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FOR A SUSTAINABLE FUTURE

Educational Package Ventilation

Lecture 3 : Mechanical (forced) ventilation

IEE/09/631/SI2.558225
28.10.2011

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 and Blowers
- Basic Acoustic Terminology
- Noise sources
- Design criteria
- Air filters

Supply-Only ventilation system

4 basic types of ventilation systems

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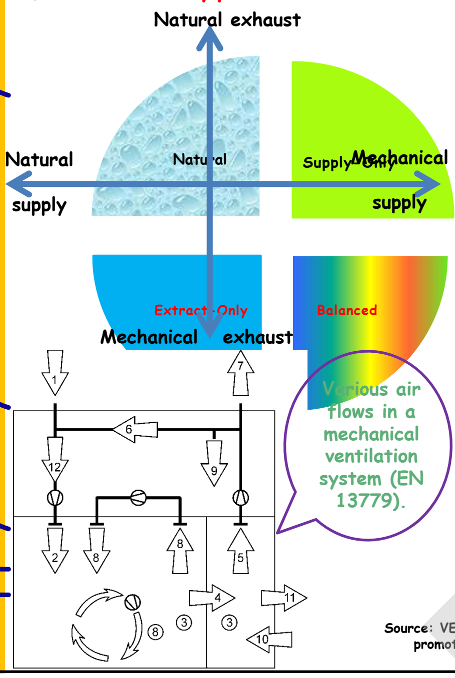

No. in fig	Type of air	Definition
1	outdoor air	air taken into the air handling system or opening from outdoors before any air treatment
2	supply air	airflow entering the treated room, or air entering the system after any treatment
3	indoor air	air in the treated room or zone
4	transferred air	indoor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

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

Supply-Only ventilation system

SOV or Positive input ventilation (PIV)

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- 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 contaminants

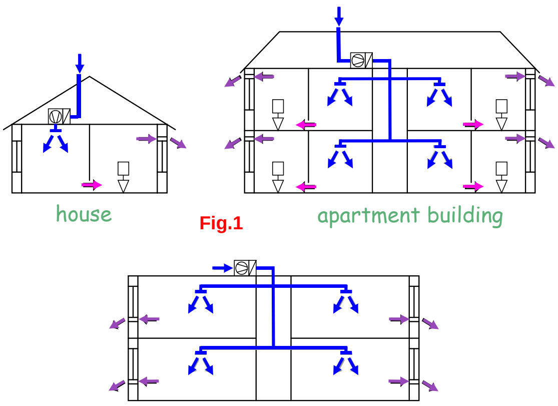

Fig.1

office building

Source: Guide pratique "La ventilation méchanique des habitation"

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Supply-Only ventilation system

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

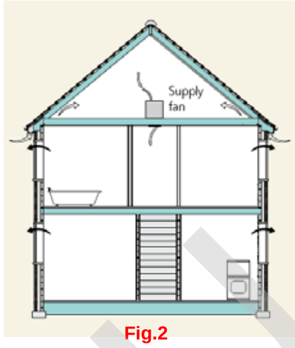

Fig.2

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.

Source: Energy efficient ventilation in dwellings – a guide for specifiers (2006 edition)

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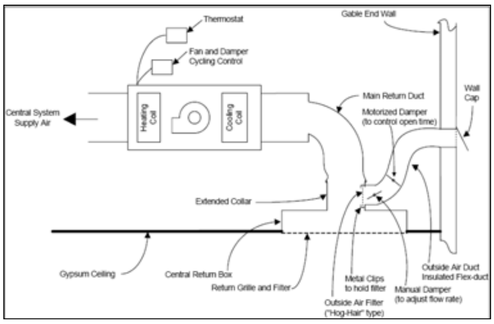
Supply-Only ventilation system

Applications

- New build: good practice – depending on the individual system's compliance with building regulations
- New build: best practice ✗
- Major refurbishment ✓
- Minor refurbishment ✓



Example of supply ventilation integrated into the return side of an existing HVAC system (Building Science Corporation)

Fig.3

Advantages

- A significant advantage of SIV in homes is that it creates positive indoor pressure, which helps prevent outdoor pollutants (e.g., radon) from entering;
- Easy to install;
- Operation is easy to understand;
- Heat gain to loft space is utilized.

Disadvantages

- Limited research into their use
- Some additional enhancement measures may be needed, dependent on building shape and layout

Methods

- Continuous supply
  - Single-point Supply
  - Multi-point supply
- Intermittent supply with inlet in return side of HVAC System

Source: Energy efficient ventilation in dwellings – a guide for specifiers (2006 edition)
Source: Marion Russell, Max Sherman and Armin Rudd, Review of Residential Ventilation Technologies , Ernest Orlando Lawrence Berkeley National Laboratory, 2005

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Extract-Only ventilation system

A - Mechanical extract ventilation (MEV)

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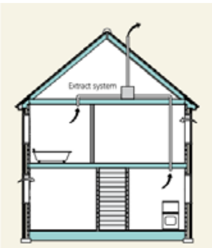
(MEV) continually extracts air
- single-point exhaust systems
- multi-point exhaust systems

Fig.4

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: Energy efficient ventilation in dwellings – a guide for specifiers (2006 edition)
Source: Dr. Sam C. M. Hui, Department of Mechanical Engineering, The University of Hong Kong, lecture "Mechanical and Natural Ventilation", 2011

Extract-Only ventilation system

A - Mechanical extract ventilation (MEV)

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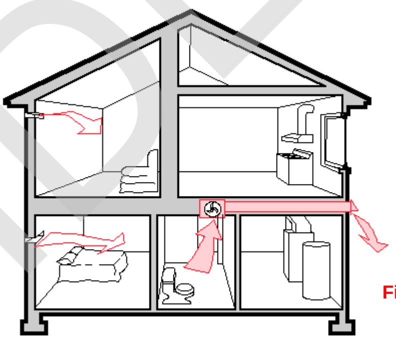
SINGLE-POINT EXHAUST SYSTEMS

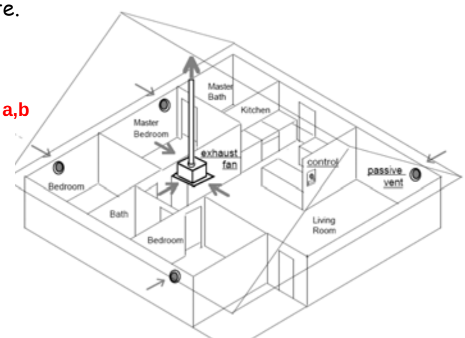


Example of a single-point local exhaust system with makeup air inlets (Oikos Green Building Source, 1995). Air inlets are needed only for tight building envelope

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.

Fig.5 a,b



Source: Judy A. Roberson, Richard E. Brown, Jonathan G. Koomey, Steve E. Greenberg, Recommended ventilation strategies for energy-efficient production homes, 1998
Source: Marion Russell, Max Sherman and Armin Rudd, Review of Residential Ventilation Technologies , Ernest Orlando Lawrence Berkeley National Laboratory, 2005

Extract-Only ventilation system

A - Mechanical extract ventilation (MEV)

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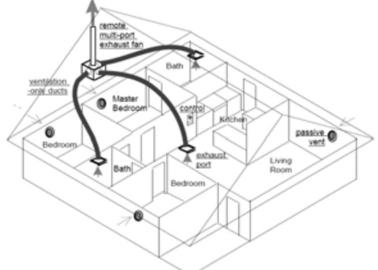
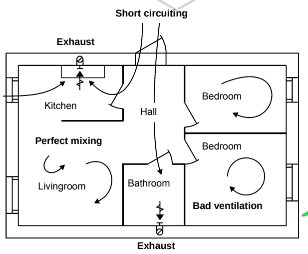
MULTI-POINT EXHAUST SYSTEMS



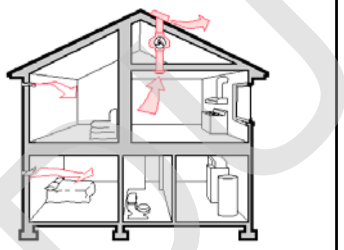
System Components:
1) quiet, efficient multi-port exhaust fan
2) several passive wall or window vents
3) 3-4" diameter ventilation ductwork, grilles
4) programmable timer with speed switch

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.

Fig.6 a,b,c



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



Inline exhaust fan with make-up trickle vents

Source: Judy A. Roberson, Richard E. Brown, Jonathan G. Koomey, Steve E. Greenberg, Recommended ventilation strategies for energy-efficient production homes, 1998
Source: Marion Russell, Max Sherman and Armin Rudd, Review of Residential Ventilation Technologies , Ernest Orlando Lawrence Berkeley National Laboratory, 2005
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

Extract-Only ventilation system

B - Intermittent exhaust

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- similar to a continuous exhaust system;
- generally it consists of one central fan to remove stale air from the building, but may also incorporate several fans in areas of high sources (*i.e. bathrooms and kitchens);*
- the fan(s) runs only part of the time at a higher rate and are sized to provide the necessary ventilation;
- the rate of ventilation when the system is operated intermittently must be larger than if it were operating continuously (Sherman, 2004);
- **several advantages:**
  - the occupant can reduce the amount of outdoor air entering the building during periods of the day when the outdoor air quality is poor;
  - peak load concerns may make it advantageous to reduce ventilation for certain periods of the day;
  - when the ventilation system is integrated with the heating and cooling system, cyclic operation may also make more sense;
- **disadvantages:**
  - the occupant controls the ventilation and must be relied on to know when ventilation is needed;
  - if the fan is noisy, the occupant may chose not to operate the system, which could result in under-ventilation
  - many systems use a timer to automatically run the fan for a certain amount of time each day so that the occupant is not relied on to sense when ventilation is needed;
  - installation and operating costs are similar to the continuous exhaust systems, but may exceed them if sophisticated control systems are installed.

Source: Energy efficient ventilation in dwellings – a guide for specifiers (2006 edition)
Source: Marion Russell, Max Sherman and Armin Rudd, Review of Residential Ventilation Technologies , Ernest Orlando Lawrence Berkeley National Laboratory, 2005

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Balanced ventilation system

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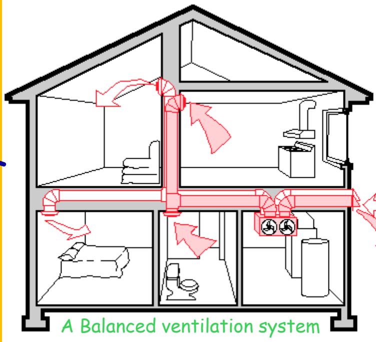

A Balanced ventilation system

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:

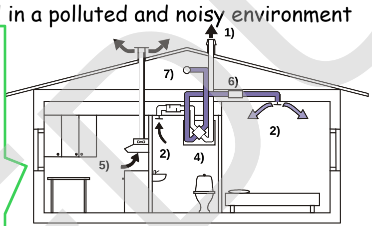
- With heat recovery
- Without heat recovery

Both can be:

- Centralized
- Decentralized

Fig. 7 a,b

1)Exhaust air
2)Extract air
3) Supply air Ventilation air in normal operation
4) Heat recovery exchanger
5)Kitchen exhaust
6) Sound attenuator
7)Outdoor air intake for ventilation.



Principle of mechanical exhaust and supply system in a house

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

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Balanced ventilation system

Balanced Ventilation with Heat Recovery

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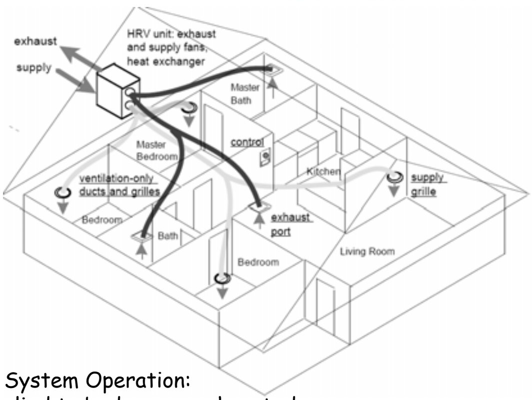
Ventilation System Components:
1) HRV unit containing exhaust and supply fans, and air-to-air heat exchanger
2) exhaust and supply ducts and grilles
3) programmable timer with speed switch



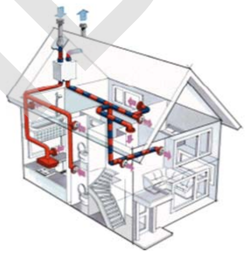


Fig. 8 a,b

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.

Source: Judy A. Roberson, Richard E. Brown, Jonathan G. Koomey, Steve E. Greenberg, recommended ventilation strategies for energy-efficient production homes, 1998
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

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Balanced ventilation system

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A-Single room heat recovery ventilators (SRHRVs)

- Advantages
  - Easy to install.
  - Provides continuous 'low level' background ventilation.
  - Heat recovery from extracted air.
  - Almost silent in operation at trickle speed.

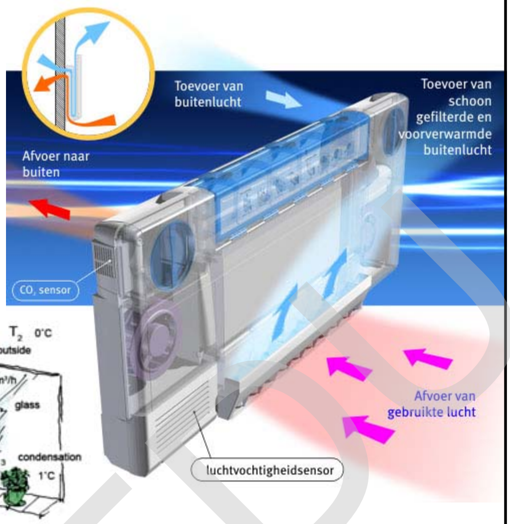
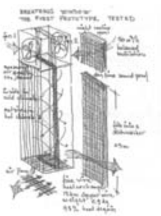
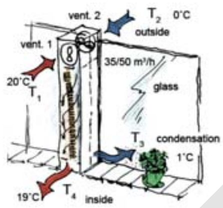


Fig. 9 a,b,c





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

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Balanced ventilation system

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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

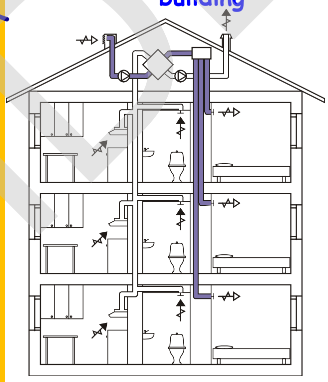
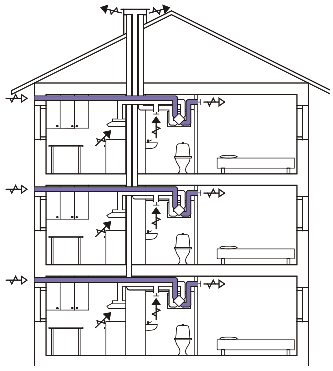


Fig.10 a,b



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
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

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Balanced ventilation system

B-Whole house mechanical ventilation with heat recovery (MVHR)

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- 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 then 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

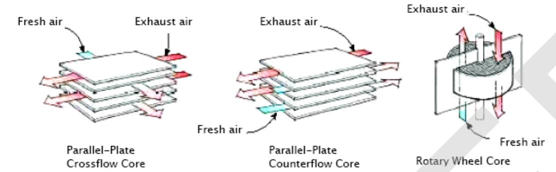
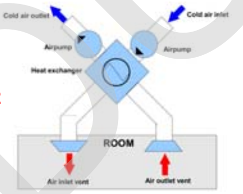


Fig. 12



Source: Jacob Verhaart, Balanced Ventilation System Part of the problem or part of the solution?, Final Report, 2010
Source: Energy efficient ventilation in dwellings – a guide for specifiers (2006 edition)
Source: Chiel BOONSTRA, Loes JOOSTEN, TREES Training for RenovatedEnergyEfficient Social housing, Intelligent Energy-Europe programme, contract n°EIE/05/110/SI2.420021, Section 1 – Techniques 1.3 Ventilation

Balanced ventilation system

Large Heat Recovery Systems

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- 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;
- a **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.

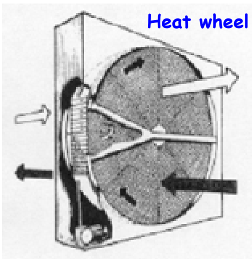

Fig.13

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 built-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.

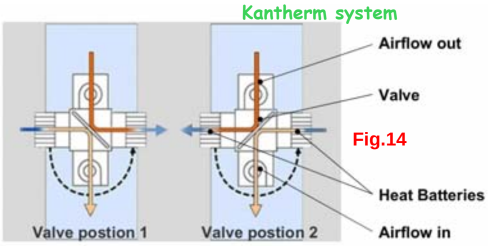

Fig.14

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

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Fans and Blowers

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.

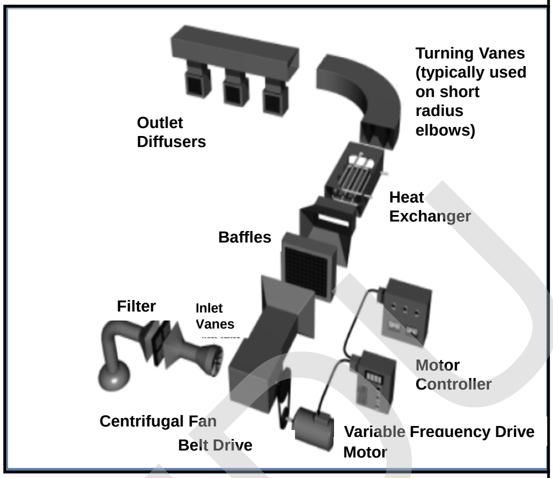
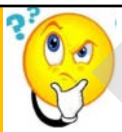


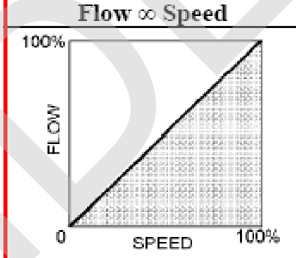
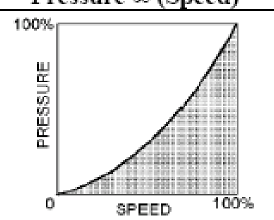
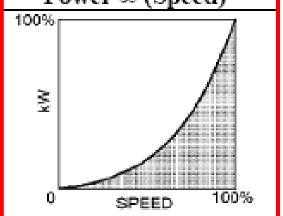
Fig.15

Source: Advanced Variable Air Volume System design Guide, 2007
Source: www.energyefficiencyasia.org

Fans and Blowers



Fans' laws

Flow ∝ Speed	Pressure ∝ (Speed)^2	Power ∝ (Speed)^3
		
$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{SP_1}{SP_2} = \left(\frac{N_1}{N_2}\right)^2$	$\frac{kW_1}{kW_2} = \left(\frac{N_1}{N_2}\right)^3$
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)

Fig.16

Source: Fans & Blowers, Presentation from the "Energy Efficiency Guide for Industry in Asia", www.energyefficiencyasia.org

Fans and Blowers

Fans

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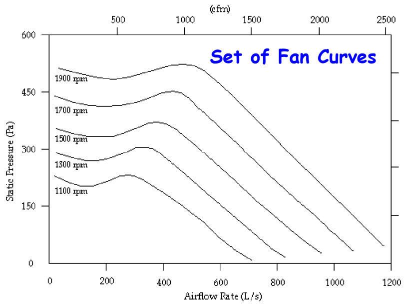
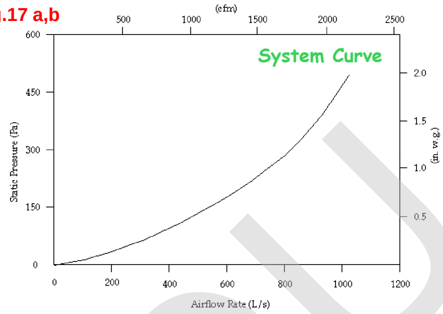
- the performance of a fan is described by a **FAN CURVE** that relates the static pressure increase across a fan to the airflow rate through the fan at a constant fan speed in revolutions per minute (rpm).

Fig.17 a,b





- 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

Fans and Blowers

System's functioning

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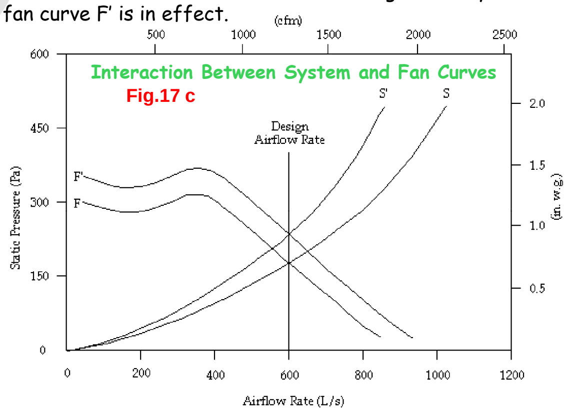
- The intersection of the system curve and the fan performance curve defines the point at which the pressure across the fan and through the system are equal, and thereby defines the airflow rate;
- If the airflow resistance of the system is accurately estimated during the design and the fan is properly 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.

Fig.17 c



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

Fans and Blowers

Fan classification

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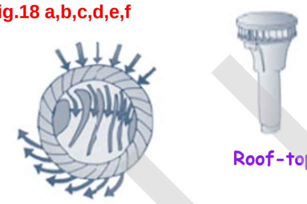
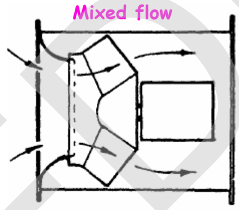
CENTRIFUGAL (flow radial to fan shaft)
- Blade Type
  - Backward Inclined
    - Straight/Flat Blade (BI)
    - Air Foil (AF)
  - Radial – (typically only for industrial applications)
  - Forward Inclined
    - Straight/Flat Blade
    - Forward Curved
- Housing Type
  - Scroll Type (housed fan)
    - 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)

Fig.18 a,b,c,d,e,f





Source: Advanced Variable Air Volume System design Guide, 2007

Fans and Blowers

IDES-EDU INTELLIGENT ENERGY EUROPE

Fan classification

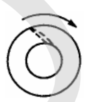
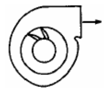
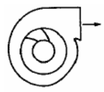
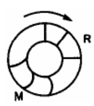
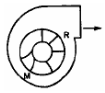
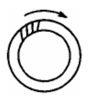
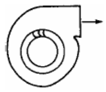
TYPE			IMPELLER DESIGN		HOUSING DESIGN
CENTRIFUGAL FANS	AIRFOIL		• Highest efficiency of all centrifugal fan designs. • 10 to 16 blades of airfoil contour curved away from direction of rotation. Deep blades allow for efficient expansion within blade passages. • Air leaves impeller at velocity less than tip speed. • For given duty,has highest speed of centrifugal fan designs.		• Scroll-type design for efficient conversion of velocity pressure to static pressure. • Maximum efficiency requires close clearance and alignment between wheel and inlet.
	BACKWARD-INCLINED BACKWARD-CURVED		• Efficiency only slightly less than airfoil fan. • 10 to 16 single-thickness blades curved or inclined away from direction of rotation. • Efficient for same reasons as airfoil fan.		• Uses same housing configuration as airfoil design.
	RADIAL		• Higher pressure characteristics than airfoil, backward-curved, and backward-inclined fans. • Curve may have a break to left of peak pressure and fan should not be operated in this area. • Power rises continually to free delivery.		• Scroll. Usually narrowest of all centrifugal designs. • Because wheel design is less efficient, housing dimensions are not as critical as for airfoil and backward-inclined fans.
	FORWARD-CURVED		• Flatter pressure curve and lower efficiency than the airfoil, backward-curved, and backward-inclined. • Do not rate fan in the pressure curve dip to the left of peak pressure. • Power rises continually toward free delivery. Motor selection must take this into account.		• Scroll similar to and often identical to other centrifugal fan designs. • Fit between wheel and inlet not as critical as for airfoil and backward-inclined fans.

Fig.19 a

Source: FAN TYPES, Kruger Technical Bulletin TBN007.0/1998

Fans and Blowers

Fan classification

IDES-EDU INTELLIGENT ENERGY EUROPE

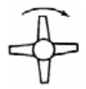
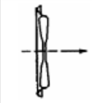
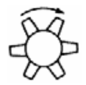
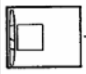
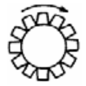
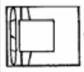
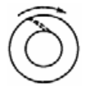
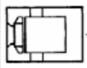
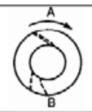
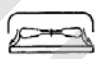
AXIAL FANS	PROPELLER		• Low efficiency • Limited to low-pressure applications. • Usually low cost impellers have two or more blades of single thickness attached to relatively small hub. • Primary energy transfer by velocity pressure.	 • Simple circular ring, orifice plate, or venturi. • Optimum design is close to blade tips and forms smooth airfoil into wheel.
AXIAL FANS	TUBEAXIAL		• Somewhat more efficient and capable of developing more useful static pressure than propeller fan. • Usually has 4 to 8 blades with airfoil or single-thickness cross section. • Hub usually less than transfer by velocity pressure.	 • Cylindrical tube with close clearance to blade tips.
AXIAL FANS	VANEAXIAL		• Good blade design gives medium- to high-pressure capability at good efficiency. • Most efficient of these fans have airfoil blades. • Blades may have fixed, adjustable, or controllable pitch. • Hub is usually greater than half fan tip diameter.	 • Cylindrical tube with close clearance to blade tips. • Guide vanes upstream or downstream from impeller increase pressure capability and efficiency.
SPECIAL DESIGNS	TUBULAR CENTRIFUGAL		• Performance similar to backward-curved fan except capacity and pressure are lower. • Lower efficiency than backward-curved fan. • Performance curve may have a dip to the left of peak pressure.	 • Cylindrical tube similar to vaneaxial fan, except clearance to wheel is not as close. • Air discharges radially from wheel and turns 90° to flow through guide vanes.
SPECIAL DESIGNS	POWER ROOF VENTILATORS – CENTRIFUGAL		• Low-pressure exhaust systems such as general factory, kitchen, warehouse, and some commercial installations. • Provides positive exhaust ventilation, which is an advantage over gravity-type exhaust units. • Centrifugal units are slightly quieter than axial units.	 • Normal housing not used, since air discharges from impeller in full circle. • Usually does not include configuration to recover velocity pressure component.
SPECIAL DESIGNS	POWER ROOF VENTILATORS – AXIAL		• Low-pressure exhaust systems such as general factory, kitchen, warehouse, and some commercial installations. • Provide positive exhaust ventilation, which is an advantage over gravity-type exhaust units.	 • Essentially a propeller fan mounted in a supporting structure. • Hood protects fan from weather and acts as safety guard. • Air discharges from annular space at bottom of weather hood.

Fig.19 b Source: FAN TYPES, Kruger Technical Bulletin TBN007.0/1998,

Fans and Blowers

IDES-EDU INTELLIGENT ENERGY EUROPE

Fan performance & applications

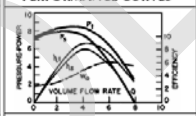
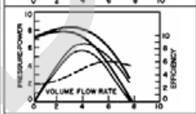
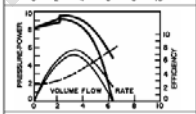
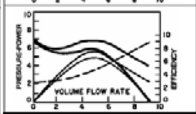
	TYPE	PERFORMANCE CURVES*	PERFORMANCE CHARACTERISTICS	APPLICATIONS
CENTRIFUGAL FANS	AIRFOIL		• Highest efficiencies occur at 50 to 60% of wide open volume. This volume also has good pressure characteristics. • Power reaches maximum near peak efficiency and becomes lower, or self-limiting, toward free delivery.	• General heating, ventilating, and air-conditioning applications. • Usually only applied to large systems, which may be low-medium- or high-pressure applications. • Applied to large, clean -air industrial operations for significant energy savings.
CENTRIFUGAL FANS	BACKWARD-INCLINED BACKWARD-CURVED		• Similar to airfoil fan, except peak efficiency slightly lower.	• Same heating, ventilating, and air-conditioning applications as airfoil fan. • Used in some industrial applications where airfoil blade may corrode or erode due to environment.
CENTRIFUGAL FANS	RADIAL		• Higher pressure characteristics than airfoil and backward-curved fans. • Pressure may drop suddenly at left of peak pressure, but this usually causes no problems. • Power rises continually to free delivery.	• Primarily for materials handling in industrial plants. Also for some high-pressure industrial requirements. • Rugged wheel is simple to repair in the field. Wheel sometimes coated with special material. • Not common for HVAC applications.
CENTRIFUGAL FANS	FORWARD-CURVED		• Pressure curve less steep than that of backward-curved fans. Curve dips to left of peak pressure. • Highest efficiency to right of peak pressure at 40 to 50% of wide open volume. • Rate fan to right of peak pressure. • Account for power curve, which rises continually toward free delivery, when selecting motor.	• Primarily for low-pressure HVAC applications, such as residential furnaces, central station units, and packaged air conditioners.

Fig.19 c Source: FAN TYPES, Kruger Technical Bulletin TBN007.0/1998,

Fans and Blowers

Fan performance & applications

IDES-EDU INTELLIGENT ENERGY EUROPE

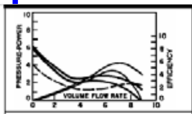
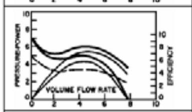
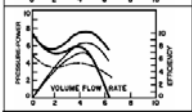
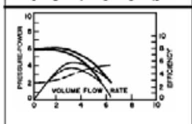
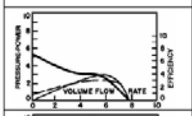
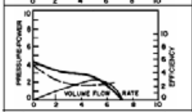
			Performance curves	Performance characteristics	Applications
AXIAL FANS	PROPELLER			• High flow rate, but very low-pressure capabilities. • Maximum efficiency reached near free delivery. • Discharge pattern circular and airstream swirls.	• For low-pressure, high-volume air moving applications, such as air circulation in a space or ventilation through a wall without ductwork. • Used for makeup air applications.
	TUBEAXIAL			• High flow rate, medium-pressure capabilities. • Performance curve dips to left of peak pressure. Avoid operating fan in this region. • Discharge pattern circular and airstream rotates or swirls.	• Low- and medium-pressure ducted HVAC applications where air distribution downstream is not critical. • Used in some industrial applications, such as drying ovens, paint spray booths, and fume exhausts.
	VANEAXIAL			• High-pressure characteristics with medium-volume flow capabilities. • Performance curve dips to left peak pressure due to aerodynamic stall. Avoid operating fan in this region. • Guide vanes correct circular motion imparted by wheel and improve pressure characteristics and efficiency of fan.	• General HVAC systems is low-, medium-, and high-pressure applications where straight-through flow and compact installation are required. • Has good downstream air distribution. • Used in industrial applications in place of tubeaxial fans. • More compact than centrifugal fans for same duty.
SPECIAL DESIGNS	TUBULAR CENTRIFUGAL			• Performance similar to backward-curved fan, except capacity and pressure is lower. • Lower efficiency than backward-curved fan because air turns 90°. • Performance curve of some designs is similar to axial flow fan and dips to left of peak pressure.	• Primarily for low-pressure, return air systems in HVAC applications. • Has straight-through flow.
	POWER ROOF VENTILATORS	CENTRIFUGAL		• Usually operated without ductwork; therefore, operates at very low pressure and high volume. • Only static pressure and static efficiency are shown for this fan.	• Low-pressure exhaust systems, such as general factory, kitchen, warehouse, and some commercial installations. • Low first cost and low operating cost give an advantage over gravity flow exhaust systems. • Centrifugal units are somewhat quieter than axial flow units.
		AXIAL		• Usually operated without ductwork; therefore, operates at very low pressure and high volume. • Only static pressure and static efficiency are shown for this fan.	• Low-pressure exhaust systems, such as general factory, kitchen, warehouse, and some commercial installations. • Low first cost and low operating cost give an advantage over gravity flow exhaust systems.

Fig.19 d Source: FAN TYPES, Kruger Technical Bulletin TBN007.0/1998,

Fans and Blowers

Centrifugal Fans

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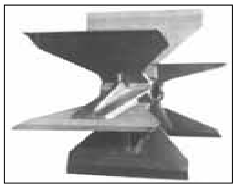
Radial fans

Advantages

- High pressure and temperature
- Simple design
- High durability
- Efficiency up to 75%
- Large running clearances

Disadvantages

- Suited for low/medium airflow rates only



(Canadian Blower)

Forward curved

Advantages

- Large air volumes against low pressure
- Relative small size
- Low noise level

Fig.20 a

(Canadian Blower)

Disadvantages

- Not high pressure / harsh service
- Difficult to adjust fan output
- Careful driver selection
- Low energy efficiency 55-65%

Backward-inclined

Advantages

- Operates with changing static pressure
- Suited for high flow and forced draft services
- Efficiency >85%

Disadvantages

- Not suited for dirty airstreams
- Instability and erosion risk

Source: www.energyefficiencyasia.org

Fans and Blowers

Axial Fans

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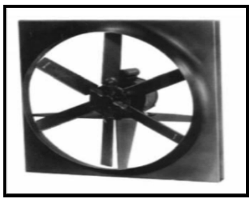
Propeller fans

Advantages

- High airflow at low pressure
- Little ductwork
- Inexpensive
- Suited for rooftop ventilation
- Reverse flow

Disadvantages

- Low energy efficiency
- Noisy



(Fan air Company)

Tube axial fans

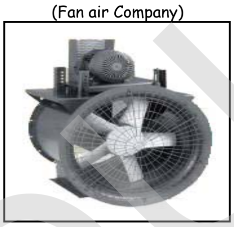
Fig.20 b

Advantages

- High pressures to overcome duct losses
- Suited for medium-pressure, high airflow rates
- Quick acceleration
- Space efficient

Disadvantages

- Expensive
- Moderate noise
- Low energy efficiency 65%



(Canadian Blower)

Vane axial fans

Advantages

- Suited for medium/high pressures
- Quick acceleration
- Suited for direct motor shaft connection
- Most energy efficient 85%

Disadvantages

- Expensive

Source: www.energyefficiencyasia.org

Fans and Blowers

Blowers

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Differences from fans:

- Much higher pressures : 1.20 kg/cm²
- Used to produce negative pressures for industrial vacuum systems

Types

- A) Centrifugal blower
- B) Positive displacement

Fig.20 c

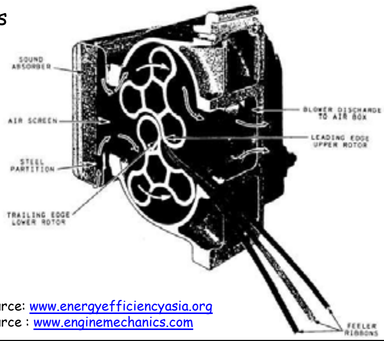
A) Centrifugal Blowers

- Gear-driven impeller that accelerates air
- Single and multi-stage blowers
- Operate at 0.35-0.70 kg/cm2 pressure
- Airflow drops if system pressure rises

Fig.21

B) Positive displacement

- Rotors trap air and push it through housing
- Constant air volume regardless of system pressure
- Suited for applications prone to clogging
- Turn slower than centrifugal blowers
- Belt-driven for speed changes



Source: www.energyefficiencyasia.org
Source : www.enginemechanics.com

Basic Acoustic Terminology

IDES-EDU INTELLIGENT ENERGY EUROPE

THE SELECTION of mechanical equipment and the design of equipment spaces should be undertaken with an emphasis on:
(1) the intended uses of the equipment;
(2) the goal of providing acceptable sound and vibration levels in occupied spaces of the building in which the equipment is located.

NOISE **propagates from the sources through the** air distribution ducts, through the structure, and through combinations of paths, reaching the occupants. All mechanical components, from dampers to diffusers to junctions, may produce sound by the nature of the airflow through and around them..

Typical Paths in HVAC Systems

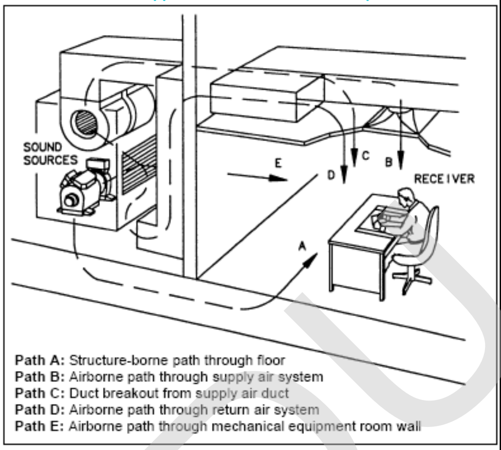


Fig.22

Adequate noise and vibration control in a heating, ventilating, and air-conditioning (HVAC) system is not difficult to achieve during the design phase of the system, providing basic noise and vibration control principles are understood

Source: Chapter 7 of the 1997 ASHRAE Handbook- HVAC Fundamentals
Source: Chapter 46 of the 1999 ASHRAE Handbook— Applications

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Basic Acoustic Terminology

IDES-EDU INTELLIGENT ENERGY EUROPE

ACOUSTICAL DESIGN OBJECTIVE

- the primary objective of HVAC system and equipment acoustical design is to create an appropriate acoustical environment for a given space. Sound and vibration are created by a source, are transmitted along one or more paths, and reach a receiver;
- **treatments** and modifications can be applied to any or all of these elements to achieve a proper acoustical environment that is free of noise and vibration.

SOUND

- a traveling oscillation in a medium exhibiting the properties of both elasticity and inertia'
- in fluid media (air or water), the disturbance travels as a longitudinal compression wave;
- sound is generated by a vibrating surface or a turbulent fluid stream.
- **the speed** of a longitudinal wave in a fluid medium is a function of the medium's density and modulus of elasticity; in air at room temperature, the speed of sound is about 340 m/s; in water, about 1500 m/s;
- **frequency** is the number of oscillations (or cycles) per unit time completed by a vibrating object. The international unit for frequency is cycles/s or hertz (Hz);
- **wavelength** is the distance between successive rarefactions or compressions of the propagation medium. Wavelength, speed, and frequency are interrelated by the following equation:

$$\lambda = \frac{c}{f}$$

Source: Chapter 7 "SOUND AND VIBRATION" of the 2005 ASHRAE Handbook Fundamentals (SI)
Source: Chapter 46 of the 1999 ASHRAE Handbook— Applications

Basic Acoustic Terminology

IDES-EDU INTELLIGENT ENERGY EUROPE

Noise

- the first and simplest definition of noise is **any unwanted sound**.
- the second definition of noise is broadband sound without distinguishable frequency characteristics, such as the sound of a waterfall.

- three types of noise in the second context are frequently encountered in acoustics:

1. **Random noise is an oscillation**, the instantaneous magnitude of which is not specified for any given instant. The instantaneous magnitudes of a random noise are specified only by probability distributions, giving the fraction of the total time that the magnitude, or some sequence of magnitudes, lies within a specified range;
2. **White noise** has a continuous frequency spectrum with equal energy/Hz over a specified frequency range. In this sense, it is like white light. White noise is not necessarily random.
3. **Pink noise** also has a continuous frequency spectrum but has equal energy per constant-percentage bandwidth

Source: Chapter 7 "SOUND AND VIBRATION" of the 2005 ASHRAE Handbook Fundamentals (SI)
Source: Chapter 46 of the 1999 ASHRAE Handbook— Applications

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Basic Acoustic Terminology

IDES-EDU INTELLIGENT ENERGY EUROPE

HUMAN RESPONSE TO SOUND

any unwanted sound! Sound becomes noise when it:

- is too loud—the sound is uncomfortable or makes speech difficult to understand;
- is unexpected (e.g., the sound of breaking glass);
- is uncontrolled (e.g., a neighbor's lawn mower);
- happens at the wrong time (e.g., a door slamming in the middle of the night);
- contains unwanted pure tones (e.g., a whine, whistle, or hum);
- contains unwanted information or is distracting (e.g., an adjacent telephone conversation or undesirable music);
- is unpleasant (e.g., a dripping faucet);
- connotes unpleasant experiences (e.g., a mosquito buzz or a siren wail);
- is any combination of the previous examples!

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Source: Chapter 7 of the 1997 ASHRAE Handbook- HVAC Fundamentals

TERMINOLOGY

Basic Acoustic Terminology

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Decibel

- basic unit of measurement in acoustics;
- numerically, the decibel is 10 times the base 10 logarithm of the ratio of two like quantities proportional to acoustical power or energy;
- the term **level, when used in relation to sound power, sound** intensity, or sound pressure, indicates that dB notation is being used.

Sound Power and Sound Power Level

- A fundamental characteristic of an acoustic source is its ability to radiate energy, whether it is weak and small in size (a cricket) or strong and large (a compressor);
- Sound power and sound pressure are expressed in dB - as a ratio relative to some reference level.
- Sound Power Level PWL in dB:

$$PWL = 10 \log_{10} (W_{source}/W_{ref})$$

  - W_{ref} is 10-12 W
  - W_{source} is sound power in W.
- Sound Pressure Level SPL in dB:

$$SPL = 10 \log_{10}(P2 / P_{ref2})$$

  - P_{ref} = 2
  - P = sound pressure in Pa
- For ducts with no attenuation, sound pressure propagation is 1-dimensional and the SPL is constant.

Source: Chapter 7 of the 1997 ASHRAE Handbook- HVAC Fundamentals
Source: Chapter 46 of the 1999 ASHRAE Handbook— Applications

TERMINOLOGY

Basic Acoustic Terminology

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- dB; dBA;

  The ear also responds in a non-linear way, with maximum sensitivity around 2 or 3 kHz and much lower sensitivity at low frequencies. A commonly used metric is the A-weighted dB (dBA) which is weighted according to the typical human ear's frequency response.
- L_{eq}; L_{A10}; L_{A90}
  - L_{eq} is the time averaged sound pressure level and is used for time-varying signals.
  - L_{A10} is the SPL which is exceeded for 10% of the time.
  - L_{A90} is the SPL which is exceeded for 90% of the time (the "background" level).

Absorption and insulation

Absorption Coefficient: $A = \Sigma i\ ai.Si$

Normalized Level Difference **DnT** in dB(A) between 2 zones: $D_{nT} = L_1 - L_2 + 10.\log (Tr / T_0)$

Sound Reduction Index **R** in dB(A) of a surface: $R = L_1 - L_2 + 10.\log (S / A)$

Reverberation time Tr (s): $Tr = 0.161V / A$ — Sabine's formula

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Source: Isolation acoustique bâtiments (Florent Cappoen)

Noise sources

TYPICAL SOURCES OF NOISE

- Rotating and reciprocating equipment such as fans, motors, pumps, and chillers;
  - noise generated by vortices shed at the trailing edges of fan blades can be tonal;
  - turbulence generated upstream of the fan and ingested into the fan is the source of broadband noise;
  - turbulence in the boundary layer on the surface of fan blades also causes broadband noise;
  - flow that separates from blade surfaces can cause low-frequency noise;
  - nonuniform inflow to fans, created by obstructions, can produce tonal noise at frequencies of blade;
  - fan imbalance produces vibration at frequencies of shaft rotation and multiples;
  - these low-frequency vibrations can couple to the structures to which the fan is attached, which can transmit the vibration over long distances and radiate low-frequency noise into rooms;
- air and fluid sounds, such as those associated with flow through ductwork, piping systems, grilles, diffusers, terminal boxes, manifolds, and pressure-reducing stations;
- flow inside ducts is often turbulent, which is a source of broadband noise;
  - sharp corners of elbows and branches can separate flow from duct walls, producing low-frequency noise;
- excitation of surfaces (e.g., friction); movement of mechanical linkages; turbulent flow impacts on ducts, plenum panels, and pipes; and impacts within equipment, such as cams and valve slap;

Source: Chapter 7 of the 1997 ASHRAE Handbook- HVAC Fundamentals

Noise sources

HOW TO ATENUATE NOISE?

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Air distribution system noise can be controlled by one or both of the following strategies:

1. Reduce sound power levels at the source (the fan and turbulence induct systems).
2. Attenuate sound generated by the noise sources.

- Central Plant
  - fans: axial fans generally have lower noise output than centrifugal fans except at low frequencies;
  - uniform flow into or out of a fan is rare in typical field applications;
  - avoid locating duct turns near the inlet or discharge of a fan;
  - components such as dampers and silencers installed close to fan equipment can produce nonuniformities in the velocity profile at the entrance to the silencer, which results in a significantly higher-than-anticipated pressure drop across that component;
  - well-designed damper or silencer can actually improve flow conditions, which may reduce noise levels.
- Noise in Airflow Systems
  - larger diameter ducts - lower air velocity, less noise;
  - diffusers - data from manufacturer;
- External Noise
  - road traffic, aircraft, rail, industrial sources, external equipment and plant

Design criteria

BASIC DESIGN TECHNIQUES

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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.

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Source: Chapter 46 of the 1999 ASHRAE Handbook— Applications

Design criteria

BASIC DESIGN TECHNIQUES

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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.

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Source: Chapter 46 of the 1999 ASHRAE Handbook— Applications

Design criteria

BASIC DESIGN TECHNIQUES

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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.

Sound Rating Methods

- **a-weighted sound pressure level (dBA)**
  - a single-number measure of the relative loudness of noise that is used extensively in outdoor environmental noise standards
  - a-weighted sound levels can be measured with simple sound level meters
- **tangent noise criteria (NC)**
  - a single-number rating that is somewhat sensitive to the relative loudness and speech interference properties of a given noise spectrum;
- **room criteria (RC)**
  - a family of criterion curves and a rating procedure
- **balanced noise criteria (NCB)**
  - used to specify or evaluate room noise and includes noise due to occupant activities
- **new RC Mark II**
  - is intended for rating the sound performance of an HVAC system as a whole

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Source: Chapter 46 of the 1999 ASHRAE Handbook— Applications

Air filters

CLASIFICATION

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- separation efficiency - ability to retain synthetic standard dust; weight and % statement;
- blacking efficiency - capability to retain atmospheric dust; optical measured and % statement;
- particle separation efficiency - capability to retain particles at fixed sizes; particle concentration measured and % statement;
- dust accumulation capacity - capability to keep standard dust before the pressure drop extend a certain value;
- airflow resistance and static pressure drop of the filters.

TYPES OF AIR CLEANERS

- **fibrous media unit filters**, in which the accumulating dust load causes pressure drop to increase up to some maximum recommended value;
- **renewable media filters**, in which fresh media is introduced into the airstream as needed to maintain essentially constant resistance and, consequently, constant average efficiency;
- **electronic air cleaners**, which, if maintained properly by regular cleaning, have relatively constant pressure drop and efficiency;
- **combination air cleaners**, which combine the above types.

Source: Chapter 24 of the 2000 ASHRAE Handbook— Systems and Equipment
Source: www.energyefficiencyasia.org

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Air filters

CLASIFICATION

IDES-EDU INTELLIGENT ENERGY EUROPE

AIR WASHERS ← water jets

DRY FILTERS ← porous medium

STATIONARY FILTERS
- perforated sheets
- zigzag sheets

ROTARY FILTERS
with automatic cleaning

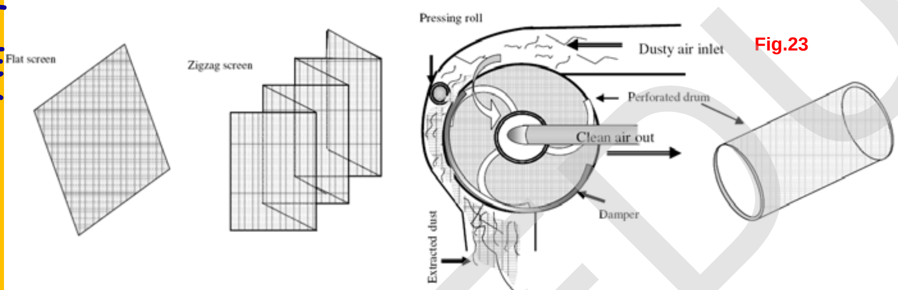

Fig.23

Source: B. Purushothama , Humidification and ventilation management in textile industry, Woodhead Publishing India (P) Ltd, 2009

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Air filters

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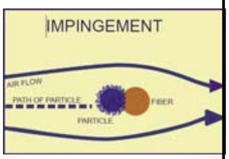
TYPES AND PERFORMANCE

VISCOUS IMPINGEMENT FILTERS

Fig.24



- **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

Air filters

TYPES AND PERFORMANCE

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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

Air filters

TYPES AND PERFORMANCE

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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.

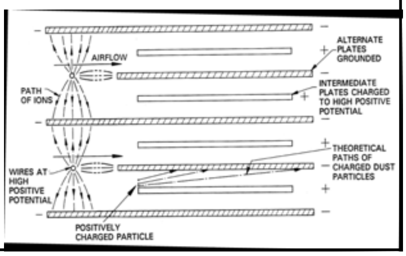

Fig.25

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

SELECTION AND MAINTENANCE

IDES-EDU

Air filters

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

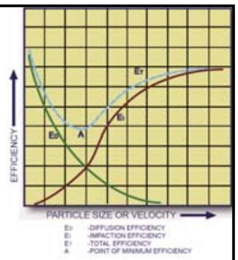

Fig.26

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

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