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Degradation of Cultural Heritage in Surrounding Environment

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1 State of the Art Statement

Deterioration problems in both modern and historic buildings are attributed to environmental conditions favouring the decay of materials and contents. For example, environmental pollution, water, humidity, temperature, UV, and lack of ventilation. The damage caused by environmental factors and biological organisms like fungi and insects, is very familiar, as is the destruction arising from attempts to eradicate them by the use of chemicals, which not only are a cause for concern to health authorities, wildlife interests and environmentalists but also lead to the development of resistance in the target organisms.

Correct identification of the fungal pest is important as not all fungi are equally destructive. Some rots are present in timber when it is cut, or are acquired in storage, and these may be present in heartwood or sapwood. Fungal infestation may also be dead or dormant, representing conditions in the past.

Environmental control and preventative maintenance are preferable to chemical means. Preventative maintenance should in most cases forestall the need for major interventions, and it is beyond doubt that it reduces the cost of the conservation of buildings. Since the internal environment of a building is the product of a number of influences, before undertaking an intervention involving any building it is advisable to study in detail the ecological factors such as temperature, humidity at micro-environmental levels and the building's response and performance.

The ongoing monitoring of the environmental conditions of buildings ensures the long-term health of building materials and structures (42).

1.1 Problem Oriented Network of Centres and Partners Institutions

Environmental Building solutions Ltd

Building Research Establishment

The National Trust

The English Heritage

Oscar Faber

1.2 Joint Project Pre-Proposals 0r Ideas Related to the 5th Frame Work

1.2.1 Environmental Monitoring and stabilisation of the historic environment to prevent deterioration of cultural heritage

1.2.2 Environmental control of deterioration of timber by fungi and insects in historic buildings

1.2.3 Health implications of fungi in historic buildings and health risk assessment

1.2.4 Development of non-destructive instrumentation and technologies for the investigation of historic fabric

2 INTRODUCTION

The study of fungi is known as mycology (Gr. mykes, mushroom or fungus; lugos, discourse). The world's ecosystems are sustained and kept in balance by a rich variety of fungi. It is estimated that there are about 1.5 million species of fungi in total, of which around 70,000 (5%) have been scientifically described.

'Building mycology' is defined as that branch of mycology dealing with the study of fungi in and around the building environment [1, 2]. This has both direct and indirect effects on the health of building materials, structures and occupants. The commonest fungi which cause damage to building structures are the dry rot fungus (*Serpula lacrymans*), cellar rot fungus (*Coniphora puteana*) and wet rot fungi (*Antrodia vaillantii, A. xantha, Asterostroma* spp, *Donkioporia expansa, Paxillus panuoides, Phellinus contignuus, Tyromyces placentus*).

The dry rot fungus *Serpula lacrymans, (Schumach. ex Fr.) Gray* previously known as *Merulius lacrymans*, is the most important timber decay fungus in buildings in Northern and Central Europe and is also of serious concern in Japan and Australia [4]. Not only does the fungus bring about the dramatic decay of timber, but it is also able to spread through a building from one timber location to another across non-nutritional surfaces. The fungus has a serious impact on the UK housing stock and also causes concern in the conservation and preservation of buildings of historic and architectural merit [5]. Timber decay investigation and eradication is therefore big business in Britain. *Serpula lacrymans* is the most deadly form of fungal attack in building timbers, and buildings of traditional construction in this country are particularly vulnerable to this form of decay [6].

The vast majority of properties in the UK contain a significant amount of wood, ranging from structural timbers such as joists and finishings such as skirtings. In order to detect the type and extent of fungal decay, remedial measures could entail the loss of decorative finishes, extensive exposures and damage to the fabric of the building and are very expensive. It is not surprising therefore that the estimated annual expenditure on timber preservation works in Britain is over 400m [4].

Building surveyors in particular have to look out for this destructive fungus when they are appraising properties. They have to consider the factors that may indicate the likely cause of internal decay whether past, present or future [4]. The technical and legal implications associated with *S. lacrymans* should not be underestimated. Building surveyors must alert their clients to the risk of timber decay when carrying out either a Structural/Building Survey or a House Buyer's Report and Valuation. Correct and early diagnosis of this form of infection in a building is essential if a later widespread outbreak is to be avoided and proper repair is to be achieved. It also minimises the chance of carrying out inadequate or excessive treatment where *S. lacrymans* is mistaken for wet rot or vice versa [4]. In addition, early correct diagnosis will help the surveyor avoid a negligence claim in the event of a future outbreak of the rot.

The fungus has occupied a specialised ecological niche in buildings in Europe with its unique biology, and is only known to occur in the wild in the Himalayas [7, 8, 9, 10, 11, 12]. The ravages of the dry rot fungus are familiar, as is the destruction caused by attempts to eradicate it, particularly involving the use of chemicals. Remedial chemical timber treatment can cause damage to the health of building occupants and is a cause for concern to environmental health authorities.

It is the lack of understanding of the biology and ecology of the dry rot fungus that has led to this radical treatment and hence considerable damage to building fabric. The Author has led several Himalayan expeditions for the search for wild dry rot in the Himalayas with a view to gathering information on its biology, ecology and genetics in the wild. It is hoped that the fundamental scientific knowledge gained through multidisciplinary research should enable us to reach a better understanding of the fungus and to develop safer, more effective and ecological control techniques and strategies [8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. Not only is fungal infection of timber unsightly and potentially hazardous to human health, it can also adversely affect the structural integrity of the timbers as well as disrupt the use of the building.

2.1 Main Characteristics of Decay of Timber

There are four key characteristics that can be used in the identification of fungal growths: (i) mycelium; (ii) appearance of decaying wood; (iii) strands; and (iv) sporophores. The table below compares these characteristics for dry rot with those of wet rot.

Main Characteristics of Fungal Decay of Timber		
Characteristic	**Dry Rot**	**Wet Rot**
Mycelium	Damp conditions: Masses of tears on silky white surface, with bright lemon patches. Drier conditions: Thin skin of silver grey in colour, with deep lilac tinges.	High humidity: Yellow to brownish in colour
Decaying Wood	Deep cuboidal cracking associated with differential drying shrinkage Reduction in weight Dull brown in colour Resinous smell gone	Cuboidal cracking on smaller scale Thin skin of sound wood Weight loss Localised infection
Strands (Rhizomorphs)	3-6mm in diameter Brittle when dry Off-white/dark grey in colour	Thinner than dry rot Flexible when dry Creamy white in colour
Sporophores (Fruiting bodies)	Tough, fleshy pancake or bracket-shaped, varying from a few cms to a metre across Ridged centre: Yellow-ochre when young, darkening to rusty red when mature Lilac/white edged Distinct mushroom smell	Not very common in buildings Must smell, rather than mushroom smell associated with an active growth of dry rot

2.2 ASSOCIATED ROTS AND MOULDS

Wet Rot This type of decay is caused by a number of Basidiomycetous fungi of which the most important are *Coniophora puteana* (cerebella), 'Poria' fungi, *Phellinus contiguus, Donkiporia expansa, Pleurotus ostreatus, Asterostroma* spp and *Paxillus panuoides*. Wet rot is also called white rot as it destroys both cellulose and lignin, leaving the colour of the wood largely unaltered but producing a soft felty or spongy texture without cross cracks. Common white rots are *Donkiporia expansa, Asterostroma* spp, *Pleurotus ostreatus* and *Phellinus contiguus* [20]. Brown rots cause the wood to become darker in colour and to crack along and across the grain; when dry, very decayed wood will crumble to dust. Many common wet rots are brown rots, for example *Coniophora puteana, C. marmorata, Paxillus panuoides* and *Dacrymyces stillatus*.

2.3 ECOLOGICAL AND ENVIRONMENTAL FACTORS

2.3.1 Ecological Factors Affecting Timber Decay

The environmental factors affecting the decay of timber are temperature, water, humidity and ventilation [21] (see Figure 1).

Figure 1. Fungal growth in buildings

Moisture in Buildings

The following factors contribute moisture in buildings:

- Penetrating damp/rising damp.
- Condensation.
- Building disaster.
- Construction moisture.
- Building defects.

Fungi differ in their optimum temperature requirements but for most the range is from about 20 to 30°C. The optimum temperature for dry rot growth in buildings is about 23°C, maximum temperatures are about 25°C and the fungus is rapidly killed above 40°C. Timber moisture contents in buildings in the 20 to 30% range are ideal for dry rot attack and other infestations.

2.3.2 Environmental and Non-environmental Factors

The following environmental parameters are considered most hazardous:

Relative humidity; UV light; air temperature; dust; pollution; pests; handling; visitors; fire and water; air movement; cultural/organisational/management factors.

Inspection Methodology

A careful, systematic methodology is required when carrying out a building survey. One of the objectives is to assess the likely location or danger of dry rot.

Unless the property is new or relatively modern, it may be safe to start with the assumption that dry rot is probably present until proven otherwise. The aim in any inspection of a building for dry rot is to identify infected or vulnerable areas and to provide a logical assessment of the risks. This is usually best achieved if the same methodical approach used for a typical building survey is adopted, as summarised:

Stage 1 - Desk Top Study: Inspect records, drawings, relevant correspondence, previous treatment contract documents relating to the property; consult owners/previous occupiers about problems with and alterations to the building; all of these sources may reveal valuable information about the building and may confirm or suggest previous outbreaks.

Stage 2 - Primary Inspection: Externally: Top down - look for typical indicators of rot; algae growth on walls, damp stains on walls, choked/overflowing gutters, defective roof coverings, leaking/faulty rainwater downpipes, defective pointing/rendering.

Internally: Top down - all visible timbers should be inspected; note symptoms such as warped or curled wall panelling boards, splitting and cracking of painted woodwork, strong mushroom smell in the vicinity of an outbreak, springing lintels or floors and, of course, fruiting bodies with a layer of red dust-like spores.

Stage 3 - Secondary Inspection: Once the 'at risk' areas have been identified, it is advisable for the surveyor to recommend further investigations which may involve an element of 'opening-up', uplifting floorboards, removing sections of timber panelling etc. The use of a fibre-optic endoscope will help to minimise such work (see below). Solum levels of sub-floor voids that are below the outside ground level are potentially troublesome areas because they are prone to flooding and are difficult to ventilate adequately. If the finish of a suspended timber floor is at or near the outside ground level, then the latter will be above the solum level, and this should be checked.

There are six main objectives in carrying out the above three-stage investigation:

1. Building Context: Establish the client's instructions and the purpose of the investigation. Ascertain the property's age, form of construction and orientation. A knowledge of its location and recent history, especially as regards the level of maintenance and occurrence of adaptations (if any), may also be revealing.

2. Moisture Zones: Identify actual or potential sources of dampness [22].

3. Timbers Affected: Forecast the probable presence of hidden timbers within the building.

4. Dampness Defects: Identify and diagnose defects that can cause dampness.

5. Risk Factors: Pin-point vulnerable areas such as floor/roof/wall voids, look for external and internal indicators such as dampness, if there has been a previous infection there is a higher risk of a further outbreak.

6. Reporting: Accurate and impartial reporting of the nature and extent of decay.

Diagnosis of Decay: The following techniques are used to diagnose the decay:

- Physiochemical and morphological characteristics of decay.
- Cultural characteristics of decay.
- Genetic fingerprinting.
- Trained animals.

Special Search Techniques: The condition of concealed timbers and cavities may be deduced from the general condition and moisture content of the adjacent structure. Only demolition or exposure work can enable the condition of timber to be determined with certainty and this destroys what it is intended to preserve. A non-destructive approach is therefore required and, to help reduce uncertainty, instrumentation and test equipment can be useful at this stage. However, it is important to remember that all tests and instruments are only aids to the surveyor, and must be interpreted with experience and care. A slavish reliance on any techniques, and failure to take into account its limitations, is a recipe for disaster. The non-destructive inspection includes the use of trained animals, fibre optic inspection, ultrasonics and infra-red techniques.

Moisture Contents

Timber Moisture Contents: Timber moisture content at the surface may be estimated by the use of a resistance-type moisture meter, fitted with insulated needle probes. This will fluctuate depending on relative humidity and temperature. A rafter may have a surface moisture content of 16% in the summer which might rise to over 20% in winter. This would not necessarily indicate increased water content from a fault in the roof, but might be water absorbed through a drop in temperature. The core of the timber will remain relatively dry and a hammer probe with insulated electrodes is recommended for measuring the subsurface moisture content.

Masonry Moisture Contents: The estimation of surface moisture content in plaster and mortar is of limited value except for comparison. A surface capacitance meter may be used on plastered walls and panelling to detect areas requiring further investigation. Absolute readings should be made by means of a carbide-type pressure meter or by the oven drying method. Moisture reading contours on the surface and in the thickness of the wall help to define the source and type of moisture giving rise to decay.

Detailed Investigation: The findings from the initial investigations are followed up by more detailed study. The aim is to determine the distribution and extent of all significant decay organisms in the building, the distribution of all micro environments pre-disposing to timber decay and the building defects that cause them. The distribution of moisture and its movement through the structure is particularly important. The extent of significant timber decay should also be determined. Active decay organisms may not yet have caused significant timber decay. Conversely, there may be significant decay even when the decay organisms that caused it have been dead for many years. Key factors to be noted are species and viability of decay organisms, moisture content of materials, ambient relative humidity and ventilation. Timber species and previous chemical treatments may also be significant.

It is important that the results of the investigation are coordinated with the building structure bearing in mind the characteristics of particular periods and methods of building. They should also be carefully recorded and quantified where possible. This allows analysis of the results by other experts, reduces the 'grey' area in which differences of opinion can arise and forms a basis on which future investigations can build. This recording of data is especially important in the current legal climate and photography can be especially valuable. A detailed investigation of this sort might take about 5 man hours for a typical 3 bedroomed house.

DETECTION OF DRY ROT

The correct and early diagnosis of dry rot requires an understanding of the pathology of the fungus as well as a sound knowledge of building construction. Determining the presence of hidden or built-in timbers is crucial to a full and accurate detection of the fungus. There are a number of techniques that the surveyor can use to help in arriving at a correct diagnosis and these are listed in the table below.

Primary Detection Methods		
Detection Methods	**Types**	**Examples**
Human senses	Visual Aural Olfactory Touch Taste	Warping or cuboidal cracking in wood, sporophores Hollow sound when tapped Musty/mushroom smell Spongy, friable when felt or probed Acrid
Non-human senses	Sniffer dogs	Specially trained hounds to locate dry rot outbreaks
Artificial detection	Moisture meter Hand mirror and torch Ultra-sonic hammer Endoscopes Genetic*	Necessary to confirm damp areas To help inspect awkward voids Can help to indicate the soundness of large joists To inspect inaccessible areas DNA analysis of rot samples

* Research in this area is being undertaken by biologists Dr N White and Dr J Palfreyman, University of Abertay, Dundee, UK.

Although dry rot primarily attacks softwoods, it can also infect hardwoods such as oak. There are various timbers within a building which are susceptible to dry rot to which the surveyor should give particular attention (see table below).

Timbers Vulnerable to Dry Rot	
Location	**Common Timbers Affected**
Walls	Safe lintels Door standards Bonding timbers Strapping and boarding of dado panelling Lathing behind plaster Skirting grounds and skirtings
Roofs	Rafter feet and ends of ceiling ties, particularly behind 'beam filling' Ceiling ties built-into wallheads Wallplates
Floors	Joists built into masonry Bressummers (large support beams) Wallplates Floorboards Skirting grounds and skirtings

Dry rot in its early stages is difficult to distinguish from other wood rots without the benefit of laboratory analysis. This involves growing samples of the fungi on an artificial medium under controlled conditions. Various media based on oatmeal, wheat flour and malt extract can be used as a nutrient to encourage fruiting of the fungus.

In its terminal stages when the fruiting bodies or sporophores have developed brown spore dust dry rot is relatively easy to distinguish from wet rot. The former, however, can spread to other timbers, even through masonry materials, whereas the latter is always restricted to the locus of the moisture source. This ability to spread is one of the distinguishing and menacing feature of *S. lacrymans*.

Other techniques used included microscopy, laboratory culture and identification of fungi and insects, hot wire anemometry and electronic RH measurement (see Figure 2). More exotic techniques may sometimes be useful such as pheromone insect traps, infra-red thermography, short wave radar, automatic weather stations, ultrasonic detection of timber boring insects, and total building monitoring using specialist data loggers. It is important to remember that any technique must be carefully justified because the value of the information from techniques not routinely used or properly calibrated can be very limited.

Ecological Factors Influencing Biodeterioration

When considering any form of biodeterioration, there are three factors of concern: the material, the environment and the organism. Ecology as an aspect of science is usually confined to a very close analysis of the interaction of organisms with one another and with their environment. The environment in which any organism lives will contribute physical, chemical and biological factors which will have a bearing on the settlement, growth and development of an organism.

Figure 2. Dr Jagjit Singh using hammer probe to measure deep moisture content of timber.

Chemical Control of Biodeterioration

A great variety of toxic chemicals are available on the market for use as wood preservatives. The ideal wood preservative should possess the following characteristics:

1. A high toxicity towards wood-destroying organisms.

2. Permanency in treated wood, that is low volatility and a high resistance to leaching.

3. Ability to penetrate deeply into the wood.

4. Non-corrosive to metals and non-injurious to the wood itself.

5. Reasonably safe to handle and without injurious effects on operatives and occupants.

Wood preservatives are regulated in the United Kingdom under the Control of Pesticides Regulations 1986.

REMEDIAL TREATMENT

Remedial Treatment of Dry Rot

- Establish the size and significance of the attack. In particular if structural timbers are affected, carry out or arrange for a full structural survey to determine whether structural repairs are necessary and, if they are, take appropriate steps to secure structural integrity.

- Locate and eliminate sources of moisture.

- Promote rapid drying of the structure.

- Remove all rotted wood cutting away approximately 300-450 mm beyond the last indications of the fungus.

- Prevent further spread of the fungus within brickwork and plaster by using preservatives.

- Use preservative-treated replacement timbers.

- Treat remaining sound timbers which are at risk with preservative (minimum two full brush coats).

- Introduce support measures (such as ventilation pathways between sound timber and wet brickwork, or, where ventilation is not possible, provide a barrier such as a damp proof membrane or joist hangers between timber and wet brickwork).

- Do not retain dry rot infected timber without seeking expert advice. There is always some risk in retaining infected wood which can be minimised by preservative treatment and subsequent reinspection.

Biological Control of Biodeterioration

Microbial interactions and biological control methods have received much attention during recent years as an alternative to existing chemical control methods, which cause extensive environmental degradation. pose potential hazards to wildlife and are of grave concern to public health authorities. Biological control involves the use of one biological agent to suppress another. There are many successful examples of the biological control of wood decay fungi, for instance use of *Trichoderma* spp against various wood-rotting fungi such as *Polyporus adustus, Polystictus hirsutus, P. versicolor, Stereum purpureum;* and *Scytalidium lignicola* against *Lentinus lepideus.* It has been demonstrated that pure cultures of *Bacillus subtilis* inhibit the growth of various wood-staining fungi such as *Alternaria tenuis, Trichoderma reesei* and *Aureobasidium pullulans in vitro*. The role of immunising commensal fungi both as preventive and curative treatments in reducing the incidence of *Lentinus lepideus* has been described.

In view of these concepts, the prevention of biodeterioration may be achieved by biological control methods. This involves placing a microorganism into a material which does not affect the properties but which successfully prevents invasion by species capable of damage.

Environmental Control of Biodeterioration [23, 24, 25, 26, 27, 28]

When considering the prevention of any form of biodeterioration, there are three factors which can be taken into account: the material, the environment and the organism. The removal or alteration of any one of these can prevent the growth of decay organisms.

The control of the environment of a susceptible material, instead of the application of biocides, is the oldest and still the most widely used method of preventing biological deterioration. Traditionally, the control of physical conditions has been by far the most important method of preventing biodeterioration. For example, in the use of timber in construction the object has been to prevent its moisture content rising to levels at which wood rotting fungi can thrive.

The basic principle in the control of fungal growth is to render the micro-environment in or around the material in buildings as hostile as possible to the settlement, germination and spread of microorganisms. This can be achieved in various ways:

(a) To prevent or limit biological agents' growth and proliferation by means of toxic chemicals.

(b) To ensure that the material to be protected is kept, or keeps itself, in such physical condition that growth of biological agents is severely limited or prevented entirely.

The second approach will be discussed in more detail as traditionally, the control of physical conditions has been the most important method of preventing biodeterioration. The application of the general principles of the control of physical conditions and the reactions of microorganisms to these conditions often results in the most effective and economical prevention of deterioration.

The Greener Approach

Environmental control relies on controlling the cause of the problem by controlling the environment [30, 31, 32, 33, 34, 35, 36, 37, 38, 39] (see Figure 3):

- Locate and eliminate sources of moisture.

- Promote rapid drying.
- Determine the full extent of the outbreak.
- Remove the rotten wood.
- Determine structural strength of timber and fabric construction.
- Institute good building practice:
  - ventilation;
  - damp proof membrane;
  - isolation.

The environmental control is complex and requires a multi-disciplinary team of scientists, engineers, surveyors and computing skills.

The Green Approach Standards

In cases of actual or suspected problems of wood rot or wood boring insects in buildings, the following standards should be met by any remedial works:

a) Investigation should be carried out by an independent specialist consultant, architect or surveyor to establish the cause and extent of the damp and timber decay including the potential risk to the health of occupants before specification or remedial work. This investigation should include:

(i) The inspection of all accessible timbers to determine whether they are subject to, or at risk from, fungal decay or insect attack.

(ii) The determination as to whether any wood rotting fungi or wood decaying insects found are active and whether their activity is significant in each particular case.

b) Specification of remedial work should be prepared by an independent consultant as in a)(i) and (ii). Such specification should provide for:

(i) The maximum conservation of materials.
(ii) The future health of the building and its occupants.

(iii) The minimal use of new materials.

(iv) The avoidance of chemical pesticide use where possible.

(v) The use of materials and techniques with minimum adverse environmental impact.

(vi) The minimum cost of the whole project including the costs of the proposed works, the disturbance of occupancy, future maintenance costs, and the cost of safe disposal of all waste materials.

c) Remedial building works should be carried out as specified above to control the timber decay, to prevent further decay and to correct any significant building defects resulting in conditions of high moisture content or poor ventilation of timber. These should provide for:

(i) The reduction of the sub-surface moisture content of all timber below 16-18%.

(ii) The isolation of timber from contact with damp masonry by air space or damp proof membrane.

(iii) The provision of free air movement around timber in walls, roofs and suspended floors.

(iv) Humidities in voids not exceeding an average relative humidity of 65%.

(v) The removal of active fungal material and any timber affected to the extent that its function is compromised or adjacent structures put at risk, in the case of insect infestation, measures to avoid contamination.

(vi) The prevention of, or protection of timber from, sources of water likely to cause wetting such as overflowing gutters, leaking plumbing, condensation and rising or penetrating damp.

(vii) The removal of all builders' rubbish from voids and cavities and vacuum cleaning to remove dust.

d) The use of chemical pesticides should be avoided wherever possible. Where their use is essential the following requirements should be observed:

(i) The minimum use of fungicides consistent with the probability of reinfestation in the light of c) (i) - (vii).

(ii) The limitation of insecticidal treatment to the locations of significant active insect attack in the light of c) (i) -(vii).

(iii) Specific agents to be used on specific organisms only. 'Combined', 'general' or 'precautionary' treatments are not to be used.

(iv) Fungicides and insecticides must be currently fully approved under the Control of Pesticides Regulations 1986. Pesticides with special dispensation or licence as of right are not to be used. As a guide products with serial numbers greater than 3000 have gone through the full HSE approval procedure.

(v) Pesticides should be applied in accordance with the manufacturer's instructions and within any regulations, codes of practice guidelines or recommendations currently recommended by the BWPA, HSE, NCC or other competent authority.

(vi) The contractor applying the pesticide must certify that the treatment will not damage the health of the occupants and of the structure or wildlife in and around it.

(vii) The contractor must certify that the disposal of surplus pesticide, pesticide containers and treated waste materials is safe, non-polluting, and in accordance with all current central or local government regulations and guidelines.

Environmental Monitoring [40, 41]

Environmental monitoring includes the data logging of temperature, humidity, moisture content and other parameters in building materials, including internal and external environmental conditions, using on-site sensors and an automatic weather station. These systems are as follows.

Remote Sensing of Moisture Content in Timber: The remote sensing of moisture content in timber and monitoring the drying of buildings provide simple and economical methods of avoiding serious timber decay. These systems accurately determine the source and distribution of moisture within the building fabric, and detect water penetration in critical areas or monitor drying following building failure, fire of flood. Data from these investigations is used to determine a policy and control the drying out of the building fabric to reduce the risk of future decay after refurbishment.

Remote Sensing of Moisture Content in Masonry: Remote sensing systems can be installed in the damp masonry or area likely to be at risk from water penetration and the data obtained can be used to determine the state of drying down and to take profiles of moisture across a thick wall which may take many months to dry out. Permanently installed systems can act as a warning for future water penetration.

These systems can be simple or complex and are tailor-made to suit a particular building. In complex remote sensing systems, the resulting data can be transferred to the computer or via a model to a central building management system.

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