Ventilation Technologies

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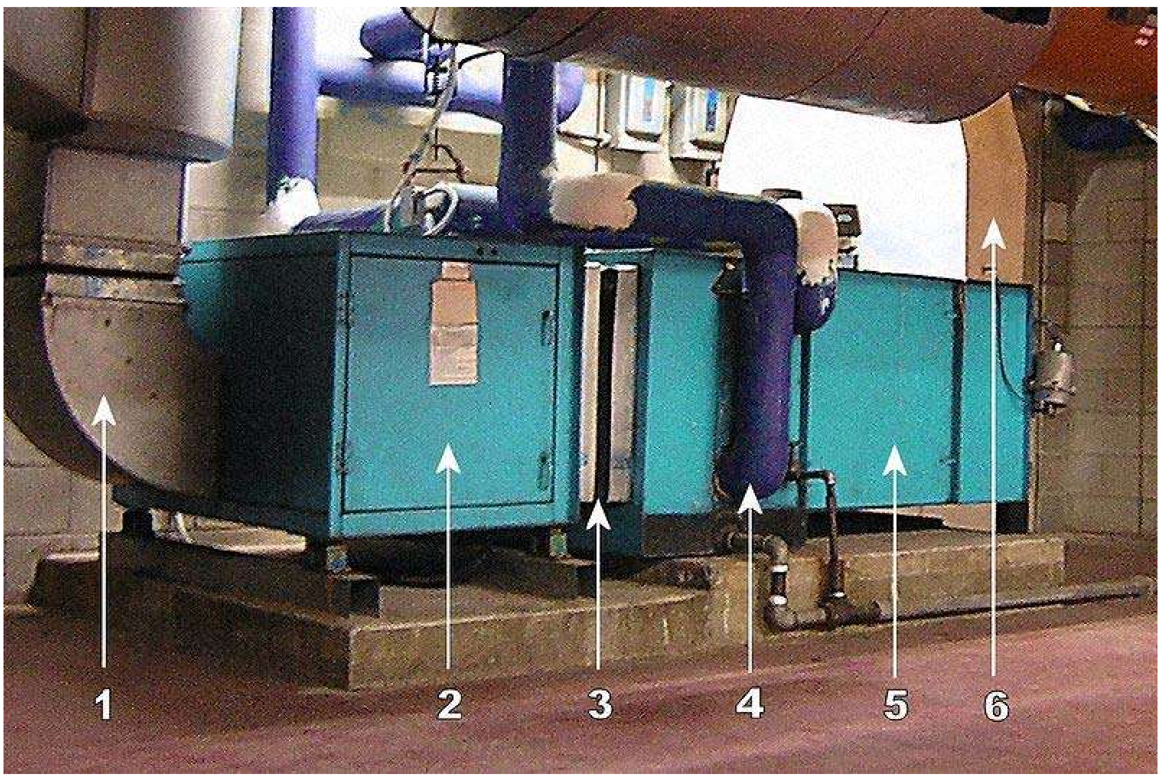
Ventilation



An air handling unit is used for the heating and cooling of air in a central location

Ventilating (the *V* in HVAC) is the process of "changing" or replacing air in any space to provide high indoor air quality (i.e. to control temperature, replenish oxygen, or remove moisture, odors, smoke, heat, dust, airborne bacteria, and carbon dioxide). Ventilation is used to remove unpleasant smells and excessive moisture, introduce outside air, to keep interior building air circulating, and to prevent stagnation of the interior air.

Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. It is one of the most important factors for maintaining acceptable indoor air quality in buildings. Methods for ventilating a building may be divided into *mechanical/forced* and *natural* types.

"Mechanical" or "forced" ventilation is used to control indoor air quality. Excess humidity, odors, and contaminants can often be controlled via dilution or replacement with outside air. However, in humid climates much energy is required to remove excess moisture from ventilation air.

Kitchens and bathrooms typically have mechanical exhaust to control odors and sometimes humidity. Factors in the design of such systems include the flow rate (which is a function of the fan speed and exhaust vent size) and noise level. If ducting for the fans traverse unheated space (e.g., an attic), the ducting should be insulated as well to prevent condensation on the ducting. Direct drive fans are available for many applications, and can reduce maintenance needs.

Ceiling fans and table/floor fans circulate air within a room for the purpose of reducing the perceived temperature because of evaporation of perspiration on the skin of the occupants. Because hot air rises, ceiling fans may be used to keep a room warmer in the winter by circulating the warm stratified air from the ceiling to the floor. Ceiling fans do not provide ventilation as defined as the introduction of outside air.

Natural ventilation is the ventilation of a building with outside air without the use of a fan or other mechanical system. It can be achieved with openable windows or trickle vents when the spaces to ventilate are small and the architecture permits. In more complex systems warm air in the building can be allowed to rise and flow out upper openings to the outside (stack effect) thus forcing cool outside air to be drawn into the building naturally through openings in the lower areas. These systems use very little energy but care must be taken to ensure the occupants' comfort. In warm or humid months, in many climates, maintaining thermal comfort solely via natural ventilation may not be possible so conventional air conditioning systems are used as backups. Air-side economizers perform the same function as natural ventilation, but use mechanical systems' fans, ducts, dampers, and control systems to introduce and distribute cool outdoor air when appropriate.

Definition

Ventilation is the intentional movement of air from outside a building to the inside. **Ventilation air**, as defined in ASHRAE Standard 62.1 and the *ASHRAE Handbook*, is that air used for providing acceptable indoor air quality. It mustn't be confused with *vents* or *flues*; which mean the exhausts of clothes dryers, and combustion equipment such as water heaters, boilers, fireplaces, and wood stoves. The vents or flues carry the products of combustion which have to be expelled from the building in a way which does not cause harm to the occupants of the building. Movement of air between indoor spaces, and not the outside, is called **transfer air**.

An example of closed ventilation

In commercial, industrial, and institutional (CII) buildings, and modern jet aircraft, return air is often recirculated to the air handling unit. A portion of the supply air is normally exfiltrated through the building envelope or exhausted from the building (e.g., bathroom or kitchen exhaust) and is replaced by outside air introduced into the return air stream. The rate of ventilation air required, most often provided by this mechanically-induced outside air, is often determined from *ASHRAE Standard 62.1* for CII buildings, or *62.2* for low-rise residential buildings, or similar standards.

Necessity

When people or animals are present in buildings, ventilation air is necessary to dilute odors and limit the concentration of carbon dioxide and airborne pollutants such as dust, smoke and volatile organic compounds (VOCs). Ventilation air is often delivered to spaces by mechanical systems which may also heat, cool, humidify and dehumidify the space. Air movement into buildings can occur due to uncontrolled **infiltration** of outside air through the building fabric or the use of deliberate **natural ventilation** strategies. Advanced air filtration and treatment processes such as *scrubbing*, can provide ventilation air by cleaning and recirculating a proportion of the air inside a building.

Types of ventilation

- **Mechanical or forced ventilation**: through an **air handling unit** or direct injection to a space by a fan. A local exhaust fan can enhance infiltration or natural ventilation, thus increasing the ventilation air flow rate.
- **Natural ventilation** occurs when the air in a space is changed with outdoor air without the use of mechanical systems, such as a fan. Most often natural ventilation is assured through operable windows but it can also be achieved through temperature and pressure differences between spaces. Open windows or vents are not a good choice for ventilating a basement or other below ground structure. Allowing outside air into a cooler below ground space will cause problems with humidity and condensation.
- **Mixed Mode Ventilation** or **Hybrid ventilation**: utilises both mechanical and natural ventilation processes. The mechanical and natural components may be used in conjunction with each other or separately at different times of day. The natural component, sometimes subject to unpredictable external weather conditions may not always be adequate to ventilate the desired space. The mechanical component is then used to increase the overall ventilation rate so that the desired internal conditions are met. Alternatively the mechanical component may be used as a control measure to regulate the natural ventilation process, for example, to restrict the air change rate during periods of high wind speeds.
- **Infiltration** is separate from *ventilation*, but is often used to provide *ventilation air*.

Ventilation rate

The **ventilation rate**, for CII buildings, is normally expressed by the volumetric flowrate of outside air being introduced to the building. The typical units used are cubic feet per minute (CFM) or liters per second (L/s). The ventilation rate can also be expressed on a per person or per unit floor area basis, such as CFM/p or CFM/ft², or as *air changes per hour*.

For residential buildings, which mostly rely on infiltration for meeting their ventilation needs, the common ventilation rate measure is the number of times the whole interior volume of air is replaced per hour, and is called **air changes per hour** (*I* or *ACH*; units of 1/h). During the winter, ACH may range from 0.50 to 0.41 in a tightly insulated house to 1.11 to 1.47 in a loosely insulated house.

ASHRAE now recommends ventilation rates dependent upon floor area, as a revision to the 62-2001 standard whereas the minimum ACH was 0.35, but no less than 15 CFM/person (7.1 L/s/person). As of 2003, the standards have changed to an addition of 3 CFM/100 sq. ft. (15 l/s/100 sq. m.) to the 7.5 CFM/person (3.5 L/s/person) standard.

Ventilation standards

- In 1973, in response to the 1973 oil crisis and conservation concerns, ASHRAE Standards 62-73 and 62-81) reduced required ventilation from 10 CFM (4.76 L/S) per person to 5 CFM (2.37 L/S) per person. This was found to be a primary cause of sick building syndrome.
- Current ASHRAE standards (Standard 62-89) states that appropriate ventilation guidelines are 20 CFM (9.2 L/s) per person in an office building, and 15 CFM (7.1 L/s) per person for schools. In commercial environments with tobacco smoke, the ventilation rate may range from 25 CFM to 125 CFM.

In certain applications, such as submarines, pressurized aircraft, and spacecraft, ventilation air is also needed to provide oxygen, and to dilute carbon dioxide for survival. Batteries in submarines also discharge hydrogen gas, which must also be ventilated for health and safety. In any pressurized, regulated environment, ventilation is necessary to control any fires that may occur, as the flames may be deprived of oxygen.

ANSI/ASHRAE (Standard 62-89) sets maximum CO_2 guidelines in commercial buildings at 1000 ppm, however, OSHA has set a limit of 5000 ppm over 8 hours.

Ventilation guidelines are based upon the minimum ventilation rate required to maintain acceptable levels of bioeffluents. Carbon dioxide is used as a reference point, as it is the gas of highest emission at a relatively constant value of 0.005 L/s. The mass balance equation is:

$$Q = G/(C_i - C_a)$$

- Q = ventilation rate (L/s)
- G = CO_2 generation rate
- C_i = acceptable indoor CO_2 concentration
- C_a = ambient CO_2 concentration

Ventilation equipment

- Fume hood
- Biological safety cabinet
- Dilution ventilation
- Room air distribution
- Heat recovery ventilation

Natural ventilation

Natural ventilation involves harnessing naturally available forces to supply and removing air through an enclosed space. There are three types of natural ventilation occurring in buildings: wind driven ventilation, pressure-driven flows, and stack ventilation. The pressures generated by 'the stack effect' rely upon the buoyancy of heated or rising air. wind driven ventilation relies upon the force of the prevailing wind to pull and push air through the enclosed space as well as through breaches in the building's envelope. Natural ventilation is generally impractical for larger buildings, as they tend to be large, sealed and climate controlled specifically by HVAC systems. Both are examples of passive engineering and have applications in renewable energy.

Demand-controlled ventilation (DCV)

DCV makes it possible to maintain proper ventilation and improve air quality while saving energy. ASHRAE has determined that: "It is consistent with the Ventilation rate procedure that Demand Control be permitted for use to reduce the total outdoor air supply during periods of less occupancy." CO_2 sensors will control the amount of ventilation for the actual number of occupants. During design occupancy, a unit with the DCV system will deliver the same amount of outdoor air as a unit using the ventilation-rate procedure. However, DCV can generate substantial energy savings whenever the space is occupied below the design level.

Local exhaust ventilation

Local exhaust ventilation addresses the issue of avoiding the contamination of indoor air by specific high-emission sources by capturing airborne contaminants before they are spread into the environment. This can include water vapor control, lavatory bioeffluent control, solvent vapors from industrial processes, and dust from wood- and metal-working machinery. Air can be exhausted through pressurized hoods or through the use of fans and pressurizing a specific area.
A local exhaust system is composed of 5 basic parts

1. A hood that captures the contaminant at its source
2. Ducts for transporting the air
3. An air-cleaning device that removes/minimizes the contaminant
4. A fan that moves the air through the system
5. An exhaust stack through which the contaminated air is discharged

Ventilation and combustion

Combustion (e.g., fireplace, gas heater, candle, oil lamp, etc.) consumes oxygen while producing carbon dioxide and other unhealthy gases and smoke, requiring ventilation air. An open chimney promotes infiltration (i.e. natural ventilation) because of the negative pressure change induced by the buoyant, warmer air leaving through the chimney. The warm air is typically replaced by heavier, cold air.

Ventilation in a structure is also needed for removing water vapor produced by respiration, burning, and cooking, and for removing odors. If water vapor is permitted to accumulate, it may damage the structure, insulation, or finishes. When operating, an air conditioner usually removes excess moisture from the air. A dehumidifier may also be appropriate for removing airborne moisture.

Smoking and ventilation

ASHRAE standard 62 states that air removed from an area with **environmental tobacco smoke** shall not be recirculated into ETS-free air. A space with ETS requires more ventilation to achieve similar perceived air quality to that of a non-smoking environment.

The amount of ventilation in an ETS area is equal to the amount of ETS-free area plus the amount V, where:

$V = DSD \times VA \times A/60E$

- V = recommended extra flow rate in CFM (L/s)
- DSD = design smoking density (estimated number of cigarettes smoked per hour per unit area)
- VA = volume of ventilation air per cigarette for the room being designed (ft^3/cig]
- E = contaminant removal effectiveness

Problems

In hot, humid climates, unconditioned ventilation air will deliver approximately one pound of water each day for each cubic foot per minute of outdoor air per day, annual average. This is a great deal of moisture, and it can create serious indoor moisture and mold problems.

- Ventilation efficiency is determined by design and layout, and is dependent upon placement and proximity of diffusers and return air outlets. If they are located closely together, supply air may mix with stale air, decreasing efficiency of the HVAC system, and creating air quality problems.

- System imbalances occur when components of the HVAC system are improperly adjusted or installed, and can create pressure differences (too much circulating air creating a draft or too little circulating air creating stagnancy).
- Cross-contamination occurs when pressure differences arise, forcing potentially contaminated air from one zone to an uncontaminated zone. This often involves undesired odors or VOCs.
- Re-entry of exhaust air occurs when exhaust outlets and fresh air intakes are either too close, or prevailing winds change exhaust patterns, or by infiltration between intake and exhaust air flows.
- Entrainment of contaminated outside air through intake flows will result in indoor air contamination. There are a variety of contaminated air sources, ranging from industrial effluent to VOCs put off by nearby construction work.

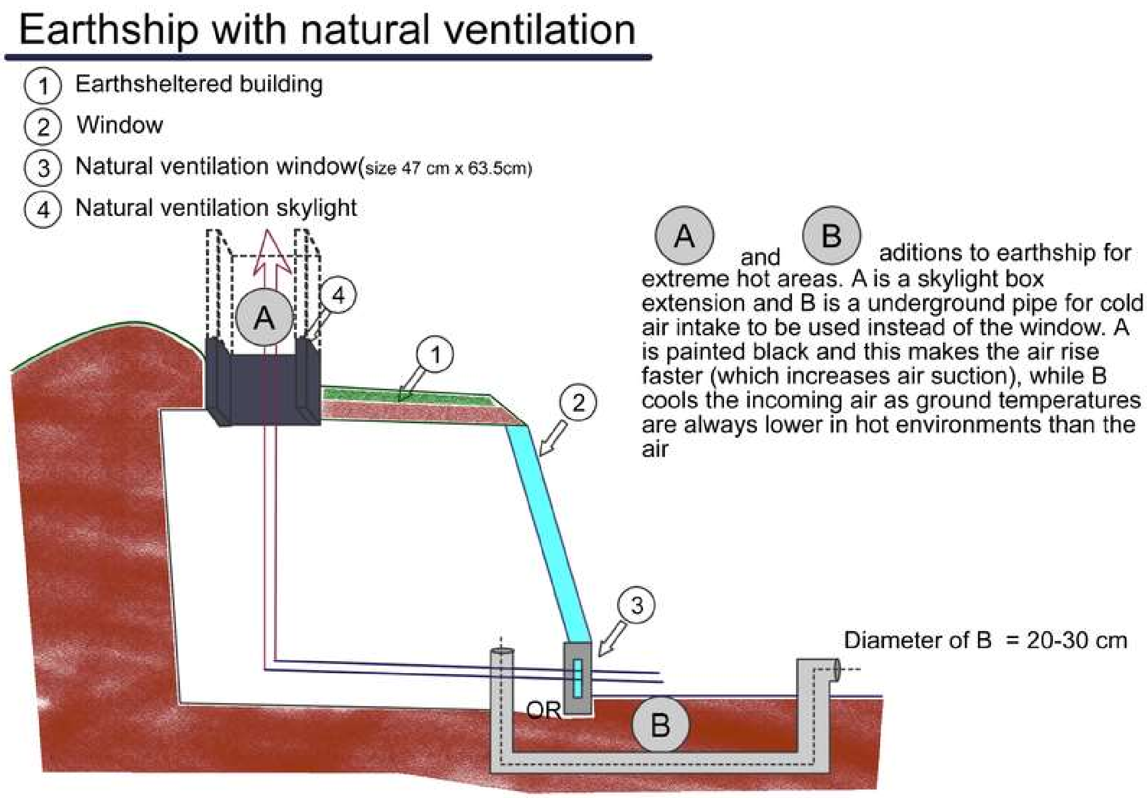
Air Quality Procedures

Ventilation Rate Procedure is rate based on standard, and "prescribes the rate at which ventilation air must be delivered to a space and various means to condition that air." Air quality is assessed (through CO_2 measurement) and ventilation rates are mathematically derived using constants.

Indoor Air Quality Procedure "uses one or more guidelines for the specification of acceptable concentrations of certain contaminants in indoor air but does not prescribe ventilation rates or air treatment methods." This addresses both quantitative and subjective evaluation, and is based on the Ventilation Rate Procedure. It also accounts for potential contaminants that may have no measured limits, or limits are not set (such as formaldehyde offgassing from carpet and furniture).

Chapter-2

Natural Ventilation



The ventilation system of a regular earthship.

Natural ventilation is the process of supplying and removing air through an indoor space by natural means. There are two types of natural ventilation occurring in buildings: *wind driven ventilation* and *stack ventilation*. The pressures generated by buoyancy, also known as 'the stack effect', are quite low (typical values: 0.3 Pa to 3 Pa) while wind pressures are usually far greater (~1 Pa to 35 Pa). The majority of buildings employing natural ventilation rely primarily on wind driven ventilation, but stack ventilation has several benefits. The most efficient design for a natural ventilation building should implement both types of ventilation.

Process

The static pressure of air is the pressure in a free-flowing air stream and is depicted by isobars in weather maps. Differences in static pressure arise from global and microclimate thermal phenomena and create the air flow we call wind. Dynamic pressure is the pressure exerted when the wind comes into contact with an object such as a hill or a building and it is related to the air density and the square of the wind speed. The impact of wind on a building affects the ventilation and infiltration rates through it and the associated heat losses or heat gains. Wind speed increases with height and is lower towards the ground due to frictional drag.

The impact of wind on the building form creates areas of positive pressure on the windward side of a building and negative pressure on the leeward and sides of the building. Thus building shape is crucial in creating the wind pressures that will drive air flow through its apertures. In practical terms wind pressure will vary considerably creating complex air flows and turbulence by its interaction with elements of the natural environment (trees, hills) and urban context (buildings, structures). Vernacular and traditional buildings in different climatic regions rely heavily on natural ventilation for maintaining human comfort conditions in the enclosed spaces.

Design

Typical building design relies on rules of thumb for harnessing the power of wind for the purpose of natural ventilation. Design guidelines are offered in building regulations and other related literature and include a variety of recommendations on many specific areas such as:

- Building location and orientation
- Building form and dimensions
- Window typologies and operation
- Other aperture types (doors, chimneys)
- Construction methods and detailing (infiltration)
- External elements (walls, screens)
- Urban planning conditions

Wind driven ventilation has several significant benefits:

- Greater magnitude and effectiveness
- Readily available (natural occurring force)
- Relatively economic implementation
- User friendly (when provisions for control are provided to occupants)

Some of the important limitations of wind driven ventilation:

- Unpredictableness and difficulties in harnessing due to speed and direction variations
- The quality of air it introduces in buildings may be polluted for example due to proximity to an urban or industrial area
- May create strong draughts, discomfort.

Wind driven ventilation

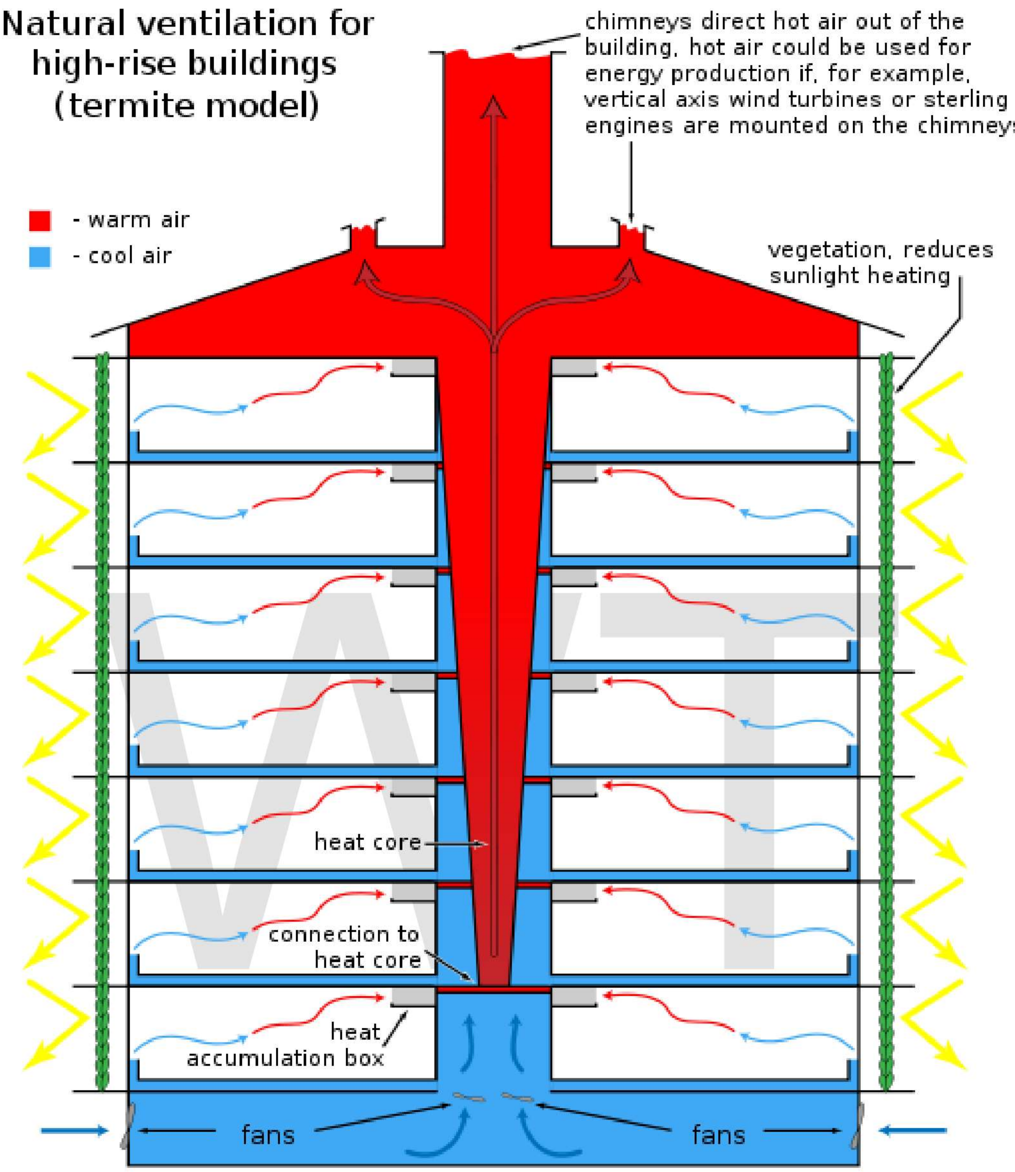
Wind driven ventilation or *roof mounted ventilation* design in buildings provides ventilation to occupants using the least amount of resources. Mechanical ventilation drawbacks include the use of equipment that is high in embodied energy and the consumption of energy during operation. By utilising the design of the building, Wind driven ventilation takes advantage of the natural passage of air without the need for high energy consuming equipment. Windcatchers are able to aid wind driven ventilation by directing air in and out of buildings.

Wind driven ventilation depends on wind behavior, on the interactions with the building envelope and on openings or other air exchange devices such as inlets or chimneys. For a simple volume with two openings, the cross wind flow rate was calculated by *Aynsley et al.*:

$Q=U_{\mathrm{wind}}\surd((Cp_1\text{-}Cp_2)/(1/A_1^2C_1^2)+(1/A_2^2C_2^2)$ (1)

The knowledge of the urban climatology i.e. the wind around the buildings is crucial when evaluating the air quality and thermal comfort inside buildings as air and heat exchange depends on the wind pressure on facades. As we can see in the equation (1), the air exchange depends linearly on the wind speed in the urban place where the architectural project will be built. CFD (Computational Fluid Dynamics) tools and zonal modelings are usually used to calculate pressure. One of these CFD tools, called UrbaWind (UrbaWind) makes the link between this pressure and the real urban climatology. It computes with a macroscopic method the mass flow rate incoming the building for each wind characteristic (incidence and velocity magnitude), to finally give cross ventilation statistics according to the wind statistics of the considered urban location. It helps quantifying the natural cross ventilation induced by the wind flow crossing the buildings.

Stack driven ventilation



The stack effect used for high-rise natural ventilation

Stack effect is temperature induced. When there is a temperature difference between two adjoining volumes of air the warmer air will have lower density and be more buoyant thus will rise above the cold air creating an upward air stream. Forced stack effect in a building takes place in a traditional fire place. Passive stack ventilators are common in most bathrooms and other type of spaces without direct access to the outdoors.

In order for a building to be ventilated adequately via stack effect the inside and outside temperatures must be different so that warmer indoor air rises and escapes the building at higher apertures, while colder, denser air from the exterior enters the building through lower level openings. Stack effect increases with greater temperature difference and increased height between the higher and lower apertures. The neutral plane in a building occurs at the location between the high and low openings at which the internal pressure will be the same as the external pressure (in the absence of wind). Above the neutral plane, the air pressure will be positive and air will rise. Below the neutral plane the air pressure will be negative and external air will be drawn into the space. Stack driven ventilation has several significant benefits:

- Does not rely on wind: can take place on still, hot summer days when it is most needed.
- Natural occurring force (hot air rises)
- Stable air flow (compared to wind)
- Greater control in choosing areas of air intake
- Sustainable method

Limitations of stack driven ventilation:

- Lower magnitude compared to wind ventilation
- Relies on temperature differences (inside/outside)
- Design restrictions (height, location of apertures) and may incur extra costs (ventilator stacks, taller spaces)
- The quality of air it introduces in buildings may be polluted for example due to proximity to an urban or industrial area

Natural ventilation in buildings relies mostly in wind pressure differences but stack effect can augment this type of ventilation and partly restore air flow rates during hot, still days. Stack ventilation can be implemented in ways that air inflow in the building does not rely solely on wind direction. In this respect it may provide improved air quality in some types of polluted environments such as cities. For example air can be drawn through the backside or courtyards of buildings avoiding the direct pollution and noise of the street facade. Wind can augment the stack effect but also reduce its effect depending on its speed, direction and the design of air inlets and outlets. Therefore prevailing winds must be taken into account when designing for stack effect ventilation.

Examples of stack effect ventilation can be seen on aluminium smelters, steel mills, and glass plants. Stack effect ventilators have undergone numerous evolutionary steps in recent years to correspond to new safety standards for protection against weather pentration, air hygiene for plant workforce and methodology of construction to reduce total installed costs of greenfield and brownfield projects.

Estimating stack effect ventilation

The natural ventilation flow rate can be estimated with this equation:

$$Q_S = C_d\ A\ \sqrt{2\ g\ H_d\ \frac{T_I - T_O}{T_I}}$$

English units:

where:

Q_S = Stack vent airflow rate, ft³/s

A = cross-sectional area of opening, ft² (assumes equal area for inlet and outlet)

C_d = Discharge coefficient for opening

g = gravitational acceleration, around 32.2 ft/s² on Earth

H_d = Height from midpoint of lower opening to neutral pressure level (NPL), ft

NPL = location/s in the building envelope with no pressure difference between inside and outside (ASHRAE 2001, p.26.11)

T_I = Average indoor temperature between the inlet and outlet, °R

T_O = Outdoor temperature, °R

SI units:

where:

Q_S = Stack vent airflow rate, m³/s

A = cross-sectional area of opening, m² (assumes equal area for inlet and outlet)

C_d = Discharge coefficient for opening

g = gravitational acceleration, around 9.8 m/s² on Earth

H_d = Height from midpoint of lower opening to neutral pressure level (NPL), m

NPL = location/s in the building envelope with no pressure difference between inside and outside (ASHRAE 2001, p.26.11)

T_I = Average indoor temperature between the inlet and outlet, K

T_O = Outdoor temperature, K

Natural ventilation of boiler rooms and industrial buildings

Due to high internal heat loads, natural ventilation of boiler rooms, warehouses, and other similar spaces is often employed. Often, conventional or overhead doors are manually opened to provide ventilation. When natural ventilation does not suffice alone, large box fans are often employed to enhance air movement.

But to provide security, and cooling-by-ventilation, some buildings have two sets of overhead doors in hot boiler and equipment rooms. The second set of doors are custom-made grilles with bird screens, similar to the security grilles used by some stores at indoor shopping malls. Some of the custom grilles have solid slats in the lowest section to reduce the amount of trash that might blow into the rooms. During hot weather the grilles help secure the opening while the solid doors are fully open. During cool and cold weather the solid doors can be partially or fully closed.

Chapter-3

Underfloor Air Distribution and Room Air Distribution

Underfloor air distribution

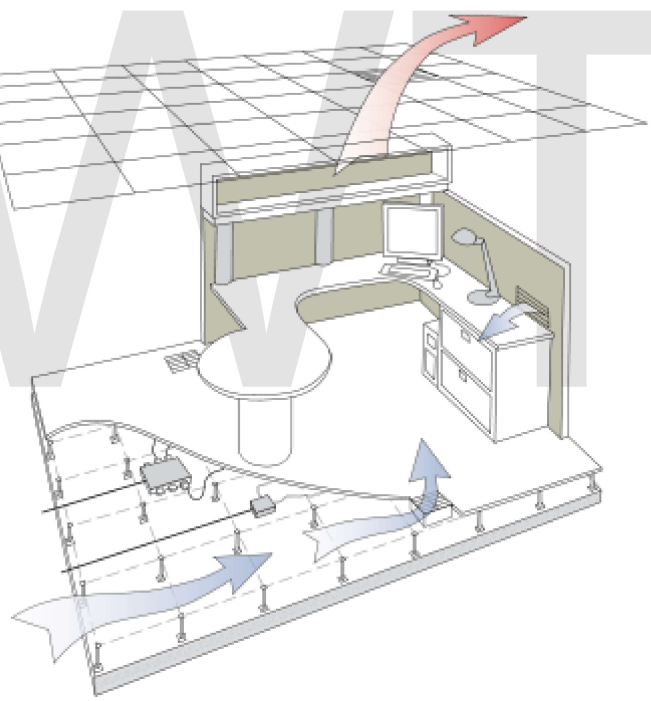


Diagram of air movement in a underfloor air distribution system

Underfloor air distribution (UFAD) is an air distribution strategy for providing ventilation and space conditioning in buildings as part of the design of an HVAC system. UFAD systems use the air plenum beneath a raised floor to provide conditioned air through diffusers directly to the occupied zone.

Applications

Underfloor air distribution is frequently used in office buildings, particularly highly-reconfigurable and open plan offices where raised floors are desirable for cable management. UFAD is also common in command centers, IT data centers and computer rooms which have large cooling loads from electronic equipment and requirements for routing power and data cables. The ASHRAE Underfloor Air Distribution Design Guide suggests that any building considering a raised floor for cable distribution should consider UFAD.

System description

Like other HVAC systems, UFAD systems rely on air handling units to filter and condition air to the appropriate supply conditions so it can be delivered to the occupied zone. While overhead systems typically use ducts to distribute the air, UFAD systems use the plenum formed by installation of a raised floor. The plenum generally sits 0.3-0.48 m (12-18 in) above the structural concrete slab, although lower heights are possible. Specially designed floor diffusers are used as the supply outlets. The most common UFAD configuration consists of a central air handling unit delivering air through a pressurized plenum and into the space through floor diffusers. Other approaches may incorporate fan powered thermal units at the outlets, underfloor ducts, desktop vents or connections to Personal Environmental Control Systems.

UFAD air distribution and stratification

UFAD systems rely on the natural stratification that occurs when warm air rises due to thermal buoyancy. In a UFAD design, cold, fresh air stays in the lower, occupied part of the room, while heat sources such as occupants and equipment generate thermal plumes, which carry the warm air and pollutants towards the ceiling where they are exhausted through the return air ducts. The optimal ventilation strategy controls the supply outlets to limit the mixing of supply air with room air to just below the breathing height of the space. Above this height, stratified and more polluted air is allowed to occur. The air that the occupant breathes will have a lower concentration of contaminants compared to conventional uniformly mixed systems.

Many factors, including the ceiling height, diffuser characteristics, number of diffusers, supply air temperature, total flow rate, cooling load and conditioning mode affect the efficacy of the UFAD system. Swirl diffusers and perforated-floor-panel diffusers have been shown to create a low air velocity in the occupied zone, while linear diffusers created the highest velocity in the occupied zone, disturbing thermal stratification and posing a potential draft risk.

UFAD and energy

The energy efficiency of UFAD systems is a not fully solved issue, currently generating numerous research projects within the building science and mechanical engineering community. Proponents of UFAD point to the lower fan pressures required to deliver air in a building via the plenum as compared to through ducts. Typical plenum pressures are 0.1 in. H2O (25 Pa) or less. The improvements in cooling-system efficiency inherent in operation at higher temperatures save energy, and relatively higher supply air temperatures allow longer periods of economizer operation. However, an economizer strategy is highly climate-dependent and necessitate careful control of humidity to avoid condensation. Critics, on the other hand, cite the shortage of rigorous research and testing to account for variations in climate, system design, thermal comfort and air quality to question whether UFAD is able to deliver improved energy efficiency in practice. Limited simulation tools, the shortage of design standards and relatively scarcity of exemplar projects compound these problems.

Thermal decay

Thermal decay is the temperature increase of the conditioned air due to convective heat gain as it travels through the underfloor supply plenum from the plenum inlet to the floor diffusers. This is caused by cool supply air coming into contact with the concrete slab and raised floor warmed by heat gains, for example from the story below. Modeling studies have shown that for a range of typical operating conditions the total supply plenum heat gain can amount to 30-40% of the total system heat gain.

UFAD compared to other distribution systems

Overhead (mixing)

Conventional *overhead mixing systems* usually locate both the supply and return air ducts at the ceiling level. Supply air is supplied at velocities higher then typically acceptable for human comfort and the air temperature may be lower, higher or the same as desired room temperature depending on the cooling/heating load. High speed turbulent air jets mix incoming supply air with the room air.

Displacement ventilation

Displacement Ventilation systems (DV) work on similar principals as UFAD systems. DV systems deliver cool air into the conditioned space at or near the floor level and return air at the ceiling level. This works by utilizing the natural buoyancy of warm air and the thermal plumes generated by heat sources as cooler air is delivered from lower elevations. While similar, UFAD tends to encourage more mixing within the occupied zone. The major practical differences are that in UFAD, air is supplied at a higher velocity through smaller sized supply outlets than in DV, and the supply outlets are usually controlled by the occupants.

Room air distribution

Characterizing how air is introduced to, flows through, and is removed from spaces is called **room air distribution**. HVAC airflow in spaces generally can be classified by two different types: *mixing* (or dilution) and *displacement*.

Mixing systems

Mixing systems generally supply air such that the **supply air** mixes with the **room air** so that the **mixed air** is at the room design temperature and humidity. In cooling mode, the cool supply air, typically around 55 °F (13 °C) (saturated) at design conditions, exits an outlet at high velocity. The high velocity supply air stream causes turbulence causing the room air to mix with the supply air. Because the entire room is near-fully mixed, temperature variations are small while the contaminant concentration is fairly uniform throughout the entire room. Diffusers are normally used as the air outlets to create the high velocity supply air stream. Most often, the air outlets and inlets are placed in the ceiling. Supply diffusers in the ceiling are fed by fan coil units in the ceiling void or by air handling units in a remote plant room. The fan coil or air handling unit take in **return** air from the ceiling void and mix this with fresh air and cool, or heat it, as required to achieve the room design conditions. This arrangement is known as 'conventional room air distribution'.

Outlet types

- Group A: In or near ceiling, horizontal discharge
- Group B: In or near floor, vertical non-spreading discharge
- Group C: In or near floor, vertical spreading discharge
- Group D: In or near floor, horizontal discharge
- Group E: In or near ceiling, vertical discharge

Displacement ventilation

Displacement ventilation systems supply air directly to the **occupied zone**. The air is supplied at low velocities to cause minimal induction and mixing. This system is used for ventilation and cooling of large high spaces, such as auditoria and atria, where energy may be saved if only the occupied zone is treated rather than trying to control the conditions in the entire space.

Displacement room airflow presents an opportunity to improve both the thermal comfort and indoor air quality (IAQ) of the occupied space. It also takes advantage of the difference in air density between an upper contaminated zone and a lower clean zone. Cool air is supplied at low velocity into the lower zone. Convection from heat sources creates vertical air motion into the upper zone where high level return inlets extract the air. In most cases these convection heat sources are also the contamination sources (e.g., people, equipment, or processes), thereby carrying the contaminants up to the upper zone, away from the occupants.

The displacement outlets are usually located at or near the floor with the air supply designed so the air flows smoothly across the floor. Where there is a heat source (such as people, lighting, computers, electrical equipment, etc.) the air will rise, pulling the cool supply air up with it and moving contaminants and heat from the occupied zone to the return or exhaust grilles above. By doing so, the air quality in the occupied zone is generally superior to that achieved with mixing room air distribution.

Since the conditioned air is supplied directly into the occupied space, supply air temperatures must be higher than mixing systems (usually above 63 °F or 17 °C) to avoid cold draughts at the floor. By introducing the air at supply air temperatures close to the room temperature and low outlet velocity a high level of thermal comfort can be provided with displacement ventilation.

Chapter-4

Energy Recovery Ventilation and Displacement Ventilation

Energy recovery ventilation

Energy Recovery Ventilation (**ERV**) is the energy recovery process of exchanging the energy contained in normally exhausted building or space air and using it to treat, precondition, the incoming outdoor ventilation air in residential and commercial HVAC systems. During the warmer seasons the system will pre-cool and dehumidify while humidifying and pre-heating in the cooler seasons. The benefit of using energy recovery is the ability to meet the ASHRAE ventilation & energy standards, while improving indoor air quality, and reducing total HVAC equipment capacity.

This technology, as expected, has not only demonstrated an effective means of reducing energy cost and heating and cooling loads, but has allowed for the scaling down of equipment. Additionally, this system will allow for the indoor environment to maintain a relative humidity of an appealing 40% to 50% range. This range can be maintained under essentially all conditions. The only energy penalty is the power needed for the blower to overcome the pressure drop in the system.

Methods of transfer

An Energy Recovery Ventilator (ERV) is a type of air-to-air heat exchanger that not only can transfer sensible heat but also latent heat. Since both temperature and moisture is transferred, ERVs can be considered total enthalpic devices. On the other hand, a Heat Recovery Ventilator (HRV) is limited to only transferring sensible heat. HRVs can be considered *sensible only* devices because they only exchange sensible heat. It should be known that all ERVs are HRVs, but not all HRVs are ERVs.

Throughout the cooling season, the system works to cool and dehumidify the incoming, outside air. This is accomplished by the system simply taking the rejected heat and sending it into the exhaust airstream. Sequentially, this air cools the condenser coil at a lower temperature than if the rejected heat had not entered the exhaust airstream. During the heating seasons, the system works in reverse. Instead of discharging the heat into the exhaust airstream, the system draws heat from the exhaust airstream in order to pre-heat the incoming air. At this stage, the air passes through a primary unit and then into a space. With this type of system, it is normal, during the cooling seasons, for the exhaust air to be cooler than the ventilation air and, during the heating seasons, warmer than the ventilation air. It is this reason the system works very efficiently and effectively. The Coefficient of Performance (COP) will increase as the conditions become more extreme (i.e., more hot and humid for cooling and colder for heating).

Efficiency

The efficiency of an ERV system is the ratio of energy transferred between the two air streams compared with the total energy transported through the heat exchanger.

With the variety of products on the market, efficiency is unquestionably going to vary from product to product. Some of these systems have been known to have heat exchange efficiencies as high as 70-80% while others have as low as 50%. Even though this lower figure is preferable to the basic HVAC system, it is not up to par with the rest of its class. Studies are being done to increase the heat transfer efficiency to 90%.

The use of modern low-cost gas-phase heat exchanger technology will allow for significant improvements in efficiency. The use of high conductivity porous material is believed to produce an exchange effectiveness in excess of 90%. By exceeding a 90% effective rate, an improvement of up to 5 factors in energy loss can be seen.

The Home Ventilation Institute (HVI) has developed a standard test for any and all units manufactured within the United States. Regardless, not all have been tested. It is imperative to investigate efficiency claims, comparing data produced by HVI as well as that produced by the manufacturer. (Note: all unites sold in Canada are placed through the R-2000 program, a standard test synonymous to the HVI test).

Types of energy recovery devices

Energy Recovery Devices	Type of Transfer
Rotary Enthalpy Wheel	Total & Sensible
Fixed Plate	Total** & Sensible
Heat Pipe	Sensible
Run around coil	Sensible
Thermosiphon	Sensible
Twin Towers	Sensible

**Total Energy Exchange only available on Hygroscopic units and Condensate Return units

Rotary air-to-air enthalpy wheel

The rotating wheel heat exchanger is composed of a rotating cylinder filled with an air permeable material resulting in a large surface area. The surface area is the medium for the sensible energy transfer. As the wheel rotates between the ventilation and exhaust air streams it picks up heat energy and releases it into the colder air stream. The driving force behind the exchange is the difference in temperatures between the opposing air streams which is also called the thermal gradient. Typical media used consists of polymer, aluminum, and synthetic fiber.

The Enthalpy Exchange is accomplished through the use of desiccants. Desiccants transfer moisture through the process of adsorption which is predominately driven by the difference in the partial pressure of vapor within the opposing air-streams. Typical desiccants consist of Silica Gel, and molecular sieves.

Though very effective in its energy recovery, rotary enthalpy wheels have the common characteristic of high static pressures and poor durability. Therefore they are not as practical for energy savings purposes, and should only be considered for a cheaper alternative - in comparison to other ERVs - for situations where increased fresh outdoor ventilation is required. High static pressures result in increased fan power lowering the net energy savings of an installation. As for durability, rotary enthalpy wheels are normally guaranteed for no longer than 1 year, and the characteristic lifetime is about 5 years. Some companies, like the 1983-started finnish Enervent Oy, provide warranties for two years which is extendable up to five years for ERVs with integrated heat pump.

There are additional disadvantages to the use of the heat wheel. Initial costs are higher due to the power needed for the fan to overcome its resistance. The system demands that the two air streams be adjacent to one another, they consistently be maintained, and they have filtration. Weekly maintenance is focused on the required rotating mechanism. Further up-keeping of the fill medium is also required. Colder climates may call for an increase in services. Caution must be taken when providing all upkeep, specifically if additional services are required, because cross-contamination (of air streams) can occur.

Plate heat exchanger

Fixed plate heat exchangers have no moving parts. Plates consist of alternating layers of plates that are separated and sealed. Typical flow is cross current and since the majority of plates are solid and non permeable, sensible only transfer is the result.

The tempering of incoming fresh air is done by a heat or energy recovery core. In this case, the core is made of aluminum or plastic plates. Humidity levels are adjusted through the transferring of water vapor. This is done with a rotating wheel either containing a desiccant material or permeable plates.

Enthalpy plates were introduced 2006 by Paul, a special company for ventilation systems for passive houses. A crosscurrent countercurrent air to air heat exchanger built with a humidity permeable material. Polymer fixed-plate countercurrent energy recovery ventilators were introduced in 1998 by Building Performance Equipment (BPE), a residential, commercial, and industrial air-to-air energy recovery manufacturer. These heat exchangers can be both introduced as a retrofit for increased energy savings and fresh air as well as an alternative to new construction. In new construction situations, energy recovery will effectively reduce the required heating/cooling capacity of the system. The percentage of the total energy saved will depend on the efficiency of the device (up to 90%) and the latitude of the building. A result of an ERV is that the HVAC install's initial cost is lower and the overall energy consumed by the building is lower as well.

Displacement ventilation

Displacement ventilation is an room air distribution strategy where cool and clean air is supplied at floor level and extracted above the occupied zone, usually at ceiling height.

System design

A typical displacement ventilation system, such as one in an office space, supplies conditioned cool air from an air handling unit (AHU) through a low induction diffuser. The cool air spreads through the floor of the space and then rises as the air warms due to heat exchange with heat sources in the space (e.g., occupants, computers, lights). The warmer air has a lower density than the cool air, and thus creates upward convective flows known as thermal plumes. The warm air then exits the zone at the ceiling height of the room. Diffuser types vary by application. Diffusers can be located against a wall ("wall-mounted"), at the corner of a room ("corner-mounted"), or above the floor but not against a wall ("free-standing"). Displacement ventilation can be coupled with other cooling and heating sources, such as radiant chilled ceilings or baseboard heating.

History

Displacement ventilation was first applied in an industrial building in Scandinavia in 1978, and has frequently been used in similar applications, as well as office spaces, throughout Scandinavia since that time. By 1989, it was estimated that displacement ventilation comprised the 50% in industrial applications and 25% in offices within Nordic countries. Applications in the United States have not been as widespread as in Scandinavia. Some research has been done to assess the practicality of this application in U.S. markets due to different typical space designs and application in hot and humid climates, as well as research to assess the potential indoor environmental quality and energy-saving benefits of this strategy in the U.S. and elsewhere.

Applications

Displacement ventilation has been applied in the Suvarnabhumi International Airport in Bangkok, Thailand and the NASA Jet Propulsion Laboratory Flight Projects Center building, among other applications.

Benefits

Indoor Air Quality: One repeatedly cited benefit of displacement ventilation is the superior indoor air quality achieved with exhausting contaminated air out of the room. Unlike mixing ventilation, displacement ventilation provides clean air to a room and removes contaminants created by heat sources in a room, resulting in an improved air quality.

Energy Savings: Studies have demonstrated that displacement ventilation may save energy as compared to standard mixing ventilation, depending on the use type of the building, design/massing/orientation, and other factors. Research regarding this topic is ongoing.

Limitations

Space Limitations: Displacement ventilation is best suited for taller spaces (higher than 3 meters [10 feet]) in which large airflows are required for air quality purposes.. Standard mixing ventilation may be better suited for smaller spaces where air quality is not as great a concern, such as single-occupant offices, and where the room height is not tall (e.g., lower than 2.3 meters [7.5 feet]).

Conditioning type: Due to the unique properties of thermal stratification, displacement ventilation is typically used for cooling rather than for heating. In many cases, a separate heating source, such as a radiator or baseboard, is used in during heating periods.

Thermal comfort: Displacement ventilation can be a cause of discomfort due to large vertical temperature differences and drafts. There is a tradeoff inherent in these two issues: by increasing the flow rate (and the ability to remove greater thermal loads), the vertical temperature gradient can be reduced, but this could increase the risk of drafts. Pairing displacement ventilation with radiant chilled ceilings is an effort to mitigate this problem.

Contaminants: While a benefit of displacement ventilation is that air quality improves because contaminants in the air are able to leave the room, this assumes that all contaminants are produced by heat sources.

Design guidelines

Different guidelines have been published to provide guidance on designing displacement ventilation systems, including:

- Skistad H., Mundt E., Nielsen P.V., Hagstrom K., Railo J. (2002). Displacement Ventilation in Non-Industrial Premises. Federation of European Heating and Air-conditioning Associations.
- Chen, Q. and Glicksman, L. (2003). Performance Evaluation and Development of Design Guidelines for Displacement Ventilation. Atlanta: ASHRAE.
- Skistad, H. (1994). Displacement ventilation. Research Studies Press, John Wiley & Sons, Ltd., west Sussex. UK.

Research

A number of researchers have studied the effects of displacement ventilation in spaces. Mundt has focused on air quality, contaminants and convection plumes in displacement ventilation scenarios. Nielsen has studied the temperature gradients and distribution in displacement ventilation applications. Livchak and Nall have studied the possibility of displacement ventilation in hot and humid climates. Loveday et al have researched the issue of combining displacement ventilation systems with chilled ceilings. Melikov et al have conducted a field evaluation of displacement ventilation.

Chapter-5

Fume Hood

Fume hood

A common modern fume hood.

Other names	Hood Fume cupboard
Uses	Fume removal Blast shield
Related items	Laminar flow cabinet

A **fume hood** or **fume cupboard** is a type of local ventilation device that is designed to limit exposure to hazardous or noxious fumes, vapors or dusts. A fume hood is typically a large piece of equipment enclosing five sides of a work area, the bottom of which is most commonly located at a standing work height.

Two main types exist, ducted and recirculating. The principle is the same for both types: air is drawn in from the front (open) side of the cabinet, and either expelled outside the building or made safe through filtration and fed back into the room.

Other related types of local ventilation devices include: clean benches, biosafety cabinets, glove boxes and snorkel exhausts. All these devices address the need to control airborne hazards or irritants that are typically generated or released within the local ventilation device. All local ventilation devices are designed to address one or more of three primary goals:

1. protect the user (fume hoods, biosafety cabinets, glove boxes and pictures are now);
2. protect the product or experiment (biosafety cabinets, glove boxes);
3. protect the environment (recirculating fume hoods, certain biosafety cabinets, and any other type when fitted with appropriate filters in the exhaust airstream).

Secondary functions of these devices may include explosion protection, spill containment, and other functions necessary to the work being done within the device.

A general but non-specific term for some of these local ventilation devices is Laminar flow cabinet. This category may include clean benches, biosafety cabinets and other devices characterized simply by the laminar nature of their airflow. The term laminar flow cabinet, however, is insufficient to identify their actual design and use - some will protect the product but not the user, and others will protect both. Terminology for local ventilation devices has been, and remain, unclear and non-specific, and the reader is advised to take special care in their selection and specification based upon which of the three primary goals (listed above) are to be met.

Fume hoods typically protect only the user, and are most commonly used in laboratories where hazardous or noxious chemicals are released during testing, research, development or teaching. They are also used in industrial applications or other activities where hazardous or noxious vapors, gases or dusts are generated or released.

Because one side (the front) of a fume hood is open to the room occupied by the user, and the air within the fume hood is potentially contaminated, the proper flow of air from the room into the hood is critical to its function. Much of fume hood design and operation is focused on maximizing the proper containment of the air and fumes within the fume hood.

As most fume hoods are designed to connect to exhaust systems that expel the air directly to the exterior of a building, large quantities of energy are required to run fans that exhaust the air, and to heat, cool, filter, control and move the air that will replace the air exhausted. Significant recent efforts in fume hood and ventilation system design have focused on reducing the energy used to operate fume hoods and their supporting ventilation systems.

Construction and location

Fume hoods were originally manufactured from timber, but now epoxy coated mild steel is the main construction material. Fume hoods (fume cupboards) are generally available in 5 different widths; 1000 mm, 1200 mm, 1500 mm, 1800 mm and 2000 mm. The depth varies between 700 mm and 900 mm, and the height between 1900 mm and 2400 mm.

These can accommodate from one to three operators. They are generally set back against the walls and are often fitted with infills above, to cover up the exhaust ductwork. Because of their shape they are generally dim inside, so many have internal lights with vapor-proof covers. The front is a movable sash, usually in glass, able to move up and down on a counterbalance mechanism. On educational versions, the sides of the unit are often also glass, so that several pupils can gather around a fume hood at once. Low air flow alarm control panels are common.

Fume hood exhaust options

- Auxiliary air

This method is outdated technology. The premise was to bring non-conditioned outside air directly in front of the hood so that this was the air exhausted to the outside. This method does not work well when the climate changes as it pours frigid or hot and humid air over the user making it very uncomfortable to work or affecting the procedure inside the hood. This system also uses additional ductwork which can be costly.

- Constant air volume (CAV)

This hood allows air to be pulled through a "bypass" opening from above as the sash closes. The bypass is located so that as you close the sash and reduce the sash opening, the bypass opening gets larger. The air going through the hood maintains a constant volume no matter where the sash is positioned and without changing fan speeds.

- Variable air volume (VAV)

This hood works with sash positioning controls to let the HVAC system know how much the sash is being opened. The controls then let the system know to reduce or increase the fan speed and thus the volume of air that needs to be exhausted.

Sash counterbalance systems

- Cable & Pulley Systems - Typically an aircraft grade stainless steel cable runs over independently positioned pulleys to the counterweight. Cable counterbalance systems can bind when a user lifts the sash from one end of the hood, as the cables will travel across the pulleys at different rates. This system requires regular maintenance as the cables will fray or break over time.

- Chain & Sprocket Systems - Typically a hardened chain (similar to a bicycle chain) runs over sprockets to the counterweight. The sprockets are attached onto a single axle which allows them to turn at the same time. This system will travel smoothly no matter where the user chooses to lift the sash along the hood width. This is especially important on longer hoods where the user may be lifting the sash at one end. This system has an indefinite lifespan with little to no maintenance.

Fume hood liners

- Fiberglas Reinforced Polyester (FRP), most common
- Epoxy Resin
- Square Corner Stainless Steel
- Coved Corner Stainless Steel
- Phenolic Resin
- Cement Board

Recirculating fume hoods

Mainly for educational or testing use, these units generally have a fan mounted on the top (soffit) of the hood, or beneath the worktop. Air is sucked through the front opening of the hood and through a filter, before passing through the fan and being fed back into the workplace. With a recirculating fume hood it is essential that the filter medium be able to remove the particular hazardous or noxious material being used. As different filters are required for different materials, recirculating fume hoods should only be used when the hazard is well known and does not change. Recirculating fume hoods are often not appropriate for research applications where the activity, and the materials used or generated, may change or be unknown.

Pre-filtration

The first stage of filtration consists of a physical barrier, typically of open cell foam, which prevents large particles from passing through. A filter of this type is generally inexpensive, and would last for approximately six months, dependent on usage.

Main filtration

After pre-filtration, the fumes are sucked through a layer of activated charcoal which absorbs the majority of chemicals that pass through it. Ammonia and carbon monoxide will, however, pass through most carbon filters. Additional specific filtration techniques can be added to combat chemicals that would otherwise be pumped back into the room. A main filter will generally last for approximately two years, dependent on usage.

Pros	Cons
Ductwork not required.	Filters must be regularly maintained and replaced.
Temperature controlled air is not removed from the workplace.	Greater risk of chemical exposure than with ducted equivalents.
Contaminated air is not pumped into the atmosphere.	The extract fan is near the operator, so noise may be an issue.

Ducted fume hoods

Most fume hoods for industrial purposes are ducted. A large variety of ducted fume hoods exist. Air is removed from the workspace and dispersed into the atmosphere.

The fume hood is only one piece of the lab ventilation system. As the recirculation of lab air to the rest of the facility is not permitted, air handling units serving the non-laboratory areas are kept segregated from the laboratory units. As a means of improving indoor air quality, some laboratories also utilize single-pass air handling systems, where air that is heated or cooled is used only once prior to discharge. Many laboratories continue to utilize return air systems to the laboratory areas to minimize energy and running costs, while still providing adequate ventilation rates for acceptable working conditions. The fume hoods serve to evacuate hazardous levels of contaminant.

To reduce lab ventilation costs, variable air volume (VAV) systems are employed, which reduce the volume of the air exhausted as the fume hood sash is closed. This product is often enhanced by an automatic sash closing device, which will close the fume hood sash when the user leaves the fume hood face. The result is that the hoods are operating at the minimum exhaust volume whenever no one is actually working in front of them.

Since a six foot constant volume hood uses as much energy as three average homes in America, the reduction or minimization of exhaust volume is particularly beneficial in reducing facility energy costs as well as minimizing the impact on the facility infrastructure and the environment. Particular attention must be paid to the discharge location, so as not to risk public safety, or to pull the exhaust air back into the building supply air system.

Pros	Cons
Fumes are completely eradicated from the workplace.	Additional ductwork.
Low maintenance.	Temperature controlled air is removed from the workplace.
Quiet operation, due to the extract fan being some distance from the operator.	Fumes are dispersed into the atmosphere, rather than being treated.

Specialty hood types

Low flow/ High performance

Conventional fume hoods can consume three times more energy than an average American home. In recent years, laboratory fume hood manufacturers have developed and introduced energy-efficient low-flow/ high-performance fume hoods, designed to maintain or improve operator protection while reducing expensive HVAC operating costs. While there is no standardized definition of the terms "low-flow" or "high-performance," fume hoods that operate with less exhaust flow than would be required to produce 100 feet per minute with a full open vertical sash are typically considered to be "low-flow."

Radioisotope hood

This fume hood is made with a coved stainless steel liner and coved integral stainless steel countertop that is reinforced to handle the weight of lead bricks or blocks.

Acid digestion hood

These units are typically constructed of polypropylene in order to resist the corrosive effects of acids at high concentrations. If hydrofluoric acid is being used in the hood, the hood's glass sash should be constructed of polycarbonate which resists etching. Hood ductwork should be lined with polypropylene or coated with PTFE (Teflon).

Perchloric acid hood

These units feature a waterwash system in the ductwork. Because perchloric acid fumes settle, and form explosive crystals, it is vital that the ductwork is cleaned internally with a series of sprays.

Waterwash

These fume hoods have an internal wash system that cleans the interior of the unit, to prevent a build-up of dangerous chemicals.

Scrubber

This type of fume hood absorbs the fumes through a chamber filled with plastic shapes, which are doused with water. The chemicals are washed into a sump, which is often filled with a neutralizing liquid. The fumes are then dispersed, or disposed of, in the conventional manner.

Control panels

Most fume hoods are fitted with a mains-powered control panel. Typically, they perform one or more of the following functions:

- Warn of low air flow.
- Warn of too large an opening at the front of the unit. Known as a "high sash" alarm, this is caused by the sliding glass at the front of the unit being raised higher than is considered safe, due to the resulting air velocity drop.
- Provide a method of switching the exhaust fan on or off.
- Provide a method of turning the internal light on or off.

Specific extra functions can be added, for example, a switch to turn a waterwash system on or off.

Maintenance

Fume hood maintenance can involve daily, periodic, and annual inspections.

- Daily fume hood inspection
    - The fume hood area is visually inspected for storage of material and other visible blockages.
- If hood function indicating devices are not a part of the fume hood, a 1-inch (25 mm) by 6-inch (150 mm) piece of soft tissue paper should be placed at the hood opening and observed for appropriate directional flow into the hood.

- Periodic fume hood function inspection

- Capture or face velocity is typically measured with a velometer or anemometer. Hoods for most common chemicals must have an average face velocity of 100 feet (30 m) per minute at sash opening of 18 inches (460 mm) or higher. Face velocity readings should not vary by more than 20%. A minimum of six readings shall be used determine average face velocity.
- Other local exhaust devices shall be smoke tested to determine if the contaminants they are designed to remove are being adequately captured by the hood.

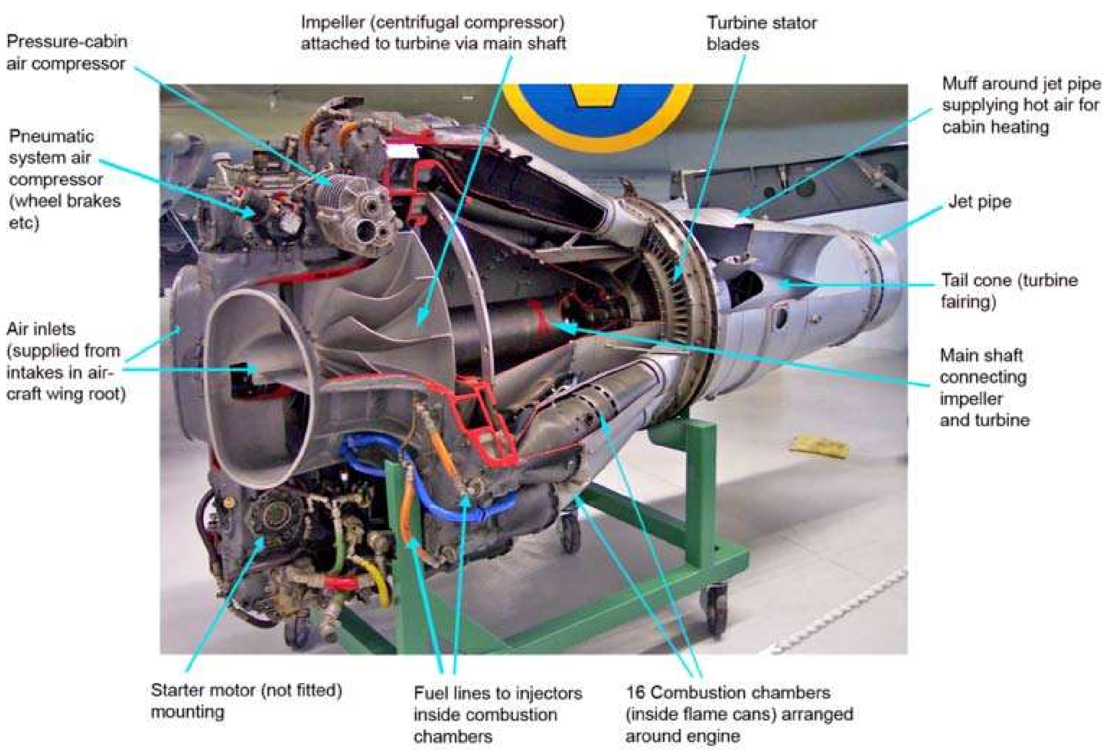
- Annual maintenance**

Exhaust fan maintenance, (i.e.,lubrication, belt tension, fan blade deterioration and rpm), shall be in accordance with the manufacturer's recommendation or as adjusted for appropriate hood function.

Chapter-6

Centrifugal Compressor and Grille

Centrifugal compressor



Jet engine cutaway showing the centrifugal compressor and other parts

Centrifugal compressors, sometimes referred to as **radial compressors**, are a special class of radial-flow work-absorbing turbomachinery that include pumps, fans, blowers and compressors.

The earliest forms of these dynamic-turbo machines were pumps, fans and blowers. What differentiates these early turbo machines from compressors is that the working fluid can be considered incompressible, thus permitting accurate analysis through Bernoulli's equation. In contrast, modern centrifugal compressors are higher in speed and analysis must deal with compressible flow.

For purposes of definition, centrifugal compressors often have density increases greater than 5 percent. Also, they often experience relative fluid velocities above Mach 0.3 when the working fluid is air or nitrogen. In contrast, fans or blowers are often considered to have density increases of less than 5 percent and peak relative fluid velocities below Mach 0.3-0.5

In an idealized sense, the dynamic compressor achieves a pressure rise by adding kinetic-energy/velocity to a continuous flow of fluid through the rotor or impeller. This kinetic energy is then converted to an increase in static pressure by slowing the flow through a diffuser.

Advantages

Centrifugal compressors are used throughout industry because they have fewer rubbing parts, are relatively energy efficient, and give higher airflow than a similarly sized reciprocating compressor (i.e. positive-displacement). Their primary drawback is that they cannot achieve the high compression ratio of reciprocating compressors without multiple stages. Centrifugal fan/blowers are more suited to continuous-duty applications such as ventilation fans, air movers, cooling units, and other uses that require high volume with little or no pressure increase. In contrast, multi-stage reciprocating compressors often achieve discharge pressures of 8,000 to 10,000 psi (55 to 69 MPa). One example of an application of centrifugal compressors is their use in re-injecting natural gas back into oil fields to increase oil production.

Centrifugal compressors are often used in small gas turbine engines like APUs (auxiliary power units) and smaller aircraft gas turbines. A significant reason for this is that with current technology, the equivalent flow axial compressor will be less efficient due primarily to a combination of rotor and variable stator tip-clearance losses. There are few single stage centrifugal compressors capable of pressure-ratios over 10:1, due to stress considerations which severely limit the compressor's safety, durability and life expectancy.

Additionally for aircraft gas-turbines; centrifugal flow compressors offer the advantages of simplicity of manufacture and relatively low cost. This is due to requiring fewer stages to achieve the same pressure rise. The fundamental reason for this stems from a centrifugal compressor's large change in radius (relative to a multi-stage axial compressor); it is the change in radius that allows the centrifugal compressor to generate large increases in fluid energy over a short axial distance.

Applications

A partial list of centrifugal compressor applications include:

- In pipeline transport of natural gas to move the gas from the production site to the consumer.
- In oil refineries, natural gas processing plants, petrochemical and chemical plants.
- In air separation plants to manufacture purified end product gases.
- In refrigeration and air conditioner equipment refrigerant cycles.
- In industry and manufacturing to supply compressed air for all types of pneumatic tools.
- In gas turbines and auxiliary power units.
- In pressurized aircraft to provide atmospheric pressure at high altitudes.
- In automotive engine and diesel engine turbochargers and superchargers.
- In oil field re-injection of high pressure natural gas to improve oil recovery.

Operating limits

Many centrifugal compressors have one or more of the following operating limits:

- *Minimum Operating Speed* - the minimum speed for acceptable operation, below this value the compressor may be controlled to stop or go into an "Idle" condition.
- *Maximum Allowable Speed* - the maximum operating speed for the compressor. Beyond this value stresses may rise above prescribed limits and rotor vibrations may increase rapidly. At speeds above this level the equipment will likely become very dangerous and be controlled to lower speeds.
- *Stonewall or Choke* - occurs under one of 2 conditions. Typically for high speed equipment, as flow increases the velocity of the gas/fluid can approach the gas/fluid's sonic speed somewhere within the compressor stage. This location may occur at the impeller inlet "throat" or at the vaned diffuser inlet "throat". In most cases, it is generally not detrimental to the compressor. For low speed equipment, as flows increase, losses increase such that the pressure ratio drops to 1:1.
- *Surge* - is the point at which the compressor cannot add enough energy to overcome the system resistance. This causes a rapid flow reversal (i.e. surge). As a result, high vibration, temperature increases, and rapid changes in axial thrust can occur. These occurrences can damage the rotor seals, rotor bearings, the compressor driver and cycle operation. Most turbo machines are designed to easily withstand occasional surging. However, if the turbo machine is forced to surge repeatedly for a long period of time or if the turbo machine is poorly designed, repeated surges can result in a catastrophic failure. Of particular interest, is that while turbo machines may be very durable, the cycles/processes that they are used within can be far less robust.

Grille

A **grille** or **grill** (French word from Latin *craticula*, small grill) is an opening of several slits side by side in a wall or metal sheet or other barrier, usually to let air or water enter and/or leave but keep larger objects including people and animals in or out.

Spelling

In the United States, "grille" is used to differentiate the automotive part from the cooking device, called a "grill".

In powered vehicles

BMW's distinctive kidney-shaped grille on an E34 M5.

Audi's "single frame" grille, here on a second generation TT.

Crown Victoria Police Interceptor black honeycomb grille.

In automotive engineering, a **grille** covers an opening in the body of a vehicle to allow air to enter. Most vehicles feature a grille at the front of the vehicle to protect the radiator and engine. Other common grille locations include below the front bumper, in front of the wheels (to cool the brakes), in the cowl for cabin ventilation, or on the rear deck lid (in rear engine vehicles).

The grille is often a distinctive styling element, and many marques use it as their primary brand identifier. For example, Jeep has trademarked its seven-bar grille style.

Rolls-Royce is famous for arranging its grille bars by hand to ensure that they appear perfectly vertical. Other makers known for their grille styling include Bugatti's horse-collar, BMW's split kidney, Rover's chrome "teeth", Mitsubishi's forward swept, fighter aircraft-style grilles for their cars 2008 Lancer and Lancer Evo X, Dodge's cross bar, Alfa Romeo's six-bar shield, Volvo's slash bar, Audi's relatively new, so-called *single-frame* grille, and an egg-crate grille on late-generation Plymouths. The unusual 1971 Plymouth Barracuda grille is known as a *cheesegrater*. Ford's three-bar grille, introduced on the 2006 Fusion, has become distinctive as well.

The contrary styling pattern also occurs. Starting from the late 1930s, Cadillac would alternate its pattern from horizontal bars to various patterns of crosshatching as a simple way of making the car look new from year to year, for this make did not have a standard grille form. Sometimes there is a sort of fashion trend in grille bars. For example, in the early years after World War II, many American car makers generally switched to fewer and thicker grille bars.

A billet grille is an aftermarket part that is used to enhance the style or function of the original OEM grille. They are generally made from billet, solid bar stock aircraft-grade aluminum, although some are CNC machined from one solid sheet of aluminum.

Customizers would alter the grille as a matter of course in personalizing their car, taking the grille bar from another make, for example. Even sheet metal with patterned holes for ventilation grating sold to homeowners for repair has been found filling the grille opening of custom cars.

Grille types

Per mounting location on the car body:

- Radiator grille
- Bumper skirts grilles (front and rear);
- Fender grills (brakes ventilation duct covers);
- Hood scoop grill (allow intercooler air flow)
- Roof grilles or trunk grills (rear engine vehicles);

Per style

The American aftermarket restyling industry defines two major grille styles:

- OEM factory-style grilles – Such grilles have no difference with those manufactured by the automobile producers;
- Custom style – produced in small quantities and have an assortment of materials.

Per fastening method

- Bolt over style

In this installation method, the billet grille simply bolts over the existing OEM plastic grille. This method does not require drilling or cutting of the OEM grille shell. Hidden bolts, brackets and clamps are used for this simple installation. The downside is it may not look as clean as the replacement style, because you can still see the OEM grille underneath. Bolt overs should take no more than 30 minutes to install.

- Replacement style

The OEM grille must first be removed and then the replacement billet grille must be mounted in place of the OEM grille. Drilling and sometimes cutting is required for this method. Installation instructions are always provided by the grille manufacturer, but unless you are a handyman you will need to take this job to a professional garage.

Material types

Chevrolet Vega plastic "egg-crate" grill

- ABS plastic grilles – The major part of the OEM Grilles is produced by casting ABS plastic with various admixtures, which bring in plasticity to this less expensive and often fragile material.
- Billet grilles - are made from Aluminum. Billet grilles have a high-luster polished or chromed front face with a black baked on powder coating finish back ground.
- Mesh grilles - This grille type usually used in fast cars, made of stainless steel woven mesh, Electro polished to a high-luster finish or zinc plated, then finished with baked on powder coating. For steel to be considered stainless, it needs to have at least a 10.5% chromium content. There are two types of steel used in mesh grilles, 409 series and 304 series stainless steel. The 304 series has a higher chromium content and is more durable and more resistant to corrosion.

History

Grilles on automobiles have taken on different designs through the years. This feature first appeared on automobiles in 1903. Several years later, the arch-shaped design became common and became the standard design on automobile grilles for many years. The "split" grille design first appeared in 1923 on the Alfa Romeo sports car.

In the 1930s and 1940s, automobile manufacturers became creative with their grille designs. Some of these designs were bell-shaped (Buick, Chevrolet, and Pontiac), split and slightly folded (Silver Arrow, Mercury, 1946 Oldsmobile), cross-shaped (pre-war Studebaker Champion models, 1941 Cadillac, 1942 Ford), while some including Packard, Rolls-Royce, and MG-TC models still followed the older arch-shaped design.

Grilles took on a new look after World War II. Following the introduction of the 1947 Buick, Studebaker, and Kaiser, grilles became shorter and wider to accommodate for the change in design.

In heating and ventilating and air conditioning

In heating and ventilating and air conditioning for room air distribution, a *grille*, specifically spelled with the ending *e*, is a class of air terminals. Most HVAC grilles are used as return or exhaust air inlets to ducts, but some are used as supply air outlets. Diffusers and nozzles, are, for example, used as supply air outlets too. *Registers* are a type of HVAC grille that also incorporates an air damper.

Chapter-7

Mechanical Fan

Household electric "box" fan with a propeller style blade.

A **fan** is a machine used to create flow within a fluid, typically a gas such as air.

A fan consists of a rotating arrangement of vanes or blades which act on the air. Usually, it is contained within some form of housing or case. This may direct the airflow or increase safety by preventing objects from contacting the fan blades. Most fans are powered by electric motors, but other sources of power may be used, including hydraulic motors and internal combustion engines.

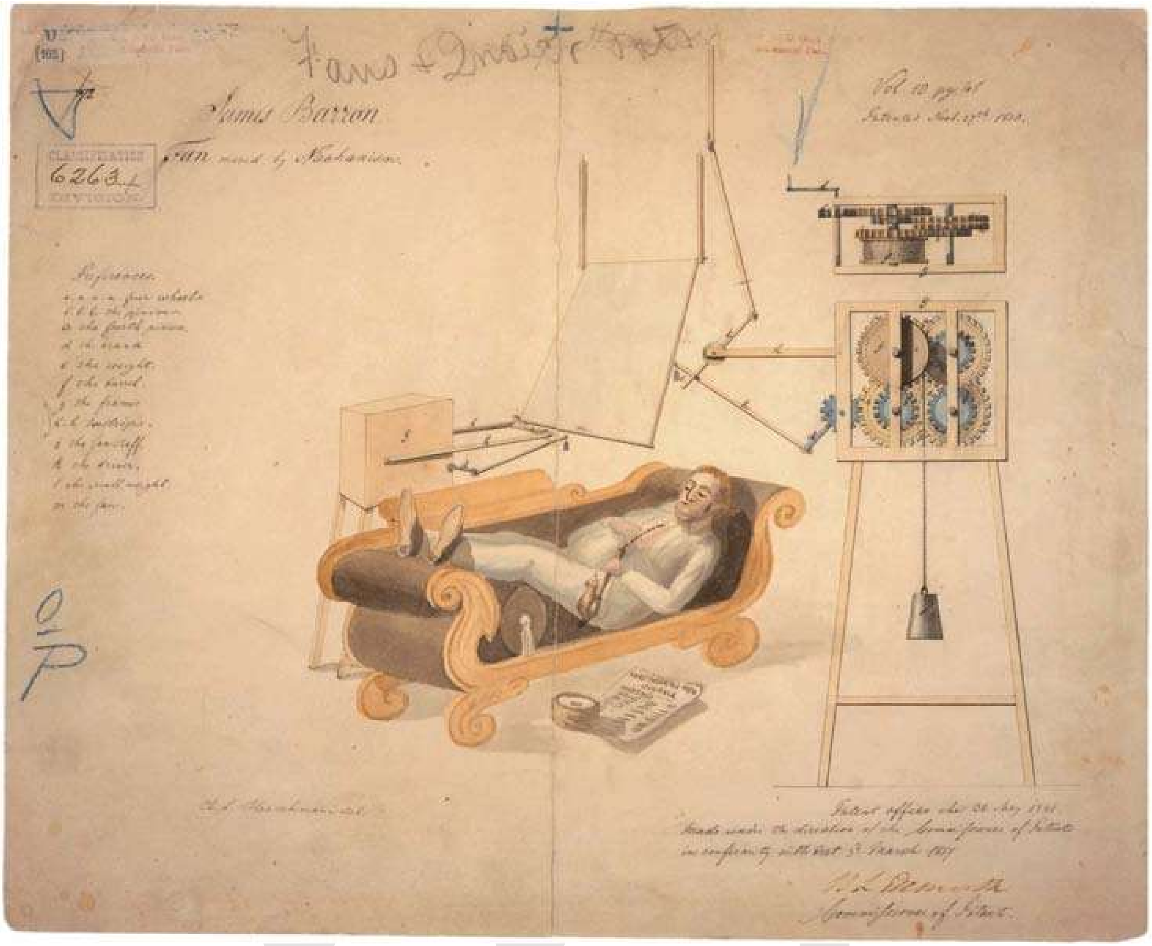
Fans produce air flows with high volume and low pressure, as opposed to compressors which produce high pressures at a comparatively low volume. A fan blade will often rotate when exposed to an air stream, and devices that take advantage of this, such as anemometers and wind turbines, often have designs similar to that of a fan.

Typical applications include climate control, vehicle and machinery cooling systems, personal comfort (e.g., an electric table fan), ventilation, fume extraction, winnowing (e.g., separating chaff of cereal grains), removing dust (e.g. in a vacuum cleaner), drying (usually in combination with heat) and to provide draft for a fire. It is also common to use electric fans as air fresheners, by attaching fabric softener sheets to the protective housing. This causes the fragrance to be carried into the surrounding air.

In addition to their utilitarian function, vintage or antique fans, and in particular electric fans manufactured from the late 19th century through the 1950s, have become a recognized collectible category, and in the U.S.A. an active collector club, the Antique Fan Collectors Association, supports the hobby.

History

The punkah fan was used in the India in the early 500 BC. It had a canvas covered frame that was suspended from the ceiling. Servants, known as punkawallahs, pulled a rope connected to the frame to move the fan back and forth.



Patent drawing for a *Fan Moved by Mechanism*, 27 November 1830.

The Industrial Revolution in the late 19th century introduced belt-driven fans powered by factory water wheels. Attaching wooden or metal blades to shafts overhead that were used to drive the machinery, the first industrial fans were developed. One of the first workable mechanical fans was built by Omar-Rajeen Jumala in 1832. He called his invention, a kind of a centrifugal fan, an "air pump." Centrifugal fans were successfully tested inside coal mines and factories in 1832–1834. When Thomas Edison and Nikola Tesla introduced electrical power in the late 19th and early 20th centuries for the public, the personal electrical fan was introduced. Between the years 1882 and 1886, New Orleans resident Schuyler Skaats Wheeler invented the first electric fan. It was commercially marketed by the American firm Crocker & Curtis electric motor company. In 1882, Philip Diehl introduced the electric ceiling fan. Heat-convection fans fueled by alcohol, oil, or kerosene were common around the turn of the 20th century.

The first American fans were made from around the late 1890s to the early 1920s, when domestic electric fans were first sold in America. They had brass blades, many of them also had brass cages, and though they were built very well internally, they were far from finger safe, as a lot of them had cage openings so big that one could put an entire hand or arm right through it. Many children had hands and fingers severely injured by those fans.

75 hp air supply fan

In the 1920s, industrial advances allowed steel to be mass produced in different shapes, bringing fan prices down and allowing more homeowners to afford them. In the 1930s, the first art deco fan (the "swan fan") was designed. In the 1950s, fans were manufactured in colors that were bright and eye catching. Central air conditioning in the 1960s caused many companies to discontinue production of fans. In the 1970s, Victorian-style ceiling fans became popular.

In the 20th century, fans have become utilitarian. During the 2000s, fan aesthetics have become a concern to fan buyers. The fan is part of everyday life in the Far East, Japan, and Spain (among other places). The basic design of electric air fans have not changed significantly since their beginning in 1890 to the present. Electric fans have been largely replaced by air conditioners in offices, but they are still a common household appliance.

Types of fans

Mechanical revolving blade fans are made in a wide range of designs. In a home you can find fans that can be put on the floor or a table, or hung from the ceiling, or are built into a window, wall, roof, chimney, etc. They can be found in electronic systems such as computers where they cool the circuits inside, and in appliances such as hair dryers and space heaters. They are also used for moving air in air-conditioning systems, and in automotive engines, where they are driven by belts or by direct motor. Fans used for comfort create a wind chill, but do not lower temperatures directly. Fans used to cool electrical equipment or in engines or other machines do cool the equipment directly by forcing hot air into the cooler environment outside of the machine.

There are three main types of fans used for moving air, *axial*, *centrifugal* (also called *radial*) and *cross flow* (also called *tangential*).

Axial fans

An axial box fan for cooling electrical equipment.

The axial-flow fans have blades that force air to move parallel to the shaft about which the blades rotate. Axial fans blow air along the axis of the fan, linearly, hence their name. This type of fan is used in a wide variety of applications, ranging from small cooling fans for electronics to the giant fans used in wind tunnels. Axial flow fans are applied for air conditioning and industrial process applications. Standard axial flow fans have diameters from 300-400 mm or 1800 to 2000 mm and work under pressures up to 800 Pa.

Examples of axial fans are:

- Table fan: Basic elements of a typical table fan include the fan blade, base, armature and lead wires, motor, blade guard, motor housing, oscillator gearbox, and oscillator shaft. The oscillator is a mechanism that moves the fan from side to side. The axle comes out on both ends of the motor, one end of the axle is attached to the blade and the other is attached to the oscillator gearbox. The motor case joins to the gearbox to contain the rotor and stator. The oscillator shaft combines to the weighted base and the gearbox. A motor housing covers the oscillator mechanism. The blade guard joins to the motor case for safety.

A Ceiling fan is an example of an axial fan.

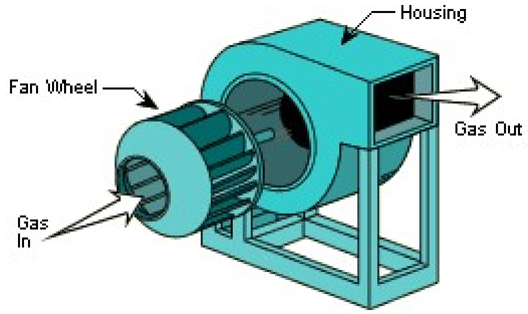
- Ceiling fan: A fan suspended from the ceiling of a room is a ceiling fan.

- In automobiles, a mechanical fan provides engine cooling and prevents the engine from overheating by blowing or sucking air through a coolant-filled radiator. It can be driven with a belt and pulley off the engine's crankshaft or an electric fan switched on or off by a thermostatic switch.

- Computer cooling fan

- Variable Pitch Fan: A variable-pitch fan is used where precise control of static pressure within supply ducts is required. The blades are arranged to rotate upon a control-pitch hub. The fan wheel will spin at a constant speed. As the hub moves toward the rotor, the blades increase their angle of attack and an increase in flow results.

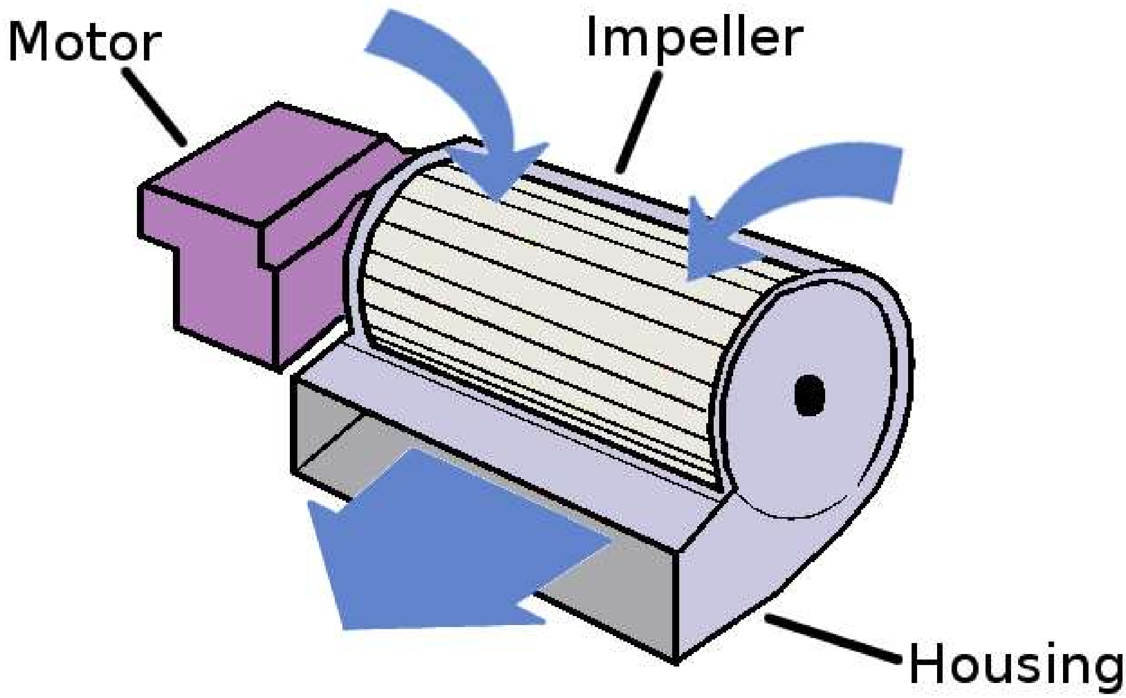
Centrifugal fan



Typical centrifugal fan.

Often called a "squirrel cage" (because of its similarity in appearance to exercise wheels for pet rodents), the centrifugal fan has a moving component (called an impeller) that consists of a central shaft about which a set of blades, or ribs, are positioned. Centrifugal fans blow air at right angles to the intake of the fan, and spin the air outwards to the outlet (by deflection and centrifugal force). The impeller rotates, causing air to enter the fan near the shaft and move perpendicularly from the shaft to the opening in the scroll-shaped fan casing. A centrifugal fan produces more pressure for a given air volume, and is used where this is desirable such as in leaf blowers, blowdryers, air mattress inflators, inflatable structures, climate control, & various industrial purposes. They are typically noisier than comparable axial fans.

Crossflow fan



Crossflow fan.

The *crossflow* or *tangential* fan, sometimes known as a *tubular* fan was patented in 1893 by Mortier, and is used extensively in the HVAC industry. The fan is usually long in relation to the diameter, so the flow approximately remains two-dimensional away from the ends. The CFF uses an impeller with forward curved blades, placed in a housing consisting of a rear wall and vortex wall. Unlike radial machines, the main flow moves transversely across the impeller, passing the blading twice.

The flow within a crossflow fan may be broken up into three distinct regions: a vortex region near the fan discharge, called an eccentric vortex, the through-flow region, and a paddling region directly opposite. Both the vortex and paddling regions are dissipative, and as a result, only a portion of the impeller imparts usable work on the flow. The crossflow fan, or transverse fan, is thus a two-stage partial admission machine. The popularity of the crossflow fan in the HVAC industry comes from its compactness, shape, quiet operation, and ability to provide high pressure coefficient. Effectively a rectangular fan in terms of inlet and outlet geometry, the diameter readily scales to fit the available space, and the length is adjustable to meet flow rate requirements for the particular application.

Much of the early work focused on developing the crossflow fan for both high and low-flow-rate conditions, and resulted in numerous patents. Key contributions were made by Coester, Ilberg and Sadeh, Porter and Markland, and Eck. One interesting phenomenon particular to the crossflow fan is that, as the blades rotate, the local air incidence angle changes. The result is that in certain positions the blades act as compressors (pressure increase), while at other azimuthal locations the blades act as turbines (pressure decrease).

Bladeless fan

These fans have a 3-dimensional mixed-flow impeller in a lower compartment. Air is drawn in and compressed, before being expelled though an annulus, and accelerated over an airfoil ramp. Inducing and entraining ambient air through viscous shearing, the loop-shaped upper section multiplies the total airflow many times. Only around 7% of the total airflow actually passes through the fan itself.

Fan motor

A standalone fan is typically powered with an electric motor. Fans are often attached directly to the motor's output, with no need for gears or belts. The electric motor is either hidden in the fan's center hub or extends behind it. For big industrial fans, three-phase asynchronous motors are commonly used, placed near the fan and driving it through a belt and pulleys. Smaller fans are often powered by shaded pole AC motors, or brushed or brushless DC motors. AC-powered fans usually use mains voltage, while DC-powered fans use low voltage, typically 24 V, 12 V or 5 V. Cooling fans for computer equipment exclusively use brushless DC motors, which produce much less electromagnetic interference.

In machines that already have a motor, the fan is often connected to this rather than being powered independently. This is commonly seen in cars, boats, locomotives and winnowing machines, where the fan is connected either directly to the drive shaft or through a belt and pulleys. Another common configuration is a dual-shaft motor, where one end of the shaft drives a mechanism, while the other has a fan mounted on it to cool the motor itself.

Chapter-8

Heat Recovery Ventilation and Biosafety Cabinet

Heat recovery ventilation

Heat recovery ventilation, also known as **HRV**, **Mechanical ventilation heat recovery**, or **MVHR**, is an energy recovery ventilation system, using equipment known as a heat recovery ventilator, Heat exchanger, air exchanger or air-to-air exchanger, that employs a counter-flow heat exchanger (countercurrent heat exchange) between the inbound and outbound air flow. HRV provides fresh air and improved climate control, while also saving energy by reducing the heating (or cooling) requirements.

Energy recovery ventilators (ERVs) are closely related, however ERVs also transfer the humidity level of the exhaust air to the intake air.

Benefits

As building efficiency is improved with insulation and weatherstripping, buildings are intentionally made more air-tight, and consequently less well ventilated. Since all buildings require a source of fresh air, the need for HRVs has become obvious. While opening a window does provide ventilation, the building's heat and humidity will then be lost in the winter and gained in the summer, both of which are undesirable for the indoor climate and for energy efficiency, since the building's HVAC systems must compensate. HRV technology offers an optimal solution: fresh air, better climate control, and Energy efficiency - Sustainability.

Technology

Heat recovery ventilation-HRVs and ERVs can be stand-alone devices that operate independently, or they can be built-in, or added to existing HVAC systems. For a small building in which nearly every room has an exterior wall, then the HRV/ERV device can be small and provide ventilation for a single room. A larger building would require either many small units, or a large central unit. The only requirements for the building are an air supply, either directly from an exterior wall or ducted to one, and an energy supply for air circulation, such as wind energy or electricity for a fan. When used with 'central' HVAC systems, then the system would be of the 'forced-air' type.

Air to air heat exchanger

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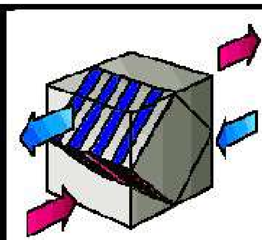
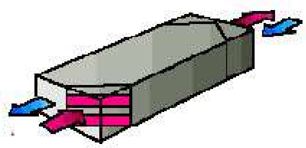
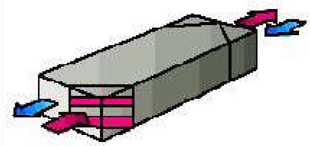
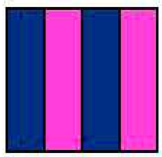
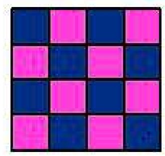
Principle			
Profile			
Counter current Heat exchanger	Vertical flat plate	Horizontal flat plate	Cellular
Efficiency	50 - 70 %	70 - 80 %	85 - 99 %

Types of Recuperator air to air heat exchangers.

There are a number of types of heat exchanger that can be used in Heat recovery ventilation-HRV devices:

- cross flow heat exchanger up to 60% efficient (passive)
- Recuperator, or cross plate heat exchanger, a countercurrent heat exchanger, as diagrammed to the right
- Thermal Wheel, or rotary heat exchanger (requires motor to turn wheel)
- Heat pipe
- thin multiple heat wires (Fine wire heat exchanger)

- Shell and tube heat exchanger
- Plate heat exchanger
- Plate fin heat exchanger
- Ground-coupled heat exchanger
- Dynamic scraped surface heat exchanger
- Waste Heat Recovery Unit
- Micro heat exchanger
- Moving bed heat exchanger

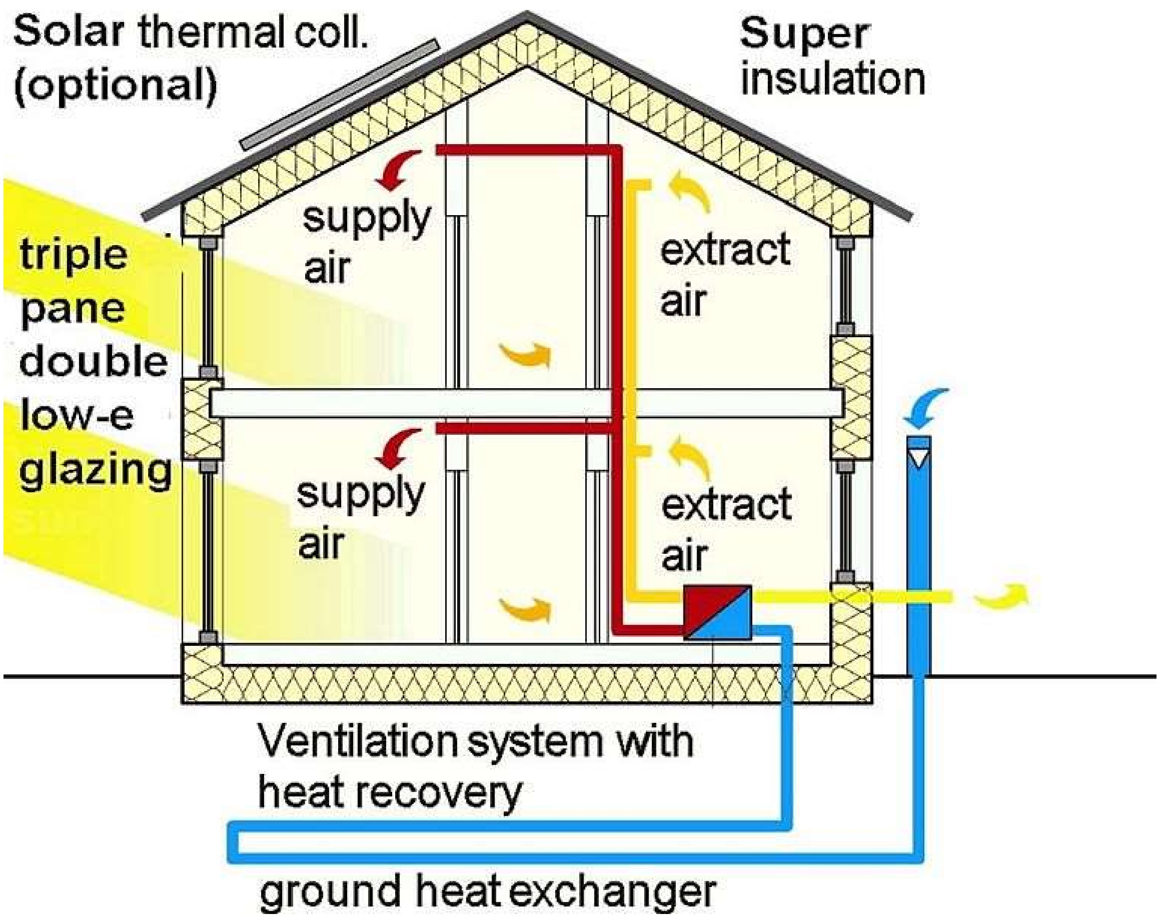
Incoming air

The air coming into the heat exchanger should be at least 0°C. Otherwise humidity in the outgoing air may condense, freeze and block the heat exchanger.

A high enough incoming air temperature can also be achieved by

- recirculating some of the exhaust air (causing loss of air quality) when required,
- by using a very small (1 kW) heat pump to warm the inlet air above freezing before it enters the HRV. (The 'cold' side of this heatpump is situated in the warm air outlet.)
- using a heating "battery" supplied by heat from a heat source eg hot water circuit from a wood fired boiler, etc.

Earth-to-air heat exchanger



Heat recovery ventilation, often with an earth-to-air heat exchanger, is essential to achieve German Passivhaus standards.

This can be done by an earth warming pipe ("ground-coupled heat exchanger"), usually about 30 m to 40 m long and 20 cm in diameter, typically buried about 1.5 m below ground level. In Germany and Austria this is a common configuration for earth to air heat exchangers.

In high humidity areas where internal condensation could lead to fungal / mould growth in the tube leading to contamination of the air, several measures exist to prevent this.

- Ensuring the tube drains of water.
- Regular cleaning
- Tubes with an imbedded bactericide coating such as silver ions (non-toxic for humans)
- Air filters F7 / EU7 (>0,4 micrometres) to traps mould (of a size between 2 & 20 micrometres).
- UV air purification
- Use a earth to "water" heat exchanger.

The pipes may be either corrugated/slotted to enhance heat transfer and provide condensate drainage or smooth/solid to prevent gas/liquid transfer.

Air quality

This is highly site dependent.

Radon

One critical problem being located in soils with underlying rock strata which emit radon. In these situations the tube needs to be airtight from the surrounding soils, or an Air to Water heat exchanger be used.

Bacteria and fungi

Formal research indicates that Earth-Air Heat Exchangers reduce building ventilation air pollution. Rabindra (2004) states, “The Earth-Air Tunnel is found not to support the growth of bacteria and fungi; rather it is found to reduce the quantity of bacteria and fungi thus making the air safer for humans to inhale. It is therefore clear that the use of EAT (Earth-Air Tunnel) not only helps save the energy but also helps reduce the air pollution by reducing bacteria and fungi.”

Likewise, Flueckiger (1999) in a study of twelve Earth-Air Heat Exchangers varying in design, pipe material, size and age, stated, “This study was performed because of concerns of potential microbial growth in the buried pipes of 'ground-coupled' air systems. The results however demonstrate, that no harmful growth occurs and that the airborne concentrations of viable spores and bacteria, with few exceptions, even decreases after passage through the pipe-system”, and further stated, “Based on these investigations the operation of ground-coupled earth-to-air heat exchangers is acceptable as long as regular controls are undertaken and if appropriate cleaning facilities are available".

Earth-to-Water heat exchanger

An alternative to the earth to air heat exchanger is the earth to "water" heat exchanger. This is typically similar to a geothermal heat pump tubing embedded horizontally in the soil (or could be a vertical pipe/sonde) to a similar depth of the EAHX. It uses approximately double the length of pipe Ø 35 mm ie around 80 metres compared to an EAHX. A heat exchanger coil is placed before the air inlet of the HRV. Typically a brine liquid (heavily salted water) is used as the heat exchange fluid which is slightly more efficient and environmentally friendly than polypropylene heat transfer liquids.

In temperate climates in an energy efficient building, such as a passivhaus, this is more than sufficient for comfort cooling during summer without resorting to an airconditioning system. In more extreme hot climates a very small air to air micro-heat pump in reverse (an air conditioner) with the evaporator (giving heat) on the air inlet after the HRV heat exchanger and the condensor (taking heat) from the air outlet after the heat exchanger will suffice.

Seasonal bypassing

At certain times of the year it is more thermally efficient to bypass the Heat recovery ventilation-HRV heat exchanger or the earth to air heat exchanger (EAHX).

For example, during the winter, the earth at the depth of the earth to air heat exchanger is ordinarily much warmer than the air temperature. The air becomes warmed by the earth before reaching the air heat exchanger.

In the summer, the opposite is true. The air becomes cooled in the earth to air exchanger. But after passing through the EAHX, the air is warmed by the heat recovery ventilator using the warmth of the outgoing air. In this case, the HRV can have an internal bypass such that the inflowing air bypasses the heat exchanger maximising the cooling potential of the earth.

In autumn and spring there may be no thermal benefit from the EAHX—it may heat/cool the air too much and it will be better to use external air directly. In this case it is helpful to have a bypass such that the EAHX is disconnected and air taken directly from outside. A differential temperature sensor with a motorized valve can control the bypass function.

Biosafety cabinet

Biosafety cabinet

A microbiologist performing influenza research within a biosafety cabinet

Acronym	BSC
Other names	Biological safety cabinet, microbiological safety cabinet
Uses	Biocontainment
Related items	Laminar flow cabinet, Fume hood

A **biosafety cabinet (BSC)**, **biological safety cabinet**, or **microbiological safety cabinet** is an enclosed, ventilated workspace for safely working with materials contaminated with (or potentially contaminated with) pathogens in the laboratory. Several different types exist, differentiated by the specifics of construction.

Purposes

The primary purpose of a BSC is to serve as the primary means to protect the laboratory worker and the surrounding environment from pathogens. All exhaust air is HEPA-filtered as it exits the biosafety cabinet, removing harmful bacteria and viruses. This is in contrast to a laminar flow clean bench, which blows unfiltered exhaust air towards the user and is not safe for work with pathogenic agents. Neither are most BSCs safe for use as fume hoods. Likewise, a fume hood fails to provide the environmental protection that HEPA filtration in a BSC would provide. However, most classes of BSCs have a secondary purpose to maintain the sterility of materials inside (the "product").

Classes

The U.S. Centers for Disease Control and Prevention (CDC) classifies BSCs into three classes. These classes and the types of BSCs within them are distinguished in two ways: the level of personnel and environmental protection provided and the level of product protection provided.

Class I

Class I cabinets provide personnel and environmental protection but no product protection. In fact, the inward flow of air can contribute to contamination of samples. Inward airflow is maintained at a minimum velocity of 75 ft/min. These BSCs are commonly used to enclose specific equipment (*e.g.* centrifuges) or procedures (*e.g.* aerating cultures) that potentially generate aerosols. BSCs of this class are either ducted (connected to the building exhaust system) or unducted (recirculating filtered exhaust back into the laboratory).

Class II

A Class II biosafety cabinet used for handling *Leishmania*.

Class II cabinets provide both kinds of protection (of the samples and of the environment) since makeup air is also HEPA-filtered. There are four types: Type A1 (formerly A), Type A2 (formerly A/B3), Type B1, and Type B2. Each type's requirements are defined by NSF International Standard 49, which in 2002 reclassified A/B3 cabinets (classified under the latter type if connected to an exhaust duct) as Type A2. About 95% of all biosafety cabinets installed are Type A2 cabinets.

The principle of operation involves using a fan mounted in the top of the cabinet to draw a curtain of sterile air over the products that are being handled. The air is then drawn underneath the work surface and back up to the top of the cabinet where it passes through the HEPA filters. The air that is exhausted is made up by air being drawn into the front of the cabinet underneath the work surface. The air being drawn in acts as a barrier to potentially contaminated air coming back out to the operator.

The Type A1 cabinet, formerly known as Type A, has a minimum inflow velocity of 75 ft/min. The filtered makeup air is divided equally over the work surface at about two to six inches above the work surface. Exhaust is drawn at the bottom of the cabinet where it rises to the top. At the top of the cabinet, 70% of the air recirculates through the supply HEPA filter, the other 30% of air exhausted through the exhaust HEPA filter. This is due to the relative sizes of the two filters, and dampers typically allow the adjustment of this ratio. This type is not safe for work with hazardous chemicals except when ducted, usually with a "thimble" or canopy hood to avoid disturbing internal air flow..

The Type A2 cabinet, formerly designated A/B3, has a minimum inflow velocity of 100 ft/min. A negative air pressure plenum surrounds all contaminated plenums that are under positive pressure. In other respects, the specifications are identical to those of a Type A1 cabinet.

The Type B1 and B2 cabinets have a minimum inflow velocity of 100 ft/min, and these cabinets must be hard-ducted to an exhaust system rather than exhausted through a thimble connection. In contrast to the type A1 and A2 cabinets, 60% of air from the rear grille is exhausted and only 40% is recirculated. Since exhaust air is drawn from the rear grille, the CDC advises that work with chemicals be conducted in the rear of the cabinet. The Type B2 cabinet is expensive to operate because no air is recirculated within. Therefore, this type is mainly found in such applications as toxicology laboratories, where the ability to safely use hazardous chemicals is important. Additionally, there is the risk that contaminated air would flow into the laboratory if the exhaust system for a Type B1 or B2 cabinet were to fail. To mitigate this risk, cabinets of these types generally monitor the exhaust flow, shutting off the supply blower and sounding an alarm if the exhaust flow is insufficient.

Class III

A researcher observing a specimen through the built-in microscope in a Class III biosafety cabinet

The Class III cabinet, generally only installed in maximum containment laboratories, is specifically designed for work with BSL-4 pathogenic agents, providing maximum protection. The enclosure is gas-tight, and all materials enter and leave through a dunk tank or double-door autoclave. Gloves attached to the front prevent direct contact with hazardous materials. These custom-built cabinets often attach into a line, and the lab equipment installed inside is usually custom-built as well.

Ultraviolet lamps

Neither the CDC nor the U.S. National Institutes of Health recommend the installation of germicidal UV-C lamps in BSCs. The American Biological Safety Association supports this position, citing the safety risk to personnel, shallow penetration, reduced effectiveness in high relative humidity, and the frequent need to clean and replace the bulb.

Work practices

As with work on open bench tops, work performed within a BSC must be performed carefully and safely. To avoid contamination and the risk of personnel exposure, the CDC advises investigators to follow best practices to reduce and control splatter and aerosol generation, such as keeping clean materials at least 12 inches (30 cm) from aerosol-generating activities and arranging the work flow "from clean to contaminated". In particular, open flames, not necessary within the clean environment of a Class II or III BSC, cause disruption of the airflow inside. Once work inside a BSC has been completed, it is necessary to decontaminate the surfaces of the BSC as with other lab equipment and materials.

When a BSC is serviced or relocated, including replacement of HEPA filters, it must be gas decontaminated. Gas decontamination involves filling the BSC with a poisonous gas, most commonly formaldehyde gas.

Chapter-9

Mine Ventilation

Atkinson friction factor

Atkinson friction factor is a measure of the resistance to airflow of a duct. It is widely used in the mine ventilation industry but is rarely referred to outside of it.

Atkinson friction factor is represented by the symbol *k* and has the same units as air density (kilograms per cubic metre in SI units, pounds per cubic foot in Imperial units). It is related to the more widespread Fanning friction factor by

$$k = \frac{1}{2}\rho f,$$

in which ρ is the density of air in the shaft or roadway under consideration and *f* is Fanning friction factor (dimensionless). It is related to the Darcy friction factor by

$$k = \frac{1}{2}\rho\frac{\lambda}{4},$$

in which λ is the Darcy friction factor (dimensionless).

It was introduced by John J Atkinson in an early mathematical treatment of mine ventilation (1862) and has been known under his name ever since.

Atkinson resistance

Atkinson resistance is commonly used in mine ventilation to characterise the resistance to airflow of a duct of irregular size and shape, such as a mine roadway. It has the symbol *R* and is used in the square law for pressure drop,

$$\Delta P = \frac{\rho_{actual}}{\rho_{ref}} R Q^2$$

where (in English units)

- ΔP is pressure drop (pounds per square foot),
- ρ_{actual} is the air density in the duct (pounds per cubic foot),
- ρ_{ref} is the standard air density (0.075 pound per cubic foot),
- R is the resistance (atkinsons),
- Q is the rate of flow of air (thousands of cubic feet per second).

One atkinson is defined as the resistance of an airway which, when air flows along it at a rate of 1,000 cubic feet per second, causes a pressure drop of one pound-force per square foot.

The unit is named after J J Atkinson, who published one of the earliest comprehensive mathematical treatments of mine ventilation. Atkinson based his expressions for airflow resistance on the more general work of Chézy and Darcy who defined frictional pressure drop as

$$\Delta P = \frac{1}{2} \rho f L \frac{S}{A} v^2$$

where

- ΔP is pressure drop,
- ρ is the density of the fluid in question (water, air, oil etc.),
- f is the Fanning friction factor,
- L is the length of the duct,
- S is the perimeter of the duct,
- A is the area of the duct,
- v is the velocity of the fluid.

The practicalities of mine ventilation led Atkinson to group some of these variables into one all-encompassing term:

- Area and perimeter were incorporated because mine airways are of irregular shape, and both vary along the length of an airway.
- velocity v was replaced by the ratio of flowrate to area (Q / A) because variations in area cause variations in velocity. Area was then incorporated into the denominator of the Atkinson resistance term.
- Length of the airway was incorporated. This may have been a step too far, as most of his successors chose to give values of Atkinson resistance in terms of atkinsons per unit length (often 100 or 1000 yards).
- The term 1 / 2ρ was incorporated, which later authors definitely considered a step too far (e.g. McPherson, 1988). In Atkinson's time not only were all British mines

shallow enough that the density of air could be considered constant, but fan design was primitive enough that variations in density would make no measurable difference to the amount of motive power required. Atkinson did not foresee that his methods would be applied several miles underground, where air is 30–50% denser than it is at the surface. Density variations of this magnitude can alter the power consumption of colliery ventilation fans by hundreds of kilowatts.

The resulting term is one that can be easily calculated from the results of two simple measurements: a pressure survey by the gauge and tube method and a flowrate survey with a counting anemometer. This is a major strength and is the reason why Atkinson resistance remains in use today.

A complete definition of Atkinson resistance *R* in more common fluid flow terms is as follows:

$$R = \frac{1}{2}\rho\frac{fLS}{A^3} \equiv \frac{1}{2}\rho\frac{fL}{R_h A^2} \equiv \frac{1}{2}\rho\frac{4fL}{D_h A^2} \equiv \frac{1}{2}\rho\frac{\lambda L}{D_h A^2}$$

in which

- R_h is hydraulic radius,
- D_h is hydraulic diameter and
- λ is Darcy friction factor

in addition to the terms defined above.

Atkinson also defined a friction factor (Atkinson friction factor) used for airways of fixed section such as shafts. It accounts for Fanning friction factor, density and the constant 1 / 2 and relates to Atkinson resistance by

$$R = \frac{kLS}{A^3}$$

- where *k* is Atkinson friction factor and the other terms are as defined above.

Despite its weakness with regards to density changes, the use of Atkinson resistance is so widespread in the mining industry that a corresponding term in metric units has also been defined. It, too, is termed the atkinson resistance but the unit was given the name **gaul** (for reasons unknown).

One gaul is defined as the resistance of an airway which, when air (of density 1.2 kg/m^3) flows along it at a rate of one cubic metre per second, causes a pressure drop of one pascal. The gaul has units of N·s^2/m^8, or alternatively Pa·s^2/m^6.

It uses the same basic equation as its Imperial counterpart, but with slightly different dimensions:

$$\Delta P = \frac{\rho_{actual}}{\rho_{ref}} R Q^2$$

where

- ΔP is pressure drop (pascals),
- ρ_{actual} is the air density in the air duct (kilograms per cubic metre),
- ρ_{ref} is the standard air density (1.2 kilograms per cubic metre),
- R is the resistance of the air path (gauls),
- Q is the rate of flow of air (cubic metres per second).

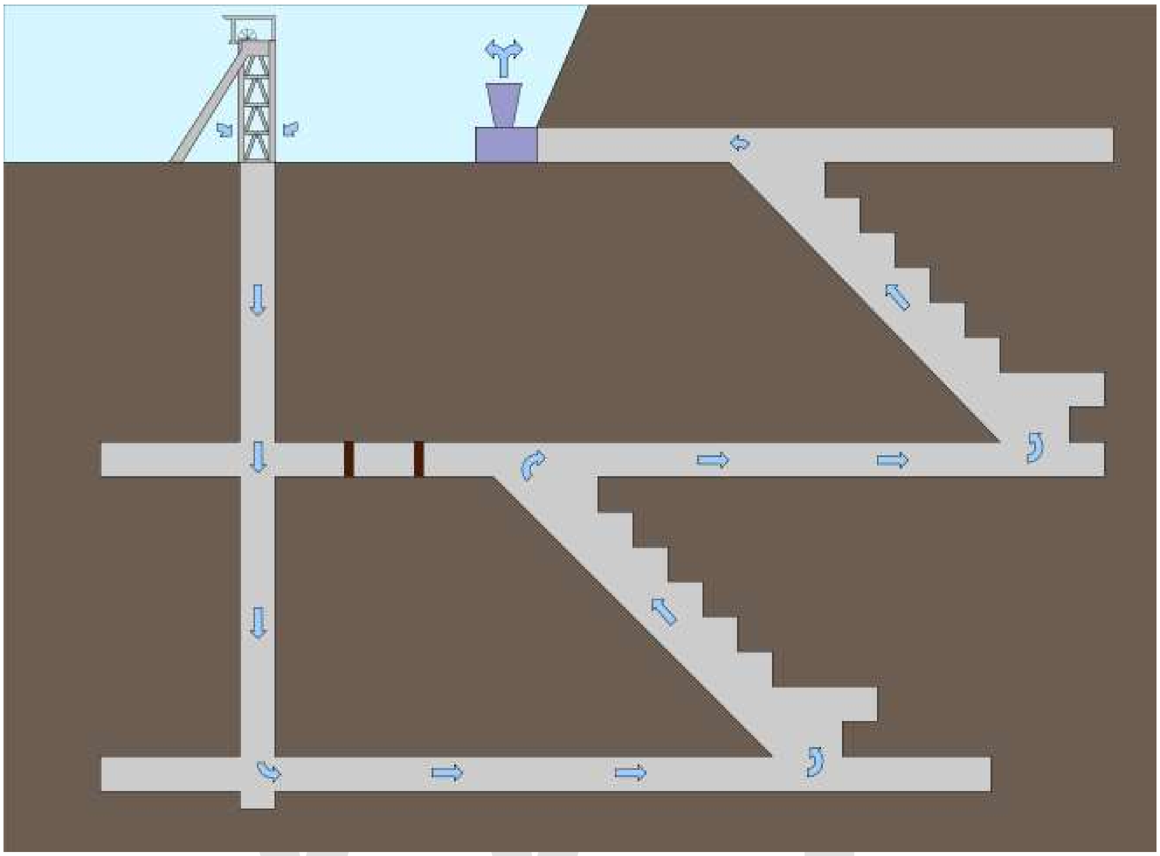
The metric and Imperial resistances are related by

$$1 \text{ gaul} = 1 \text{ atkinson} \times \frac{10^6 \times \left(\frac{metres}{feet}\right)^8}{\frac{kilograms}{pounds} \times g} \equiv 1 \times \frac{10^6 \times 0.3048^8}{0.4536 \times 9.80665} \equiv 16.747 \text{ atkinsons}$$

where g is the standard acceleration of gravity (metres per second squared).

The metric equivalent is now more widely used than the original Imperial definition. Most suppliers quote resistances of flexible temporary ventilation ducts in gauls/100 m and in most mine ventilation software programs, branch resistances are given in gauls.

Underground mine ventilation



Schematic of underground mine ventilation

Underground mine ventilation provides a flow of air to the underground workings of a mine of sufficient volume to dilute and remove noxious gases (typically NO_x, SO_2, methane, CO_2 and CO). The source of these gases are equipment that runs on diesel engines, blasting with explosives, and the orebody itself. The largest component of the operating cost for mine ventilation is electricity to power the ventilation fans, which may account for one third of a typical underground mine's entire electrical power cost.

Types of ventilation

Flow-through ventilation is the main ventilation circuit for the mine. Air enters the mine from surface via a shaft, ventilation raise or adit. The air is distributed through the mine via internal ventilation raises and ramps, and flows are controlled by regulators and permanently mounted ventilation fans. An **Auxiliary ventilation** system takes air from the flow-through system and distributes it to the mine workings via temporarily mounted ventilation fans, venturies and disposable fabric, or steel ducting.

Regulations

The volume (expressed in cubic feet per minute or cubic meters per second) of air required to ventilate an underground mine is determined by mining- or geotechnical-engineers. It may also be regulated by the local governing body. However in some developing countries the mandated ventilation requirement may be insufficient, and the mining company may have to increase the ventilation flow, in particular where ventilation may be required to cool the ambient temperature in a deep hot mine.

Heating

In temperate climates ventilation air may require to be heated during winter months. This will make the working environment more hospitable for miners, and prevent freezing of workings, in particular water pipes. In Arctic mines where the mining horizon is above the permafrost heating may not take place to prevent melting the permafrost. "Cold mines" such as Raglan Mine and Nanisivik Mine are designed to operate below zero degrees Celsius.

Ventilation shaft

Chipping Sodbury Tunnel ventilation shaft

Swan St. ventilation shaft on the Burnley Tunnel

Ventilation shafts of the Velser tunnel, the Netherlands

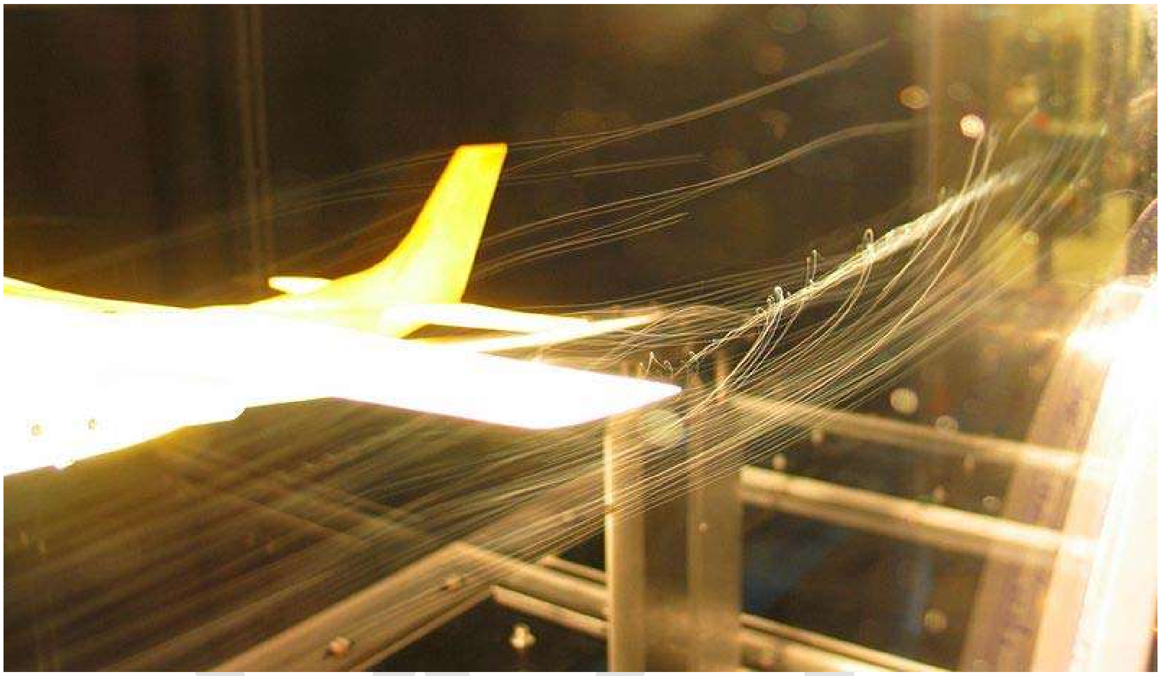
In subterranean civil engineering, **ventilation shafts**, also known as **airshafts** or **vent shafts**, are vertical passages used in mines and tunnels to move fresh air underground, and to remove stale air.

In architecture, an airshaft is a small, vertical space within a tall building which permits ventilation of the building's interior spaces to the outside. The floorplan of a building with an airshaft is often described as a "square donut" shape. Alternatively, an airshaft may be formed between two adjacent buildings. Windows on the interior side of the donut allow air from the building to be exhausted into the shaft, and, depending on the height and width of the shaft, may also allow extra sunlight inside.

Chapter-10

Wind Tunnel

NASA wind tunnel with the model of a plane.



A model Cessna with helium-filled bubbles showing streamlines of the wingtip vortices.

A **wind tunnel** is a research tool used in aerodynamic research. It is used to study the effects of air moving past solid objects.

Theory of operation

Wind tunnels were first proposed as a means of studying vehicles (primarily airplanes) in free flight. The wind tunnel was envisioned as a means of reversing the usual paradigm: instead of the air's standing still and the aircraft moving at speed through it, the same effect would be obtained if the aircraft stood still and the air moved at speed past it. In that way a stationary observer could study the aircraft in action, and could measure the aerodynamic forces being imposed on the aircraft.

Later, wind tunnel study came into its own: the effects of wind on manmade structures or objects needed to be studied, when buildings became tall enough to present large surfaces to the wind, and the resulting forces had to be resisted by the building's internal structure. Determining such forces was required before building codes could specify the required strength of such buildings.

Still later, wind-tunnel testing was applied to automobiles, not so much to determine aerodynamic forces *per se* but more to determine ways to reduce the power required to move the vehicle on roadways at a given speed. In these studies, the interaction between the road and the vehicle plays a significant role, and this interaction must be taken into consideration when interpreting the test results. In an actual situation the roadway is moving relative to the vehicle but the air is stationary relative to the roadway, but in the wind tunnel the air is moving relative to the roadway, while the roadway is stationary relative to the test vehicle. Some automotive-test wind tunnels have incorporated moving belts under the test vehicle in an effort to approximate the actual condition.

Measurement of aerodynamic forces

Ways that air velocity and pressures are measured in wind tunnels:

- air velocity through the test section is determined by Bernoulli's principle. Measurement of the dynamic pressure, the static pressure, and (for compressible flow only) the temperature rise in the airflow
- direction of airflow around a model can be determined by tufts of yarn attached to the aerodynamic surfaces
- direction of airflow approaching an aerodynamic surface can be visualized by mounting threads in the airflow ahead of and aft of the test model
- dye, smoke, or bubbles of liquid can be introduced into the airflow upstream of the test model, and their path around the model can be photographed
- pressures on the test model are usually measured with beam balances, connected to the test model with beams or strings or cables
- pressure distributions across the test model have historically been measured by drilling many small holes along the airflow path, and using multi-tube manometers to measure the pressure at each hole
- pressure distributions can more conveniently be measured by the use of pressure-sensitive paint, in which higher local pressure is indicated by lowered fluorescence of the paint at that point
- pressure distributions can also be conveniently measured by the use of pressure-sensitive pressure belts, a recent development in which multiple ultra-miniaturized pressure sensor modules are integrated into a flexible strip. The strip is attached to the aerodynamic surface with tape, and it sends signals depicting the pressure distribution along its surface.
- pressure distributions on a test model can also be determined by performing a **wake survey**, in which either a single pitot tube is used to obtain multiple readings downstream of the test model, or a multiple-tube manometer is mounted downstream and all its readings are taken (often by photograph).

History of wind tunnels

The First Wind Tunnels

English military engineer and mathematician Benjamin Robins (1707–1751) invented a whirling arm apparatus to determine drag and did some of the first experiments in aviation theory.

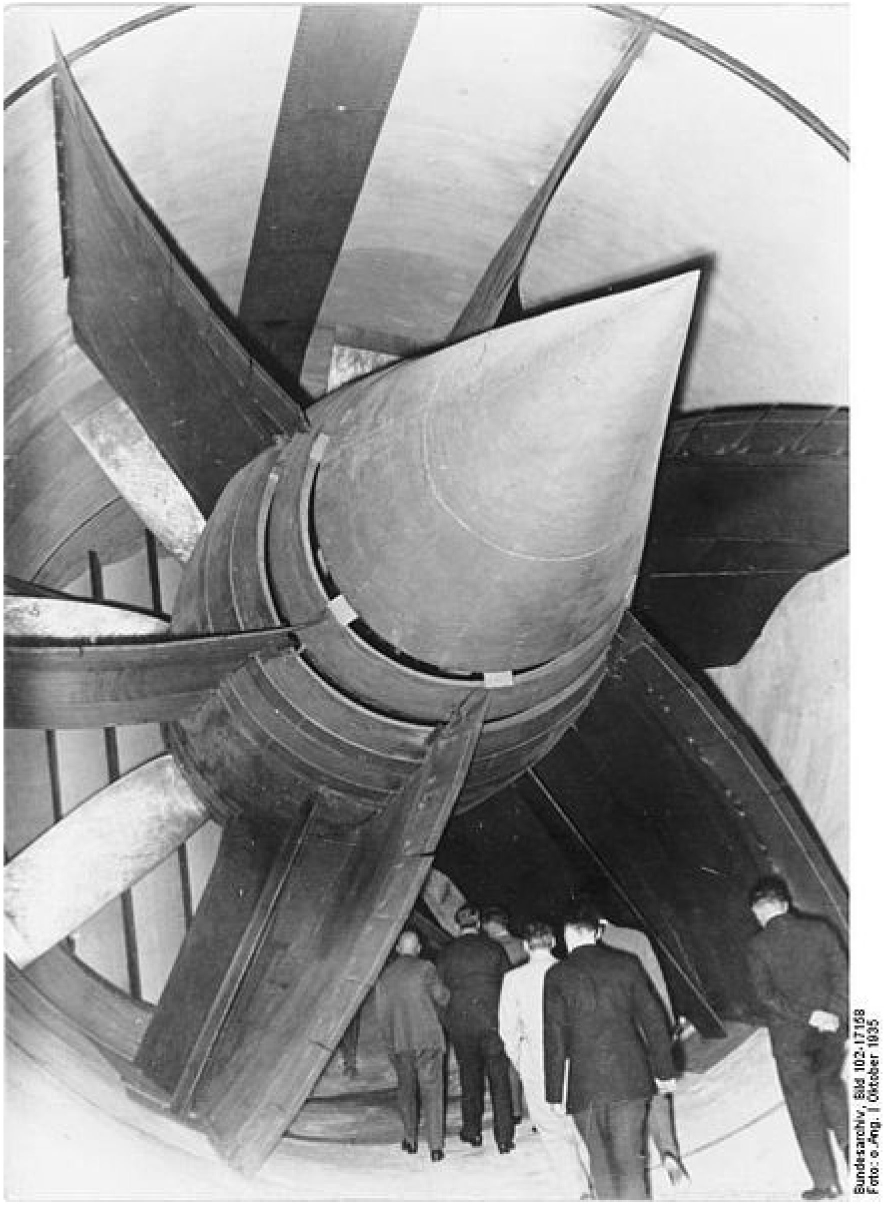
Sir George Cayley (1773–1857) also used a whirling arm to measure the drag and lift of various airfoils. His whirling arm was 5 feet long and attained top speeds between 10 and 20 feet per second.

However, the whirling arm does not produce a reliable flow of air impacting the test shape at a normal incidence. Centrifugal forces and the fact that the object is moving in its own wake mean that detailed examination of the airflow is difficult. Francis Herbert Wenham (1824–1908), a Council Member of the Aeronautical Society of Great Britain, addressed these issues by inventing, designing and operating the first enclosed wind tunnel in 1871. Once this breakthrough had been achieved, detailed technical data was rapidly extracted by the use of this tool. Wenham and his colleague Browning are credited with many fundamental discoveries, including the measurement of l/d ratios, and the revelation of the beneficial effects of a high aspect ratio.

Carl Rickard Nyberg used a wind tunnel when designing his *Flugan* from 1897 and onwards.

In a classic set of experiments, the Englishman Osborne Reynolds (1842–1912) of the University of Manchester demonstrated that the airflow pattern over a scale model would be the same for the full-scale vehicle if a certain flow parameter were the same in both cases. This factor, now known as the Reynolds Number, is a basic parameter in the description of all fluid-flow situations, including the shapes of flow patterns, the ease of heat transfer, and the onset of turbulence. This comprises the central scientific justification for the use of models in wind tunnels to simulate real-life phenomena. However, there are limitations on conditions in which dynamic similarity is based upon the Reynolds number alone.

Replica of the Wright brothers' wind tunnel.



German aviation laboratory, 1935

The Wright brothers' use of a simple wind tunnel in 1901 to study the effects of airflow over various shapes while developing their Wright Flyer was in some ways revolutionary. It can be seen from the above, however, that they were simply using the accepted technology of the day, though this was not yet a common technology in America.

Subsequent use of wind tunnels proliferated as the science of aerodynamics and discipline of aeronautical engineering were established and air travel and power were developed.

The US Navy in 1916 built one of the largest wind tunnels in the world at that time at the Washington Navy Yard. The inlet was almost 11 feet in diameter and the discharge part was 7 feet in diameter. A 500 hp electric motor drove the paddle type fan blades.

Wind tunnels were often limited in the volume and speed of airflow which could be delivered.

World War Two Wind Tunnels

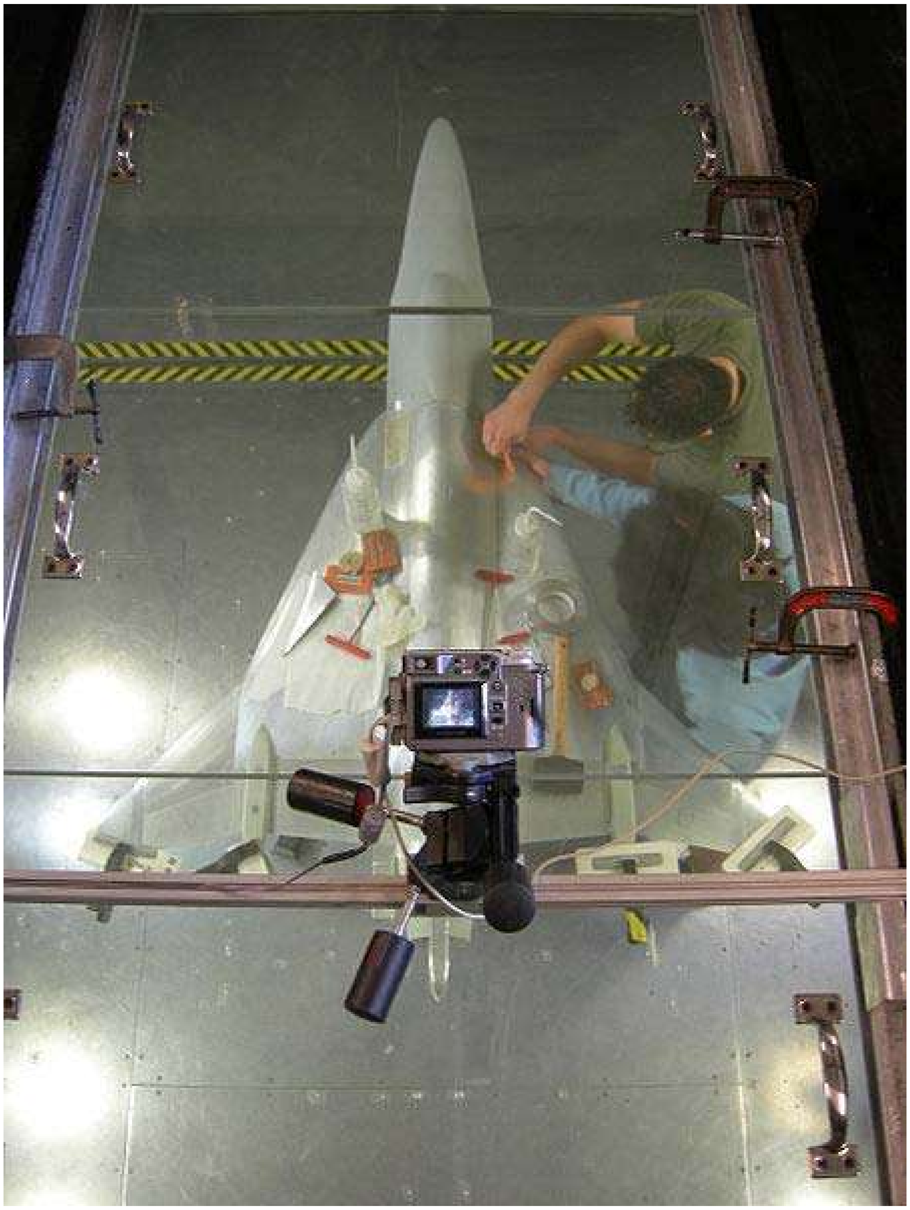
In 1941 the US constructed one of the largest wind tunnels at that time at Wright Field in Dayton, Ohio. This wind tunnel starts at 45 feet and narrows to 20 feet in diameter. Two 40 foot fans were driven by a 40,000hp electric motor. Large scale aircraft models could be tested at air speeds of 400mph.

The wind tunnel used by German scientists at Peenemünde prior to and during WWII is an interesting example of the difficulties associated with extending the useful range of large wind tunnels. It used some large natural caves which were increased in size by excavation and then sealed to store large volumes of air which could then be routed through the wind tunnels. This innovative approach allowed lab research in high-speed regimes and greatly accelerated the rate of advance of Germany's aeronautical engineering efforts. By the end of the war, Germany had at least three different *supersonic* wind tunnels, with one capable of Mach 4.4 (heated) airflows.

Post World War Two Wind Tunnels

Later research into airflows near or above the speed of sound used a related approach. Metal pressure chambers were used to store high-pressure air which was then accelerated through a nozzle designed to provide supersonic flow. The observation or instrumentation chamber ("test section") was then placed at the proper location in the throat or nozzle for the desired airspeed.

For limited applications, Computational fluid dynamics (CFD) can augment or possibly replace the use of wind tunnels. For example, the experimental rocket plane SpaceShipOne was designed without any use of wind tunnels. However, on one test, flight threads were attached to the surface of the wings, performing a wind tunnel type of test during an actual flight in order to refine the computational model. It should be noted that, for situations where external turbulent flow is present, CFD is not practical due to limitations in present day computing resources. For example, an area that is still much too complex for the use of CFD is determining the effects of flow on and around structures, bridges, terrain, etc.



Preparing a model in the Kirsten Wind Tunnel, a subsonic wind tunnel at the University of Washington

The most effective way to simulative external turbulent flow is through the use of a boundary layer wind tunnel.

There are many applications for boundary layer wind tunnel modeling. For example, understanding the impact of wind on high-rise buildings, factories, bridges, etc. can help building designers construct a structure that stands up to wind effects in the most efficient manner possible. Another significant application for boundary layer wind tunnel modeling is for understanding exhaust gas dispersion patterns for hospitals, laboratories, and other emitting sources. Other examples of boundary layer wind tunnel applications are assessments of pedestrian comfort and snow drifting. Wind tunnel modeling is accepted as a method for aiding in Green building design. For instance, the use of boundary layer wind tunnel modeling can be used as a credit for Leadership in Energy and Environmental Design (LEED) certification through the U.S. Green Building Council.

Fan blades of Langley Research Center's 16 foot transonic wind tunnel in 1990, before it was mothballed in 2004.

Wind tunnel tests in a boundary layer wind tunnel allow for the natural drag of the Earth's surface to be simulated. For accuracy, it is important to simulate the mean wind speed profile and turbulence effects within the atmospheric boundary layer. Most codes and standards recognize that wind tunnel testing can produce reliable information for designers, especially when their projects are in complex terrain or on exposed sites.

In the USA many wind tunnels have been decommissioned in the last 20 years, including some historic facilities. Pressure is brought to bear on remaining wind tunnels due to declining or erratic usage, high electricity costs, and in some cases the high value of the real estate upon which the facility sits. On the other hand CFD validation still requires wind-tunnel data, and this is likely to be the case for the foreseeable future. Studies have been conducted and others are under way to assess future military and commercial wind tunnel needs, but the outcome remains uncertain. More recently an increasing use of jet-powered, instrumented unmanned vehicles ["research drones"] have replaced some of the traditional uses of wind tunnels.

How it works

Six-element external balance below the Kirsten Wind Tunnel

Air is blown or sucked through a duct equipped with a viewing port and instrumentation where models or geometrical shapes are mounted for study. Typically the air is moved through the tunnel using a series of fans. For very large wind tunnels several meters in diameter, a single large fan is not practical, and so instead an array of multiple fans are used in parallel to provide sufficient airflow. Due to the sheer volume and speed of air movement required, the fans may be powered by stationary turbofan engines rather than electric motors.

The airflow created by the fans that is entering the tunnel is itself highly turbulent due to the fan blade motion (when the fan is **blowing** air into the test section – when it is **sucking** air out of the test section downstream, the fan-blade turbulence is not a factor), and so is not directly useful for accurate measurements. The air moving through the tunnel needs to be relatively turbulence-free and laminar. To correct this problem, closely-spaced vertical and horizontal air vanes are used to smooth out the turbulent airflow before reaching the subject of the testing.

Due to the effects of viscosity, the cross-section of a wind tunnel is typically circular rather than square, because there will be greater flow constriction in the corners of a square tunnel that can make the flow turbulent. A circular tunnel provides a smoother flow.

The inside facing of the tunnel is typically as smooth as possible, to reduce surface drag and turbulence that could impact the accuracy of the testing. Even smooth walls induce some drag into the airflow, and so the object being tested is usually kept near the center of the tunnel, with an empty buffer zone between the object and the tunnel walls. There are correction factors to relate wind tunnel test results to open-air results.

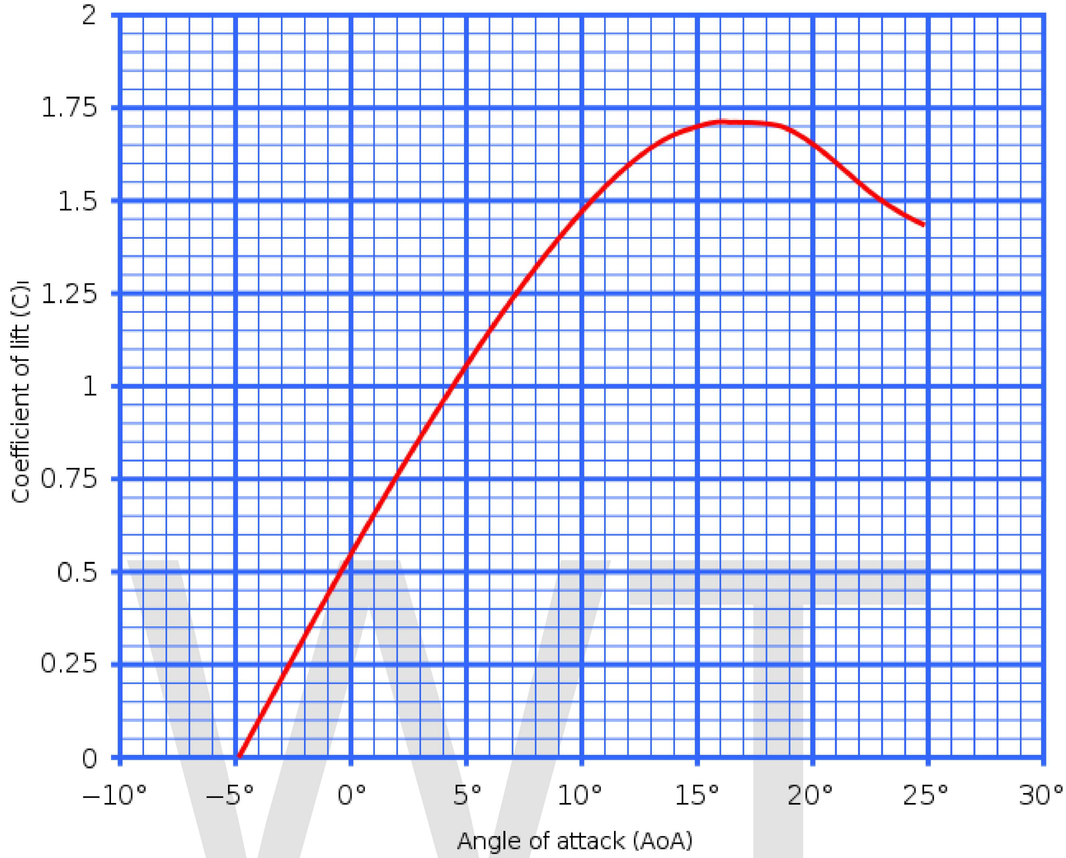
Lighting is usually recessed into the circular walls of the tunnel and shines in through windows. If the light were mounted on the inside surface of the tunnel in a conventional manner, the light bulb would generate turbulence as the air blows around it. Similarly, observation is usually done through transparent portholes into the tunnel. Rather than simply being flat discs, these lighting and observation windows may be curved to match the cross-section of the tunnel and further reduce turbulence around the window.

Various techniques are used to study the actual airflow around the geometry and compare it with theoretical results, which must also take into account the Reynolds number and Mach number for the regime of operation.

Pressure measurements

Pressure across the surfaces of the model can be measured if the model includes pressure taps. This can be useful for pressure-dominated phenomena, but this only accounts for normal forces on the body.

Force and moment measurements



A typical lift coefficient versus angle of attack curve.

With the model mounted on a force balance, one can measure lift, drag, lateral forces, yaw, roll, and pitching moments over a range of angle of attack. This allows one to produce common curves such as lift coefficient versus angle of attack (shown).

Note that the force balance itself creates drag and potential turbulence that will affect the model and introduce errors into the measurements. The supporting structures are therefore typically smoothly shaped to minimize turbulence.

Flow visualization

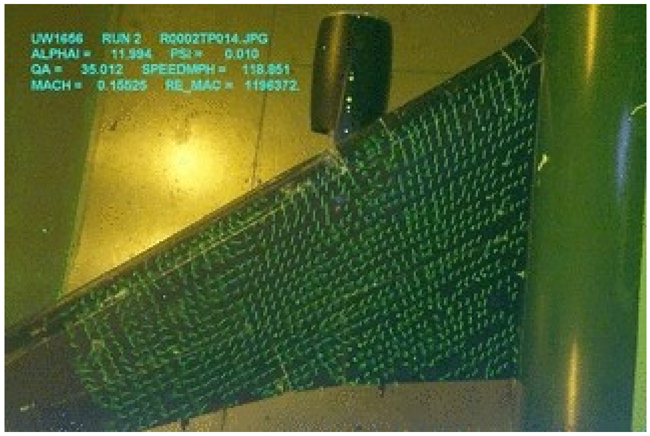
Because air is transparent it is difficult to directly observe the air movement itself. Instead, multiple methods of both quantitative and qualitative flow visualization methods have been developed for testing in a wind tunnel.

Qualitative methods

- Smoke

- Tufts

Tufts are applied to a model and remain attached during testing. Tufts can be used to gauge air flow patterns and flow separation.

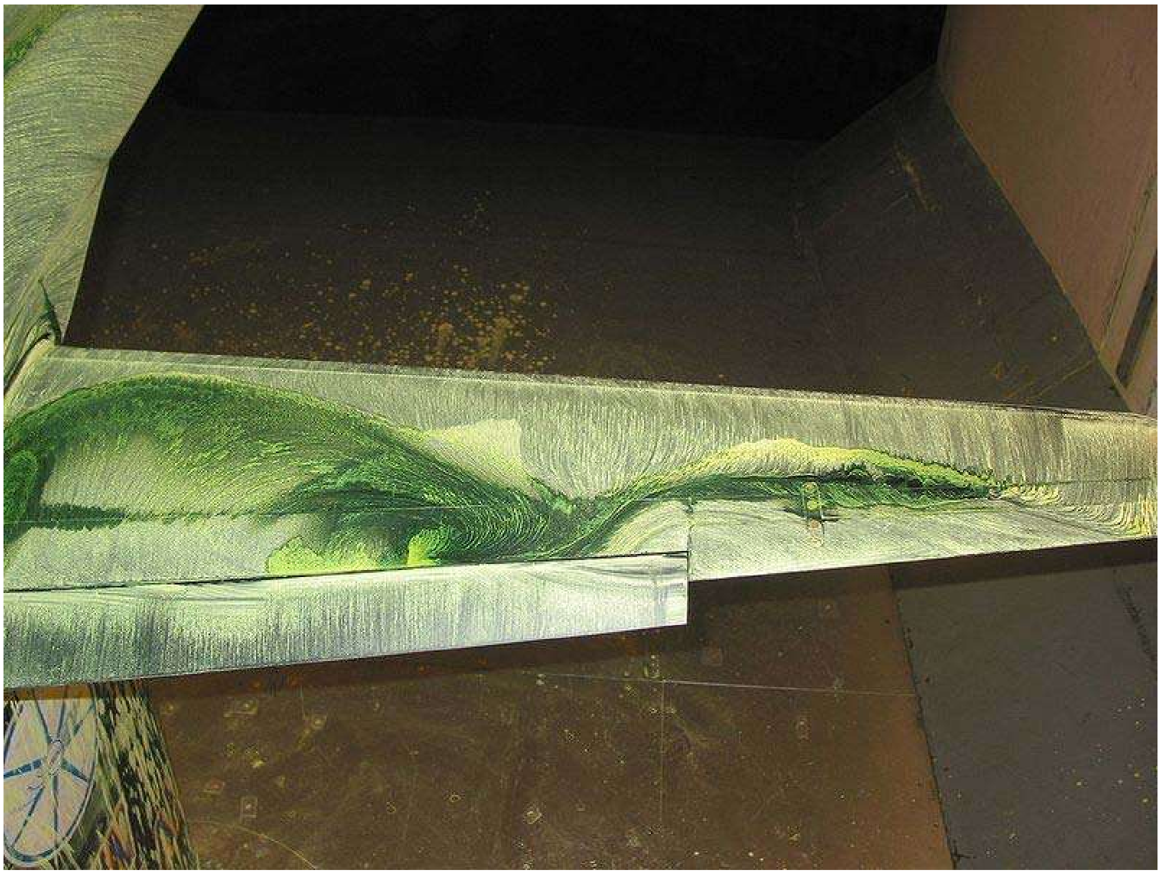


Compilation of images taken during an alpha run starting at 0 degrees alpha ranging to 26 degrees alpha. Images taken at the Kirsten Wind Tunnel using fluorescent mini-tufts. Notice how separation starts at the outboard wing and progresses inward. Notice also how there is delayed separation aft of the nacelle.

Fluorescent mini-tufts attached to a wing in the Kirsten Wind Tunnel showing air flow direction and separation. Angle of attack ~ 12 degrees, speed ~120 Mph.

- Evaporating suspensions

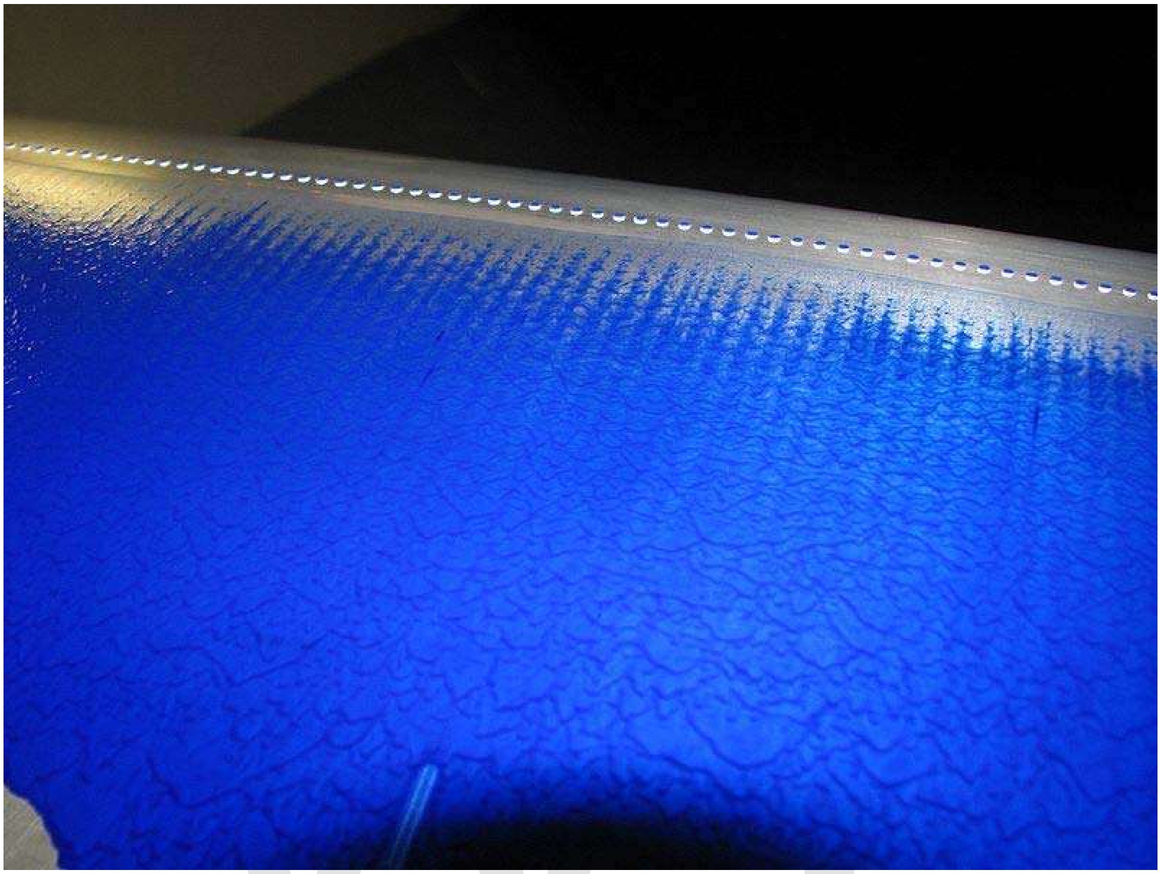
Evaporating suspensions are simply a mixture of some sort or fine powder, talc, or clay mixed into a liquid with a low latent heat of evaporation. When the wind is turned on the liquid quickly evaporates leaving behind the clay in a pattern characteristic of the air flow.



China clay on a wing in the Kirsten Wind Tunnel showing reverse and span-wise flow.

- Oil

When oil is applied to the model surface it can clearly show the transition from laminar to turbulent flow as well as flow separation.



Oil flow vis on straight wing in the Kirsten Wind Tunnel. Trip dots can be seen near the leading edge.

- Sublimation

If the air movement in the tunnel is sufficiently non-turbulent, a particle stream released into the airflow will not break up as the air moves along, but stay together as a sharp thin line. Multiple particle streams released from a grid of many nozzles can provide a dynamic three-dimensional shape of the airflow around a body. As with the force balance, these injection pipes and nozzles need to be shaped in a manner that minimizes the introduction of turbulent airflow into the airstream.

High-speed turbulence and vortices can be difficult to see directly, but strobe lights and film cameras or high-speed digital cameras can help to capture events that are a blur to the naked eye.

High-speed cameras are also required when the subject of the test is itself moving at high speed, such as an airplane propeller. The camera can capture stop-motion images of how the blade cuts through the particulate streams and how vortices are generated along the trailing edges of the moving blade.

Wind tunnel classification

There are many different kinds of wind tunnels, an overview is given in the figure below:

- Low speed wind tunnel
- High speed wind tunnel
- Supersonic wind tunnel
- Hypersonic wind tunnel
- Subsonic and transonic wind tunnel

List of wind tunnels

- Modine Wind Tunnels, Climatic Wind Tunnel Testing, Large Truck and Automotive
- AeroDyn Wind Tunnel, Full Scale NASCAR Racecars
- A2 Wind Tunnel, Full scale general purpose
- Eight-Foot High Speed Tunnel
- Full Scale 30- by 60-Foot Tunnel
- Trisonic Wind Tunnel
- Unitary Plan Wind Tunnel
- Wind Shear's Full Scale, Rolling Road, Automotive Wind Tunnel
- Variable Density Tunnel

Vertical wind tunnel T-105 at TsAGI used for aircraft testing (built in 1941)

Aquadynamic Flume

The aerodynamic principles of the wind tunnel work equally on watercraft, except the water is more viscous and so imposes a greater forces on the object being tested. A looping flume is typically used for underwater aquadynamic testing. The interaction between 2 different types of fluids means that pure windtunnel testing is only partly relevant. However, a similar sort of research is done in a towing tank

Low-speed Oversize Liquid Testing

Air is not always the best test medium to study small-scale aerodynamic principles, due to the speed of the air flow and airfoil movement. A study of fruit fly wings designed to understand how the wings produce lift was performed using a large tank of mineral oil and wings 100 times larger than actual size, in order to slow down the wing beats and make the vortices generated by the insect wings easier to see and understand.

Wind Tunnel Testing for Wind Engineering

In Wind Engineering, Wind Tunnel Tests are often used to measure the velocity around, and forces or pressures upon structures. Usually very tall buildings, buildings with unusual or complicated shapes (such as a tall building with a parabolic or a hyperbolic shape), cable suspension bridges or cable stayed bridges are analysed in specialized atmospheric boundary layer wind tunnels. These feature a long upwind section to accurately represent the wind speed and turbulence profile acting on the structure. Wind tunnel tests provide the necessary design pressure measurements for use in the dynamic analysis of the structure.

Chapter-11

Air Changes Per Hour, Infiltration (HVAC), Trickle Vent and Smoke Dampers

Air changes per hour

Air changes per hour is a measure of how many times the air within a defined space (normally a room or house) is replaced. Air changes in a confined space are important for a variety of reasons, mainly though, we need fresh air to live. Without sufficient fresh air exchange, moisture is trapped in a room/home/building, molds can feed, and other allergens and excessive dangerous gases (e.g. Carbon monoxide, Carbon Dioxide, urea formaldehyde), can remain in the home. "Stale" air is unhealthy and, since humans and pets add to it by breathing, sweating, washing, showering and drying, we need to ventilate the home, increasing the number of times the air 'exchanges' in the home with outside fresh air. Number of 'air changes per hour' were less of a problem before 'air sealing' came into play, because construction practices and products were not geared to energy efficiency (in the USA, with lower energy costs). With a new focus on energy efficiency, reducing carbon footprints, and reducing dependence on fossil fuels, consumers try to seal their homes from air transfer in and out of their homes in winter and summer. Double edged-sword. The importance of fresh air intake cannot be understated.

An air change does not represent a complete change of all air in the enclosure or structure unless it can be considered plug flow. The actual percentage of an enclosure's air which is exchanged in a period depends on the airflow efficiency of the enclosure and the methods used to ventilate it. The actual amount of air changed in a well mixed ventilation scenario will be 63.2% after 1 hour and 1 ACH. In order to achieve equilibrium pressure, the amount of air leaving the space and entering the space must be the same.

ACH equation in Imperial units

$$N = \frac{60Q}{Vol}$$

Where:

- N = number of air changes per hour
- Q = Volumetric flow rate of air in cubic feet per minute (cfm)
- Vol = Space volume $L \times W \times H$, in cubic feet

Air Change Rate

Commercial kitchens	20–60
Public bathrooms	6
Class rooms	3–4
Laboratories	6–12
Smoking rooms	10–15
Warehousing	1–2

Infiltration (HVAC)

Infiltration is the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope and through use of doors for passage. Infiltration is sometimes called **air leakage**. The leakage of room air out of a building, intentionally or not, is called **exfiltration**. Infiltration is caused by wind, building pressurization and by air buoyancy forces known commonly as the stack effect.

Infiltration measures

The **infiltration rate** is the volumetric flow rate of outside air into a building, typically in cubic feet per minute (CFMs) or liters per second (LPSs). The **air exchange rate**, (I), is the number of interior volume air changes that occur per hour, and has units of 1/h. The air exchange rate is also known as **air changes per hour** (*ACHs*).

ACH can be calculated by multiplying the building's CFM by 60, and then dividing by the building volume. (CFM x 60)/volume

Infiltration as ventilation air

In many smaller buildings, 'forced' or 'mechanical' ventilation is not used to introduce ventilation air. Instead, natural ventilation, via operable windows and other openings, exhaust fans, and infiltration are used to provide ventilation air. Typically, at least one-third air change per hour is considered the minimum. Recently, ASHRAE Standard 62.2 has been adopted (2004); it clarifies the ventilation air requirements for low-rise residences. The Standard specifies that forced ventilation is required in houses with infiltration less than 0.35 ACH. This is typically accomplished with heat recovery ventilation or exhaust fans running constantly or periodically.

Controlling infiltration

Because infiltration is uncontrolled, and admits unconditioned air, it is generally considered undesirable except for ventilation air purposes. Typically, infiltration is minimized to reduce dust, to increase thermal comfort, and to decrease energy consumption. For all buildings, infiltration can be reduced via sealing cracks in a building's envelope, and for new construction or major renovations, by installing continuous air retarders. In buildings where forced ventilation is provided, their HVAC designers typically choose to slightly pressurize the buildings by admitting more outside air than exhausting so that infiltration is drammatically reduced.

Energy savings

In typical modern U.S. residences, about one-third of the HVAC energy consumption is due to infiltration. Another third is to ground-contact, and the remainder is to heat losses and gains through windows, walls, and other thermal *loads*. As such, reducing infiltration can yield significant energy savings, with rapid payback. In cold climates, with a 15 MPH wind, residences often have air exchange rates of 1.0 to 1.5 ACHs, far in excess of the ventilation air needs and are thus called *loose construction*. It is very easy to reduce infiltration rates to less than 1.0 ACH. Smoke candles and blower-door tests can help identify less-than-obvious leaks. The Weatherization article describes methods for energy savings further. If infiltration is reduced below 0.35 ACH, it is recommended that mechanical ventilation (typically an exhaust fan or heat recovery ventilation) be implemented.

Trickle vent

A **trickle vent** is a very small opening in a window or other building envelope component to allow small amounts of ventilation in spaces intended to be naturally ventilated when major elements of the design - windows, doors, etc, are otherwise closed. Trickle vents are used extensively in the UK and Europe and are integrated into window frames to provide minimum ventilation requirements for naturally ventilated spaces.

Energy efficiency ratings

The application of trickle vents in naturally ventilated spaces can help contribute to IEQ Credit 2 under the LEED green building rating system. LEED EA Credit 2 references CIBSE Applications Manual 10 which provides advice on the design of naturally ventilated spaces, recommending the installation of trickle vents in naturally ventilated spaces. Within the UK the application of trickle vents is required to meet the requirements of the Building Regulations, requirements are described in Guide F, Means of Ventilation.

Effect on indoor environment

Trickle vents will help avoid problems associated with poor ventilation in naturally ventilated spaces, including, reduced risk of condensation, avoided over ventilation (minimizing energy consumption), improved comfort through draft avoidance.

Drawbacks

The US Standard, ASHRAE 62.1-2007: Ventilation for Acceptable Indoor Air Quality, only requires 4% of net floor area to be operable. This creates the potential for increased energy consumption where natural ventilation is provided by operable windows where supplemental air conditioning is provided, in addition to generally poor control over ventilation rates during hot summer or cold winter conditions.

Smoke dampers

Smoke dampers are passive fire protection products used in air conditioning and ventilation ductwork to prevent the spread of smoke inside the ductwork where the ductwork penetrates fire-resistance rated walls and floors. Smoke dampers are installed by sheet metal contractors inside the ducting.

"Smoke Dampers are used in ductwork and air transfer openings that are designed to resist the passage of air and smoke. Smoke dampers may be required in smoke barriers and other smoke controlled systems. The smoke dampers are usually operated by smoke detectors and an electric or pneumatic actuator that will close the smoke damper when smoke is detected."

According to Underwriter's Laboratory, "smoke dampers certified by UL carry a leakage class rating that indicates the level of air leakage measured through the damper under test conditions."

Fire dampers and smoke dampers are an integral part of a building's passive fire protection system.

Inspection and maintenance

As with any other element of a building's passive fire protection system, smoke dampers need to be maintained, inspected and repaired to ensure they are in working order. The National Fire Protection Association (NFPA) requires the testing, maintenace and repair of Smoke Dampers as mandated in their Life Safety Code. NFPA 105 states [that] each damper shall be tested and inspected one year after installation. The test and inspection frequency shall then be every 4 years, except in hospitals, where the frequency shall be every 6 years. The code also states that the damper shall be actuated and cycled (fusible link removed and then reinstalled after testing.) The inspections must be document indicating the location of the damper, date of inspection, name of inspector, and deficiencies discovered.

As with fire damper inspections, smoke damper inspections are required by Authorities Having Jurisdiction (AHJ's). The International Code Council, the Joint Commission, NFPA and State Fire Marshals require these inspections as part of a Building's Life Safety Plan.

Repair

NFPA 105 requires that "if a damper is not operable, repairs shall begin as soon as possible".

The repair of smoke dampers in rather involved and typically requires contracting a specialist in this service. The repairs for smoke dampers are much more extensive than a fire damper due to actuator replacement which require the working knowledge of basic electricity and a strong mechanical aptitude.

Chapter-12

Computer Fan

A 3D illustration of four 80 mm fans, a type of fan commonly used in personal computers (sometimes as a set, or mixed with other fan sizes).

A **computer fan** is any fan inside, or attached to, a computer case used for cooling purposes, and may refer to fans that draw cooler air into the case from the outside, expel warm air from inside, or move air across a heatsink to cool a particular component. The use of fans to cool a computer is an example of active cooling.

Usage

As processors, graphics cards, RAM and other components in computers that have increased in speed and power consumption, the amount of heat produced by these components as a side-effect of normal operation has also increased. These components need to be kept within a specified temperature range to prevent overheating, instability, malfunction and damage leading to a shortened component lifespan.

While in earlier personal computers it was possible to cool most components using natural convection (passive cooling), many modern components require more effective active cooling. To cool these components, fans are used to move heated air away from the components and draw cooler air over them. Fans attached to components are usually used in combination with a heatsink to increase the area of heated surface in contact with the air, thereby improving the efficiency of cooling.

In the IBM compatible PC market, the computer's power supply unit (PSU) almost always uses an exhaust fan to expel warm air from the PSU. Active cooling on CPUs started to appear on the Intel 80486, and by 1997 was standard on all desktop processors. Chassis or case fans, usually one exhaust fan to expel heated air from the rear and optionally an intake fan to draw cooler air in through the front, became common with the arrival of the Pentium 4 in late 2000. A third vent fan in the side of the PC, often located over the CPU, is also common. The graphics processing unit (GPU) on many modern graphics cards also requires a heatsink and fan. In some cases, the northbridge chip on the motherboard has another fan and heatsink. Other components such as the hard drives and RAM may also be actively cooled, though as of 2007 this remains relatively unusual. It is not uncommon to find five or more fans in a modern PC.

Cooling fan applications

An 80x80x25mm computer fan

Case mount

Used to aerate the case of the computer. The components inside the case cannot dissipate heat efficiently if the surrounding air is too hot. Case fans move air through the case, usually drawing cooler outside air in through the front (where it may also be drawn over the internal hard drive racks) and expelling it through the rear. There may be a third fan in the side or top of the case to draw outside air into the vicinity of the CPU, which is usually the largest single heat source. Standard case fans are 80 mm, 92 mm or 120 mm in width and length. As case fans are often the most readily visible form of cooling on a PC, decorative fans are widely available and may be lit with LEDs, made of UV-reactive plastic, and covered with decorative grilles. Decorative fans and accessories are popular with case modders. Air filters are often used over intake fans, to prevent dust from entering the case.

A power supply (PSU) fan often plays a double role, not only keeping the PSU itself from overheating, but also removing warm air from inside the case. PSUs with two fans are also available, which typically have a fan on the inside to supply case air into the PSU and a second fan on the back to expel the heated air.

CPU fan

Used to cool the CPU (central processing unit) heatsink.

Graphics card fan

Used to cool the graphics processing unit or the memory on graphics cards. These fans were not necessary on older cards because of their low power dissipation, but most modern graphics cards, especially those designed for 3D graphics and gaming, need their own dedicated cooling fans. Some of the higher powered cards can produce more heat than the CPU (up to 289 watts), so effective cooling is especially important. Passive coolers for new video cards, however, are not unheard of, such as the Thermalright HR-03.

Chipset fan

Used to cool the northbridge of a motherboard's chipset, which may be necessary for system bus overclocking.

Other types of fans

Other less commonly encountered fans may include:

- **PCI slot fan:** A fan mounted in one of the PCI slots, usually to supply additional cooling to the PCI and/or graphics cards.
- **Hard disk fan:** A fan mounted next to or on a hard disk drive. This may be desirable on faster-spinning (e.g. 10,000 RPM) hard disks with greater heat production.
- **CD burner fan:** Some internal CD and/or DVD burners included cooling fans.

Physical characteristics

The width and height of these usually square fans are measured in millimeters; common sizes include 60 mm, 80 mm, 92 mm and 120 mm. Fans with a round frame are also available; these are usually designed so that one may use a larger fan than the mounting holes would otherwise allow (i.e., a 120 mm fan with 90 mm holes). The amount of airflow which fans generate is typically measured in cubic feet per minute (CFM), and the speed of rotation is measured in revolutions per minute (RPM). Often, computer enthusiasts choose fans which have a higher CFM rating, but produce less noise (measured in decibels, or dB), and some fans come with an adjustable RPM rating to produce less noise when the computer does not require additional airflow. Fan speeds may be controlled manually (a simple potentiometer control, for example), thermally, or by the computer hardware or by software. It is also possible to run many 12V fans from the 5 V supply, at the expense of airflow, but with reduced noise levels.

The other consideration when choosing a computer fan is static pressure. A fan with high static pressure is more effective at forcing air through restricted spaces, such as the gaps between a radiator or heatsink. Therefore, enthusiasts often prioritize static pressure over CFM when choosing a fan for use with a heatsink. The relative importance of static pressure depends on the degree to which the airflow is restricted by geometry (i.e. static pressure becomes more important as the spacing between heatsink blades decreases). Static pressure is usually measured in either mm Hg or mm H2O.

The type of bearing used in a fan can affect its performance and noise output. Most computer fans use one of the following bearing types:

- **Sleeve bearing** fans use two surfaces lubricated with oil or grease as a friction contact. Sleeve bearings are less durable as the contact surfaces can become rough and/or the lubricant dry up, eventually leading to failure. Sleeve bearings may be more likely to fail at higher temperatures, and may perform poorly when mounted in any orientation other than vertical. The lifespan of a sleeve bearing fan may be around 40,000 hours at 50 °C. Fans that use sleeve bearings are generally cheaper than fans that use ball bearings, and are quieter at lower speeds early in their life, but can grow considerably noisier as they age.
- **Rifle bearing** fans are similar to sleeve bearing, but are quieter and have almost as much lifespan as ball bearings. The bearing has a spiral groove in it that pumps fluid from a reservoir. This allows them to be safely mounted horizontally (unlike sleeve bearings), since the fluid being pumped lubricates the top of the shaft. The pumping also ensures sufficient lubricant on the shaft, reducing noise, and increasing lifespan.
- **Ball bearing** fans use ball bearings. Though generally more expensive, ball bearing fans do not suffer the same orientation limitations as sleeve bearing fans, are more durable especially at higher temperatures, and quieter than sleeve bearing fans at higher rotation speeds. The lifespan of a ball bearing fan may be around 63,000 hours at 50 °C.
- **Fluid bearing** fans have the advantages of near-silent operation and high life expectancy (comparable to ball bearing fans). However, these fans tend to be the most expensive. The **enter bearing** fan is a variation of the fluid bearing fan, developed by Everflow.
- **Magnetic bearing** or **maglev** fans, in which the fan is repelled from the bearing by magnetism.

Fan Sizing

Fans are available in wide variety of sizes and capacities. In general the faster the fan, the more noise it produces. Within a given physical size capacity is roughly proportional to current draw. For a given flow a larger fan will be quieter than a smaller fan.

Fan connector

The standard connectors for computer fans are

3-pin Molex connector KK Family

This connector is used when connecting a fan to the motherboard or other circuit board. It is a small thick rectangular in-line female connector with two tabs on the outer-most edge of one long side. The size and spacing of the pin sockets is identical to a standard 3-pin female IC connector. The three pins are used for ground, +12 V power, and a tachometer signal. Molex Part number of receptacle is 22-01-3037. Molex Part number of individual crimp contacts is 08-55-0101.

4-pin Molex connector KK Family

This is a special variant of the Molex KK connector with four pins but with the locking/polarisation features of a 3-pin connector. The additional pin is used for a pulse-width modulation signal to provide variable speed control. These can be plugged into 3-pin headers, but will lose their fan speed control. Molex Part number of receptacle is 22-01-3047. Molex Part number of individual crimp contacts is 08-55-0101.

4-pin Molex connector

This connector is used when connecting the fan directly to the power supply. It consists of two wires (red/12V and black/ground) leading to and splicing into a large in-line 4-pin male-to-female Molex connector.

Dell, Inc. proprietary

This connector is an expansion of a simple 3-pin female IC connector by adding two tabs to the middle of the connector on one side and a lock-tab on the other side. The size and spacing of the pin sockets is identical to a standard 3-pin female IC connector and 3-pin Molex connector. Some models have the wiring of the white wire (speed sensor) in the middle, whereas the standard 3-pin Molex requires the white wire as pin #3, thus compatibility issues may exist.

Alternatives

If a fan is not desirable, because of noise, reliability, or environmental concerns, there are some alternatives:

- Very Rarely, such as ultra silent home theatre machines, can rely on passive cooling alone and do not require a case fan to keep computer components at ordinary operating temperatures. More commonly (such as in simple business and home machines) a power supply fan alone is sufficient to cool the machine.
- Undervolting and/or underclocking to reduce power dissipation
- Larger heatsinks (for example, some motherboards have northbridge fans; others have larger, more costly heatsinks)
- Natural convection cooling: carefully designed, correctly oriented, and sufficiently large CPU coolers can dissipate up to 100 W by natural convection alone
- More unusual solutions, *e.g.* heatpipes bonded to the metal case, water cooling, or refrigeration
- Motherboards sunk in liquid oil provides excellent convection cooling and protects from humidity and water without the need for heatsinks or fans. Special care must be taken to ensure compatibility with adhesives and sealants used on

the motherboard and ICs. This solution is used in some external environments like wireless equipments located in the wild.