A Breath of Fresh Air or a Howling Gale: How much is too much?

or

Wind in the Windows: Air leakage into a small victorian terrace house.

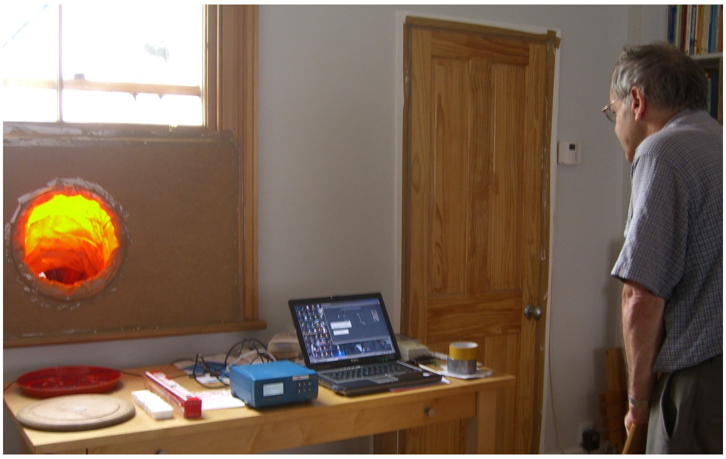
Improved insulation is the key to reducing energy use for space heating in homes. It is also pretty clear that a draughty home is a cold home and so requires a lot of energy to heat it. On the other hand people have a feeling that you shouldn't live in a stuffy home with no movement of air from outside. So what level of ventilation is best?

The Victorian Terraced Cottage Example

Build tight, ventilate right is fine as a maxim for new build but doesn't help when you are trying to improve an old house. To continue to reduce our household carbon footprint by around 10-20% per year makes it necessary to understand which improvements can yield the greatest reductions. By mid-2009 we were planning to add further wall insulation and to reduce heat loss through draught reduction but had no idea which was most significant.

Estimating heat loss by conduction through walls, windows and roof is relatively straightforward since we can quote U values. The ground flooring is more of an unknown since we didn't know much about its construction (except that it has original suspended wood floorboards over which oak flooring had been laid).

Apparently the heat loss through draughts (infiltration is the technical word) can often be equal to conduction loss in many older leaky houses so it made sense to try to find out how badly our terraced cottage leaked.



We hired a 30 cm diameter fan, improvised a hardboard seal between it and a window opening (gaps covered with duct tape), borrowed a precision barometer able to sense pressure changes of one in one hundred thousandth of normal air pressure. With all external doors and windows closed and all interior doors open we found that our fan, delivering an estimated flow of 0.66m^3/s, produced a pressure difference between inside and outside of around 12 Pa. The *envelope* of the house has a surface area A of about 275m^2 so these numbers give a figure of merit (Q_{50} value, see appendix) of 36m^3/hr/m^2 at 50Pa. This figure is considerably higher than you would expect for a house built to existing relatively relaxed standards, for which Q_{50} values of around 10 are expected. Eco houses should achieve anything in the range from 3 to less than 1, the latter figure being that for the German Passivhaus standard.

Can we estimate how much heat loss there will be as a result of this leakage? There are complex mathematical models which aim to answer this question quantitatively, provided the strength and direction of the wind, the outside temperature and the nature of the wall and roof coverings are all known. This is too difficult for our purposes but it seems there is a reasonably accurate relationship for the *average* rate of infiltration under variable weather conditions,

$$Q_{av} \sim Q_{50}/k$$

where k is around 20.

Another much used figure of merit is n_{50}, the number of air changes per hour for a pressure difference of 50 Pa between inside and outside.

For a temperature difference ΔT the total loss of heat from the house over a time interval t becomes

$$P = Q_{av} A C_v \Delta T t$$

Here C_v is the heat capacity of air at average atmospheric pressure and temperature (~10^5Pa and 15°C). To get an overall heat loss figure for a year we need to average the temperature difference ΔT between inside and outside throughout that part of the year when the central heating is on. Although we maintain the living room at 19°C in the day and the central heating is only on for part of the day, typically around 6 hours (and always off at night) the average temperature inside is closer to 16°C. The average outside air temperature is ~ 8°C over the 160 days (approximately) that the heating is on each year. Putting all of these figures into this equation for P results in an annual heat loss through infiltration of 1.7MWh/year, representing about 40% of the estimated space heating energy requirement of 4.4MWh/year.

Appendices:

How do draughts cost energy?

If the air outside is colder than that inside and there is a flow of air between inside and outside this will require extra space heating energy to maintain the temperature difference in the face of the flow. If the rate of flow of air can be measured and the temperature difference is known it is easy to calculate this extra energy. But how to measure the flow?

There are at least three sources of air flow:

1. Diffusion of air through gaps in the building fabric
2. Air flow through these gaps driven by a pressure difference or direct external movement of air (wind) between inside and outside.
3. Convection, driven by internal and external temperature differences. This particularly relates to the *chimney (or stack) effect.*

The figure of merit for air leakage which is generally used by the building industry is Q_{50}, the flow of air in m^3/s per unit area (m^2) of the dwelling envelope for a 50 Pa pressure difference between outside and inside. This is generally measured by sealing a large fan with known flow rate through a door or window space. Then, with all the external doors and windows closed but all internal doors open, a highly sensitive barometer or a precision differential pressure gauge measures the pressure difference between inside and outside when the fan is switched on. Ideally the fan should have a variable speed, providing a range of flow rates resulting in a range of pressure differences. If the fan produces an air flow rate of I m^3/s and this is sufficient to produce a pressure difference ΔP then

$$Q_{\Delta P} = I\frac{\Delta P}{A}$$

This figure of merit should certainly be a good way to compare leakiness of different houses but how well does it relate to heat loss through infiltration? We have no independent way of checking this as yet, so we have to rely on the relationship Q_{av} given above.

Time Variation of Pressure

When measuring the leakiness of the house we had to assume that the air flow rate of the fan was as quoted by the manufacturer. This may be a big assumption and it would be nice to check it by another method. The rate at which the pressure varies when the fan is turned on should in principle provide such a method.

Suppose that the fan sucks at a constant flow rate I m^3/s where the mass flow is proportional to P_0I where P_0 is the outside pressure, assumed constant. The inside pressure $P(t)$ is a function of time which depends on the outflow of air and the inflow through the leak L where it is assumed that the latter is proportional to the pressure difference ΔP between inside and outer pressure $\Delta P(t)=P(t)-P_0$. Then the following differential equation applies:

$$P_0 I = V\frac{dP(t)}{dt} + L(P(t) - P_0)$$

where L is the leakage rate into the room. Note that L, I have dimensions m^3/s whereas V has dimensions m^3.

At $t = 0$ we switch on the fan so that $P(t) = P_0$ for $t < 0$. This gives the boundary condition that $dP/dt|_{t=0} = P_0I/V$

When the fan has been on for a long time T the pressure stabilises at

$$P(T) = P_0 - \Delta P(T) = constant$$

At this point $dP(t)/dt = 0$ or $\Delta P(T) = P_0I/L$.

Switching off the fan at time $t = T$ sets $I = 0$ and leads to a return of the pressure towards P_0 with an initial rate of change given by $dP/dt|_{t=T} = L\Delta P(T) = - P_0I/V$. So the initial slopes on turning on and off the fan should have the same magnitude and opposite sign. If the rate of change is measured and V is calculated then I can be calculated too.

This seems like a neat trick to avoid having to believe the manufacturer's quoted figure for the fan flow rate. However it makes the assumption that pressure measurements can be made rapidly on a time scale set by the rate of change of pressure in the room. In our case this turned out not to be so. Pressure equilibrium was achieved in only around 1 second, comparable with the time constant of the precision barometer so no independent check was possible.

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The Green Building Bible (vol. 2)