system with heat recovery in an apartment building

Fig. 10 a, b

- Centralized ventilation is easier to control by demand
- The number of components requiring maintenance is higher

- Better heat recovery efficiency
- More complex control

Source: Jacob Verhaart, Balanced Ventilation System Part of the problem or part of the solution?, Final Report, 2010
the most common ones are cross-flow and counterflow air to air HE;
in cross-flow exchangers, the airflows through the different layers flow perpendicular to each other;
more effective than a cross-flow exchanger is the counterflow HE; the two streams flow in opposite directions; temperature difference as large as possible; disadvantage the pipes have to cross at one end and the inlet as well as the exit pipes need to be connected with the exchanger in between;
when designing a BVS, there is always a trade-off between heat transfer, which needs to be as high as possible, size (preferably as compact as possible to reduce costs) and electricity use;
electricity use by the ventilators is related to the drag of the HE;
more drag with a finer mesh of channels, but a finer mesh also means a more effective heat transfer;
there is a disadvantage in using a direct air-to-air HE; warmer air can contain more moisture, before it is saturated. When this air is cooled off in the HE, moisture can condense inside the exchanger!!
this can cause damage, because the walls in heat exchangers are thin for maximum efficiency, which make them fragile;
in older systems, the ventilation air by-passes the HE, when there is a risk of freezing;
in modern systems outside air is mixed with air from inside the house, to pre-heat it till there is no risk of freezing.

Fig.11 a,b,c

Source: Jacob Verhaart, Balanced Ventilation System Part of the problem or part of the solution?, Final Report, 2010
Source: Chiel BOONSTRA, Loes JOOSTEN, TREES Training for Renovated Energy Efficient Social housing, Intelligent Energy-Europe programme, contract n°EIE/05/110/SI2.420021, Section 1 – Techniques 1.3 Ventilation
Large Heat Recovery Systems

- Heat is stored in solid heat batteries ➔ metal (mostly aluminium or copper) mesh of small channels, through which the air can flow.
- The smaller the channels, the larger the surface area for heat transfer, and the larger the aerodynamic drag.
- **Heat wheel** ➔ a honeycomb mesh made of heat storing material rotates through the two airflows. First heating up in the flow out and then releasing that heat in the incoming flow.
- **Kantherm system** ➔ two heat batteries are stationary and the airflow through them is alternated via a valve. The valve changes the direction of the airflow every 50 s. The first 50 seconds, one of the batteries is loading and the other is releasing heat. The next 50 seconds the roles reverse and the loaded battery releases its heat and the other battery heats up.

Larger systems use solid material in the heat batteries to temporarily store heat and reverse the airflow from cold to hot ➔ the chance of the exchanger getting damaged by freezing of condensation is much lower!

**Condensation and ice can only build-up for the period of half a cycle!**

Installations using solid heat batteries have typically a lower overall efficiency, but are better suited for larger ventilation capacities.

Source: Jacob Verhaart, Balanced Ventilation System Part of the problem or part of the solution?, Final Report, 2010
Fans

*provide air for ventilation and industrial processes that need air flow*

The factors to consider when selecting a fan include:
- **Redundancy** - a single fan or multiple fans;
- **Duty** - CFM and static pressure at design conditions;
- **First cost** - more efficient fans are often more expensive;
- **Space constraints** - a tight space may limit fan choices;
- **Efficiency** - varies greatly by type and sizing;
- **Noise** - different fan types have different acoustic performance;
- **Surge** - some fan selections are more likely to operate in surge at part-load conditions.

Source: www.energyefficiencyasia.org
**Fans' laws**

<table>
<thead>
<tr>
<th>Flow ( \propto ) Speed</th>
<th>Pressure ( \propto (\text{Speed})^2 )</th>
<th>Power ( \propto (\text{Speed})^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="https://via.placeholder.com/150" alt="Graph" /></td>
<td><img src="https://via.placeholder.com/150" alt="Graph" /></td>
<td><img src="https://via.placeholder.com/150" alt="Graph" /></td>
</tr>
</tbody>
</table>

- \( \frac{Q_1}{Q_2} = \frac{N_1}{N_2} \)
- \( \frac{SP_1}{SP_2} = \left( \frac{N_1}{N_2} \right)^2 \)
- \( \frac{kW_1}{kW_2} = \left( \frac{N_1}{N_2} \right)^3 \)

**Varying the RPM by 10% decreases or increases air delivery by 10%.**

**Reducing the RPM by 10% decreases the static pressure by 19% and an increase in RPM by 10% increases the static pressure by 21%.**

**Reducing the RPM by 10% decreases the power requirement by 27% and an increase in RPM by 10% increases the power requirement by 33%.**

Where \( Q \) – flow, \( SP \) – Static Pressure, \( kW \) – Power and \( N \) – speed (RPM)

**Fans**

× the performance of a fan is described by a **FAN CURVE** that relates the static pressure increase across a fan to the airflow rate through the fan at a constant fan speed in revolutions per minute (rpm).

Air pressure decreases through the ventilation system, and this pressure drop is equal to the total airflow resistance of all the system components and the ductwork. This pressure drop depends on the airflow rate and is described by a **SYSTEM CURVE**.

× The **SYSTEM CURVE** is affected by changes in damper position, dirty filters, condensation on coils, holes in ductwork and obstruction of outlets or inlets.

Source: Andrew K. Persily, Manual for Ventilation Assessment in Mechanically Ventilated Commercial Buildings, 1994, Building and Fire Research Laboratory National Institute of Standards and Technology, Gaithersburg, MD 20899
System's functioning

- The intersection of the system curve and the fan performance curve defines the point at which the pressure across the fan and through the system are equal, and thereby defines the airflow rate;
- If the airflow resistance of the system is accurately estimated during the design and the fan is properly selected and installed, then the point of intersection will be at the design airflow rate of the system;
- If the system resistance increases, then a new system curve $S'$ replaces the original system curve $S$; the fan and system curves will intersect at a higher pressure difference and a lower airflow rate; the airflow rate can be returned to its design value by increasing the fan speed, such that a new fan curve $F'$ is in effect.

Source: Andrew K. Persily, Manual for Ventilation Assessment in Mechanically Ventilated Commercial Buildings, 1994, Building and Fire Research Laboratory National Institute of Standards and Technology, Gaithersburg, MD 20899
Fan classification

CENTRIFUGAL (flow radial to fan shaft)
   Blade Type
   Backward Inclined
      Straight/Flat Blade (BI)
      Air Foil (AF)
   Radial – (typically only for industrial applications)
   Forward Inclined
      Straight/Flat Blade
      Forward Curved
   Housing Type
      Scroll Type (housed fan)
         Single Width (ducted inlet from one side)
         Double Width (air enters from two sides)
      Plug Type
         In-line (tubular)
         Roof-top (dome) – (used for low static exhaust)
         Plenum

AXIAL (flow parallel to fan shaft)
   Blade Type
      Slanted Blades
      Air Foil
      Cambered Twist
   Housing Type
      Propeller – (common for relief, low pressure exhaust)
      Tube-axial
      Vane-axial
      Fixed Pitch
      Adjustable Pitch
      Variable Pitch

MIXED FLOW (hybrid – part centrifugal and part axial)
   Blade Type
      Contoured Single Thickness
      Air Foil
   Housing Type
      In-line (tubular)

BASIC DESIGN TECHNIQUES

1. Design the air distribution system to minimize flow resistance and turbulence. High flow resistance increases the required fan pressure, which results in higher noise being generated by the fan. Turbulence increases the flow noise generated by duct fittings and dampers in the air distribution system, especially at low frequencies.

2. Select a fan to operate as near as possible to its rated peak efficiency when handling the required quantity of air and static pressure. Also, select a fan that generates the lowest possible noise but still meets the required design conditions for which it is selected. Using an oversized or undersized fan that does not operate at or near rated peak efficiency can result in substantially higher noise levels.

3. Design duct connections at both the fan inlet and outlet for uniform and straight air flow. Failure to do this can result in severe turbulence at the fan inlet and outlet and in flow separation at the fan blades. Both of these can significantly increase the noise generated by the fan.

4. Select duct silencers that do not significantly increase the required fan total static pressure. Duct silencers can significantly increase the required fan static pressure if improperly selected. Selecting silencers with static pressure losses of 87 Pa. or less can minimize silencer airflow regenerated noise.

5. Place fan-powered mixing boxes associated with variable-volume air distribution systems away from noise-sensitive areas.

Source: Chapter 46 of the 1999 ASHRAE Handbook—Applications
6. Minimize flow-generated noise by elbows or duct branch takeoffs, whenever possible, by locating them at least four to five duct diameters from each other. For high velocity systems, it may be necessary to increase this distance to up to ten duct diameters in critical noise areas.

7. Keep airflow velocity in the duct as low as possible (7.5 m/s or less) near critical noise areas by expanding the duct cross-section area. Flow separation, resulting from expansion angles greater than 15°, may produce rumble noise. Expanding the duct cross-section area will reduce potential flow noise associated with turbulence in these areas.

8. Use turning vanes in large 90° rectangular elbows and branch takeoffs.

9. Place grilles, diffusers and registers into occupied spaces as far as possible from elbows and branch takeoffs.

10. Minimize the use of volume dampers near grills, diffusers and registers in acoustically critical situations.

11. Vibration isolate all vibrating reciprocating and rotating equipment if mechanical equipment is located on upper floors or is roof-mounted. Also, it is usually necessary to vibration isolate the mechanical equipment that is located in the basement of a building as well as piping supported from the ceiling slab of a basement, directly below tenant space. It may be necessary to use flexible piping connectors and flexible electrical conduit between rotating or reciprocating equipment and pipes and ducts that are connected to the equipment.
12. Vibration isolate ducts and pipes, using spring and/or neoprene hangers for at least the first 15 m from the vibration-isolated equipment.
13. Use barriers near outdoor equipment when noise associated with the equipment will disturb adjacent properties if barriers are not used. In normal practice, barriers typically produce no more than 15 dB of sound attenuation in the mid frequency range.

Source: Chapter 46 of the 1999 ASHRAE Handbook—Applications
TYPES AND PERFORMANCE

VISCOUS IMPINGEMENT FILTERS

- Panel filters made up of coarse fibers with a high porosity;
- The filter media are coated with a viscous substance, such as oil which causes particles that impinge on the fibers to stick to them;
- Design air velocity through the media is usually in the range of 1 to 4 m/s;
- Low pressure drop, low cost, and good efficiency on lint but low efficiency on normal atmospheric dust!
- This type of filter is commonly used in residential furnaces and air conditioning and is often used as a pre-filter for higher-efficiency filters.

DRY EXTENDED-SURFACE FILTERS

- Media of random fiber mats or blankets of varying thicknesses, fiber sizes, and densities;
- Media in these filters are frequently supported by a wire frame in the form of pockets, or V-shaped or radial pleats;
- Efficiency is usually higher than that of panel filters, and the variety of media available makes it possible to furnish almost any degree of cleaning efficiency desired;
- Media velocities range from 0.03 to 0.5 m/s, although approach velocities run to 4 m/s.

Source: Chapter 24 of the 2000 ASHRAE Handbook—Systems and Equipment
**TYPES AND PERFORMANCE**

**VERY HIGH-EFFICIENCY DRY FILTERS**

- HEPA (high-efficiency particulate air) filters
- ULPA (ultralow-penetration air)
- Filters are made in an extended-surface configuration of deep space folds of submicrometre glass fiber paper;
- Operate at duct velocities near 1.3 m/s, with resistance rising from 120 to more than 500 Pa over their service life;
- Are the standard for clean room, nuclear, and toxic particulate applications.

**MEMBRANE FILTERS**

- Are used mainly for air sampling and specialized small-scale applications where their particular characteristics compensate for their fragility, high resistance, and high cost;
- Available in many pore diameters and resistances and in flat sheet and pleated forms.

**ELECTRET FILTERS**

- Composed of electrostatically charged fibers;
- The charges on the fibers augment collection of smaller particles by interception and diffusion (Brownian motion) with Coulomb forces caused by the charges;
- There are three types of these filters: resin wool, electret, and an electrostatically sprayed polymer;
- Efficiency of charged-fiber filters is determined by both the normal collection mechanisms of a media filter and the strong local electrostatic effects.

Source: Chapter 24 of the 2000 ASHRAE Handbook—Systems and Equipment
RENEWABLE MEDIA FILTERS

(1) Moving curtain viscous impingement filters
the resistance remains approximately constant as long as proper operation is maintained. A resistance of 100 to 125 Pa at a face velocity of 2.5 m/s is typical of this class.

(2) Moving-curtain dry media roll filter
operating duct velocities near 1 m/s are generally lower than those of viscous impingement filters.

ELECTRONIC AIR CLEANERS

can remove and collect airborne contaminants with an initial efficiency of up to 98% at low airflow velocities (0.8 to 1.8 m/s) when tested according to ASHRAE Standard 52.1;

Efficiency decreases:
(1) as the collecting plates become loaded with particulates
(2) with higher velocities
(3) with nonuniform velocity.

Fig. 25
SELECTION AND MAINTENANCE

the following factors should be considered:

- Degree and type of air cleanliness required
- Disposal of dust after it is removed from the air
- Amount and type of dust in the air to be filtered
- Operating resistance to airflow (pressure drop)
- Space available for filtration equipment
- Cost of maintaining or replacing filters
- Initial cost of the system

The performance of different filter media is normally as follows:

- Flat panel type (disposable filters): air velocity 0.1-1.0 m s\(^{-1}\), resistance 25-250 N m\(^{-2}\), efficiency 20-35%
- Continuous roll (self cleaning filters): air velocity 2.5 m s\(^{-1}\), resistance 30-175 N m\(^{-2}\), efficiency 25%
- Bag filters: efficiency 40-90%
- HEPA filters: efficiency 99.97% for 0.3 micron particles and larger
- ULPA filters: efficiency 99.9997 for 0.12 micron particles or larger
- Viscous filters panel type (cloth with viscous fluid coating: washable or disposable): plates about 500 × 500 mm, air velocity 1.5-2.5 m s\(^{-1}\), resistance 20-150 N m\(^{-2}\)
- Viscous filters (Continuous roll - continuously moving, self cleaning). Air velocity 2.5 m s\(^{-1}\), resistance 30-175 N m\(^{-2}\)
- Electrostatic precipitators. Cleaned automatically, air velocity 1.5-2.5 m s\(^{-1}\), resistance negligible, efficiency 30-40%
- Absolute. Dry panel with special coating: disposable or self cleaning, air velocity 2.5 m s\(^{-1}\), resistance 250-625 N m\(^{-2}\)

Source: Chapter 24 of the 2000 ASHRAE Handbook— Systems and Equipment
Source: B. Purushothama, Humidification and ventilation management in textile industry, Woodhead Publishing India (P) Ltd, 2009