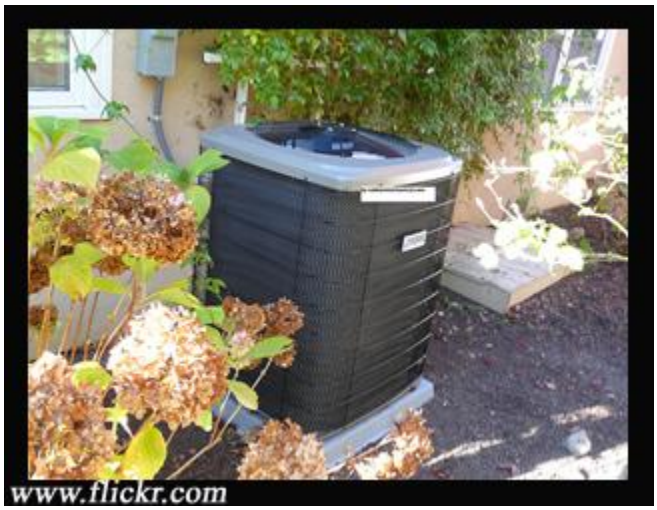
The Science of Refrigeration – Part 2

What is HVAC?

HVAC is an acronym that stands for "heating, ventilating, and air conditioning". HVAC is sometimes referred to as climate control and is particularly important in the design of medium to large industrial and office buildings such as skyscrapers and in marine environments such as aquariums, where humidity and temperature must all be closely regulated whilst maintaining safe and healthy conditions within. Refrigeration is sometimes added to the field's abbreviation as HVAC&R or HVACR, or ventilating is dropped as HACR (such as the designation of HACR-rated circuit breakers).



Heating, ventilating, and air conditioning is based on the basic principles of thermodynamics, fluid mechanics, and heat transfer, and two inventions and discoveries made by Michael Faraday, Willis Carrier, Reuben Trane, James Joule, William Rankine, Sadi Carnot, and many others. The invention of the components of HVAC systems goes hand-in-hand with the industrial revolution, and new methods of modernization, higher efficiency, and system control are constantly introduced by companies and inventors all over the world.

The three functions of heating, ventilating, and air-conditioning are closely interrelated. All seek to provide thermal comfort, acceptable indoor air quality, and reasonable installation, operation,

and maintenance costs. HVAC systems can provide ventilation, reduce air infiltration, and maintain pressure relationships between spaces. How air is delivered to, and removed from spaces is known as room air distribution.

In modern buildings the design, installation, and control systems of these functions are integrated into one or more HVAC systems. For very small buildings, contractors normally "size" and select HVAC systems and equipment. For larger buildings where required by law, "building services" designers and engineers, such as mechanical, architectural, or building services engineers analyze, design, and specify the HVAC systems, and specialty mechanical contractors build and commission them. In all buildings, building permits and code-compliance inspections of the installations are the norm.

Heating

Heating systems may be classified as *central* or *local*.

Central heating

Central heating is often used in cold climates to heat private houses and public buildings. Such a system contains a boiler, furnace, or heat pump to heat water, steam, or air, all in a central location such as a furnace room in a home or a mechanical room in a large building. The system also contains either ductwork, for forced air systems, or piping to distribute a heated fluid and radiators to transfer this heat to the

air. The term radiator in this context is misleading since most heat transfer from the heat exchanger is by convection, not radiation. The radiators may be mounted on walls or buried in the floor to give under-floor heat.

In boiler fed or radiant heating systems, all but the simplest systems have a pump to circulate the water and ensure an equal supply of heat to all the radiators. The heated water can also be fed through another (secondary) heat exchanger inside a storage cylinder to provide hot running water.

Forced air systems send heated air through ductwork. During warm weather the same ductwork can be used for air conditioning. The forced air can also be filtered or put through air cleaners.

Heating can also be provided from electric, or resistance heating using a filament that becomes hot when electricity is caused to pass through it. This type of heat can be found in electric baseboard heaters, portable electric heaters, and as backup or supplemental heating for heat pump (or reverse heating) system.

The heating elements (radiators or vents) should be located in the coldest part of the room, typically next to the windows to minimize condensation and offset the convective air current formed in the room due to the air next to the window becoming negatively buoyant due to the cold glass. Devices that direct vents away from windows to prevent "wasted" heat defeat this design intent. Cold air drafts can contribute significantly to subjectively feeling colder than the

average room temperature. Therefore, it is important to control the air leaks from outside in addition to proper design of the heating system.

Ventilation

Ventilation is the changing of air in any space in order to remove moisture, odors, smoke, heat, and airborne bacteria. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. Methods for ventilating a building may be divided into *natural* and *forced* types.

Displacement ventilation

Airflow in ventilated spaces generally can be classified by two different types; mixing (or dilution) ventilation and displacement ventilation. Mixing ventilation systems generally supply air in a manner such that the entire room air is fully mixed. The cool supply air exits the outlet at high velocity, inducing room air to provide mixing and temperature equalization. Since the entire room is fully mixed, temperature variations are small while the contaminant concentration is uniform throughout the entire room.

Displacement-ventilation systems introduce air at low velocities which causes minimal induction and mixing. The displacement outlets are usually located at or near the floor. The system utilizes buoyancy forces (generated by heat sources such as people, lighting, computers, electrical equipment, etc.) in a

room to move contaminants and heat from the occupied zone. By so doing, the air quality in the occupied zone is generally superior to that achieved with mixing ventilation.

Displacement ventilation presents an opportunity to improve both the thermal comfort and indoor air quality (IAQ) of the occupied space. Displacement ventilation 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 outlets extract the air. In most cases these convection heat sources are also the contamination sources, i.e. people or equipment, thereby carrying the contaminants up to the upper zone, away from the occupants.

Outlets are typically located at or near the floor level, and air is supplied directly into the occupied zone. This supply air is spread over the entire floor and then rises as it is heated by the heat sources in the occupied zone. Returns are typically located at or close to the ceiling and exhaust the warm contaminated room air.

Since the conditioned air is supplied directly into the occupied space, supply air temperatures must be higher than mixing systems (usually above 63 deg F) to avoid cool temperatures at the floor. By introducing the air at elevated supply air temperatures and low outlet velocity a high level of thermal comfort can be provided with displacement ventilation.

Natural ventilation

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 operable windows 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 (chimney effect) thus forcing fresh cool air to be drawn into the building naturally though openings in the lower areas. These systems use very little energy but care must be taken to ensure the occupants' comfort.

$$Q_S = \frac{60 C_d A \sqrt{2 g H_d (T_I - T_O)}}{T_I}$$

Q_S = Stack vent airflow rate, cfm

A = cross sectional area of opening. sqft (assumes equal area for inlet and outlet)

C_d = Discharge coefficient for opening

g = 32.2 ft/sec2, gravitational constant

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

NPL is the Location/s in the building envelope where there is no pressure difference between inside and outside (ASHRAE 2001, p.26.11)

T_I = Average indoor temperature between the inlet and outlet, °R (°R = °F + 460)

T_O = Outdoor temperature, °R

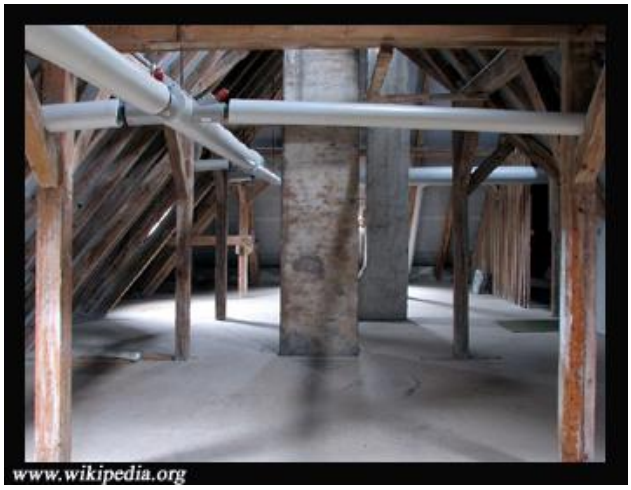
Forced ventilation

Forced ventilation may be used to control humidity or odors. Kitchens and bathrooms typically have mechanical ventilation to control both. 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 the

ducting for the fans traverse unheated space (e.g. an attic), the ducting should be insulated as well to prevent condensation on the ducting. Heat recovery ventilation systems employ heat exchangers to bring the fresh air temperature to room temperature.

Ceiling fans and table/floor fans are very effective in circulating the air in the room. Paradoxically, because heat rises ceiling fans may be used to keep a room warmer.

Ventilation issues in houses/ Proper ventilation in the attic:



- Keeps the house cool in the summer. (Attics radiate heat downward in the summer when they are hotter than the living area.)
- Keeps the attic cold in the winter, which can prevent ice dams.
- Allows moisture to escape from the house. Some warm, moist air finds its way into the attic, so ventilation is essential. This is important year-round, for preventing mold and rot, but it is especially in the winter, when the moisture is more likely to condense.
- Be aware that increased ventilation decreases the effectiveness of any insulation that is a poor barrier to air infiltration, such as fiberglass batts. The increased ventilation will create low pressure areas, so that the house will push conditioned air through the insulation faster than it normally would.

With insufficient ventilation

- Attic heat can penetrate into living areas during summer.
- There will be excessive humidity, which can cause mold and, eventually, rot.
- Water vapor can condense and collect on insulation, on rafters, and on the underside of roof sheathing. This will reduce the effectiveness of the insulation, and can greatly hasten the activity of mold and rot.
- Condensation and mold will also occur in the living area, especially on perimeter walls (because they are coolest) and where ventilation is poorest, such as in corners and around furniture.

You will need more ventilation than usual if:

- You live in a damp climate.
- Your house is in the shade.
- The crawlspace or basement has a dirt floor.
- There isn't much wind.
- You have a modern, super tight house.
- You have a solid masonry house.
- You have a house with impermeable siding such as vinyl or aluminum.
- You do not have sufficient (or any) vapor barriers.

Most houses treat the attic and basement as unconditioned space. You can think of unconditioned space as outdoor space, minus the rain and snow. The unconditioned space

surrounding the living area shouldn't be wide open, but it shouldn't be sealed shut either. A good compromise is to have two foundation vents in the basement and two different types of vents in the attic. Vents should always exist in pairs (but not necessarily two of the same type) to allow for cross-ventilation. In an attic, one member of the pair should be low on the roof, and the other member should be higher up, so that outside air is pulled through one and out the other. Natural attic ventilation through these vents is usually sufficient. Powered vents in the attic may interfere with proper furnace and fireplace venting.

Some ways to ventilate an attic naturally:

- Soffit vents.
- Ridge vent (you can cover the ridge vent with shingles).
- Gable vents.

Modern homes often incorporate all three types of attic vents, providing continuous cross-ventilation via multiple air pathways. Make sure gable vents have screens to keep out insects and animals, and keep the screens clean to maintain proper ventilation. Never close or block off the vents to a damp basement or crawlspace, except in extreme cold to prevent pipes from freezing. Closing the vents to a damp basement or crawlspace will cause mold, rot, and structural defects. Sometimes, a basement or crawlspace will look bone dry, but is transpiring moisture through the

dirt floor at a rapid rate. To see if this is the case, lay down some clear plastic on the dirt floor for a few days and observe how much water collects on its underside.

If your basement or crawlspace is dry and has been dry for several years, you can:

- Close the foundation vents in the winter to conserve energy, and open them again in the warmer months, to allow interior moisture from the house to escape.
- Close the foundation vents permanently, install a polyethylene vapor barrier on the floor (just to be safe), insulate the basement or crawlspace walls, and part of the floor, if necessary, and include the basement or crawlspace as part of the conditioned space of the house. If you take this route, you don't need to insulate the floor above the basement or crawlspace, but it doesn't hurt if the floor is already insulated. Keep an eye on humidity. There will be less condensation on walls and pipes, but possibly greater humidity because of trapped air, requiring increased ventilation in the upper floors and attic to compensate.

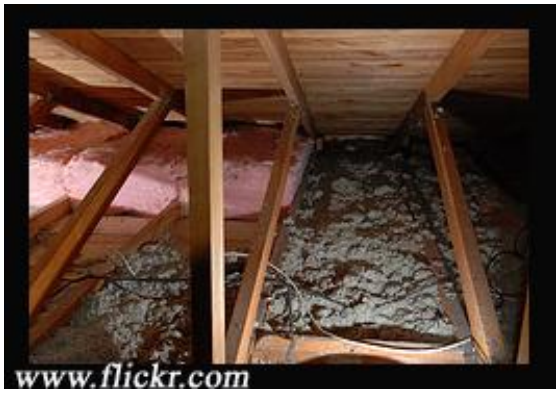
Advantages of insulating a dry basement and crawlspace and making them part of the conditioned space of the house:

- Decreased condensation, because walls are closer in temperature to the air inside the house, and because cold pipes are not exposed to outdoor air during the warmer months.
- Reduced energy losses from ducts passing through the basement.
- Reduced risk of pipes freezing in winter.

Ventilation checklist:

- Vent sources of moisture directly to the outside. This is especially important for the bathroom, which normally produces more moisture than any other room in the house, and for the dryer, which produces more moisture than any other appliance.
- Do not vent moisture directly into the attic. The last thing you want to do is put warm, moist air into the attic. A whole-house fan is acceptable because of its usual location, installed in the attic floor near a gable vent, and because it is not directly connected to a source of moisture. The whole-house fan can help to remove cooking odors and can cool the entire house when it is not hot enough to turn on the air conditioning.
- If you cannot vent the bathroom directly to the outside, install the vent up through the attic and down through a soffit vent. This will prevent water from dripping back down into the vent as it would if you installed the duct straight up through the roof. Wire the bathroom vent to a timer switch, so that people can turn it on without having to remember to turn it off.
- Always vent the clothes dryer to the outside with a smooth-walled, metal (not plastic) duct that is as short as possible. To prevent a house fire, check the duct for clogs regularly. Do not vent the dryer directly into the laundry room. This puts much too much moisture into the house.
- Kitchens should have a vent hood with an exhaust fan. The vent hood should have a back draft flap to keep out insects and cold air - but some cold air will inevitably seep in.

- Install ceiling fans to improve ventilation and distribute heat. To disperse heat properly, run the ceiling fan in reverse, so that it pushes warm air up against the ceiling and down along the walls, where people tend to sit.
- Do not block air intake vents for heating or air conditioning equipment. Blocking these vents will starve the equipment for air, causing it to run inefficiently.
- If your unfinished basement has windows, keep them closed on hot, humid days to prevent moisture from condensing on the walls continuously, all day long. Open the windows once the humidity drops below the natural humidity of the basement, so that moisture doesn't build up inside.
- People, in their zeal to do a good job, sometimes pack insulation into the eaves, blocking the soffit vents, because they don't know that the vents exist or don't know what they are for. If you are installing insulation in the attic for the first time, do not cover the soffit vents with insulation.
- If your attic is already insulated on the floor, make sure insulation is not blocking the soffit vents. This is more of a problem for loose-fill, since wind can scatter the fill around. To prevent loose-fill from scattering and covering the soffit vents, you can install baffles between the rafters. You staple the baffles to the underside of the roof sheathing, and the baffles maintain 2 inches of ventilation space next to the sheathing.



- Wind coming through soffit vents can also push batt insulation up off the floor, causing cold airflow against the ceiling and cold spots high up on exterior walls. Baffles installed

near the eave should also prevent this problem, by keeping the batts from flipping up and over.

- If you are going to install batts or spray foam between the rafters, you should extend the baffles all the way up to the ridge vent. This will keep the sheathing dry and prevent it from rotting invisibly behind the insulation.
- Likewise, when you insulate between the floor joists in the ceiling of an unconditioned basement or crawlspace, you should leave some space between the insulation and the sheathing (sub floor) to allow water vapor to escape.

Air-conditioning:

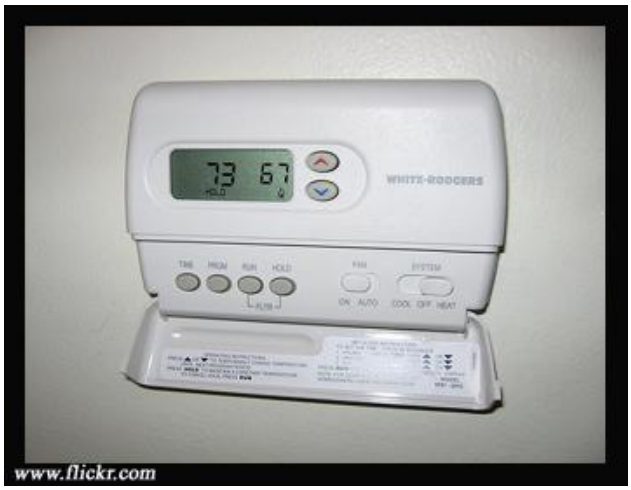
The term air conditioning refers to the cooling and dehumidification of indoor air for thermal comfort. In a broader sense, the term can refer to any form of cooling, heating, ventilation or disinfection that modifies the condition of air. An air conditioner is an appliance, system, or mechanism designed to stabilize the air temperature and humidity within an area (used for cooling as well as heating depending on the air properties at a given time), typically using a refrigeration cycle but sometimes using evaporation, most commonly for comfort cooling in buildings and motor vehicles.

Dehumidifier:

A dehumidifier is a household appliance that reduces the level of humidity in air, usually for health reasons, as humid air can cause mold and mildew to grow inside homes, which has various health risks. Very high humidity levels can be unpleasant, causing unsightly condensation and can make it hard to dry laundry or sleep.

Thermostats:

A thermostat is a device for regulating the temperature of a system so that the system's temperature is maintained near a desired set point temperature. The thermostat does this by controlling the flow of heat energy into or out of the system. That is, the thermostat switches heating or cooling devices on or off as needed to maintain the correct temperature.



Thermostats can be constructed in many ways and may use a variety of sensors to measure the temperature. The output of the sensor then controls the heating or cooling apparatus.