HISTORIC SCOTLAND

Technical Conservation Group

Technical Paper 6

Indoor air quality and energy efficiency
In traditional buildings

Sandy Halliday
(Gaia Research)
March 2009

Indoor Air Quality and Energy Efficiency in Traditional Buildings

for Historic Scotland

Scoping Study

Final Report

HISTORIC SCOTLAND

By
Sandy Halliday
Gaia Research
For
Historic Scotland

Dated: March 2009

Contents

Summary ____ 4

1 *Introduction* ____ 6

2 *Aim and Objectives* ____ 7

3 *Context* ____ 8

4 *Human Health and Air Quality Issues* ____ 9

5 *Pollution Mitigation Strategies and Energy Efficiency* ____ 15

6 *Literature Review – Principal Papers* ____ 21

7 *Case Studies* ____ 30

8 *Conclusion and Scope for Further Research* ____ 37

9 *Bibliography* ____ 39

Summary

This short report is the result of a scoping study undertaken for Historic Scotland. The study comprises a brief overview of indoor air quality and energy efficiency issues in traditional buildings of relevance to Historic Scotland. It has involved a desk study of existing publications, web based information and ongoing research.

The context of the study is the desire to better understand indoor air quality issues in buildings in Scotland at a time when there is an imperative to address problems of resource consumption, the contribution of carbon dioxide emissions to climate change and issues surrounding building-related ill-health. All of these issues are being tackled by regulatory and fiscal measures that also seek to improve energy efficiency in buildings.

New buildings are designed to more stringent energy standards than traditional buildings with increasing standards of insulation imposed through the latter part of the 20th C, and more recently increasing focus on the need for air tightness. Concerns have been expressed about the impact on indoor air quality that may result from changes to the envelope of a building. It can be deduced from fundamental principals that such changes have the potential to affect indoor environmental quality. For example, by reducing draughts in a building the heat loss will be reduced, however, this may also have adverse implications for the building's ability to deal with moisture. The choice and location of insulation material may also impact on a building's ability to manage moisture. Buildings therefore need to be dealt with holistically.

Particular concern is raised about the potential chemical loads in buildings due to a number of factors, including the prevalence of furnishings, finishes and cleaning agents that may contain potentially harmful elements that can become air borne. The wide use of fire retardants and volatile organic compounds is a relatively recent phenomenon and inevitably there is concern about the quantities, their impact and their synergistic effects. The choice of insulation material, whether new or retrofitted, may also introduce toxins. Hence the issue transcends building age and touches on a range of physical properties of buildings from their response to temperature and moisture and the control of air movement, to fixtures, fittings and furnishings, and to the habits and preferences of occupants.

The energy efficiency of buildings of different ages has been the subject of study in house condition surveys in both Scotland and England.[1] Findings indicate that the energy efficiency in older domestic buildings is lower than that found in more recent construction types. Organisations involved in promoting energy efficiency and those involved in the care of the historic environment have published guidance notes outlining energy efficiency measures that can be adopted in traditional buildings.[2] Yet, even agreeing on comfortable conditions and the implications for energy efficiency is a thriving debate.

[1] Scottish House Condition Survey, Key Findings (2007), The Scottish Government
English House Condition Survey, Technical Report (2005), Department of Communities and Local Government

[2] Warm, P., Oxley, R., (2002), Guide to building services for historic buildings – Sustainable services for traditional buildings, CIBSE, London

This study identified very little published research into chemical loads in buildings and found that issues associated with maintaining a healthy indoor environment are barely touched upon. It identified no studies of the effect on human health of making changes to traditional buildings to meet energy efficiency targets.

It is likely that legislative measures to improve energy efficiency in new homes will be extended to the renovation of traditional dwellings in order to meet stringent targets that cannot be met by focussing on new building alone. It is vitally important that the potential consequences for indoor air quality are well understood.

It is worthwhile to note that only about half of the CO_2 emissions from existing homes result from heating, and are therefore responsive to changes in fabric. There are in fact numerous ways to significantly improve energy efficiency including specification of efficient lighting and appliances, domestic hot water management, and occupant guidance. As such measures are unlikely to affect indoor air quality they might be further investigated and promoted by Historic Scotland but are not touched on further in this report.

There is a widely held belief that traditional buildings have better indoor air quality than more recently constructed ones due to higher ventilation rates. The study found little evidence of comparisons of indoor air quality in buildings of different ages, hence this could not be substantiated. Anecdotal evidence would indeed highlight traditional buildings that exhibit both draughty and stuffy rooms, which is highly dependent on how buildings and individual rooms are occupied and used.

Intermittent, though sometimes highly public debate is generated around the subject of building health and durability resulting from changes in construction but there is little evidence that the industry, policy makers or the public is well informed on such matters. There is a need to address this issue, especially within the context of remedial works undertaken to improve energy efficiency. There would also be benefit in investigating further the impact of material choice on the internal environment in traditional buildings. It may be that the research would also inform policy on new forms of construction, furnishing and fit out.

We have concluded that there is a dearth of research in this area. The issue is not simply one for Historic Scotland, it is an issue for Scotland as a whole. Appropriate information on the relationship between energy efficiency and indoor air quality in traditional and new build homes is vital if we are to secure a safe and healthy built environment for all.

The scoping study presents case study examples of buildings that demonstrate some of the issues. We were unable to identify many studies where energy and indoor air quality were both considered.

The study concludes with recommendations on future research that might assist Historic Scotland to be able to appropriately respond to, engage in and influence debate and policy. The best sources of information, that could be the foundation for future work, are highlighted in an annotated literature review. As the variables are incalculable, future research should be focused on strategic guidance and a precautionary approach.

1.0 Introduction

There is wide spread recognition that conditions inside buildings are a factor in human health, particularly in breathing related disability. People in developed countries spend up to 90% of their time indoors and as a consequence the impact of internal air on human physiology is important. There are numerous cases where buildings have been associated with ill-health in individuals or sectors of a population. However, issues concerning health effects of buildings are complex, and a wide range of environmental and genetic factors are known to be involved. Consequently, there has been no conclusive evidence on the causes of building related ill-health and slow progress towards determining appropriate responses.

In recent years houses have been designed to be better insulated and more tightly sealed to achieve much needed energy efficiency improvements. Fresh air requirements have been increasingly regulated with mechanical ventilation, with heat recovery, increasingly becoming the norm. Refurbishment of traditional houses has led to chimney flues being sealed off, and windows sealed. These changes have dramatically reduced the amount of ventilation in most homes compared to a generation or two before. In energy terms this is highly beneficial as there is a need to have adequate ventilation without the energy loss or energy use with which it can be associated. However, there is a concern that changes to building fabric in pursuit of energy efficiency can lead to a build up of pollutants and/or to excessive moisture levels in some circumstances. The reasons for this are wide-ranging.

A build up of internal pollution can result from treatments, finishes and activities within a building. Internal moisture levels are dependent on a wide range of variables including external moisture, ventilation, indoor activity and the ability of a building to deal effectively with changes in moisture due to its properties of thermal and moisture mass. Research by Fanger, in the 1970s, into air quality in commercial buildings identified input ventilation systems as a principal source of indoor pollution.[3] The quality of the external air, as well as maintenance regimes,were both identified as contributory factors.

In the commercial sector building design norms have changed from traditional tall rooms with predominantly natural ventilation and daylight to sealed rooms of relatively low height with mechanical ventilation and predominantly artificial lighting. This opened up the potential for deep plan buildings where internal rooms had no external windows, daylight or views. The perceived commercial benefit of more floor area for a set footprint proved to be marginal due to the need for plenum layers at each level to carry mechanical services. The legacy from this intermittent era is deep plan buildings with internal rooms that cannot be naturally ventilated or daylit.

Fanger's research showed that the mechanical ventilation systems that replaced natural ventilation were problematic. In a study of 15 offices: - 25% of the internal pollution derived from smoking, 20% from materials & furnishings and 42% from the ventilation equipment. The approach to building design has subsequently given way to taller rooms and a move back towards natural systems, views, daylight and well-controlled natural ventilation in contemporary commercial buildings. Natural ventilation has, however, become increasingly difficult to achieve as external environments have become increasingly noisy and polluted.

[3] Fanger P.O. et al. (1990) *A simple method to determine the olf load in a building, Fifth International Conference on Indoor Quality and Climate* (Indoor Air '90), Vol. 1, pp. 537-42.

2.0 Aim and Objectives

2.1 Aim

The aim of the scoping study is to highlight the research on energy efficiency and indoor climate issues that has been undertaken to date that might be of relevance to Historic Scotland (HS) and to identify any gaps that HS may wish to take account of in procuring further research.

2.2 Objectives

The following objectives have been identified for the scoping study:

a) Understand and review the extent and depth of existing research work on air quality in traditionally built houses in Scotland.

b) Discuss energy efficiency in relation to building design and indoor climate issues.

c) Identify and explain the key themes/subject areas (such as materials choice, toxicity, moisture management, ventilation and thermal mass) and provide an overview of each and their relevance to traditional buildings.

d) Explore the role of ventilation in historic buildings. Outline health considerations resulting from poor ventilation and the type of passive mitigation for this.

e) Understand the issues surrounding the toxicity of materials and the effects on indoor air quality and the wider environment, and ways that traditional materials can play their part in mitigating these effects.

f) Articulate the role of natural internal finishes in passively managing internal humidity.

g) Use case study examples to demonstrate ‘best practice’ examples of refurbishment or existing scenarios.

h) Identify areas/gaps in existing literature and research that could be effectively filled by Historic Scotland commissioned work.

i) Collate a literature review, with an annotated bibliography, covering the key areas.

3.0 Context

The concept of sustainable development has emerged as a major driver of policy and legislative change aimed at increasing quality of life for all.

The Scottish Government has set a target of an 80% reduction in greenhouse gas emissions from 1990 levels by 2050. To date the majority of policy initiatives have focused on new build. This is despite the estimation that the over 70% of the buildings that will be standing in 2050 have already been built[4]. There is therefore a real and pressing need to develop coherent guidance on how best to incorporate energy efficiency measures into existing buildings.

Historic Scotland are fully aware that older buildings have a contribution to make in combating climate change and are actively engaged in identifying appropriate solutions that maximise benefits. Historic Scotland also understand that there is a need to better understand indoor air quality issues in buildings in Scotland and are actively seeking more information in relation to traditional buildings.

There are over 600 conservation areas and 47,000 listed buildings of specific historical or architectural interest in Scotland. The nation as a whole recognises that it is important that due care is given to preserving the character of traditional buildings and areas. In addition and in line with national, and international targets on CO_2 reduction, it is also important that renovations of traditional buildings make best use of existing and emerging practices to increase energy efficiency. It is vital that this is not done in a way that compromises the integrity of the buildings or the comfort or health of occupants.

There are a number of challenges that face those making alterations to buildings of traditional construction. Careful planning and attention is required to ensure that any proposed works will be beneficial and effective whilst preserving the historical character of the building. It is important to understand the type of construction, the materials used and the probable impact of any proposed changes. Furthermore, many modern building techniques are incompatible with traditional methods and can have adverse repercussions if applied.

It is imperative that any alterations seeking to improve energy efficiency make maintaining or improving on indoor air quality a central focus of any works. This will include consideration of a building's ability to regulate internal moisture levels and ensuring that materials introduced do not have a deleterious effect on human and environmental health.

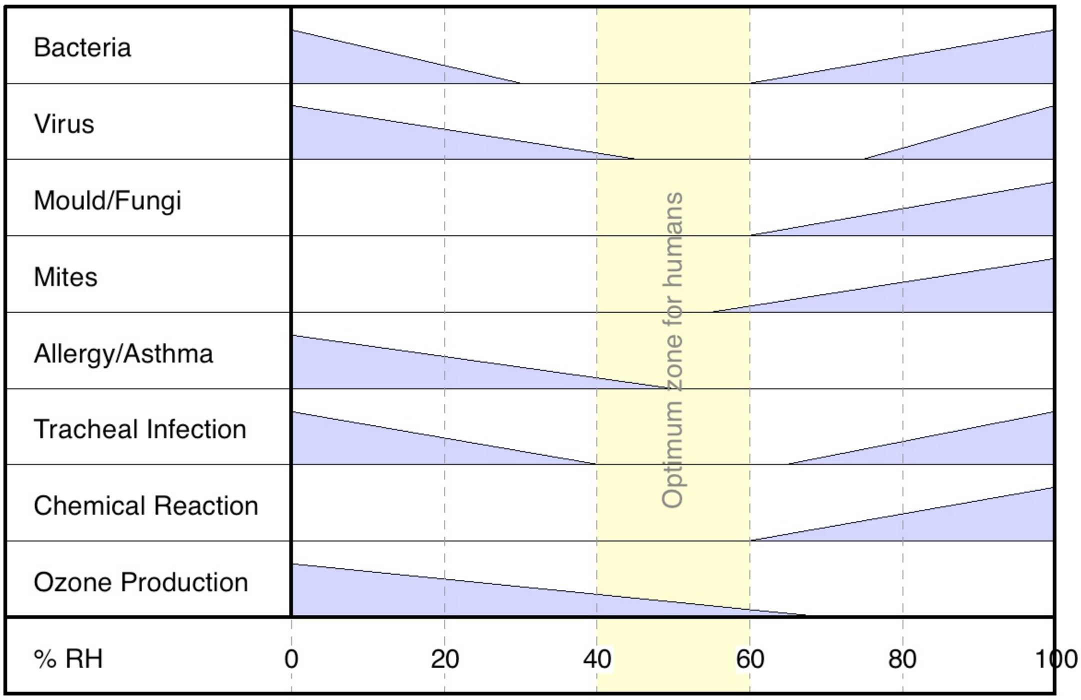
[4] UK Green Building Council, Report on carbon reductions in new non-domestic buildings, Department for Communities and Local Government, 2007

4.0 Human Health and Air Quality Issues

There is real and increasing concern that indoor conditions can adversely affect human health and well-being, including that they are a factor in breathing related disability. Issues concerning health effects of buildings are complex, and a wide range of environmental and genetic factors are involved. Consequently, there has been no conclusive evidence on causes and slow progress towards determining appropriate responses. Meanwhile, in recent decades, the problems of breathing related disabilities have got notably worse.

Evidence indicates that 1 in 13 adults and 1 in 8 schoolchildren in the UK currently suffer from asthma whilst over 40% of people suffer from some kind of allergy.[5] Principle triggers include damp, relative humidity (both high and low), the proliferation of dust mite allergens and the presence of other known allergen such as formaldehyde.

Figure 1: -Arundel, V., et al. Indirect Health Effects of Relative Humidity in Indoor Environments[6]



A danger of close controlled ventilation systems is that they can result in the internal environment oscillating rapidly between the optimum of 40 -60% humidity. This rapid oscillation can create the worst of situations by generating all of the conditions in which health problems arise. There is little research identified into the potential for improved conditions by enabling the changes to happen more slowly using passive means such as hygroscopic materials.

There is also growing evidence to support a cautious approach to the use of chemicals in the internal environment. The identification of single toxic materials, within a more complex cocktail of products and materials, and proof of their

---

[5] 2004 Asthma Audit, National Asthma Campaign

[6] Arundel, V., et al. Indirect Health Effects of Relative Humidity in Indoor Environments, Environmental Health Perspectives, Vol. 65, pp. 351-361, 1986

contribution to a hostile indoor climate, is difficult to determine hence the need for a precautionary approach.

Some of the principal factors: - environmental, chemical, and materials, known to have an impact on indoor health are identified and discussed below.

4.1 Volatile Organic Compounds

Volatile organic compounds (VOCs) are chemicals that are emitted as gases from certain solids or liquids at room temperature. VOCs include a number of chemicals that are known to be detrimental to human health. Risks are posed through high-dose short-term exposure and long-term low-level exposure. Symptoms can include eye, nose and throat irritation, headaches, loss of co-ordination, nausea, damage to the liver, kidney and central nervous system[7]. Some VOCs are suspected or known carcinogens. VOCs are found in a wide range of building products including paints, varnishes, wood preservatives, glues and adhesives as well as cleaning products. VOCs are generally found in far greater quantities indoors than outdoors.

Studies have shown that VOC levels are highest in new or newly decorated homes, due to increased emission rates from new materials and recently applied finishes and adhesives. Excluding recently built or decorated homes; there is no evidence of a correlation between building age and VOC levels.

The five factors identified with increased levels of VOCs were:

- Stored materials or car/fuel
- Decorating/fittings and furnishings
- Combustion of gas
- Petrol
- Combustion of petrol and/or tobacco

Many of the materials originally used in traditional building construction emit little or no VOCs. This has led to a resurgence of some traditional materials and finishes such as protein glues, limewash and linoleum. There are also a number of modern building materials that do not emit VOCs such as cellulose insulation and a new generation of paints.

4.2 Aldehydes

An aldehyde is a highly reactive organic chemical generally formed through the oxidisation of primary alcohols. Formaldehyde is the principal aldehyde found in the indoor environment. It is present in many natural materials such as wood, but at very low levels of concentration. It is also found in products that contain the adhesive urea formaldehyde such as pressed wood (i.e. particle board) and insulation. Formaldehyde is also a product of combustion. Concentrations are generally highest in new materials. Formaldehyde will cause irritation to the eyes nose and throat. It is a registered carcinogen and a known asthma trigger.[8]

Formaldehyde is predominantly used in new materials and furnishings, and reducing exposure in buildings of any age can be achieved through product selection.

---

[7] www.epa.gov/iaq/voc.html

[8] http://www.iarc.fr/en/Media-Centre/IARC-Press-Releases/Archives-2006-2004/2004/IARC-classifies-formaldehyde-as-carcinogenic-to-humans

4.3 Lead

Lead has been used for centuries in buildings. However its compounds are known to be a harmful environmental pollutant and poisonous to humans. It can cause nerve damage and blood and brain disorders.

The predominant risks from lead in traditional buildings arise from the removal of lead paint or through the presence of lead in dust[9]. Lead-based paint was used extensively before the First World War but its use continued until the 1980s.[10] [11] Lead-based paint only becomes a serious hazard when it is disturbed and the particles can be inhaled or ingested. Tests are required to identify the presence of lead in painted surfaces. Although a general ban on the use of lead paint has existed since 1988, an exception was made for the use of lead paint for works of art or listed historic buildings[12]. Care should be exercised during all renovation work to ensure that dust is removed effectively.

4.4 Carbon Dioxide

Carbon dioxide (CO_2) is generated in the home through human respiration and the combustion of fossil fuels. High concentrations of CO_2 in a building will cause occupants to feel drowsy and lose cognitive functioning and may cause headaches. High levels are indicative of inadequate ventilation. It is essential that adequate levels of ventilation are maintained in buildings when adopting measures to increase energy efficiency through reduced air infiltration.

4.5 Carbon Monoxide

Carbon monoxide is a highly toxic gas and can kill quickly without warning. It colourless and odourless and is a product of incomplete combustion of fossil fuels including gas, oil, wood and coal. Carbon monoxide poisoning is a significant risk in buildings with defective fossil based heating systems. Effects include nausea, unconsciousness and death. Dangerous build up of carbon monoxide is a significant risk in all buildings where fossil based systems are not adequately maintained and where there is insufficient ventilation.

4.6 NOx

The most common oxides of nitrogen found in the home are nitrogen dioxide (NO_2) and nitrogen oxide. Both are toxic and can cause eye nose and throat irritation as well as impaired lung function and respiratory problems. Nitrogen dioxide can also cause increased symptoms in asthmatics. Fossil fuel combustion is the principal sources of indoor NOx. Ensuring that appliances in buildings are well maintained and that rooms are properly ventilated will reduce NOx.

---

[9] http://www.epa.gov/iaq/lead.html

[10] Hazardous Building Materials – A Guide to Selecting the Alternatives

[11] http://www.defra.gov.uk/environment/chemicals/lead/index.htm

[12] www.defra.gov.uk/environment/chemicals/lead/advice4.htm

4.7 Particulate Matter

Particulate matter refers to fine particles of a solid or liquid that are suspended in a gas. This can be produced naturally (e.g. by volcanoes or dust storms) or released to the atmosphere through process such as through the burning of fossil fuels in vehicles, power plants or industrial processes.

Increased levels of particulate matter in air is related to heart disease, altered respiratory function and lung cancer. Particles smaller than 10 micrometers (PM10) pose particular threat as they are not filtered out by the throat or nose and can enter the bronchi and lungs.

Particulate matter can be generated by activities within the home, as well as entering the internal environment from outside. In many cases increased particulate matter can be attributed to poor cleaning regimes, outdoor air pollution levels or environmental tobacco smoke. Of particular relevance to traditional buildings is the operation of any fire, furnace or woodstove.

4.8 Damp and Condensation

Damp, condensation, and associated mould growth, are significant problems in some buildings. In principle all buildings, of any age, are vulnerable. Problems arise through poor maintenance of an existing building, bad design – including cold bridging or inadequate ventilation, and/or poor construction. It can also arise through inappropriate materials used for repairs and modifications.

The major sources of damp in traditional buildings are rainwater penetration, rising damp, lack of uniformity of surface temperatures and condensation. It is recognised as one of the major causes of decay in traditional buildings if inadequately dealt with[13].

The Scottish Housing Condition Survey found that over 1 in 10 buildings in Scotland have condensation in one or more rooms and around 1 in 20 buildings suffer from rising or penetrating damp[14] (Note: This data does not account for building age). The English House Condition Survey found that 6% of pre 1919 buildings suffered from condensation or mould and 21.7% suffered from some form of damp[15]. This is significantly higher than buildings built post 1919.

A number of studies have drawn a correlation between the presence of damp and a number of health effects. A study of 597 households in public housing in Edinburgh, Glasgow and London found that damp and mouldy living conditions have an adverse effect on symptomatic health, particularly among children[16]. A study of 699 adults in Finland found that those who report moisture in their homes are more likely to suffer from sinusitis, acute bronchitis, nocturnal cough, nocturnal dyspnoea, sore throats, colds and tonsillitis[17]. A similar study in Finland observed an increased

---

[13] Thomas, A., R., et al. The Control of Damp in Old Buildings, SPAB, 1992

[14] Scottish House Condition Survey, Key Findings 2007, The Scottish Government

[15] Summary Statistics Table SS5.1: Damp and mould – homes, English House Condition Survey Standard Tables, 2006, Department of Communities and Local Government

[16] Platt, S., et al. Damp housing, mould growth, and symptomatic health state, British Medical Journal, 1989, 298:1673-1678

[17] Koskinen, O.M., et al. The relationship between moisture or mould observations in houses and the state of health of their occupants, European Respiratory Journal, 14(6): 1363-1367

occurrence of common respiratory infections and moisture damage in school buildings[18]. There are many other publications on the issue. The publication Damp Indoor Spaces and Health discusses the issues extensively[19].

4.9 Moulds and Bacteria

Fungal contaminants grow at moisture levels exceeding 60% RH. They produce a variety of toxins in the form of airborne spores that can adversely affect health and are associated with respiratory allergies. They are prevalent in damp areas such as poorly ventilated bathrooms and kitchens and where there is water leakage or lack of uniformity of surface temperatures through cold bridging. It is absolutely necessary to remove fungal growth in order to protect occupant health. The problem is best addressed by removing the cause of moisture ingress, damp or condensation that gives rise to conditions in which mould and harmful bacteria can proliferate.

The vast majority of bacteria are harmless and some may even be beneficial. However, the accumulation of pathogenic bacteria in the indoor environment can seriously impact on the health of occupants. Mould growth is usually accompanied by bacterial growth. Maintaining a relative humidity of under 60% significantly reduces the potential for growth. Some indoor sources of bacteria originate from poor cleaning regimes, through exposure to contaminated water or through exposure to infected human hosts. High levels of bacteria in ventilation systems have been identified as a source of building related ill-health.

4.10 Dust Mites

An estimated 5.1 million people in the UK suffer from asthma of which over 80% are allergic to the house dust mite. This equates to nearly 7% of the UK population and is a very significant factor in the provision of a healthy indoor environment. Mites are commonly found in bedding, pillows, carpets, soft toys and furnishings. No studies identified have suggested that building age is a significant factor in dust mite concentrations,

Research has indicated that strict allergen avoidance and cleaning regimes can both reduce asthma/allergy attacks and improve control. Effective moisture control is also a significant factor in controlling dust mite colonisation. Dust mites are most active between 40% and 70% relative humidity. Good control by whatever means may also reduce sensitisation and contribute to prevention of the development of asthma and allergies.

4.11 Radon

Radon is a naturally occurring, radioactive gas. It is emitted from soils and rocks that contain small quantities of uranium and can be emitted from ground or some building materials. It occurs in potentially dangerous concentrations in some regions of the UK. These are identified in the Building Regulations. Radon is officially the second largest cause of lung cancer in the UK after smoking[20].

---

[18] Husman, T., et al. Respiratory Infections among children in moisture damaged schools

[19] Damp Indoor Spaces and Health, Institute of Medicine: Committee on Damp Indoor Spaces and Health, The National Academy Press 2004

[20] www.cancerhelp.org.uk/help/default.asp?page=2962 accessed 18/12/08

It disperses quickly in the atmosphere and does not usually present a hazard. However, due to its high density, it can accumulate under buildings in some circumstances, and seep into buildings through cracks and openings. Concentrations of radon are influenced by location, the construction type and the degree of ventilation. It can subsequently be affected by any modification or renovation to a building. Modern buildings in high risk areas are designed to minimise radon related risks.

Testing buildings for radon is a relatively simple process. If levels are found to be in excess of The Health Protection Agency advised safe levels then action is recommended. Mitigation strategies generally involve modifying the way the building is ventilated.

4.12 Conclusions

In general, building age or type will have marginal impact on the occupants' exposure to potential pollutants. More generic factors such as building location, materials, finishes and furnishings, the provision of adequate ventilation, how a building is operated and the state of repair will have more influence.

There is evidence to indicate that there is a greater incidence of damp in traditional buildings. The state of repair will clearly be a factor. Damp also occurs in modern buildings due to poor quality of construction and can occur anywhere due to poor cleaning and maintenance regimes. Condensation can occur anwhere that there is lack of uniformity of surface temperatures.

There is the possibility that certain pollutants may accumulate over time, for example, in dust. However, this phenomenon is also not restricted to traditional buildings.

Careful consideration needs to be given to aspects of a minority of traditional buildings that can pose significant and severe health risks if disturbed, such as where lead paint is found. This is extensively covered in guidance and legislation.

The following section will discuss some of the key areas for consideration in the mitigation of indoor pollution, and summarise the related energy efficiency issues.

5.0 Mitigation Strategies and Energy Efficiency

This chapter comprises of a brief overview of the guidance on how design can contribute to delivering both good indoor air quality and energy efficiency.

5.1 Ventilation and Infiltration

The rate of air exchange within a building is an important factor in the accumulation of many indoor pollutants.

It is important to distinguish between ventilation and infiltration. Infiltration refers to uncontrolled seepage of air into a room or a space through for example cracks in the building fabric, around windows and under doors. Reducing infiltration by sealing holes and cracks in the building fabric, draught proofing windows and doors and creating draught lobbies and installing internal doors can all be effective measures in reducing the flow of pollutants into, and the heat lost out of, a building. They are generally simple and cost-effective to employ and maintain. However, attention is required to ensure that the airflow throughout a building is not overly restricted. The requirement for fresh air and the need to disperse and remove internal pollutants and moisture is the limiting factor when adopting such measures.

Ventilation is the design of openings or systems to provide a desired air exchange rate that is sufficient to remove or dilute smells, airborne pollutants and moisture from occupied spaces. Ventilation should be specifically designed to remove moisture and pollutants from the internal environment. The extent to which these elements are present will influence the ventilation requirement. The issues are therefore interconnected. There is no standard approach to ventilation. Each room in a building needs to be considered individually and no single ventilation strategy will suit all spaces within a building due to differences such as occupancy patterns and use.

Ventilation can involve mechanical systems to move air. Alternatively it can exploit natural forces such as the stack effect and the differing pressures on a building façade to create the required air movement. Using passive measures to control humidity (such as hygroscopic materials (see 0)) and avoiding polluting building materials can reduce the requirement for ventilation and increase potential energy savings. Ensuring that a building is well maintained can have a significant impact on the presence of damp and therefore can also impact the ventilation requirement.

Contemporary best practice in building design is moving from a strong reliance on mechanical systems towards exploitation of natural forces – with mechanical systems as supports for natural systems rather than as substitutes for them. In some circumstances, it may be beneficial to seal windows and doors next to busy roads where pollution is higher, or locate inlets for mechanical ventilation systems away from busy roads.

Air quality sensors or occupancy sensors can be used to improve the effectiveness of ventilation strategies. Sensors that monitor CO_2 or indoor humidity levels are increasingly used to activate mechanical systems or to draw attention to the need to control vents or window openings, in response to indoor air quality. This can be an effective means of controlling ventilation in buildings or rooms with varying occupancy such as occurs in schools, museums or sports buildings. These can be fitted retrospectively. Infrared sensors can also be installed to adjust ventilation rates according to whether a space is occupied or empty. Such systems need effective control, calibration and maintenance, but can reduce energy consumption.

5.1.1 Ventilation in Traditional Buildings

The vast majority of traditional buildings were passively ventilated with varying results. In many cases some additional ventilation such as an extractor fan in a kitchen or bathroom has been retrospectively installed. Subsequent work may have removed or restricted original sources of ventilation. Internal doors may have been added and chimney and flues sealed, blocking traditional airflow paths. Some traditional buildings will have undergone more extensive refurbishments and/or changes of use. Floor plans may have changed and additional floors been added.

Due to the leaky nature of older buildings, energy efficiency measures predominantly focus on reducing air infiltration. This has to be done in a way that gives full consideration to the management of moisture and indoor pollutants. Reducing the amount of ventilation or infiltration in traditional buildings through modification or renovation can potentially have a serious impact on the ability of the building to deal with indoor pollutants and moisture and needs to be considered carefully.

Although there are rules of thumb (see 6.1) that govern the appropriate ventilation rates in traditional buildings the particular conditions in a building need to be assessed through inspection, investigation and monitoring.

Changes can be done in a way that preserves or enhances a traditional ventilation strategy, or undermines it. In some cases, original ventilation strategies will have been poorly designed and inadequate for the healthy functioning of some buildings or rooms, and require additional means of ventilation to be added through time. A building or room may also suffer from excessive ventilation, resulting in a draughty and inefficient space.

In traditional rooms with insufficient ventilation, there would be benefit in increasing ventilation rates particularly in areas with a higher concentration of pollutants or moisture. For example, if sub floor vents have been blocked then this could have an impact on the ability of the building to deal with ground moisture and the removal of radon. Re-establishing such ventilation paths would generally be beneficial.

5.2 Relative Humidity (RH)

Relative humidity is a measure of the water vapour present in a gaseous mixture of water and air. It is expressed as a ratio between the amount of water present in the air at a given temperature over the maximum amount that could be present in the air at that temperature. The maximum relative humidity (i.e. 100% RH) is referred to as the dew point.

Maintaining an adequate relative humidity is an important factor in creating a healthy indoor environment. High indoor relative humidity can lead to mould growth and dust mite proliferation. High or low relative humidity can increase the occupants' susceptibility to bacteria and viruses as well as increasing symptoms of allergic rhinitis and asthma. Maintaining a relative humidity in the range of 40 – 60 % is considered optimum. Traditional buildings deal with moisture in the air through a combination of ventilation and passive moisture management, with varying success.

5.2.1 What Affects Moisture?

In order to maintain the moisture equilibrium in a traditional building the materials need to be able to release moisture through evaporation, both to the external and internal environment. The ability of a traditional building to maintain this balance depends on the following factors:

- Provision of sufficient ventilation to remove internal moisture
- Use of hygroscopic materials to maintain traditional methods of moisture transfer
- Minimising barriers to moisture flow

Any changes to the fabric or the heating or ventilation strategy in a building can impact on the ability of the building to deal with moisture and must be carefully considered. Problems will occur when the flow of moisture through materials becomes restricted trapping the moisture in the material, where condensation occurs (either in unheated areas of the building or at thermal bridges) or where ventilation has been reduced or restricted. Fabric performance can be readily undermined by inappropriate painting for example by applying a plasticized paint to a moisture transfusive wall.

5.3 Material Selection

Many modern synthetic materials and some traditional materials can be deleterious to indoor air quality. Risks can be posed during and directly after application of the material, when concentrations of associated pollutants are highest, or over a prolonged period of time. As is the case with many chemicals found in the indoor environment there is often scientific uncertainty over the risk posed to humans. This is due to the large number of chemicals currently present in the indoor environment. Of the 75,000 chemicals in common commercial use, only 3% have been tested for carcinogenicity[21]. At the beginning of the 20th Century around 50 materials were used in buildings. There are now around 55,000 building materials are available and over half are manmade[22]. The Royal Commission on Environmental Pollution highlighted our current failure to secure the public:

"… the current system for managing the risks from chemicals fails to secure public confidence and is overloaded by the massive backlog of chemicals waiting to be assessed. … A more inclusive, precautionary and effective approach is urgently required."[23]

Where there is scientific uncertainty over the safety of a material, and plausible evidence to indicate that it has the potential to pose a risk to human health and the environment, the precautionary principle can be adopted. This essentially means that scientific uncertainty should not come in the way of introducing measures to protect the quality of the internal environment. For example, many chemicals have been found to be animal carcinogens, but establishing whether a chemical is a human carcinogen can be more difficult to achieve. Furthermore, humans are exposed to a number of different chemicals in their daily life, and identifying

---

[21] Steingraber, S. (1997) 'Living Downstream', Virago Press, London
[22] Roalkvam., (1997) Naturlig Ventilasjon NABU/NFR
[23] Royal Commission on Environmental Pollution (2003) 'Chemicals in Products' TSO

causative effects from one chemical can be very difficult. Therefore, it is wise to practice a caution in the context of uncertainty.

It should be noted that many materials can have a deleterious effect on the environment and pose health risks throughout their life cycle[24]. There is an increased awareness surrounding the impact of chemical toxicity and some of this has been reflected in legislation as well as best practice guidance and policy. In order to meet policy commitments set to enhance wellbeing, health and biodiversity, the materials used in buildings need to minimise the toxic load imposed on constructors, users and the environment. Berge (2000), Liddell (2007) and Curwell (1986) address this issue further. This includes re-used and recycled materials the use of which may not be a positive environmental activity due to embodied toxicity. As yet, there are no mechanisms in place to vet the toxicity of recycled materials and the responsibility lies with the designer or contractor. Building owners need to consider the future liability of disposal of toxic materials.

5.3.1 Traditional Building Materials

Appropriate selection of materials for use in traditional buildings is a priority. During refurbishment it is paramount to have a full understanding of the properties of the materials being used and the function of any materials being replaced. Traditional materials may not be immediately replaceable with modern materials.

Many of the materials used in traditional buildings are hygroscopic (meaning that they readily absorb moisture), and wall constructions are moisture transfusive (meaning that they allow moisture to pass through their fabric). This allowed traditional buildings to deal with moisture by a combination of absorption and evaporation.

It is vital that any materials selected do not compromise the ability of the building to deal with moisture. Maintaining the vapour permeability of traditional materials can be an important factor in maintaining a healthy indoor environment in traditional buildings. Permeability will be undermined by the application of impervious paints and finishes and many modern materials and finishes are impermeable. Applying such materials and finishes to traditional buildings can compromise the ability of the building to deal with moisture leading to problems associated with high relative humidity, including mould growth, and in many cases causing significant damage to the fabric of the building. Hygroscopic, moisture-open materials are infinitely superior. Furthermore, studies have shown that materials with hygroscopic properties can be used as moisture buffers to reduce the extremes of internal relative humidity (see 0).

By way of example, lime is one of the most important non-metallic minerals used in the construction industry and its use in buildings dates back to the Neolithic Period. It was used extensively both internally and externally in traditional buildings in Scotland. Lime plaster is increasingly being used as an internal surface finish due to its hygroscopicity. It is known that mould will not grow if the pH level is higher than 6.0, and as lime is alkaline it has historically been used to provide protection against mould or fungal growth. However, there is a lack of scientific information to back these claims and further study is recommended (see 8.0).

---

[24] Liddell, H., et al, Design and Detailing for Toxic Chemical Reduction in Buildings, 2008, SEDA

In light of increasing evidence, serious consideration needs to be given to avoiding the use of materials that pollute the internal environment and pose a risk to the health of occupants. In part, this has led to the re-emergence of traditional buildings in modern '*green'* construction. A discussion of the history and lifecycle issues associated with modern and traditional materials and treatments is presented in the book Ecology of Building Materials (see 6.2).

5.4 Thermal Mass

Thermal mass is a product of the mass of a body and the specific heat capacity of the material. In terms of construction, it refers to the ability of the mass of the building to provide thermal inertia over temperature fluctuations. For example, heavy weight buildings take longer to heat up and cool down, whereas lightweight buildings heat up and cool down quickly. The speed at which a building heats up or cools down is referred to as the thermal lag. The thermal lag of a building can be designed to compliment the occupancy patterns.

Care needs to be taken in traditional buildings with a high thermal mass to ensure that the heating strategy does not have a damaging effect on the building fabric or the indoor air quality. In a bid to reduce energy consumption, intermittent heating strategies are frequently adopted in traditional buildings with varying occupancy levels. This can pose problems in buildings with a high thermal mass particularly if there is also evidence of damp problems. When the heating comes on and the building warms up, the internal surfaces release moisture into the indoor environment increasing the dew point of the air. This increase can result in condensation when the air comes into contact with colder areas of the building or at thermal bridges. This results in moisture being transferred through the building from warmer parts to colder parts, and can ultimately result in mould growth and damage to the fabric of the building.

To provide comfort, air temperatures are often higher to counteract the impact of the radiant heat loss from the occupants to the cold walls. These rapid changes in temperature and humidity can cause a cycle of recrystalisation of hygroscopic salts residing in building materials, which can cause significant damage to the fabric over time.

5.5 Conclusions

Reducing the exposure to certain indoor pollutants can be readily achieved through informed material selection and is an important mitigation strategy in buildings of all ages. Providing adequate ventilation and moisture management is a more complex issue, and requires an informed and individual response. It is particularly important that the materials used in traditional buildings do not restrict the moisture balance in the building, as this could damage the building fabric and create an unhealthy indoor environment.

There is a need for traditional buildings to meet modern expectations of energy efficiency and thermal comfort. However, there has been little research into the impact on health of such measures. Although there are some general rules, each building and each room needs individual consideration to determine the most suitable course of action to ensure that a healthy indoor environment is maintained. Whilst reducing infiltration and the rate of ventilation may help reduce energy bills, if done to the extreme, it may impair the ability of a building to provide adequate fresh air and deal sufficiently with moisture. Further study into this field in Scotland could help to establish the effectiveness of current practices and indicate the measures and knowledge required to inform on best practice and appropriate resources efficiently.

6.0 Literature Review– Principal Papers

6.1 Guide to building services for historic buildings – Sustainable services for traditional buildings, CIBSE, 2002

This publication looks at the ways in which modern expectations and standards of services can be incorporated into traditional building design, and details some of the risks posed to the building fabric. It discusses moisture movement in traditional buildings, the differences between traditional and modern materials, the complexity of adding insulation, ventilation and draughtproofing, thermal mass and controls, conservation heating and the need for initial and ongoing monitoring. The guide states some simple and non-intrusive ways of improving energy efficiency. It includes a brief section on improving health and the internal environment. This highlights the need to consider the combined effects of heating, ventilation and insulation on the environmental equilibrium of the building and highlights the risks that can be posed by damp buildings. It also suggests assessing the risks posed by potentially toxic materials.

The guide emphasises that traditional buildings need more ventilation than modern buildings. It recommends a rule of thumb of 0.4 air changes per hour in a domestic setting to cover the ventilation required for occupants and another 0.4 changes per hour to remove damp from a breathing structure in a good condition. It states that 'some traditional buildings are damper and will need more – though this can often be reduced by repair and maintenance work'. The guide contains a number of case study examples that detail renovations to the building services in historic buildings.

6.2 Berge, B., Ecology of Building Materials, 2000, Architectural Press

This book discusses the ecological impact of a wide range of building materials and presents alternatives to commonly used materials. The book focuses on the life cycle impact of materials including the production of the material, the raw materials required, the energy used and the pollution created. Of particular importance to this study is the consideration given to the pollution emitted from materials 'in use'. Table 2.5 highlights the environmental poisons and ozone reducing substances that can be attributed to some common materials – there is a specific column for health that details health threats to the working environment and the internal environment. Table 9.4 in Chapter 9 details some of the health effects associated with different solvents used in the building industry, and the adjacent text discusses where the solvents are commonly used. Similarly table 9.5 details oil based chemicals with a high environmental risk – the table details areas of use and potential health effects. Chapter 9 goes on to discuss general uses of plastics in buildings, the use of additives in plastics, pollution from plastics (in use and in production) and the gases emitted on combustion.

Chapter 14 discusses the climatic properties of materials. The section on moisture-regulating materials is of particular interest to this study. The use of hygroscopic materials as a buffer for humidity levels in a building and their potential to reduce dust mite concentrations or the growth of micro-organisms. The book states that the use of hygroscopic materials can result in gas contaminates, such as nitrogen oxides and formaldehyde, being removed from the internal environment through the absorption of water vapour – a process which is only effective if the pollutants stay in the material or are broken down internally. Table 14.9 details different insulation materials and grades their associated indoor pollution and their hygroscopicity.

Chapter 15 discusses the issues surrounding the selection of surface materials including floor coverings, sheeting and renders. It includes information on potential indoor air quality issues. Tables 15.9 & 15.10 give environmental profiles for internal claddings and floor finishes. Chapter 17 gives an introduction to chemical binders and discusses potential health risks. A number of traditional glues and adhesives are considered. Chapter 18 considers the ecological issues surrounding the use of paints, varnishes, stains and wax including a discussion on the historical use of paints. Attention is given to both the environmental impact of a paint and its vapour permeability. Chapter 19 discusses the issues surrounding impregnating agents including a list of the poisons used for impregnation and a list of the least dangerous impregnating substances.

6.3 The need for old buildings to "breathe", Philip Hughes, Society for the Protection of Ancient Buildings, 1986

This is an information sheet produced by the Society for the Protection of Ancient Buildings. It introduces the concept of the breathing wall used in traditional building design and discusses the problems caused to the building fabric through the use of impervious materials. In this section it looks at the use of paints, external renders, pointing and internal plaster and also includes a brief paragraph on the risk of modern extensions. The guidance note finishes by advising on the correct approach for the treatment of old buildings. The particulars of material selection are covered in more depth in Historic Scotland's Guide for Practitioners – Rural Buildings of the Lothians, Conservation and Conversion.

6.4 Ucci, M., et al. Ventilation rates and moisture-related allergens in UK dwellings, Proceedings of the 2nd WHO International Housing and Health Symposium. WHO, pp. 328-334

This paper discusses the role of ventilation rates in the control of allergens in UK dwellings. Of particular concern to the study is the role of decreased ventilation through energy efficiency measures. Findings for the literature review carried out indicate that there are very few studies that investigate whether there is a direct link between ventilation rates and respiratory problems although some studies have indicated a strong association. The report goes on to state that there are a number of studies that indicate a link between ventilation and moisture related pollutants as well as studies that indicate a link between moisture related pollutants and ill health.

The paper states that modelling studies have indicated that house dust mite infestations are likely to occur at high internal temperatures with ventilation rates below 0.5 ach^{-1} (however, no distinction is made for traditional construction types). The study analyses data from the English House Conditioning Survey. Findings indicated that there is a lower incidence of asthma in people living in buildings built before 1919, however, it should be stressed that this was not a comprehensive study - the study highlighted that the issues are complex and that no conclusion could be drawn on the impact of energy efficiency measures.

6.5 Watt, D., et al. Assessing the impact of chemical treatments on the health of buildings and their occupants, 2000, RICS, Vol. 3 No. 13

This paper produced by the Centre for Conservation Studies at Leicester School of Architecture focuses on the issues surrounding the chemical treatment of buildings and explores the issues of concern for potential health effects on occupants. The paper discusses building defects, fungal infections and insect infestations and outlines the difficulties associated with establishing clinical diagnosis of the effects of indoor air quality. The paper acknowledges that the pesticides selected for their biological activity are necessarily toxic and it is not surprising that they may cause some adverse health effects on humans following exposure. Furthermore, the solvents used as pesticide carriers may also cause adverse health reactions. The paper goes on to discuss chemical sensitivity and immunological response. The paper states that 'there is a growing body of information from the medical and legal professions on the effects that chemical treatments might have on the health of buildings and their occupants'. It goes on to reference publications that link chemical exposure and health.

The paper calls for a greater understanding of chemical sensitivity including research to develop a deeper understanding of the causes and symptoms and to consider the effects of low doses of chemicals. It highlights that children are at greater risk.

6.6 Liddell, H., et al, Design and Detailing for Toxic Chemical Reduction in Buildings, 2008, SEDA

This publication has been written from the perspective of a practising architect seeking to design healthy buildings. It aims to outline the main issues surrounding chemical toxicity in the built environment highlighting the principal sources of toxicity and detailing alternative materials and solutions. It is of interest to this scoping study as it highlights potential sources of indoor air pollution from building materials, and identifies the materials that pose the greatest threat.

The publication states that there is compelling evidence that toxicity in a very large number of ubiquitous building materials is a contributory trigger to people with asthma and allergies. It discusses the current context and highlights the issue of scientific uncertainty in the use of many modern materials. The guide explores current best practice for reducing toxic chemicals in buildings and provides design details. Of particular interest to traditional buildings is section 6.4 where detailing is given for the rehabilitation of a traditional materials – a specification is given for the application of hygroscopic insulation that will maintain the vapour permeability of the stone wall. Many of the materials recommended, such as clay and lime plaster, are similar to those originally used in traditional buildings. These material recommendations include the use of lime based building materials and the use of low VOC natural paints which, along with the use of a breathing wall system are recommended as part of a humidity control strategy.

In the UK, identification of single toxic materials, within a more complex cocktail of products and materials, and proof of their contribution to a hostile indoor climate, is difficult to determine.

6.7 Berry, R.W., et al, Indoor air quality in homes Part 1, BRE, 1996

This publication details the findings of a study into the study of the levels of specific pollutants in a sample of normally occupied homes. The main pollutants identified in the study were:

- Formaldehyde
- Total volatile organic compounds and selected individual compounds
- Nitrogen dioxide
- Airborne bacteria
- Airborne fungi, and
- House dust mites in furnishings

The study was carried out in 174 homes in Avon, England over a 12-month period. Buildings were categorised according to age. However, the publication states that the significance of findings found to be related to the age of the building should be viewed with caution. As an example, the study indicates that a significant number of the older dwellings were smaller in size and were found in built up areas whereas a significant number of newer homes were bigger and were found in less built up areas. This could impact on the amount of outdoor pollutants found inside dwellings.

Findings for the study included:

- That the mean formaldehyde concentration in homes built since 1982 is around three times higher than the concentrations found in homes built before 1919.
- The age of the dwellings was not a significant factor in house dust mite concentrations in the tested properties. A number of other publications that support these findings are listed in the paper.
- The study found that the age of the dwelling was occasionally significant in the level of fungi and bacteria in dwellings, principally that pre 1941 dwellings had a significantly higher average yearly mean of fungal value than dwellings built between 1941-1975. However, there was not a significant difference between pre-1941 houses and the post 1975 houses. It states that the findings should be viewed with caution. Two publications where age of dwelling was found to be significant factor are listed.
- VOC levels were found to be dominated by painting and decorating.

6.8 Coward, S.K.D., et al, Indoor Air Quality in Homes in England – Volatile Organic Compounds, BRE, 2002

This study investigates the indoor air quality in 876 homes in England – it is a supplement to the report 'Indoor Air Quality in Homes in England'. The five factors that were identified as being the principal sources of VOCs:
Stored materials or car/fuel
Decorating/fittings and furnishings
Combustion of gas
Petrol
Combustion of petrol and/or tobacco

The age of the building was found to be significant in one of the compounds assessed. This compound was 2,2,4-trimethyl-1,3-pentanediol diisobutyrate (TPDDIB). TPDDIB is a plasticiser used in the manufacture of flooring and is an irritant. It was found in greater concentration in newer homes.

6.9 Bordass, W., Bemrose, C., Heating Your Church, 3rd Ed 1996

This book discusses the main issues associated with providing an effective heating system in a church. It is quick to highlight that each church is unique and that the appropriate solution will depend on the churches structure, location, condition, contents, present heating and the expectations of the congregation. Changes to a churches heating system are often driven by a change in use patterns and an increased desire for thermal comfort. When changing the heating system ventilation, building, contents users and operations must all be taken into account. Designing a more efficient heating system that focuses on keeping occupants comfortable at require times can cut running costs but often results in less heat being put into the building than before and unless this is considered, it can result in the building getting damper.

The paper discusses some of the common mistakes made when installing a heating system, and highlights the principal differences between different heating systems and common problems. Thermal comfort is covered with attention given to convection, conduction and radiation. The effects of moisture and air movement on thermal comfort and the building fabric are discussed. The origin and control of draughts are also discussed.

6.10 Straube, J.F., de Graauw, J.P., Indoor Air Quality and Hygroscopically Active Materials, ASHRAE Transaction, Vol 107, Pt 1, 2001
This paper discusses some of the issues surrounding breathing walls and indoor air quality. It focuses on the role of the breathing wall in new build structures, but some statements made in the paper are of interest to the traditional context. The paper states that hygroscopic materials can moderate relative humidity and permanently absorb some VOCs. It also states that 'Lime and cement plasters are alkaline enough that mould growth is stymied.' It explains that it was for this reason that lime was traditionally used to whitewash buildings and stables. 'This level of alkalinity makes the growth of fungi and even viruses very difficult'. The paper contains graphs on the hygroscopic properties of a range of building materials.

6.11 Singh, J., Fungi in Buildings – Holistic Conservation and health, Environmental Building Solutions, 2000
This paper alludes to the significant threats posed to the building occupants through the use of fungicidal chemicals. It states that environmental control and preventative measures are preferential to chemical treatment. Further papers that discuss this issue include:

Watt, D., Risks associated with chemical treatment residues in buildings, Structural Survey, 1998, Vol 16 Issue 3 Page: 110-119
Hutton, T.C., Singh, J., The environmental control of timber decay Green Treatment of Timber, Conference 17th -18th Feb 1994, Taymouth Castle

According to the paper a 'greener' approach to timber decay includes the following measures:

- Locate and eliminate sources of moisture
- Promote rapid drying
- Determine full extent of outbreak
- Remove rotten wood
- Determine the structural strength of timber and fabric construction
- Institute good building practice
    - Ventilation
    - DPC
    - Isolation

6.12 Jacob, E.H., Notes on the Ventilation and Warming of Houses, Churches, Schools and Other Buildings, 1894, SPCK
Despite its age, this publication is of interest to this study as it discusses some of the principal intents of ventilation strategies of the period and the patterns of air movement within traditional buildings. It discusses the vital role that chimneys played in ventilating homes, by drawing air into rooms. Due to the polluting nature of the heating and lighting fuels of the period, the book makes many references to the requirement for adequate levels of ventilation to provide a healthy internal

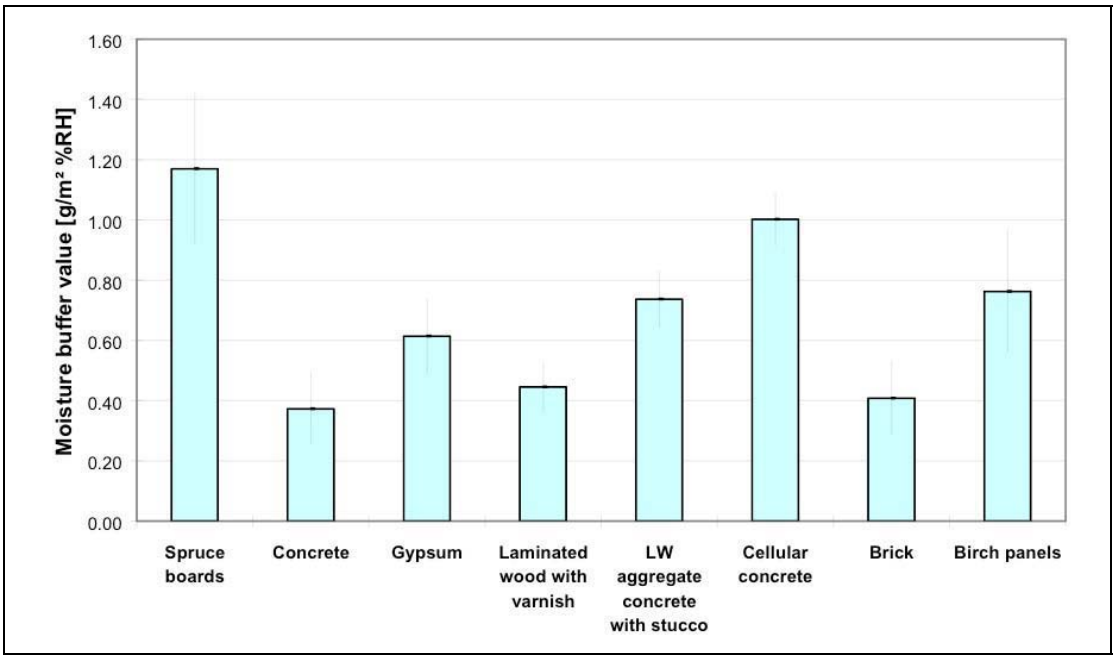
environment. Some of the solutions advised are quire innovative 'Sash windows are the most convenient in this respect, as they may be kept slightly open at the top, or better, provided with a board fixed against the sill, so that the lower sash may be raised about four inches without air being admitted below'.

The book goes on to discuss the ventilation strategies and heating strategies in churches, schools, hospitals, theatres and workshops. It discusses the principals behind mechanical ventilation in larger buildings, which was an emerging technology at the time. On many occasions, the book highlights that the removal of bad air and the provision of thermal comfort was a significant factor in providing a healthy internal environment.

6.13 Baker, P., et al, Investigation of wetting and drying behaviour of replica historic wall constructions, 2007, Centre for Sustainable Heritage, UCL
This publication was included as part of the Engineering Historic Futures Project. The paper discussed the outcomes of tests that were carried out on test walls that were constructed at Glasgow Caledonian University. The purpose of the tests was to assess the moisture distributions within the walls under different ambient conditions and to test the effectiveness of different approaches to drying. Of interest to this scoping study is that the spraying process undertaken in the laboratory to simulate rain only affected the relative humidity on the cold side of the sandstone wall and had no effect on the warm side. This was important in determining that the water ingress in the building that the test wall was designed to emulate was largely due to the deterioration of rainwater goods attached to the stonework. From this the study concluded that a well-constructed and well-maintained wall should keep moisture out of the case study building under the present climatic conditions found at the site.

6.14 Curwell, S.R., March, C.G., Hazardous Building Materials – A Guide to the Selection of Alternatives, E. & F.N. Spon 1986
This book focuses on the materials used in buildings that can pose a risk to the occupants' health. The work includes a number of papers from various authors that discuss particular threats including those relating to natural materials, man-made materials, metals, plastics and toxic chemicals. This edition (and the subsequent edition released in 2001) includes data on the environmental impact, cost, health, safety and technical performance of a range of building materials. Through the use of building data sheets the book highlights a number of key design areas in a building and discusses the potential hazards. Of particular use to this study is the discussion of hazardous materials in existing buildings and the identification of risks that can be posed to health during and after maintenance or DIY work. Materials such as asbestos and lead are avoided in new constructions but can still be found in traditional buildings. In light of ongoing study, the 2nd edition of this book carries more up-to-date information on the toxicity of materials.

6.15 Rode, C., et al, Moisture Buffering of Building Materials, 2005, Department of Civil Engineering, Technical University of Denmark
There is increasing recognition of the ability of absorbent, porous materials to help reduce extreme levels of relative humidity in indoor environments. This paper sets out to characterise the moisture buffering properties of specific building materials. In order to standardise results, the moisture buffer value was defined (units $kg/m^2.\%RH$). The paper then goes on to determine the moisture buffering value of a range of materials based on experimental test data. A graph of the findings can be seen below (taken directly from the report).



From the results the study goes on to estimate (through calculation) the potential impact of using hygroscopic materials in a bedroom to decrease the impact of overnight moisture production on the relative humidity in the room.

6.16 Halliday, S., et al. Affordable Low Allergy Housing
In light of contemporary concerns regarding building related ill-health, the Office of the Deputy Prime Minister (ODPM) supported research into an affordable low allergy building specification. Fourteen low allergy houses were designed, built and monitored at the World Habitat Awarded commended Fairfield Estate in Scotland, to a specification conforming to stringent affordable housing guidelines. The research looked at the interplay of specification and servicing strategies for housing, health, energy and longevity. Building materials and a range of ventilation strategies were investigated. Evaluation included comparison of allergen & humidity levels with assessed critical levels from other research.

Along with the final report, a guidance note for building designers was published. The note gives an introduction to some of the principle issues associated with the design of the low allergy homes and presents some legal case studies. This report is of interest to this scoping study as it explores the issue of providing health housing in a modern context, and was done to an affordable budget.

A copy of the final report can be obtained from the Department of Communities and Local Government ref 39/3/658(BD2224). A copy of the Guidance Note can be downloaded from Gaia Group website (pdf 1.1Mb).

6.17 Howieson, S.G., et al, Domestic ventilation rates, indoor humidity and dust mite allergens – Are our homes causing the asthma pandemic?
This study is concerned with the historic changes in domestic ventilation and vapour dissipation rates and the associated risk of dust mite colonisation. The paper highlights that a number of changes in the way that building are designed has led to changes in ventilation rates and the ability to deal with moisture. Changes include a reduction in open fireplaces affecting air exchange rates, reduced thermal mass

increasing diurnal temperature fluctuations, reduced water vapour transmission through construction layers, increased average whole house temperatures, internal clothes drying increasing moisture burden and retrofit double glazing resulting in reduced background ventilation.

The paper sets out to evaluate the historical reduction in domestic ventilation rates. This was done by modelling five different housing types using the ESP-r modelling including a 19th century tenement, a 1930's semi-detached villa, a 1950's 3 storey tenement, a 1970's multi storey and a 2000's timber frame. The main construction characteristics including volume, materials, heating systems, flues, window type, crack length and trickle vents were input as boundary conditions. The modelled ventilation rate in the two older dwelling were a lot higher than in the three more recent dwellings – in terms of volumetric airflow the late Victorian tenement has over nine times the rate of a contemporary timber frame model.

The study also modelled moisture dissipation rates. It showed that relatively tight, energy efficient modern dwellings would be subject to progressive and cumulative moisture build-ups during the winter months if windows remain closed. The moisture content of the internal air in winter months is of importance as this is thought to be crucial in inhibiting dust mite colony size and activity.

The paper also discusses the findings from a study into the effectiveness of introducing measures aimed at reducing allergen reservoirs and dust mite activity. This included adopting remedial measures in the homes of 68 asthmatics in North Lanarkshire. There was no discussion of building age. The study concluded that as room volume drops and air tightness increases then complementary ventilation regimes need to be adopted to control dust mite allergen.

6.18 Blades, N., et al, Guidelines on pollution control in heritage buildings
This paper discusses the issues surrounding pollution control in heritage buildings with particular reference to concerns over indoor air quality in museums, galleries, libraries and archives. The guidelines present information to aid improvements in indoor air quality and energy efficiency. It is important to emphasise that 'heritage' refers to the artefacts beings stored and therefore pollution is predominantly discussed from the collection's point of view. No distinction is made between pollution controls in modern or traditional buildings. Furthermore, the health impacts of indoor air quality are given cursory attention. For example, VOCs and carbon monoxide do not normally damage heritage materials so are not discussed in any detail.

There is general consensus over which pollutants pose a risk to heritage materials but there is still scientific uncertainty over the full extent of the problem. The guide indicates which materials are susceptible to which pollutants. The pollutants are split into those generate internally, which can be removed through ventilation and those brought into the internal environment from outdoors by ventilation. Sources of indoor pollution are identified as human and animal metabolism, combustion, cooking, introduced materials and chemicals, and offgassing from building materials and contents.

The ability of some materials to adsorb pollutants is discussed. The paper indicates that porous and alkaline paints will adsorb more pollutants and that the greater the surface area of adsorbent materials then the greater the adsorption. It is suggested that adsorbent surfaces could be used to control internally generated indoor pollutants such as carbonyls (a group of chemicals which include aldehydes such as formaldehyde).

Table 4 on page 30 of the paper contains useful information on the advantages and disadvantages of different pollution control measures. A number of brief case studies are presented in the paper, which evaluates the success of pollution control techniques applied and monitored in museum buildings.

6.19 English Heritage (2002) Building Regulations and Historic Buildings *Balancing the needs for energy conservation with those of building conservation: an Interim Guidance Note on the application of Part L. English Heritage*

This publication was written to assist those responsible for overseeing the implementation of the Building Regulations Approved Document Part L, *Conservation of Fuel and Power* (DTLR, 2001)in historic buildings, The regulation came into force in 2002. It was written for designers, inspectors and control, conservation, housing and environmental health officers to assist in preparing proposals for work on historic buildings.

It was intended to help prevent conflicts between energy conservation policies enshrined in the revised Building Regulations and policies concerned with planning and the conservation of the historic environment. It seeks to promote the right balance between reducing energy use and conserving the national and local heritage.

The document makes no reference to the impacts of changes on indoor air quality.

7.0 Case Studies

7.1 Toll House Gardens

The Toll House Gardens development consists of 14 homes that were completed in 2003. The homes provide an example of housing that aims to minimise allergy triggers as well as providing affordable warmth and a high quality environment for tenants. The homes were designed by Gaia Architects and constructed within benchmark costs. They are managed by Fairfield Housing Co-operative (FHC).

The 1-2 storey development comprises 1,2 and 3 bedroom units arranged around a car-free courtyard. Only benign materials were specified and materials containing known allergens or triggers have been avoided.

All of the buildings were designed with an air-tight, moisture transfusive fabric, hygroscopic materials including the insulation; and non-toxic specification. Three ventilation strategies were incorporated:

- five units were fitted with a MVHR ventilation scheme;
- dynamic insulation was incorporated into a further five units for passive ventilation;
- remaining units fitted with conventional trickle ventilation in windows and extract fans in bathrooms and kitchens;

A research project by Gaia Research for the ODPM included comparison of the effects of conventional ventilation with those of whole house ventilation and dynamic insulation. It concluded that the differences between the approaches were significantly less than might be anticipated when compared with the general stock. Naturally ventilated buildings tend to more closely follow external moisture levels with greater highs and lows than found here. It recommended further investigation of the beneficial effects of using hygroscopic materials to buffer humidity changes.

An economic analysis looked at the implications for widespread implementation of healthy housing on savings in treatments costs and drugs. It concluded that the project fully integrated and demonstrated the inter-related benefits of the three aspects of sustainability policy – social, environmental and economic.

The report, *Affordable Low Allergy Housing*[25], discusses asthma triggers and how they are exacerbated by high internal moisture levels.

[25] Affordable Low Allergy Housing A Guidance Note Gaia Research and Gaia Architects © Gaia Research 2005 ISBN 1-904680-18-6

7.2 10 Nicolson Street, Edinburgh


Nicolson Street was formed about the middle of the 18th century. 10 Nicholson Street is a Grade 2 Listed 5 storey Georgian tenement building located on the south side of Edinburgh's city centre. In the late 1970's the tenement was radically altered internally to provide 24 x 1 bedroom single person flats. By 2003 the tenement was in poor condition internally, with structural problems identified in a report
Gaia were commissioned by the Edinvar Housing Association to refurbish the block. Edinvar Housing Association was keen to produce a demonstration project that explored the twin areas of refurbishment and ecological design. The project enabled Gaia to develop their experience from Toll House Gardens and to apply the low allergy specification to a traditional building.

It was decided that the internal layout and the housing mixed was unsuitable. The most suitable solution was for the tenement is to retain the external walls, but to demolish the internal structure and rebuild behind the facade.

The original structure had survived largely intact although with some alterations. Many of the internal partitions have been partially removed, replaced or lined to upgrade fire protection and sound insulation between the existing flats. As a result most of the original decorative plasterwork, joiner work and fireplaces have either been completely removed or where they do survive they are incomplete or damaged.


The renovation project focused on the following key principles:

1. Health & Safety
    - Use only benign materials, i.e. avoidance of materials that pose a risk to human health and / or the environment including
        - During production
        - In use (construction and occupation)
        - In disposal

2. Healthy Indoor Climate
    - Avoidance of toxins and materials known to contain recognised asthma/allergy triggers (formaldehyde, solvents, plasticizers, gas combustion)
    - Ventilation beyond technical standards requirements
        - Heat recovery ventilation units (whole house or individual units) which operate continuously at low level, and minimal cost, and are boosted when sensors register increased humidity
    - Moisture management to reduce the risk of dust mite and mould colonisation
        - Use of materials such as clay & lime that can absorb excessive moisture and release it again when the air is dry
        - Use of breathable surface finishes e.g. natural paints that maintain the properties of the hygroscopic materials and do not seal the surface as conventional paints and wallpapers do.
    - Avoidance of electrical ring mains

3. Energy Conservation
    - Insulation beyond technical standards requirements (external walls 150mm, 250mm to roof)
    - Avoiding cold bridges
    - Detailing for high levels of air tightness to avoid heat loss through infiltration
    - Low energy electrical fittings
    - Improving natural light in common areas


In line with these objectives the following material choices were made for the refurbishment:

Materials containing formaldehyde were avoided. The following alternatives were selected:

- Cellulose insulation in lieu of foamed insulation.
- Paint in lieu of wallpaper and associated glues
- Natural timber in lieu of MDF and chipboard (Note: timber naturally contains formaldehyde, but at levels which are acceptable)
- Formaldehyde-free MDF used for cills.

Solvents were avoided. The following alternatives were selected:

- Natural water-based emulsion paint.
- Linseed oil based gloss paint.
- Avoidance of materials containing or requiring glues, e.g. manufactured wood products, wall paper; where necessary (e.g. for installation of rubber flooring) use of solvent & formaldehyde free glues
- Avoidance of timber treatments through detailing

PVC was avoided. The following alternatives were selected:

- Stainless steel conduits
- PE, PP or rubber sheathing to wiring
- copper or PE water pipes; cast iron rainwater goods
- Rubber in lieu of vinyl floor coverings

The reduction in room size after applying insulation was thought to be worthwhile as the floor plans were larger than is often the case. Secondary glazing was deemed to be an acceptable alternative to the use of double glazing and is the only option available to the project given that the existing windows are to be retained. All secondary glazing is well draught-proofed and easy to keep clean and maintained. The work was a continuation of Gaia Architects experience in the construction of 14 low allergy homes in Perth (see 0).

7.3 Norton Park, Edinburgh

"The principle of sustainable development will be applied through the Trusts activities to maximise the overall social, economic and environmental benefit to the wider community."
(Norton Park Business Plan, 1996)


Norton Park was built in 1902 and operated as a school until the late 60s. By the early 90s the council were struggling to justify the heating and maintenance costs involved in running it as a workshop space and warehouse. By 1992 the council had gained planning permission to convert the school into office and community space.

In what was the first project of its kind, in Edinburgh, Norton Park brought together under one roof a number of charities and voluntary organisations. The project that focuses on delivering affordable office accommodation in an environment that encourages the sharing of experience and resources. It has boasted of 100% occupancy and a waiting list for tenants since opening.

To manage the conversion of Norton Park, the Albion Trust was set up in 1994 as a charitable organisation and charged with the task of raising £3 million for the development. It was a key feature of The Albion Trust's philosophy that the funding provided would sustain the surrounding environment and increase the value of what was a run down inner city area. In 1995, ownership of Norton Park passed to The Albion Trust from Edinburgh Council. During the same year the building was listed as a Category B building requiring fresh planning consent but opening up the opportunity for further funding.

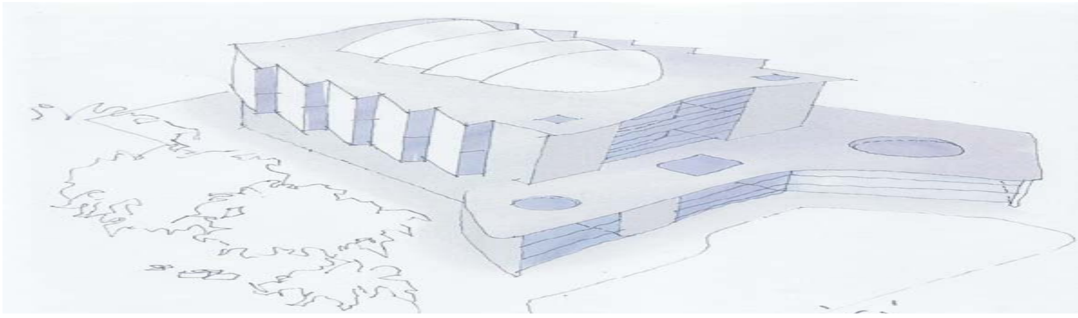
Although structurally sound, Norton Park was in need of refurbishment. In line with the Norton Park business plan, this had to be done in as sustainable a way as possible. Accessibility was a central issue in the refurbishment; an elevator was installed to ensure wheelchair access to all levels; disabled toilets and kitchens were built on each floor; ramps were installed at access points and the rear entrance was enlarged. Mezzanine levels were installed in the office space to increases the available space by 25% thereby increasing the viability of the project. A total of 28 offices were created providing 3750m^2 of net lettable floor space.

To capture the heritage of the building many of the original features were retained including tiles, radiators, doors, windows, banisters and some of the wooden flooring.

In order to improve the indoor air quality and the energy efficiency of the building the following measures were adopted:

- Known allergenic and toxic materials were avoided in the construction
- All the paint used in the renovation was solvent free and mineral based
- All timber was left untreated
- A ‘no PVC’ strategy was adopted
    - Wood based trunking system
    - Natural rubber alternatives were selected
    - Linoleum was used in place of vinyl
- Where MDF was required a formaldehyde- free MDF was used.
- The mechanical ventilation system was fitted with heat exchangers to recover heat from exhaust air was installed (air conditioning was avoided)
    - A minimum ventilation rate of 1 air change per hour and up to 10 air changes per hour for small spaces was provided
    - Windows can be opened to provide natural ventilation
    - During the summer months the ventilation can also work during the night to pre-cool the building for increased comfort
- Walls and roof highly insulated with mineral wool (0.3W/m^2K and 0.1 W/m^2K respectively)
- Wooden framed double-glazing (installed as secondary glazing to the original sash and case windows) was installed
- Efficient gas powered combination boilers heat the building, replacing the old, inefficient oil fuelled boilers which dated back to 1910.
- The building is divided into 15 heating zones with thermostatic radiator valves
- A Building Management System was installed at the property to monitor and control the ventilation and heating systems with a separate system installed to control the lighting Building
- A rainwater harvesting system, which captures rainwater from the roof was installed to reduce mains water consumption

7.4 BreathingSpace



Following attendance at an RIBA training session on sustainable design given by Howard Liddell, Gaia were approached to act as specialist advisors to this £7m residential and day-care project for ex-miners and industry workers with respiratory problems.

BreathingSpace was conceived to provide the UK's leading, and possibly the world's largest rehabilitation service for people with a form of respiratory disease known as chronic obstructive pulmonary disease (COPD). The funding was obtained through a partnership between the Coalfields Regeneration Trust and Rotherham Primary Care Trust with the support of Rotherham Borough Council.

The building required expert knowledge on healthy indoor climates and Rotherham Council asked Gaia to fulfil this role.

The approach to BreathingSpace was to apply the features employed in many of Gaia's projects: - excellent daylight, high levels of insulation and air-tightness, designed ventilation, healthy and hygroscopic materials and structure to aid moisture management in combination with careful space planning to create a fresh, clean environment and super-efficient building.

8.0 Conclusion and Scope for Further Research

This study summarises the principle issues of importance when considering indoor air quality in traditional buildings. An investigation of existing research has been conducted and a synopsis of a number of the most relevant publications provided.

Much published information on traditional buildings focuses on conservation of the building fabric. There is a lack of published information on the quality of the internal environment in traditional dwellings, and in particular, information on the impacts of energy efficiency measures. There is enough evidence to indicate that measures aimed at increasing energy efficiency could pose a risk to the health of the occupants and there is a need for further investigation and guidance.

A holistic approach is crucial when considering alterations aimed at increasing the energy efficiency of properties to ensure that the indoor air quality is not compromised. An integrated approach is required.

Research into indoor air quality is challenging as it invariably requires the extrapolation of laboratory test data to real world phenomena. Uncertainties arise when attempting to identify causation within a complex and variable environment. Identifying the impact of indoor pollutants, and the quality of internal environment, on the health of the occupants can be particularly difficult, especially when considering low-level exposure over a number of years.

More study into such areas is warranted and it is an issue of concern for all involved in the design of the built environment. This is particularly relevant prior to embarking on programmes of work to deliver energy efficiency if potential long term problems are to be avoided.

The following have been identified as beneficial areas of further study:

1. Investigate all aspects of indoor air quality in traditional buildings in Scotland through a programme of monitoring, and identify exposure compared with modern building types. Give attention to the concentrations of outdoor pollutants in the indoor environment.
2. Investigate the role of hygroscopic materials and construction in relation to energy efficiency, comfort, pollution and indoor air quality.
3. Collate information on traditional Scottish building materials with reference to their impact on indoor air quality and their effectiveness in regulating indoor humidity.
4. Investigate the role of modern materials that are compatible with traditional construction types.
5. Review typical renovations or remedial works carried out on different types of traditional buildings in Scotland and quantify the impact on fabric and air quality. Give attention to any energy saving measures adopted and investigate the energy efficiency and efficacy of the ventilation stratgies adopted.
6. Review traditional methods of ventilation and present case study examples of modern conversions or renovations where their function has been successfully retained or improved on in an energy efficient manner. Also identify case studies where problems have arisen.
7. Further investigate, document and champion the numerous ways to significantly improve energy efficiency including specification of efficient

lighting and appliances, domestic hot water management, and occupant guidance.

8. Investigate the fungicidal properties of lime in the context of its continued use in traditional buildings and highlight any beneficial properties this could have for IAQ and health in buildings including microbiological aspects.

During this scoping study it became clear that many publications allude to the need for maintaining good indoor air quality in traditional buildings in Scotland, but few discuss the current conditions in traditional buildings in Scotland or explore in depth the implications of energy efficiency measures on the quality of their internal environment.

Further research into indoor air quality and its relationship to materials and the impact of energy efficiency measures, on buildings and health will help to secure the long-term future of healthy traditional buildings and well-being of occupants and may provide useful information for contemporary use.

9.0 Bibliography

2004 Asthma Audit, National Asthma Campaign

Arundel, V., Sterling, E.M., Biggin, J.H., Sterling, T.D., (1986) Indirect Health Effects of Relative Humidity in Indoor Environments, Environmental Health Perspectives, Vol. 65, pp. 351-361

Baker, P., et alforman., (2007) Investigation of wetting and drying behaviour of replica historic wall constructions, Centre for Sustainable Heritage, UCL

Berge, B., (2000) The Ecology of Building Materials, Architectural Press, Oxford

Berry, R.W., Brown, V.M, Coward, S.K.D, Crump, D.R., Gavin, M., Grimes, C.P., Higham, D.F., Hull, A.V., Hunter, C.A., Jeffery, I.G., Lea, R.G., Llewellyn, J.W., Raw, G.J., (1996) Indoor air quality in homes Part 1, BRE

Blades, N., Oreszczyn, T., Bordass, W., Cassar, M., (2000) Guidelines on pollution control in heritage buildings, Re:Source – The Council for Museums, Archives and Libraries

Bordass, W., Bemrose, C., (1996) Heating Your Church, 3rd Ed

CAG Consultants, Energy Action Scotland, (2008) Carbon Countdown for Homes – How to make Scotland's existing homes low carbon, WWF, Dunkeld

Colome, S., McCunney, M.D., Samet, J.M., Swankin, D., Indoor Air Pollution – An Introduction for Health Professionals, American Lung Association, EPA, Consumer Product Safety Commission, American Medical Association

Coward, S.K.D., Brown, V.M, Crump, D.R., Raw, G.J., Llewellyn, J.W., (2002) Indoor Air Quality in Homes in England – Volatile Organic Compounds, BRE

Curwell, S., R., March, C., G., (1986) Hazardous Building Materials – A Guide to the Selection of Alternatives, E. & F.N. Spon, London

Damp Indoor Spaces and Health, Institute of Medicine: Committee on Damp Indoor Spaces and Health, (2004) The National Academy Press

Empty Homes Association, (2008) New Tricks with Old Bricks – How reusing old buildings can cut carbon emissions, EHA, London

English Heritage (2002) Building Regulations and Historic Buildings *Balancing the needs for energy conservation with those of building conservation: an Interim Guidance Note on the application of Part L. English Heritage*

Fanger P.O. et al. (1990) A simple method to determine the olf load in a building, 5th International Conference on Indoor Quality and Climate (Indoor Air '90), Vol.1, pp.537-42.

Gaia Group (2005), Affordable Low Allergy Housing – A Guidance Note, Gaia Research, Edinburgh

Halliday, S. P., Chapman, B., Jones, P., Liddell, H., L., (2005) Affordable Low Allergy Housing, Gaia Research, Edinburgh

Howieson, S.G., Lawson, A., McSharry, C., Morris, G., McKenzie, E., Jackson, J., (2003) Domestic ventilation rates, indoor humidity and dust mite allergens – Are our homes causing the asthma pandemic?, Building Services Engineering Research and Technology, 24 (3) pp 137-147

Hughes P., (1986) The need for old buildings to “breathe”, Philip Hughes, Society for the Protection of Ancient Buildings

Jacob, E.H., (1894) Notes on the Ventilation and Warming of Houses, Churches, Schools and Other Buildings, SPCK

Liddament, M.W., (1996) A Guide to Energy Efficient Ventilation, International Energy Agency,

Liddell, H., Gilbert, J., Halliday, S., (2008), Design and Detailing for Toxic Chemical Reduction in Buildings, SEDA Design Guides for Scotland: No3

Lstiburek, J., Carmody, J ((1993) Moisture Control Handbook – Principles and Practices for Residential and Small Commercial Buildings, Van Nostrand Reinhold

Rode, C., et al, Moisture Buffering of Building Materials, (2005) Department of Civil Engineering, Technical University of Denmark

Scottish House Condition Survey, Key Findings (2007) The Scottish Government

Singh, J., Fungi in Buildings – Holistic Conservation and Health (2000) Environmental Building Solutions

Stirling, C., Thermal Insulation: avoiding risks – A Good practice guide supporting building regulations requirements, 2002 edition, BRE Scotland

Straube, J.F., de Graauw, J.P., (2001) Indoor Air Quality and Hygroscopically Active Materials, ASHRAE Transaction, Vol 107, Pt 1

Summary Statistics Table SS5.1: Damp and mould – homes, English House Condition Survey Standard Tables, (2006) Department of Communities and Local Government

Ucci, M., et al., (2004) Ventilation rates and moisture-related allergens in UK dwellings, Proceedings of the 2nd WHO International Housing and Health Symposium. WHO, pp. 328-334

UK Green Building Council, Report on carbon reductions in new non-domestic buildings, (2007) Department for Communities and Local Government

Warm, P., Oxley, R., (2002), Guide to building services for historic buildings – Sustainable services for traditional buildings, CIBSE, London

Watt, D., Colston B., Spalding, D., (2000) Assessing the impact of chemical treatments on the health of buildings and their occupants, RICS, Vol. 3 No. 13

Published by
Technical Conservation Group

March 2009

Historic Scotland, Longmore House, Salisbury Place, Edinburgh, EH9 1SH
Tel: 0131 668 8600

Publications: 0131 668 8638
Website: www.historic-scotland.gov.uk
Email: hs.technicalconservationgroup@scotland.gsi.gov.uk