CONDENSATION in HISTORIC ROOFS

IAIN McCAIG and BRIAN RIDOUT

Georgian Bath: increasing levels of insulation could lead to a rash of roof vents across the historic roofscape, but would they reduce condensations? (Photo: Jonathan Taylor)

A **HOUSEHOLDER IN** the West Midlands was anxious to upgrade the thermal performance of the pitched roof on his terraced house. The glass fibre insulation between the ceiling joists had sunk to about 50mm thickness so a further 200mm-thick layer was added. When the weather became colder and the house was heated he noticed condensation streaming down the underside of the bituminous felt underlay. Also, items that had been stored in the loft safely for years became mouldy. Somehow, he had destabilised the roof environment.

Another correspondent who added an extra 200mm of insulation at ceiling level reported a similar result. In this case a dehumidifier had to be used to dry out the insulation. Although this appears to be an increasingly common problem, the reasons for it remain unclear.

The purpose of the added insulation in a roof is to further reduce heat loss through the ceiling from the rooms below. If this is successful then the roof environment must become colder, but why should this increase condensation? If a dry house with a dry roof is left empty and unheated for a few weeks in winter the roof does not begin to run with moisture. There are several possibilities, and the starting point for discussion must be a consideration of how a normal roof environment works.

THE DRY ROOF

If the air moisture (measured as g/m^3 or as vapour pressure) outside the building and within the roof space are monitored, the outlines of the graph curves obtained will be very similar (compare the green and blue traces in Figure 1). The environment in the roof space responds to external moisture fluctuations, although muted to some extent by the properties of the construction materials.

The data shown in Figure 1 (overleaf), recorded at a semi-detached house in the south of England, also shows that the next most important factor influencing the roof environment is solar gain (compare the red and blue traces). Ventilation, despite popular belief, does not have a significant effect because the air entering the roof has a similar moisture content to the air already there.

Condensation may form on impermeable surfaces such as roofing felt (even those described as vapour permeable) when the temperature of those surfaces dips below dew point (the point of air saturation where condensation occurs). But this is generally a transient event, and moisture deposited during a cold night is re-absorbed by the air when the temperature rises again in the daytime.

If the air moisture content within a roof space is basically tracking external fluctuations and condensation occurs only briefly, then moisture to destabilise the roof environment must come from the rooms below.

MOISTURE FROM OCCUPANCY

It is generally accepted that moisture from occupancy rises into the roof. The Building Research Establishment has calculated that about 20 per cent of the moisture entering a loft comes from within the building. Most of this is thought to come from air leakage through cracks, gaps around service pipes, or loft hatches. Some may be the result of vapour diffusion through the ceiling, but moisture will tend to be retained within the pore structure of the plaster. This has been demonstrated in monitoring carried out by Historic England which has not yet been able to demonstrate that normal usage of a bathroom will raise the moisture content of the air immediately above the ceiling.

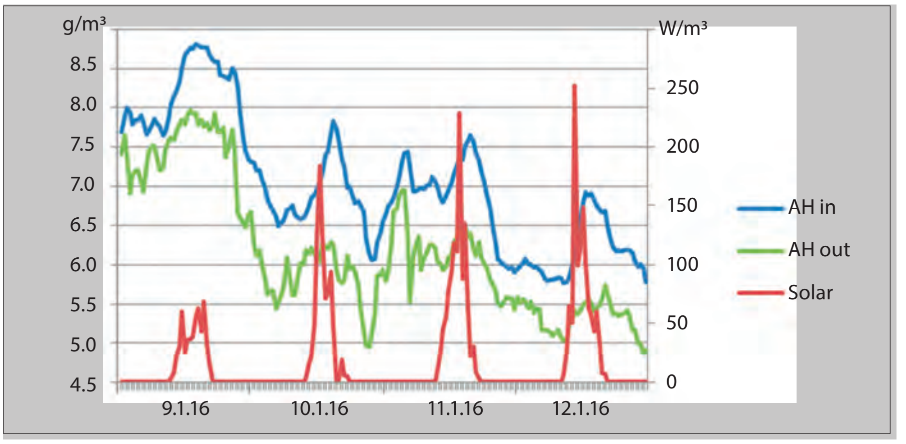

Figure 1. *Absolute humidity levels inside the roof space (blue) generally follow the rise and fall of those outside (green), with divergences coinciding with peaks in solar gain (red).*

Figure 2 shows data from a bathroom, bedroom and air beneath the insulation at ceiling joist level. The plot from the bathroom shows numerous spikes of high air moisture content caused by usage. But the curve obtained beneath the insulation remains similar to the curve obtained beneath the insulation above the bedroom. Most of the additional water vapour will have condensed in the bathroom and been dispersed within the building's general air moisture loading.

MOISTURE BUFFERING BY CONSTRUCTION TIMBERS

As air in the loft cools, its relative humidity will increase. However, this does not necessarily alter the roof environment significantly because the timber structure acts as a buffer to humidity change. Wood is hygroscopic and porous, and acquires a moisture content dependent on the relative humidity of the air surrounding it (temperature does not make much difference except to the rate of change). The surface moisture content in the ~~first~~ outer few millimetres of the wood responds dynamically to short-term humidity fluctuations, while the moisture content at greater depth will be more in equilibrium with seasonal fluctuations.

Several Scandinavian studies have demonstrated that timber can modulate a room environment and the same effect will occur in a roof space. Because only the surface few millimetres of the components respond dynamically, it is the surface area of the timbers that is important and historic roofs generally have a far greater surface area of wood than modern light-weight constructions. Ancient oak is even more effective in buffering moisture because the surface often has an increased porosity. The risk that moisture rising from a normally dry building will cause condensation under normal usage should therefore be small, even after insulation has been added.

This certainly suggests that excess condensation might be more likely in modern light-weight roofs, but does not explain why reducing the transmission of heat from the building might suddenly trigger moisture destabilisation.

WHY MIGHT A ROOF ENVIRONMENT BECOME UNSTABLE?

The first suggestion might be that the excessive condensation occurs where usage is not normal and is caused by excess moisture from patterns of occupancy. If excess moisture entered the roof space then dew point would be raised and more easily reached by restricting heat movement from below. However, this idea is not supported by observation. We investigated three out of a row of four houses in the Midlands. One was tenanted by a family at home all day with two children and had clothes drying on the landing. One was occupied by a childless couple at work each day, and the third had a tenant who was only in residence at weekends. The only common factor was that the heating system was in use. The roof space above each occupancy was running with condensation.

Another suggestion is that heat rising from the house, before the extra insulation was added, maintained the surface temperature of the roofing felt above dew point. But it seems highly unlikely that the relatively small amount of heat rising through the house would be enough to overcome the cooling effect of the roof surface on cold winter nights.

A third suggestion is that the extra insulation, even without extra moisture, somehow raised the dew point, but this is not possible. If 100mm of insulation is added between the ceiling joists then the roof temperature drops and the relative humidity rises, but dew point does not change because the absolute moisture content of the air in the loft does not change. Extra insulation might lower the temperature further but this still cannot affect the dew point. All it will do is elevate the relative humidity of the air in the loft still further.

But what effect on the performance of a roof might this volume of air in the loft have if it has a persistently high relative humidity? When relative humidity remains very high, the way in which timber absorbs moisture changes. Figure 3 shows a graph of wood moisture content at different relative humidities.

Over most of its sorption curve (see Figure 3) wood adsorbs water in the vapour phase and its surface moisture content therefore fluctuates with relative humidity. At humidities near dew point the end section of the sorption curve becomes steep because the wood is now absorbing water in the liquid phase. Condensation may commence in the wood capillaries at less than 100 per cent humidity and so the timber becomes self-wetting at high humidities. Water slowly penetrates deep into the wood and it is no longer a surface effect. This, together with any water forming on impervious surfaces and coalescing into rivulets, saturates the timber so that a rise in temperature has only a slow drying effect. In a dry roof, condensation may occur on cold nights but the extra moisture is taken back by the air when the temperature rises again. If excess condensation occurs and the timbers become wet, raising the surface temperature will just pull more water from the timber and the very high humidities will not reduce substantially.

INFESTATION AND DECAY

If relative humidity rises then so does wood surface moisture content, but this does not present a risk to the timber over the normal range of roof humidities in a dry roof when there is moisture adsorption in the vapour phase. If the roof remains humid (above about 80% humidity) for an extended period of time then there might be some mould growth and

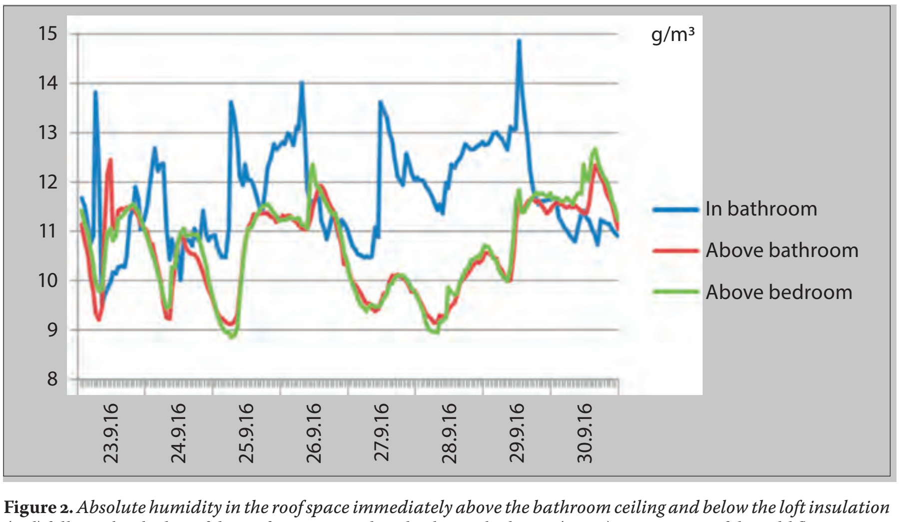

Figure 2. *Absolute humidity in the roof space immediately above the bathroom ceiling and below the loft insulation (red) follows closely that of the roof space immediately above a bedroom (green), irrespective of the wild fluctuations in the bathroom below (blue). This suggests that plasterwork alone provides an effective vapour barrier.*

insect attack might be a possibility, but there are other controlling factors to consider. Neither furniture beetle (woodworm) nor deathwatch beetle can attack the heartwood of oak or pine (normal construction materials) unless its chemistry has been modified by fungus. The beetles would only be able to infest any residual sapwood and, in a historic building, this will probably have been damaged decades or centuries before (the old carpenters used to call this 'wormed-out'). This is the reason why the precautionary treatment of old timbers is generally pointless, except to meet the requirement for a guarantee.

Decay, caused by fungus, will only occur when liquid water starts to form and the relative humidity is too high to measure accurately. If the building and its roof are basically dry then this will only occur adjacent to a fault that is allowing direct water penetration.

VENTILATION AND THE STABLE ENVIRONMENT

Ventilation will achieve nothing useful in a dry roof because the air that enters will have the same moisture content as the air that is already there. Increasing the air flow will not protect the wood. The vents may only change the roof's appearance and provide more hibernation opportunities for a range of insects. This is important because the popular concept of 'breathing buildings' is easily misapplied. Most historic roofs, even those covered with lead, have survived well without anybody making holes in them.

The idea that ventilation somehow prevents decay comes from a 19th-century lack of understanding about its causes. Many people will still look at fungus growing under a floor or in a roof and say the problem was lack of ventilation. This is almost certainly wrong unless the problem is caused entirely by condensation. The cause of the problem would be a large and prolonged source of water, and ventilation would have no effect unless the air introduced was dry enough and moving fast enough to absorb and remove this water. This also assumes that the moisture supply is finite, which it generally isn't unless the causal fault has been rectified.

Therefore, the only valid reason to add extra ventilation is to prevent condensation. But condensation does not occur in the roofs of most historic buildings, provided they are normally dry. Furthermore, increasing the rate of air change within a roof can also increase the migration of air and moisture from the rooms below. Increasing the air flow through an unventilated void when there is moisture rising from below might have unexpected consequences.

VENTILATION AND THE UNSTABLE ENVIRONMENT

Unfortunately, interventions in pursuit of energy efficiency mean that roofs may not remain dry and the only solution to a consequent condensation problem may be air exchange via extra ventilation. The external air might sometimes have a high relative humidity but not for the induced period caused by the intervention so that air exchange should have a drying effect. The combination which commonly triggers this instability seems to be roofing felt, thick insulation and no air exchange. The latter may be because there never was any or, perhaps, eaves vents have become blocked by added insulation. The amount of moisture permeating up into the roof space does not need to be excessive.

In an effort to gain a better understanding of induced condensation and other problems in historic roofs, Historic England has been monitoring the hygrothermal behaviour of a number of pitched roofs with insulation at ceiling level. These roofs have either impermeable, permeable or no underlay. Meteorological data has also been collected from weather stations set up near the roofs. (This project is part of a wider programme of research about the energy performance of historic buildings and the effects of measures to increase energy efficiency.)

The monitoring programme has yielded a large quantity of data which is currently the subject of statistical analysis. The findings will demonstrate how particular roof environments react to changing internal and external environmental loads, and may challenge some of the assumptions commonly made about the performance of roofs, in particular the role of ventilation.

Monitoring the interior environment of the roof of a typical semi-detached house showed that its humidity levels naturally followed conditions outside: contrary to popular belief, increasing ventilation would not affect its ability to dry. (Photo: Brian Ridout)

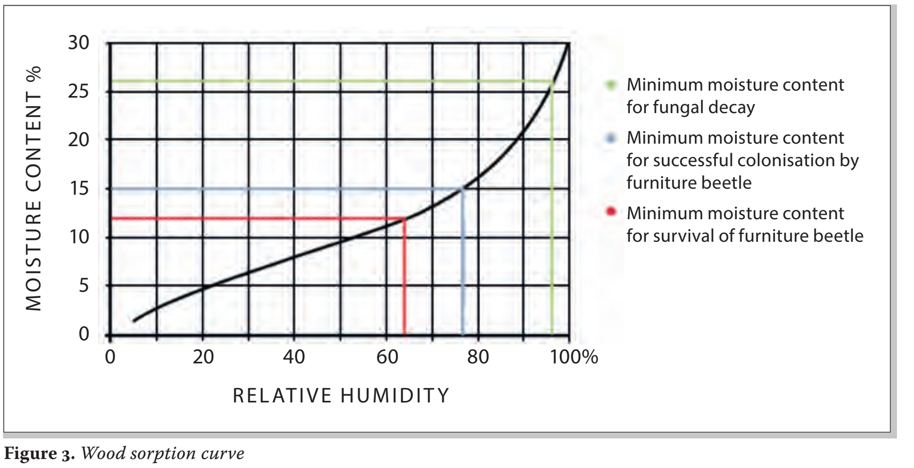

Figure 3. *Wood sorption curve*

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