

## How air conditioning works

The essential ingredients in an air conditioning system are a fan to blow air around, a cold surface to cool and dehumidify the air, a warm surface and a source of water vapour. In a large system there will also be a tangle of tubes to distribute the air and collect it again.

Notice that the cold surface has two independent jobs to do: it is used to cool the air and it is also used to dehumidify, by condensing water from the air. This means that the air is cooled more than is necessary for temperature control, so that it must be heated again afterwards.

Air conditioning wastes energy. It also wastes space, because air has to be pumped around in quite large tubes, so that it doesn't make a rushing noise. It does, nevertheless, generate a disturbing background noise if the room is otherwise quiet. There is worse news to come: air conditioning is spreading to more and more buildings in climates that we once thought were so mild that they would be immune.

The origin of this technological epidemic is not the subject of this article. I will however mention some reasons which are relevant to museum conservators. Modern museums, and old ones as well, are showpieces designed to be admired for bold and original architecture. They tend to be massive, and those old museums which originally had courtyards to give light and air are now glassed over with domes and atria. The heat and moisture cannot easily escape to the outside: they have now to be pumped out.



The subtle elegance of buildings designed for their purpose counts for little nowadays. Grand Gestures are fashionable, and air conditioning hides the architects' and engineers' lack of understanding or respect for natural ventilation. One must say that conservators have reinforced this trend, because they have set specifications for allowable variation of temperature and relative humidity that can only be achieved by mechanical air conditioning.

The purpose of this article is to explain how air conditioning works, in order to show why one cannot just pluck values from some standard or recommendation without risking unexpected penalties in energy use, maintenance cost and noise. Furthermore, once the mess of steel boxes and ducts is installed, you cannot dial the temperature and humidity exactly as you want them without risking surprisingly expensive side effects of energy consumption, climatic instability and hidden condensation.

I will describe two typical systems. The first is air conditioning for a single room, the second is a full system for a large building. Most of the available literature, particularly on the internet, takes it for granted that air conditioning is a good thing and then proceeds to tell you how to design it. This article is designed to help you understand other people's designs, and judge their suitability for your purpose.

### Simple air conditioning

A fan draws air from the room first through a cooling device, consisting of metal fins extending from a pipe through which cooling fluid circulates, at a rate determined by the thermostat or by the humidistat. The air next passes over a heater, usually electrical, which is energised on instructions from the room thermostat.

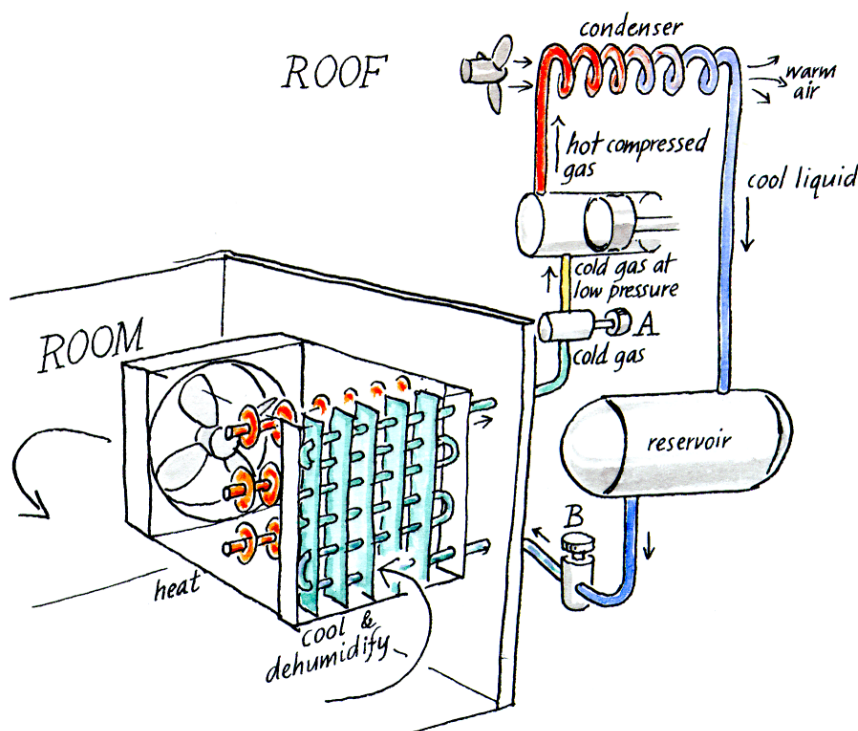


Figure 2. Minimal air conditioning. The part of the system in the room, on the left, pulls air first over a cool surface and then over a warming surface. The part of the system on the right recirculates the cooling fluid. The fluid passes from the reservoir through a valve **B** into the lower pressure within the cooling unit in the room. There the liquid boils, removing heat from the air. The boiling point is fixed by the constant pressure set by valve **A**. The vapour is then compressed and condensed back into a liquid which collects in the reservoir ready for another cycle.

Air conditioning has in the past been used where the climate is too hot for comfort. Cooling will increase the relative humidity of the air, so humidification is not usually built into these systems. If it is necessary, the usual method is to inject steam from electrically boiled water.

That is all there is to the part of the system in the room, which is sketched on the left in figure 2. The bit that is more difficult to understand, or at least unfamiliar to most people, is how the cooling fluid is produced and controlled. That is the part on the right of the diagram.

The cooling fluid used to be a chlorofluorocarbon compound, and often still is, though they all more or less ravage the earth's ozone layer. The essential characteristics of these fluids is that they have quite a low boiling point at atmospheric pressure and that they can stay in the pipes for a long time without decomposing either themselves or the pipes. Finally they need to have some lubricating ability, or the ability to carry a lubricant, because the fluid has to be compressed and pumped round the system. This rare set of necessary properties has proved difficult to combine with friendliness to the earth's atmosphere.

The liquid is let into the cooling unit through a valve marked **B** on the diagram. It evaporates while it passes through the pipe, taking heat from the air just as water evaporating from a towel laid on your fevered brow cools you when on holiday in the Mediterranean. The temperature in the cooling coil depends partly on the amount of fluid let in by the valve, which is controlled by the thermostat or the humidistat. But now comes a crucial difference from your Mediterranean experience: the minimum temperature at the cold surface can be fixed by controlling the pressure in the cooling coil, with the valve marked **A** on the diagram. The boiling point of any liquid depends on the pressure. One could use water in the cooling coil, if the pressure is kept low enough. At 1000 Pa pressure, which seems a lot but is just 1% of atmospheric pressure, water boils at 7 degrees. It isn't used in cooling coils of this evaporative type because it has practical disadvantages.

The reason for wanting to limit the minimum temperature is to stop ice clogging the air passage. There are clever systems which notice when ice has formed and hold a melting pause, but that adds to the cost. The pressure controller is therefore set to make the cooling fluid boil at the lowest temperature that is likely to be needed to control the humidity, but always over zero degrees. The temperature needed for cooling is nearly always higher than that needed for dehumidification so it is the RH setting that is decisive.

This brings me to the first point that conservators need to understand: **it is expensive to produce air at a dew point below about 4 degrees in this type of equipment.** This dewpoint corresponds to 50% RH at 15°C. This sort of air conditioning is entirely suitable for keeping people comfortable but it is not good for specialised stores, for films or for furs, for example, where one needs a temperature below 15 degrees. Such equipment is, however, often used for such places. A better solution is to use an absorption dehumidifier, which will be described in a later article.

Now back to the main story: The vapour that emerges through the pressure controller is gathered up by a compressor. The compression also heats the gas, as will be understood by anyone who has pumped up a cycle tyre. The hot gas is then led away from the room, to be cooled down. This is often done on the roof or in a small enclosure which vibrates to the roar of the fan blowing air over the fins of a condenser. The cooled, now liquid coolant is piped back to the reservoir, ready for its next tour through the room air conditioner.

The entire process described above is inefficient and uses electricity, which is itself produced by inefficient conversion of heat energy. Such systems are therefore confined to small places where the inefficiency is compensated by the generally high reliability and freedom from maintenance.

### Large air conditioning systems

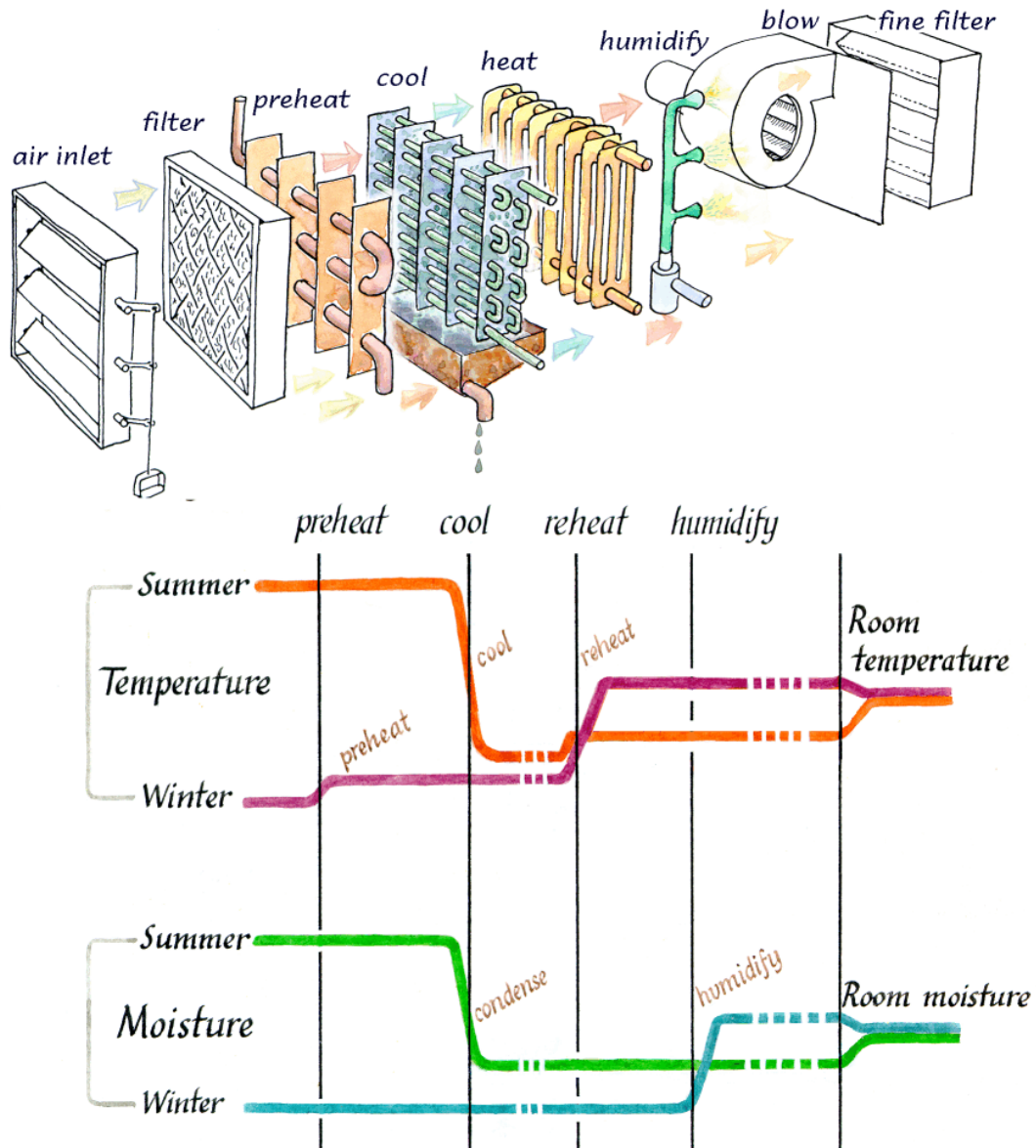


Figure 3. A large air conditioning system functions much like that described in figure 2, except that chilled water is used to cool the air. Outside air is drawn in, filtered and heated before it passes through the main air conditioning devices. The coloured lines in the lower part of the diagram show the changes of temperature and of water vapour concentration (not RH) as the air flows through the system.

The principle of operation is the same as that of the small system described above except that the cooling fluid is usually water, which has itself been cooled by the refrigeration system described above. The air is circulated through ducts, with a portion of fresh air added. There is

therefore a pre-heater, because the outside air may be below zero and will therefore freeze the water in the cooling coil. A humidifier and various filters have also been added in figure 3.

### **Putting together the entire system**

There are many variations on the basic design sketched in this article. Most refinements are to save energy. The ratio of recycled air to fresh air can be increased when the outside air has, by chance, the right water content and temperature to push the room climate in the right direction. This is called enthalpy control, to make common sense seem scientific. The heat generated in the coolant condenser can be re-used in the heater, fed by recirculating hot water.

The amount of air circulating in the system is vastly more than that required for the inhabitants to breathe, to avoid carbon dioxide narcosis and to avoid smelling each other. Air is mainly used to carry heat and moisture to all corners of the building. Since the heat capacity of air is rather small, quite large amounts are needed to ensure the uniformity of temperature that is required by the specification. Here is another example of the danger of specifying without adequate understanding. If the building is old and uninsulated the heat loss through the outer walls will force a large air circulation, which will in turn require large ducts or make a lot of noise. A leaky building requires considerable moisture added in winter. The RH of the air leaving the humidifier will then be rather high, with a risk that pathological microorganisms will thrive in remote corners of the ducts. Fitting air conditioning into existing buildings is not easy.

Some refinements to the basic system compensate for the different heat requirements of different rooms in the building. Figure 4 (next page) shows a complete system, with two details that have not been mentioned yet: the outer zone, which loses more heat in winter, has radiators to supplement the heat supply through the air conditioning. The inner zone has, in this example, an archive room that is not much used and so is cooler, and drier, than the rooms with people, computers and coffee machines. To keep the climate uniform throughout the building there is a little local heater and humidifier placed just before the air reaches the room. The main air supply is kept a little too cold and a little too dry. Any one of these many local humidifiers can give trouble, with rapid over-humidification of the room. Again, here is a dangerous detail that is provided by the engineer to protect himself against complaints that the equipment does not achieve the standard required.

I hope that I have persuaded the reader who ever finds herself having to provide specifications for the climate in a building, that there is more to making a sensible specification than stealing numbers from the standards, most of which assume that the institution has piles of dollars and its employees are too dumb to work out intelligent compromises that fit the needs of that particular building and the materials and activities that it shelters.

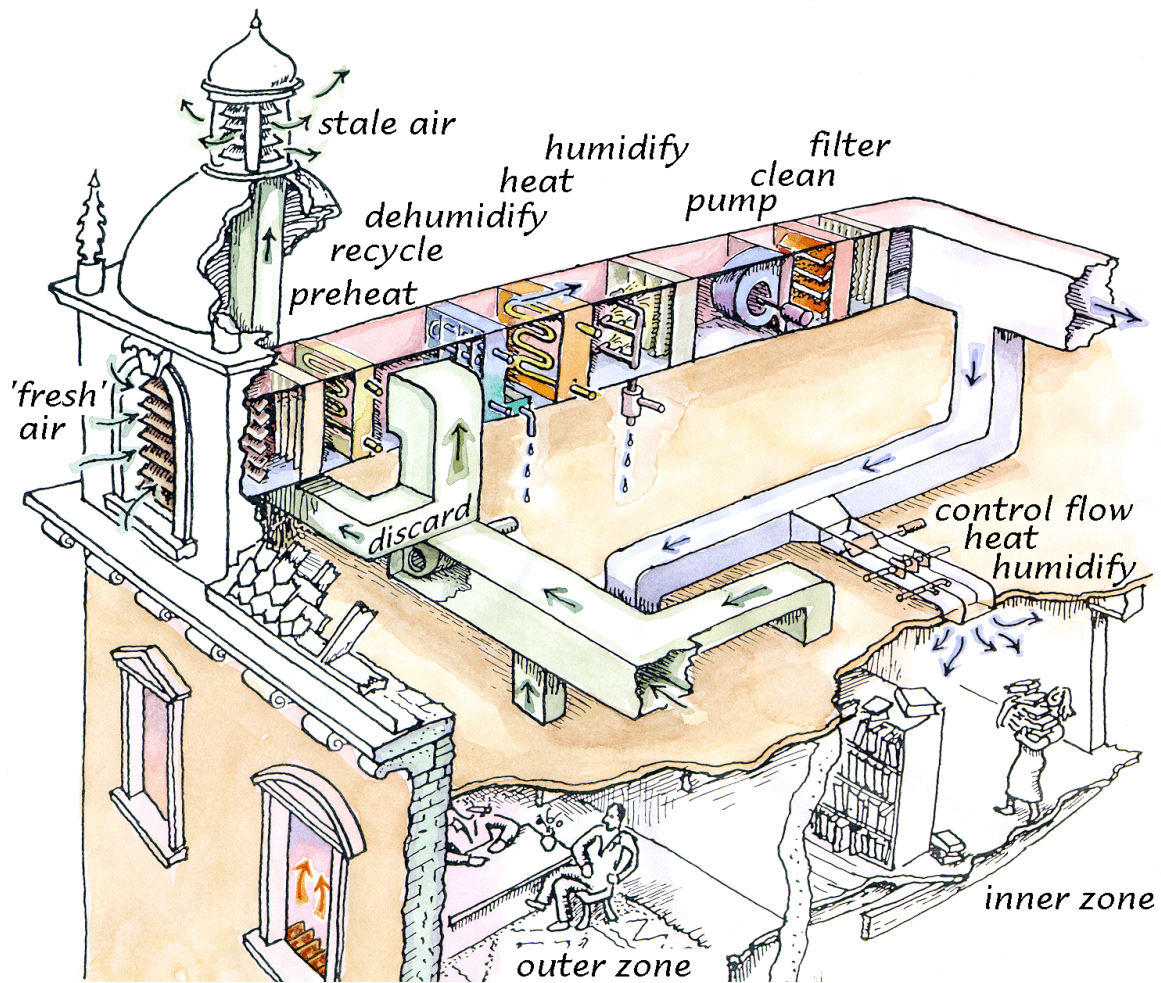


Figure 4. An air conditioning system with variable fresh air mixer and dust and pollutant filtration. Notice supplementary heating with radiators in the outer rooms and individual mini heater and humidifier in the air stream to each room.