Building pathology & environmental monitoring;
The development of holistic sustainable conservation solutions - an over view

Dr Jagjit Singh, Director, Environmental Building Solutions Ltd, UK

1. Summary

The majority of environmental problems in buildings are associated with lack of maintenance, chronic neglect and building defects leading to water ingress, condensation and dampness in the building fabric.

Deterioration of historical building materials such as in Churches, Abbeys, Castles, Monuments and buildings of historic and architectural interest are attributed to changes in the built environment. The main environmental parameters affecting the decay of materials are water, humidity, temperature, UV light and lack of ventilation.

The causes of deterioration are influenced by the internal building environment, which has a varied microclimate depending upon the building structure and the envelope of the internal building fabric.

Buildings affect the health of occupants in many ways, for example building related illnesses (BRI), Sick Building Syndrome (SBS) and allergy and environmental health problems (AEHP).

Management of biodeterioration and health problems in buildings is a complex issue; it required a multi-disciplinary integrated approach, which combines the skills of material scientists, environment monitoring and health specialists, conservation science engineers and architects.

2. Introduction

The Oxford dictionary meaning of the "*environment is external conditions or surroundings, especially those in which people live or work, which tends to influence their development and behaviour and Environmentalist is a specialist in the maintenance of ecological balance and the conservation of the environment*". The oxford dictionary meaning of the "*monitor is a person or a piece of equipment that warns, checks, controls, or keeps a continuous record of something*".

Environmental monitoring of the built environment seeks to study the interrelationships of the internal environment created by the interactions of building architecture, materials, structures, services, contents, decorations and occupants with their external environments.

Environmental monitoring consultant is a specialist in the holistic multidisciplinary understanding of the total environmental performance of the building and in the development of environmental monitoring and control programme for long-term sustainable conservation solutions.

Environmental monitoring falls in two broad categories for example external environmental monitoring and internal environmental monitoring. These two categories of monitoring will be described in detail in the following text.

The external and internal environmental monitoring can be carried out both for the health of the building fabric, contents, finishes, structures and for the health comfort and productivity of the occupants.

2.1 Building pathology

Building Pathology is the scientific study of abnormalities in the structure and functioning of the building envelope and its parts. Building Pathology seeks to study the interrelationship of building materials, construction, services and spatial arrangement with their environments, occupants and contents, which are very complex and can influence the health of building fabric and of the occupants.

Building can be likened to living organisms and the useful life of a building depends on its internal and external environments, both in terms of longevity of materials and as an appropriate habitat for its occupants.

Building work as spatial environmental ecosystems and provide ecological niches and pockets of microclimates in their built environment for the development of building pathology and must be understood as a whole. Building biology encompasses holistic understanding of the interactions of life forms and the built environment. Building Pathology seeks to understand the total performance of the building envelope through multidisciplinary scientific study of the causes and symptoms of failures.

The primary impetus for this chapter is to provide understandable information on the environmental monitoring of the following subject areas;

- monitoring historic building pathology,
- monitoring biodeterioration of building materials,
- monitoring indoor air pollution and health effects.

2.2 Medical pathology

Pathology is the study of the disease by scientific methods and analysis. Disease may in tern be defined as abnormal variation in the structure and function of any parts of the body. Diseases have causes and pathology includes not only observation of the structural and functional changes throughout the course of the disease, but also elucidation of the factors, which cause it. It is only by establishing the cause of the disease that logical methods can be sought and developed for its prevention and cure. Pathology may thus be defined as scientific study of the causes and effects of disease.

2.3 Health hazards in buildings

The health of occupants in buildings is affected by the emission of pollutants from a range of sources in buildings. The environmental monitoring can be carried out for the following;

- Chemical pollutants and hazards
- Physical pollutant and hazards
- Biological pollution and hazards and
- Psychological factors

The emissions of chemical, biological and physical pollutants in buildings can be as below from;

- Buildings materials and structures
- Indoor and outdoor environments
- The wider environmental impact

There are several specialist monitoring techniques and services available to monitor occupants health in the indoor and outdoor environment. These includes, for example;

3 Monitoring for health hazards in buildings

3.1 Occupational hygiene

Occupational hygiene that is monitoring of airborne concentrations of dusts, fumes and gases in the workplace to assess compliance with the requirements of the Control of Substances Hazardous to Health (COSHH) Regulations 2002.

3.2 Anthrax monitoring and management

Anthrax management for example monitoring and assessing the risks associated with anthrax contamination with the use of animal hair in historic building fabric for example used in binding of lath and plaster.

3.3 Local exhaust ventilation monitoring

Local exhaust ventilation monitoring that is measurement of the efficiency of local exhaust ventilation systems to ensure effective operation in accordance with the requirements of HS(G) 54 “Maintenance, Examination and Testing of Local Exhaust Ventilation”.

3.4 Contaminated land monitoring

Contaminated land monitoring and assessment for example comprehensive monitoring and investigation to review the site history and to assess contamination and the likely environmental impact associated with it.

3.5 Environmental noise

Environmental noise that is measurement of noise exposure in the workplace, to assess compliance with present and impending legislation. Following environmental monitoring comprehensive advice and assistance can be provided to reduce noise levels. Measurement of ambient noise levels for a variety of purposes such as nuisance assessment, preparation of planning applications or selection of control measures.

3.6 Monitoring health comfort and productivity in buildings

Allergy in the workplace environment is a growing concern to employers and it is a complex issue, which requires a multidisciplinary integrated approach. Exposure to indoor allergens is a risk factor for the development of allergic reactions and the incidence of the problem is increasing at an alarming rate (Mukerji, KG, Chamola, BP & Singh J 2000).

This reflects on the health, comfort and productivity of the occupants and also increases the rate of sickness at work places. In this chapter we will be discussing monitoring allergic reactions in buildings, their signs & symptoms, types of allergies, indoor allergens & their management (Sick Building Syndrome, CIA, Singh J, (199c)).

3.7 Building health

Buildings affect the health of occupants in many ways, for example building related illnesses (BRI), Sick Building Syndrome (SBS) and allergy and environmental health problems (AEHP).

The most common building health problems in domestic housing relates to dampness and condensation resulting in mould growth, house dust mite and a range of other fungal and insect pests, aggravating respiratory problems and allergies (Singh J (1993).

Frequent complaints are:

Itching eyes	Headache
Difficulties with contact lenses	Extreme fatigue
Blocked nose	Lack of concentration
Sore throat	Lack of memory
Hoarseness	General malaise
Burning sensation of the skin	Lethargy
Recurrent sinusitis	Dizziness

3.8 Monitoring for allergies

Signs and Symptoms of Allergic Reactions

Nose: itching, soreness, blocked, running, sneezing;

Eyes: dryness, itching, redness, and soreness, swelling of the lids, weeping

Chest: discomfort, tightness, wheezing, breathlessness, and cough;

Skin: itching, redness, wheeling, blistering, scaling, and oozing.

The possible mechanisms for development of these symptoms mentioned above seem to be multifactoral. Irritative, toxic and immunological influences from different types of component such as fungal allergens, mycotoxins, endotoxins (components from gram-negative bacterial) and microbial volatiles.

There is evidence, which indicates that specific fungi may be the causal agents in individual cases of allergic respiratory conditions. These includes, for example, species of, *Alternaria,, Aspergillus, Cladosporium* and *Penicillium.*

These have been known to cause asthma and/or rhinitis among atopics. Cladosporium and the dry-rot fungus (*Serpula lacrymans*) have been the cause of the rare instances of extrinsic allergic alveolitis (hypersensitivity pneumonitis) resulting from exposure to high concentrations of spores indoors. The presence of certain fungal pathogens such as Aspergillus *fumigatus* and *Stachybotrys chartarum (atra)* should be considered unacceptable in indoor air and their presence pose a risk to the health of the occupants where appreciable number of these are found (Singh J, 1999, Singh J, 2000).

The other specific allergic reaction to inhalation of moulds or mouldy material is extrinsic allergic alveolitis. In this type of antigen/antibody reaction, IgE is not involved. Other antibodies mediate the reaction. The condition is generally associated with an occupational disease, which can, for example, affect farmers handling mouldy hay (farmer's lung), Workers occupied with whisky production handling mouldy barley (malt worker's disease), workers removing fungal growth from cheese (cheese washer's lung) or People handling mouldy wood chips for fuel or moist timber (wood trimmer's disease).

The specific names of these diseases cover the same diagnosis: Type III allergy is also called Extrinsic Allergic Alveolitis, hypersensitivity pneumonitis or ODTS or organic dust toxic syndrome.

There is a strong link between damp in buildings and mould growth and associated respiratory disease in relation to air quality of residences (Singh J, and Walker, B, 1994b).

3.9 Indoor air quality, mycology and health

Indoor air quality affects the health of the occupants and the holdings. Indoor Mycology is defined as that branch of mycology, which deals with the study of fungi, associated with building indoor environments, structures, contents and their outdoor environments, which has a direct or indirect effect on the performance of building materials and structures and the health of the contents and occupants. These aspects of building performance and health interactions require the multidisciplinary understanding (Singh, 1996).

Identification and risk management of moulds and fungal health problems in buildings is a complex issue. This requires a multi-disciplinary integrated approach, in order to identify, evaluate, monitor and remedy allergic reactions in buildings which combines the skills of material scientists, environment monitoring and health specialists, building mycologists, toxicologists, engineers and architects.

A diverse range of allergens including fungal spores may cause allergies Flanningan, B. 1992, Miller, J. D., 1992, Morris Greenberg, (1990) and Gravesen, S, Frisvad,J C and Samson, R A, (1994). The following paragraphs describe the range and size of fungal species and the symptoms they could induce in susceptible individuals.

A diverse range of microbial and biological agents can cause allergy, illness and stress in buildings. For example: microbes; viruses; bacteria including mycobacteria and actinomycetes, fungi and mycoplasmas.

Generally offices carry higher chemical pollutant load than biological contamination, this result from furniture, furnishings, materials and office hardware. However, exceptional situations can result in dissemination of contamination. For example HVAC systems when properly built and maintained, can decrease the biological contamination load from outside by filtering the incoming air and decrease the build-up of indoor contamination by diluting it with air from outside.

However, when contamination is present these systems can disperse contamination to all ventilated rooms. Most of the serious problems in offices relate to bacterial contamination of water reservoirs of either humidifiers or air conditioning units. However, large concentrations of biological agents mostly result from the misplanned management protocol of HVAC systems and can be linked to insufficient fresh air intake (allowing the build up of indoor contaminants), condensation or water accumulation in cooling coils, humidifiers and dust accumulation in air filters.

Other biological agents include, for example: mites (House dust mite) and their faeces, insects such as moths and cockroaches, dander from mammalian pets and pests, pollen, rodents, birds (Singh J, 1996).

4.0 Environmental monitoring for volatiles

Fungal volatiles affect health of the occupants by causing, for example, nasal irritation and feelings of stuffiness. Moulds can produce a variety of volatile substances, including, alcohols and ketones such as 3-methylbutanol, octen-3-one, octan-3-one, octain-3-ol, 2-octen-1-ol, 1-octen-3-01 and 1,10-dimethyl-trans-9-decalol (geosmin).

Other compound such as 2-methyl isoborneol and 2-methoxy-3-isopropylpyrazine, which may contribute to “musty”, “mouldy” or “earthy” odours associated with mould growth in damp buildings. The principal volatile of moulds is ethanol in damp buildings.

5.0 Environmental monitoring for mycotoxins

Mould spores contain a variety of biologically active molecules called mycotoxins other than allergens. There is adequate evidence that inhalation of fungi, particularly those that produce mycotoxins – results in immunological disregulation, with potential neurological effects i.e. interference with pulmonary macrophage function. It is also possible that straightforward mycotoxicosis from inhalation exposure occurs under some circumstances.

6.0 Environmental exposure and assessment of spores

The spores not just the vegetative mycelium, of many toxigenic moulds have been demonstrated to contain mixtures of the toxins, which are known to be produced by the species. For example, the conidia of number of moulds contains toxins, these include, *Fusarium graminearum* (DON), F. sporotrichioides (T-2), F. moniliforme (fumonisin), *Stachybotrys chartarum (atra)* (satratoxins), *Penicillium expansum* (citrinin), P, chrysogenum (roquefortine C), P. brevicompactum (mycophenolic acid), *Aspergillus versicolor* (sterigmatocystin), A flavus, A. parasiticus (aflotoxins).

Exposures to the spores of *Stachybotrys chartarum (atra)* from handling contaminated hay and a wide variety of symptoms associated with such exposures have been reported, including respiratory tract bleeding. Occupants of an office building and other cases of building related exposure to S. *chartarum* (atra) and its toxins contaminated by the organism have been reported to cause respiratory and other symptoms.

Fungal spores contain biologically-active B-1,3-glucan as a component in walls of spores and hyphae. A variety of substances in fungal spores, including mycotoxins and B-1,3-glucan, can then interfere with normal functioning of macrophage cells. Both inactivation and stimulation of pulmonary alveolar macrophage cells would have important physiological consequences, as macrophages are primarily responsible for the clearance of insoluble particles. The response of pulmonary alveolar macrophages and the immune system to B-1,3-glucan is only partially understood, but it appears that exposure causes inflammation reactions in lymphocytes affecting lymphocyte mitogenicity, affects IL-1 secretion (via T-calls) and stimulates bacterial and tumour defence. The glucan decreases the number of pulmonary alveolar macrophages and also phagocytosis.

Inhalation exposure to very high concentrations of fungal spores leading to hypersensitivity pneumonitis, lower levels of exposure to conidia also have consequences, for atopic and non-atopic individuals. In addition to allergic effects that they may have on atopics, such exposures apparently produce a variety of non-allergic effects on lung function, particularly interference with pulmonary alveolar macrophage cells. A variety of undesirable effects occur if sufficient numbers of these cells are damaged a variety of biochemical changes occur. Unusual exposure to fungal spores, alone and in combination with biotic and abiotic factors can be expected to promote viral and bacterial disease and decrease general well being (Rylander, R. & Goto, H., 1991).

Table 1: Monitoring for range and size of fungal species and symptoms in susceptible individuals.

Size (um)	Site	Symptoms	Fungi isolated
>10	Nose	Rhinitis Type I Allergic reaction Sneezing & Eye watering	*Alternaria spp.* *Epicoccum spp.* *Fusarium spp*.
4-10	Bronchi & Bronchioles	Asthma Type I Allergy	*Cladosporium spp.* *Mucor spp.*
2-4	Alveoli	Extrinsic allergic alveolitis Type III Allergy (a fever like condition) 4-6 hours after the exposure	*Aspergillus spp.* *Penicillium spp.*

Fungal spores and their concentrations differ greatly in allergenic potential. Generally exposure to really massive concentrations of spores is required (e.g. 500-3000 x $10^6/m^3$) to induce Type III allergenic reaction.

However if the occupants have a hereditary history of allergies of Type I and may already be allergic to pollen for example, they can react to lower concentrations of spores. Occupants most at risk from lower concentration of fungal spore's exposure are elderly and those on immuno-suppressant drugs.

The production and nature of the allergic response from exposure to mould spores in poor indoor air quality varies with the immunological reactivity of the subject, the nature of inhaled particles and the circumstances of exposure as described above.

8. Measurement techniques for assessing hazards, monitoring and risk assessment

A range of instrumentation is available for monitoring physical, biological and chemical pollutants in the buildings. For example, a range of instrumentation can be used to carry out biological risk assessment of moulds, bacteria and house dust mites in the indoor environment (photograph 5). The physical environmental monitoring for example temperature and humidity (see graph 1) can be carried out to determine the ideal conditions in the indoor environment.

The choice of sampler requires careful consideration of the purposes of the investigation, the information required, the characteristics of the biological pollutants in the environment being studied and the sampling and trapping efficiencies of the available samplers (Singh J, 1999)

Other methods include sampling airborne allergens, airborne mycotoxins, sampling volatile metabolites and endotoxins.

Similarly sampling methods for man-made mineral fibres, natural dusts and particulates, gases, vapours and fumes are available.

It is important to establish, from a health and safety point of view the following

- Maximum exposure limits
- Occupational exposure standards
- Compliance with regulatory standards

Moulds and Micro-organisms for example, bacteria, viruses, actinomycetes, pollens, house dust mite and moulds in the indoor environment.

Most common moulds in the indoor air are Cladosporium herbarum, Eurotium herbariorum, *Penicillium spp., Aspergillus spp., Wallemia spp.*

Most common moulds from indoor dust are Alternaria alternata, Aspergillus versicolor, Aureobasidium pullulans, Mucor spp., Phoma spp., and Yeasts

9. Legislation

The advisory committee on dangerous pathogens (ACDP) named and listed pathogens in various hazards groups on the basis of hazard.

Group 1: organisms that are the most unlikely to cause human disease

Group 2: organisms may cause human disease

Group 3: organisms that may cause severe human disease and represent a serious hazard

Group 4: organisms that cause severe disease and are a serious hazard and may offer a risk of spread in the community.

However microorganisms suspended in the air, either in tiny droplets of moisture (aerosols) or as dry particles, may enter the air passages during normal breathing. Most of the particles are filtered and rendered innocuous by the natural mechanisms in the nose, trachea and bronchi. If they are small they may escape this process and reach the bronchioles where they may irritate an infection or allergy.

Examples of the airborne infections are pulmonary tuberculosis, ‘wool-sorters' disease and the common cold.

10. Biodeterioration and health – an integrated approach

Deterioration of historical building materials such as in churches, abbeys, castles, monuments and buildings of historic and architectural interest are attributed to changes in the built environment. The main environmental parameters affecting the decay of materials are water, humidity, temperature and lack of ventilation Singh J 1993).

The majority of environmental problems are associated with building defects leading to water ingress, condensation and dampness in the building fabric (photograph 1,2 and 4). Careful monitoring for signs and symptoms of deterioration, for example, severe salt efflorescence, staining, blistering of finishes and timber decay in buildings (which mainly result from water penetration) is the key for successful ecological control (photograph 3).

The causes of deterioration are influenced by the internal building environment, which has a varied microclimate depending upon the building structure and the envelope of the internal building fabric (Douglas and Singh J 1995). Management of biodeterioration and health problems in buildings is a complex issue; it required a multi-disciplinary integrated approach, which combines the skills of material scientists, environment monitoring and health specialists, conservation science engineers and architects (Singh J, 1994a).

11. Environmental monitoring

To determine the causes of the above, environmental monitoring and investigation is best carried out. This is done by employing a range of hand held instrumentation, physical sampling and sensor technology to monitor various parameters within the fabric of the building.

12. Assessment of decay organisms

Assessment of the activity of decay organisms involves the following:

Detection of decay organisms

Identification of decay organisms

Assessment of the viability of decay organisms

Quantification of the state of decay

Environmental conditions assessment

Structural assessment of decay.

13. Diagnostic, environmental inspection

The diagnostic approach involves carrying out regular inspections using a range of instrumentation and non-destructive investigation techniques. This approach enables a specific maintenance programme to be drawn up and ensuring the loss of historic fabric is kept to a minimum (Singh 1994).

The total reliance on one method of inspection or isolation technique for pest infestation organisms is not ideal. A combination of the use of instrumentation with common sense is the best way forward (Singh J, 1991(a), Singh J 1991(b) Singh J and Aneja K R 1999, Singh J, and White N 1995).

For example a number of in-situ methods for decay assessment are available; however, these involve destructive techniques and have had varying degrees of success in detecting decay and predicting the residual strength of structural materials (Drdacky M, Palfreyman JW & Singh J, 1994).

14. Monitoring and mapping the indoor environment

Historic building materials, collections and contents, other structures is inherently susceptible to fungal and insect infestation and decay, if it is not kept dry and well ventilated. Once the infestation has started it will continue to propagate, if the conditions are favourable, until eventually the materials and special collections or artefacts can no longer sustain loads. It is therefore important that the building or structure is regularly evaluated for decay to prevent failure or collapse (Singh and White 1995).

Based on this information, environmental control measures can be put in place to prevent further advancement of the decay.

15. 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 (Hutton TC et. al 1991a, Hutton et al 1991b and Lloyd H and Singh J 1994). 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.

16. 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:

16.1 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.

16.2 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.

16.3 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

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.

17. 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.

18. Dry 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 (Bagchee K 1954, Singh J, et al., 1993, The Daily Telegraph, 9 November 1992, Singh J, White N 1995, White N, et. al 1995, White N, and Singh J 1995 and Singh J, Bech-Andersen J, et. al, 1993.

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 and Findlay 1982.

Remedial chemical timber treatment can cause damage to the health of building occupants and is a cause for concern to environmental health authorities (Dobson JR, Singh J 1993 and Dobson J et. al 1993)

19. Environmental monitoring, methodology and overview of approach

The first step to investigation of a problem building is to carry out a thorough inspection of the building for defects. The second step is:

- to establish moisture contents in affected materials, such as timber, plaster, masonry, insulation materials and textiles

- to establish the humidity, temperature and dew point in the environment. Both internally and externally

- to investigate in greater detail as necessary the moisture profiles in large dimension timbers and across masonry masses.

This information can be determined by:

Moisture contents of timber can be taken directly by the use of resistance based moisture meters. Probes can also be used to measure moisture contents at depth in large section timbers and those built into masonry.

Surface moisture readings in plaster and masonry can be taken using moisture meters. These will indicate if a wall is dry but can give false readings of dampness, see below.

Where possible mortar samples should be taken of the areas affected to determine accurately the moisture and salt content of the masonry. This does however have the disadvantage of not being non-destructive.

Data loggers can be used to measure the environmental parameters, temperature, Humidity and dew point both internally and externally.

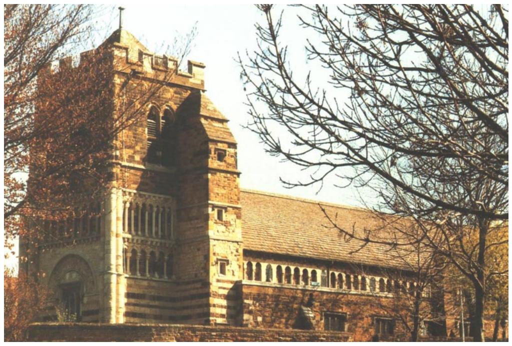
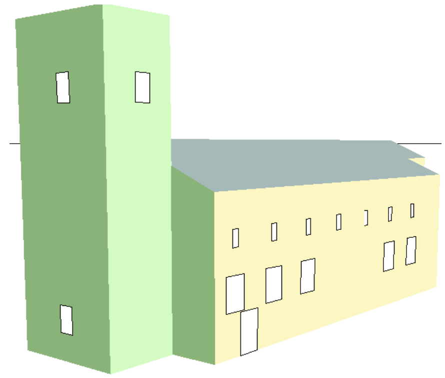
Specialist probes can be used to measure moisture across masonry walls.

The results of all or some of the above tests will establish the cause and enable a solution to the problem to be put forward.

19. Analysis of environmental data

Analysis of environmental data can take many forms, building simulation tools and techniques can be employed to analyse large quantities of historical environmental data. Building simulations should run concurrently with monitoring regimes to allow the developed models to be validated accurately.

They can be used to investigate many different areas effecting historical buildings. For example, investigating the impact of varying occupancy levels upon artefacts or the effect of altering the internal conditions to provide cost effective conservation solutions.

20. Mothballing

Mothballing is preventative conservation and is the best way forward for cost effective environmental management of deterioration to historic fabric, contents, decorative finishes and fixtures.

The key elements in mothballing of buildings are minimising further water ingress in the building and encourage natural drying of saturated areas of buildings. A range of different types of technique can be used for example:

- rectifying defects in downpipes and guttering and clearing out valley and other blockage in the rain water drainage systems.

- accelerating under floor ventilation by lifting one or two floor boards along the external elevations and set aside for reuse.

- encourage general ventilation in the building by opening up windows and internal doors, clear chimney flues, clear roof void of storage goods to encourage cross ventilation.

- removal of moisture saturated materials from the building for example floor coverings, debris and unwanted storage goods.

These measures will bring changes in the environmental conditions of the building and as a result of this the microorganisms will struggle to grow and proliferate as the optimum conditions for their survival is not met and will dramatically reduce the risk of further infestation in the building.

21. Environmental conditions

Fungi in general have a very wide temperature tolerance range from 0°- 60°C. Relative humidities exceeding 65% are generally required. They have very simple food requirements, being sustained by only small amounts of simple sugar and other organic matter. The nutrient requirements of fungi are satisfied in the built environment by dust and organic deposits. Air movement can provide sufficient oxygen. Only water availability limits the growth of fungi in buildings.

Water availability in buildings depends upon its source and movement, the occurrence of moisture reservoirs and sinks, heating, insulation, ventilation, external conditions, orientation of the building, materials and occupants. These interrelationships are very complex and one cannot draw conclusive evidence in relation to the moisture availability, growth of fungi and resulting indoor air quality.

22. Stabilising the historic environment

Once the above investigations have been carried out a strategy can be put forward to stabilise the building environment.

It is important to stabilise the historic building environment. For the holistic and sustainable conservation and preservation of the building, various building works will be required to prevent further water penetration and to maximise ventilation to damp affected materials.

Correction of these building defects, combined with measures to dry down the wet areas and to protect the decorative interior finishes by allowing ventilation of the wet areas, will prevent further deterioration.

Until the drying out of the building fabric and its associated timber elements is completed, any other actions to remedy the deterioration problems will be ineffective and a waste of time and resources. Continuous long-term monitoring and preventative maintenance of the building may be necessary and will provide the following information:

- on the state of moisture equilibrium and balance (moisture sources, reservoirs and sinks) in the building environment, building fabric and structural elements as the building dries out;

- will allow co-ordination and scheduling of work stages to prioritise the remedial work to achieve acceptable levels of moisture in the masonry and timber to prevent future deterioration problems;

- will allow a cost-effective, long-term holistic approach to environmental stabilisation of the historic environment.

23. Environmental management and sustainable holistic solutions

Fungal and Insect problems in both modern and historic buildings are mainly the result of defects in buildings, lack of maintenance and gross neglect (Robinson W H, 1996). Rectifying these defects and by ensuring proper maintenance can provide long-term sustainable, holistic solutions to these problems. Correct identification of the infestation by an independent scientist is the vital key to all such problems, as all infestation is not equally destructive. By employing a range of non-destructive inspection techniques, much of the original fabric can be retained. The environmental approach is beneficial to the building fabric, occupants and to the wider environment. Much damage has been inflicted in last Century by dealing with the symptoms of the problems and not with the causes. By proper understanding of the courses, its repetition should be avoided in this Century.

Just like the physicians and surgeons use stethoscope and keyhole surgery to examine the internal organs and check their patients, the building pathologists can use a range of non-destructive instrumentation to check their buildings. This will save unnecessary exposure work and the destruction of the historic fabric. Non-destructive inspection techniques enable the condition of materials and contents of the buildings and collections to be ascertained without opening much of the building fabric; they are therefore especially valuable in buildings of historic and architectural interest

Much damage has been inflicted in the last century by dealing with the symptoms of the problems and not with the causes. By proper understanding of the causes, its repetition should be avoided in this century.

24. References

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Photograph No 1: Lack of maintenance and general neglect causing deterioration

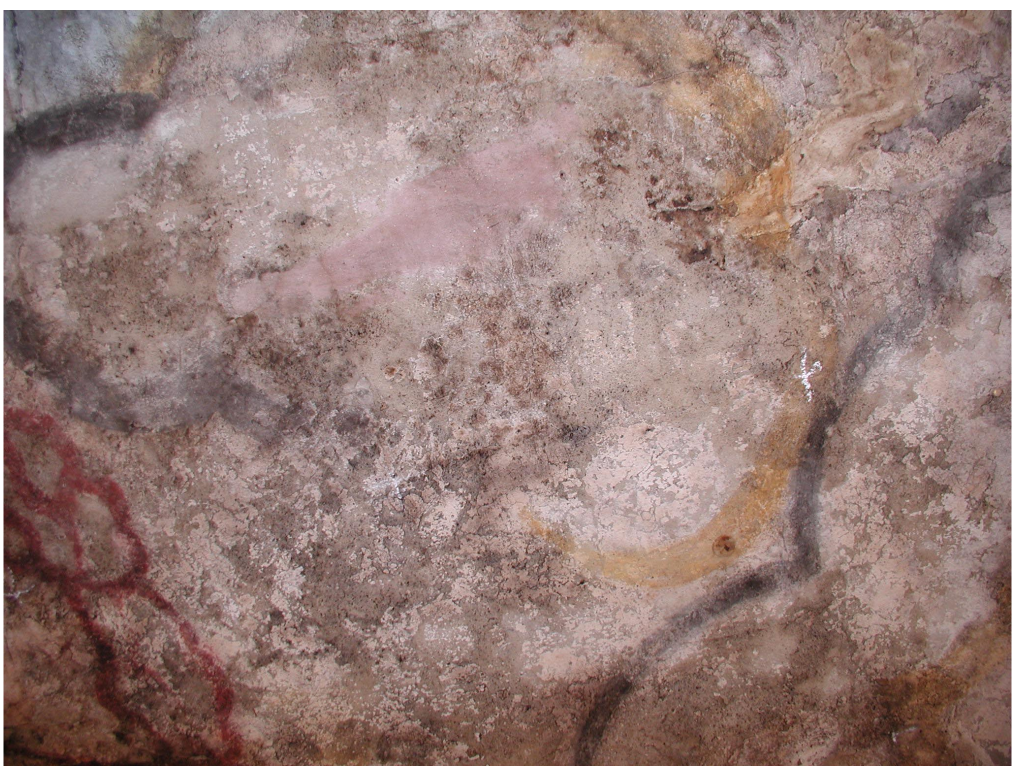
Photograph No 2: As a result of the above leads to water ingress, salt efflorescе and dry rot infestation.

Photograph No 3: Timber moisture meter to measure the moisture content of timber.

Photograph 4: Dry rot (Serpula lacrymans) fruiting bodies to the timber staircase**.**

Photograph 5: Monitoring moulds colony forming units in an office environment

Photograph 6: Mould growth to a painted historic wall frescoes



Graph 1

Environmental monitoring of temperature and humidity for health, comfort and productivity in an office building