ENVIRONMENTAL CONDITIONS IN HISTORIC CHURCHES: EXAMINING THEIR EFFECT ON WALL PAINTINGS AND POLYCHROME SURFACES

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INTRODUCTION

Over the past decade, the subject of building environment has become increasingly prominent in the conservation of wall paintings. The aim of this paper, originally presented to the EASA summer conference 2004, is to look at how environmental conditions cause deterioration, how these conditions can be investigated, and what methods can be used for their control. This is very much an overview, as each of the areas addressed is the subject of a large body of research in its own right. However, it is hoped that by drawing the various elements together, this will help with the co-operation between the conservator and the architect or surveyor, which is essential for any successful conservation programme.

The history of conservation of wall paintings has been one of the treatment of damage rather than its prevention and even today much of the training in conservation is concentrated on how to repair damaged objects. The prevention of deterioration is often regarded as being of secondary importance. However, unless conservators and other building professionals, have a clear understanding of how an object deteriorates and how this can be prevented, successful long term conservation is rarely possible.

One of the most significant elements in the deterioration of a wall painting is the environment in which it is situated. Unlike many other historic objects, which, when environmental conditions are unsuitable, can be moved to a more benign location, wall paintings are generally immovable. Indeed a wall painting is merely the inner skin of the building and so any problem with the deterioration of a wall painting is in fact a problem with the deterioration of the building itself.

MOISTURE TYPES

Next to mechanical damage caused by man, moisture, in both its liquid and vapour states, is the most significant mechanism for deterioration in wall paintings.

Although there are numerous types of deterioration associated with moisture, the most significant four are 1) cycles of salt dissolution and movement, 2) the growth of microbiological organisms, 3) dimensional change in original or added materials, and 4) the movement and deposition of dirt and other materials.

Moisture related deterioration tends to be referred to with the all encompassing term ‘damp’ and this is the beginning of the problem. Unless the specific source of moisture is identified and the type of damage defined, there is little chance that it can be efficiently controlled. Therefore, it is the problem of separating damage caused by liquid water and that associated with water vapour that will first be addressed.

Liquid water

Generally, liquid water problems are those that effect the integrity of the building envelope, and allow rain water or ground water to enter the structure either through penetration, infiltration or capillary rise. Damage associated with liquid water movement is probably the most significant
environmental cause of critical damage to wall paintings.¹

Most liquid water problems stem from a failure in either building design or its maintenance, with the result that rainwater is not successfully removed from the structure. In its simplest form this relates to damage to the envelope itself, generally the roofs, walls, windows and doors. Following from this there is the failure of the rainwater disposal system, both the rainwater goods and the drainage system, which takes the water away from the building once it has reached ground level.

If deterioration to a wall painting is taking place as a result of water penetration through a damaged roof, before contemplating the treatment of the painting, the roof should be repaired.

In some cases identifying the source of moisture by examining the nature and distribution of the damage to the building (or wall paintings), is relatively straight forward. The evenly distributed zone of evaporation on the internal and external walls, for instance, often points to capillary rise of ground water (rising damp), and isolated area of deterioration at the top of the wall often indicate damaged rainwater goods. (Plate 1)

However, there are many cases where the symptoms of damage are less than clear, and identifying the moisture source is not straightforward. It is often particularly difficult to tell whether a problem is active or historic, especially in cases where a building has undergone some level of repair in recent years, but the effect on the moisture conditions is unclear. It is in this type of case where a detailed study of the conditions and moisture routes can prove extremely useful. Failure to properly identify the moisture source can, at best, lead to inefficient remedial treatment and can, at worst, lead to treatment which exacerbates the damage.

For similar reasons it is essential that the methods of control are fully understood and are used in the right circumstances. Although most repair techniques are used correctly, there are some notable exceptions. A typical example is the ‘French Drain’, which is commonly inserted to dry out ‘damp’ walls in churches. In a case where there is horizontal transfer of liquid water into the side of the wall, the insertion of a gravel filled trench may well reduce the volume of water reaching the wall. However, within the gravel, the relative humidity will often remain at or near saturation point and so little or no evaporation can take place from the wall. Therefore, the level of drying will actually be very low. This also assumes that the French Drain is correctly maintained. In fact, in many cases, maintenance is limited and the trench swiftly fills with organic matter and earth.

In other words, while a system such as a French Drain can be relatively efficient at a specific task, (if well maintained) it is often used in an attempt to control a situation for which it is not designed.²

Water Vapour

Deterioration associated with microclimate and water vapour is more difficult to identify, and it is for this reason that it is often overlooked or misunderstood. Unlike liquid water activity where deterioration can happen extremely quickly, damage associated with water vapour tends to occur more slowly and, as a result, it is

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¹ Detail of the 19th century wall paintings in St Thomas’ Church, Douglas, Isle of Man, showing damage characteristic of rainwater penetration (in this case resulting from damaged rainwater goods).

² For similar reasons it is essential that the methods of control are fully understood and are used in the right circumstances.
often left untreated until the situation becomes very serious.

**Types of deterioration**

In broad terms there are two sources of microclimatic moisture which are of concern to us in historic buildings, *hygroscopicity* (the adsorption of water vapour) and *condensation*. As we saw earlier, these sources of moisture cause damage to wall paintings and sculpture in three main ways, firstly by activating cycles of salt dissolution and crystallisation, secondly by encouraging microbiological biodeterioration and thirdly by causing dimensional change in the original and added materials.

**Salt activity**

The first of these, *salt activity*, is probably the most damaging for wall paintings and architectural carving. (Plate 2.) The basic mechanism of salt deterioration is widely understood; hygroscopic salts have a particular equilibrium relative humidity (the level of moisture at which they change from their solid state to solution). If the relative humidity rises above this, the salt will go into solution and, as a result of osmosis, it will move through the porous structure of the building material. When the relative humidity drops below the level of equilibrium, the salt will crystallise, and as the salt crystals are physically larger than the ions in the solution, this will usually cause the disruption of the pore in which it has crystallised. While a single disrupted pore is inconsequential, when this happens in millions of pores many times every hour, the cumulative effect can be dramatic.

The difficulty with controlling this type of deterioration is that in historic buildings we tend to have very little information about the salt mixtures involved. While general ion analysis is fairly simple, the type of detailed analysis needed to characterise the actual salt species and mixtures present, is both complex and expensive. Added to this, recent research has shown that the equilibrium relative humidity levels of salt mixtures cannot be simply calculated based on an approximation of the salts present. To further complicate matters, salt concentrations and mixtures vary considerably from area to area, and so creating a model of how an historic building will respond to a specific RH is virtually impossible.

**Microbiological growth**

Microbiological growth also presents difficulties with identification and control. The main deterioration mechanisms associated with biodeterioration of this type are the *physical disruption* caused by the micro-organism as it colonises an area of material and the *chemical damage* resulting from the by-products of its lifecycle.

Typical of the damage which occurs in porous building materials, is that caused by certain fungi, the mycelium of which, can bore more that 10mm into lime plaster or limestone and which produce a wide range of acids deleterious to historic building materials.

Like salts, one of the principles in efficiently controlling microbiological deterioration is accurate identification, so that the life cycles can be understood and measures can be implemented that will disrupt them, without causing damage to other materials.

**Dimensional change**

Dimensional change can occur in many materials, but in this context, the most relevant objects are paintings on wood. Wood can respond to changes in humidity...
by an expansion and contraction of the cellular structure. *(Plate 3)*

A painted wooden structure is a composite of layers of different materials with varying levels of dimensional response to changes in the environmental conditions. Therefore changes in the microclimate which might cause the wooden substrate to expand by 5% might only cause the ground layer or the paint layer to expand by 0.5%. This will produce high levels of stress across the structure, and unless the paint layers have the elasticity to absorb the differences in movement, a failure will occur, usually in the weakest layer. This is commonly the mechanism which leads to paint delamination and flaking on timber structures.

Over time, the level of expansion and contraction and the period of response can be reduced by a mechanism known as compression setting. This occurs when the cycles of dimensional change cause cells to become permanently collapsed, and no longer responsive to changes in humidity. This may result in cracking as an expanded compressed structure reduces with a drop in humidity. It may also cause the structure to become less swiftly responsive to changes in humidity.

Although wooden structures tend to be our primary concern in churches, precisely the same principles apply to any composite structure, or to a structure that has been made into a composite, by the addition of a layer of a different material at a later date.

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**ENVIRONMENTAL MECHANISMS LEADING TO DETERIORATION**

Most parish churches have uncontrolled or semi-controlled environments. Buildings of this type tend to have a significant level of porosity, or natural ventilation, and therefore the primary long term influence on the internal microclimate is the external weather. However, many of these churches, particularly the medieval buildings, have massive structures which provide a very significant level of buffering between the internal and external conditions. Therefore, in the short term, the response to changes in the external conditions is minimal and the internal microclimate will remain relatively stable.

In the absence of any artificial influence, a state of equilibrium will be reached between the moisture in the building structure and that in the air. While this varies between building types and depends to a high degree on the condition of the structure, it is common to find that the microclimate in a well maintained, unheated (or intermittently heated) medieval church will stabilise between roughly 70% and 90%. There are of course numerous examples that fall outside this range, but usually when these cases are examined closely it is found that there is an additional factor, such as liquid water activity, effecting the conditions.

In most churches however, there are a number of artificial influences which effect the microclimate. Principle among these are heating, ventilation and building use.

**Heating**

Heating is usually installed in churches to provide comfortable conditions for people. Sometimes it is used in an attempt to provide stable environmental conditions, but generally this is a secondary requirement.

The problem with most heating in churches is that it is required to produce comfortable conditions for a short period of time, once or twice a week, at minimal cost. Therefore, a common scenario is that a church remains unheated during the week and then early on a Sunday.
morning, the heating is turned on to full power for a period of three or four hours in an attempt to heat the air mass, which, it is hoped, will heat the people.

Introduction of heating in this way has two main effects. Firstly the relative humidity falls sharply in response to an increase in temperature. Secondly, and this is generally less widely understood, as the relative humidity in the air drops, water evaporates from the building structure to maintain the equilibrium between the walls and the air. This means that although the relative humidity is lower and the church feels drier, the absolute humidity, that is the actual weight of water in the volume of air, has increased. When the heating source is turned off and the temperature falls, the additional moisture takes longer to be re-adsorbed by the walls and therefore the relative humidity remains higher than when the process started. If the temperature of the resultant moist air then reduces still further, for example by coming into contact with a cold wall, the relative humidity will rise to saturation point and condensation will occur. (Plate 4.) Each time this process occurs, salt activity will be encouraged, and the deterioration of the plaster and stonework will continue. This is an extremely common scenario, which is repeated in numerous churches every week.

Generally, heating systems used in churches produce their effect by convective or radiant means which do not introduce any further materials into the internal environment. However, there are two main exceptions which are still found in some churches. The most significant is the portable Calor gas heater. While these units are very efficient in producing fast and relatively low cost heat, they have the huge disadvantage that the main combustion product of LPG is water. Each 1kg of gas burned produces about 1.5kg water. The result is that using a number of Calor gas heaters in a large church for only one or two hours, can cause a dramatic rise in absolute humidity, resulting in condensation, immediately after they are turned off.

The other system, which is fairly rare, is the externally ventilated direct fired gas heater. This works by pulling in external air, passing it over an open gas flame and blowing the resulting hot air into the body of the church. Not only does this suffer from the same problems as the small Calor gas heaters, that is the introduction of water vapour from the LPG, but it also introduces external air which might have a far higher moisture content than the internal air.

Ventilation

Ventilation is probably the second most significant influence on the internal microclimate, but unlike heating, it is often introduced constantly for long periods of time. Ventilation in this context means the introduction of external air into the internal microclimate. This is usually recommended in an attempt to ‘dry’ the interior of a building.

The first difficulty with using ventilation in this way is that it is an attempt to treat the symptom of a problem rather than the root cause. If a wall is suffering from severe moisture damage, or the relative humidity is excessively high, there is probably an uncontrolled source of liquid water available somewhere. Unless this is tackled, no amount of air movement is going to control the problem.
The next difficulty is the moisture content of the air being introduced. Usually, when ventilation is recommended, the windows of the church are opened for a matter of months. On average it is wetter outside than inside, particularly at night, and therefore introducing external air will increase, not decrease, the volume of water in the microclimate. Even when some manual control is introduced and the windows are opened on warm sunny days, the situation is rarely improved. Because of our lack of sensitivity to humidity (and the lack of understanding of relative and absolute humidity), most people do not realise that when the sun comes out, the absolute humidity often rises, due to the evaporation of moisture from the ground. This warm wet air is then introduced into the cold church, and unsurprisingly, condensation occurs. *(Plate 5).*

Even in circumstances where condensation does not occur, there must be some question as to whether the introduction of highly unstable conditions into a church will have a beneficial effect. As has been shown salts cause damage not in their crystalline state or in solution, but when they change from one state to the other. Any measure that encourages instability will cause this type of deterioration to increase.

There are certainly cases where ventilation with external air can have a beneficial effect. For instance, if a building has suffered from a serious liquid moisture problem which has now been controlled, but the internal walls remain very wet due to the high internal relative humidity. The introduction of dry external air may well be a useful tool in hastening the drying process despite the instability. However, without a mechanical control system which compares internal conditions with those outside, even this is harder to achieve than appears at first to be the case.

Given the obvious drawbacks, why then is external ventilation so popular? The reasons, in the opinion of the author, are that it is simple to implement and it is free. Also, the damage caused by inappropriate ventilation is difficult to measure, and is often attributed to other causes. When building advisors recommend that a client spends £40,000 on a new heating system they are required to look very carefully at how it will effect the building fabric and whether it will be effective in achieving its claimed benefits. Ventilation is an equally powerful tool in terms of the effect on the building, but no such justifications are required before it is recommended.

Air movement from an internal source is a different matter and, used efficiently, can be an extremely useful tool in controlling the microclimate. However, this too is not without difficulties as recent research has shown that even minor air movements cause a huge increase in the level of evaporation. Therefore, air movement intended to prevent condensation could also cause evaporation of moisture in a wet wall and encourage salt crystallisation. This simply reinforces the point that the possible consequences of introducing these types of measures must be understood before they are implemented.

### Building Use

The third artificial influence, building use, is included here for completeness, as in fact, many of the effects on the microclimate caused by building use are indirect, being associated with heating and ventilation. People entering and leaving a building cause increased levels of ventilation, and while they are in the building they want comfort heating. The one factor which is related directly to building use is the introduction of additional moisture, either from wet coats and umbrellas, or by breathing. A single person can be expected to produce
METHODS OF INVESTIGATION: THE ENVIRONMENTAL SURVEY

The key to controlling environmental damage is to have a very clear understanding of the link between the underlying causes of deterioration and the visible symptom.

In Ipollito and Giovanni Massari’s, excellent book, Damp Buildings Old and New, Chapter 1 is entitled ‘Do not rely on common sense, dampness can and should be measured’. While the translation is a little clumsy, the point it is making is clear. Many manifestations of moisture damage are deceptive, and it is essential that careful examination is made before a conclusion is reached as to why they are occurring.

A typical example, is that of a liquid water problem on an external wall causing preferential cooling on the internal wall. As a result of external evaporation and therefore cooling through the whole depth of the wall, condensation occurs on areas of the internal wall immediately behind the liquid water problem. Unless this situation is carefully examined, this can easily be misinterpreted as liquid water penetrating the wall, and incorrect measures taken to prevent it. A similar problem can also occur at the base of the wall where capillary rise of ground water, or rising damp, can cause surface cooling, and thus cause condensation, resulting in twin moisture sources.

However, in other cases more complex problems are observed and a more detailed study is necessary. Moisture survey techniques can usefully be separated in the Liquid Moisture Survey and the Microclimate Survey. In practice however, investigations tend to include elements of both. Throughout the process, it should be remembered that an environmental survey is not an academic exercise, but a tool which should result in practical recommendations.

Liquid Moisture Survey

The core of the liquid moisture survey is an examination of the building. Starting with patterns of deterioration on the internal surfaces, an examination is made of the building envelope, the rainwater disposal system, the drainage system, and the surrounding land. The aim is to examine how rainwater and groundwater should be taken away from the building and to see whether this is being achieved successfully.

6. Schematic diagram showing the distribution of moisture in one of the walls at Holy Rood Church, Ampney Crucis, Gloucestershire.
This is generally followed by an electrical resistance or capacitance survey of the internal surfaces, examining patterns of superficial moisture and juxtaposing these with the areas of damage. Areas of deterioration are then plotted on graphics and often overlaid with moisture routes, so that patterns of deterioration and possible sources can be examined. *(Plate 6.)*

When a probable liquid moisture route is identified by these methods that requires further investigation, core sampling is often used. This involves taking a drilled sample into the core of the wall (usually a powdered sample). The sample is separated into sections and weighed. The sample is then dried at a low heat until a constant weight is reached. To test for moisture associated with hygroscopic materials, the sample is then placed in a humidity chamber at a set RH and left until a constant weight is reached. The two sets of data are then plotted on a graph so that the liquid moisture profile of the wall can be clearly seen, along with the percentage of the water which might be associated with hygroscopicity. *(water vapour) (Plate 7.)*

On the basis of this information, it is usually possible to make an accurate assessment of the sources of moisture associated with visible damage, and whether the deterioration is active or historic.

**Microclimate Survey: Environmental Monitoring**

The intention of a diagnostic environmental monitoring programme is to provide data to demonstrate whether the model of the conditions developed in the preliminary survey is correct. In other words whether a particular aspect of the damage is being caused by water vapour.

This is done by collecting data on humidity and temperature over a period of time and then analysing the data to show why particular conditions are occurring. Nowadays, this is generally carried out using electronic dataloggers which record the conditions twenty four hours per day. *(Plate 8.)*

Microclimatic conditions vary in different areas of a building, even in close proximity to each other and in most cases there is only the opportunity to monitor the conditions at a limited number of locations. Therefore, it is essential that the programme is designed with a well constructed theory in mind, so that our probes are placed in the optimum locations. Simply putting a datalogger in a church and hoping it will tell you why your painting or stonework is deteriorating is a waste of time and money.
In most churches, the weather has a direct influence on the internal microclimate. Therefore, it is important that the external conditions are also monitored, so that the variations in the internal conditions can be directly compared. This allows the buffering efficiency of the building envelope to be examined as well as the influence of ventilation, both natural and artificial.

In order to see whether superficial condensation is taking place it is necessary to examine surface temperature as well as air temperature. Given the accuracy of the sensors, this type of monitoring can only give an indication of when condensation is likely to occur. It should also be remembered that interstitial condensation, that is condensation within the pore structure, can occur at very different conditions to superficial condensation, and will not be recorded by these methods.

All of these instruments and systems are simply tools to produce data and it is important to remember that data is only as good as the interpretation put on it. Unless the conservator undertaking the study has a clear understanding of the hygrothermal parameters that they are dealing with, the data can be useless. Indeed, incorrectly interpreted data can be extremely damaging, as the addition of a nicely printed graph gives a spurious validity to even wildly inaccurate conclusions. It should also be remembered that there are severe technical limitations on the equipment used for this type of monitoring and so precise values should be treated with caution. What we are looking for are patterns of microclimate which explain the deterioration we are seeing.

By the end of the environmental investigations the conservator should have a clear idea of which areas of damage are associated with which sources of moisture, and whether the deterioration is active or historic.

**CONTROL MECHANISMS**

Most of the historic materials that we are interested in respond primarily to changes in humidity rather than temperature. This is the opposite to people, who can sense very small variations in temperature and only large ones in humidity. This becomes particularly relevant when we look at controlling microclimates to allow people to be comfortable in historic buildings. It is not the intention of this paper to look in detail at specific methods of environmental control as these vary as much as the moisture problems themselves. However, it would be useful to consider some of the principles involved.

As has been discussed above, the first and most important principle of environmental control is to have a clear understanding of the cause of deterioration.

Controlling liquid moisture problems often involves quite significant interventions (building repairs, reordering of rainwater disposal systems etc.) but in general they are relatively straightforward. Controlling microclimate tends to be a little more complex.

Preventing salt activity in wall paintings and stonework, or dimensional change in composite objects, requires stability of environmental rather than particular levels of temperature and humidity. Over ventilation, both natural and intentional is one of the most significant factors destabilising the internal microclimate and reducing unnecessary ventilation can be a remarkably effective way of reducing deterioration. There are of course specific instances where achieving an internal microclimate similar to the conditions outside might be recommended. However, the important issue with all ventilation questions is to examine exactly what effects are intended, and design the ventilation policy accordingly.

The other factor which causes major disruption is heating. Congregations usually say they want their church heated, and to achieve this they introduce large amounts of energy into the building for a short period of time. It then comes as a surprise that they do not feel particularly warm, their wall paintings start to flake, and a large bill comes in for their fuel supply.
The problem is that what congregations really want is to be warm themselves. Heating a large air mass in a tall building is not an effective way of achieving this, particularly when that building is itself very sensitive to temperature change.

Unless the intention is to have constant heating, indirect heating, that is heating the air in order to heat the person, is rarely very effective in historic buildings. Direct localised heating, that is delivering heat directly to the person from a nearby source, is far more efficient. This type of heating is nothing new, and pew heaters and infrared panels are already commonly used. The problem is that it is often used inefficiently, and therefore the system is regularly dismissed as not very effective. However, used correctly, this type of heating offers one of the most efficient and cost effective methods of heating a congregation with minimum impact on the environment and the building fabric.

Two research projects are presently being undertaken to develop systems for localised heating based on radiant sources. One is being carried out by the Building Conservation and Research Team at English Heritage and the other is the EU funded Friendly Heating Project. Both projects are expected to be completed by the end of 2005.

This type of heating will not be appropriate in all cases and indeed there are some churches where constant central heating might offer the best solution. But for occasionally heated parish churches on a limited budget, it is hoped that the localised radiant system will provide an effective comfort heating which will be sensitive to the building fabric.

CONCLUSIONS

In conclusion, it should be reiterated that the key to successfully control of environmental damage, is a clear understanding of the causes of deterioration, and the way in which the control mechanisms will effect the microclimate.

In many instances this information can only be obtained using survey techniques of the type discussed above. However, environmental surveys need to be both practical and cost effective. Most of the investigation is done with basic examination techniques. The more complex analytical tools are merely there to confirm, refine or disprove the theory and should only be used when necessary.

Long term conservation of wall paintings and other sensitive surfaces can only be achieved if the environmental conditions are satisfactory. The microclimate in the parish church will inevitably be a compromise between the comfort of the people and the stability of the fabric. However, a thorough understanding of how that microclimate works will make achieving an acceptable compromise possible.

FURTHER READING


Bemrose, C. and Bordass, W., *Heating Your Church*, London 1996


'Critical' in this case refers to damage that is severe, and happens extremely swiftly. Unlike water vapour damage which is generally very slow, liquid water damage can happen in a matter of hours.

It should be noted that empty trenches also suffer from the same problem if they are steep sided or covered over, with an inadequate level of air exchange. As with the French Drain the steep empty trench will form a barrier for the horizontal transfer of water, but because the RH remains at or near 100%, only very limited evaporation can take place from the wet wall.


Caneva, G., Pia Nugari, M., Salvadori, O., Biology in the Conservation of Works of Art, Rome 1991

Calor gas is a LPG (liquefied petroleum gas) consisting of approximately 90% propane, 8% propyne 8% and 2% butane. Pers. Comm. Calor Gas Technical Services

A modification to this system uses a heat exchange, which separates the internal and external air, but this significantly reduces the heating efficiency of the system.


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