MOISTURE
RISK ASSESSMENT AND GUIDANCE

Department of Energy & Climate Change

STBA
SUSTAINABLE TRADITIONAL BUILDINGS ALLIANCE

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CONTENTS

This document has been produced for all those concerned with the design and construction of new buildings, and with the modification of existing buildings.

It provides information about the problems caused by moisture in buildings and the mechanisms for moisture transfer. It describes the different assessment methodologies and tools that are available and gives specific guidance for which methods should be used in individual construction types.

Section 1 provides the background to the need for new moisture guidance and the outline of a new approach.

Section 2 gives simple explanations of moisture mechanisms and risks and explains the need to integrate these in moisture risk assessment.

Section 3 examines the scope and limitations of existing modelling conventions for moisture risk.

Section 4 provides an approach based on principles for use in all projects and particularly where prescriptive guidance or modelling is uncertain or unavailable.

Section 5 provides a summary of the new approach, explains how to use this approach, and then gives specific guidance for individual construction types.

The whole document is designed to be an aid to moisture risk assessment and guidance as well as a learning process. As made clear in the document, there are many uncertainties and complexities in regard to moisture risk and management, and for this reason the importance of learning cannot be understated. Learning refers not only to the understanding of moisture principles, but also to the understanding of buildings, their context and the way they are used in so far as these affect moisture risk. While this document provides guidelines for a structured process of moisture risk assessment, only in combination with a general process of learning about moisture can long term risks be effectively reduced.

This document is supported by Technical Appendices, which explain some of the technical and regulatory issues in more detail and through the use of examples also operates as a learning process.

1

INTRODUCTION

The understanding of moisture movement and moisture risk in buildings has developed considerably in the past few years. Not only have the mechanisms of moisture movement been explored more fully but the types of buildings and applications being studied have widened (in particular the retrofit of existing buildings). Furthermore the conditions under which buildings are constructed, retrofitted and occupied are changing (in particular the air permeability of buildings is being reduced). At the same time there is a growing acknowledgement of the key role of moisture in the health of occupants as well as in the health of building fabric.

With this new understanding and focus it is now apparent that a wider kind of assessment and guidance for moisture risk is required, which takes these factors into account. This needs to incorporate the latest understanding, standards and modelling and to resolve conflicts between old and new approaches wherever possible. However there are still many gaps in our knowledge[1] which means that a new approach to assessment of moisture risk is necessary.

This approach is based on the following basic considerations:

1. Moisture risk in buildings relates not only to fabric but also to occupant health.
2. Moisture risk relates to all states of water as a gas, liquid and solid, and in regard to all conditions including interstitial and surface condensation, relative humidity, absorption of liquid water, and freeze thaw effects.
3. Because moisture problems occur mainly at interfaces/ junctions between elements or materials[2], any approach to moisture risk which does not take this into account is inadequate. These effects are called connective effects in this document.
4. Moisture problems also increasingly occur at a whole building level, particularly in regard to indoor air quality but also in relation to fabric condition. This has always been so, but is now far more significant because of the increasing airtightness in buildings. These effects are called systemic effects in this document.
5. Moisture risks from systemic effects arise not only from the building fabric conditions but also from the planned and unplanned moisture production, heating and ventilation in a building. Any moisture risk assessment and strategy has to take these factors into account.
6. Moisture problems occur in the real world and must take into account the "as built" and "in service" conditions (here called ABIS conditions) which exist (in existing buildings) or which are likely to exist (in new buildings). The assessment of buildings or building elements under "as designed" or "theoretical" conditions (here called ADT conditions) can only be a partial risk assessment.

1 See for example the Responsible Retrofit of Traditional Buildings;2012; N May and C Rye;

2 For example in the Canadian Housing and Mortgage Corporation report on the failures of the condominiums in the 1990s in North America, 90% of the failures were at interfaces/ junctions. see Survey of Building Envelope Failures in the Coastal Climate of British Columbia', (MHL 1996), http://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/98102.htm

These considerations have the following consequences for the choice of an appropriate assessment method:

1 As explained in Section 3 and more fully in Appendix 3, the existing standard BS5250 and the standardised modelling method ISO 13788, which are the main guidance for moisture risk assessment in standards and regulations in the UK, are not sufficient, in many situations, to deal with a proper moisture risk assessment. The advice given in BS5250 is for ADT conditions and is correct as far as it goes in regard to interstitial condensation, surface condensation and mould formation under these conditions in many new buildings. Furthermore the principles-based information on moisture risk, detecting building faults, monitoring to understand building conditions, the need for proper ventilation and heating systems is both correct and useful in many conditions. However BS5250 cannot be considered a complete approach to moisture risk assessment except in the limited cases as identified in section 5.4 below. In one condition, the advice given on Internal Wall Insulation onto solid masonry walls in section G3.1.4 of BS5250 (2011) is now considered incorrect (rather than just incomplete).[3]

2 The standardised modelling method EN15026 (also endorsed by BS5250) is more appropriate, but still inadequate in many situations. This is partly because of the limitations of this standard (being only 1D and not including air flow or ABIS conditions) and partly because of the lack of availability of appropriate material and weather data. It also requires a high level of skill to use this modelling method correctly. Furthermore there is currently no guidance on how to use EN15026, so its use is open to variation and interpretation.

3 We therefore need to identify where existing standards (including modelling methods) can be used with confidence and clarify where they cannot be used or need to be part of an expanded assessment. This is done in section 5 below (with supporting information in the Appendices).

4 Other non-standardised modelling methods can help to deal with the issues identified in the points above. However as is apparent from Appendices 3 and 4 it is clear that such methods are still in development and cannot currently be used on their own or without reservation for moisture risk assessment. Furthermore they also suffer from the lack of accurate data and can only partially deal with many of the connective and systemic effects and ABIS conditions. Nonetheless they can be a useful additional method in understanding over all moisture risk.

5 Due to the inadequacy of the existing standards and non-standardised modelling, and the uncertainty of data, as well as the gaps in our theoretical and practical knowledge about moisture physics and risk, it is essential to develop a new approach based upon principles. This approach will be supported by or complement the existing approaches to provide a more complete and realistic moisture risk assessment procedure. Section 4 below explains these principles and how they translate into practice. Where and how these principles are useful or essential is also identified in the section 5 below.

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3 As explained in the Technical Appendices sections 2, 3 and specifically 4.4

Consequently there are in this document 3 types of assessment and guidance which need to be distinguished:

PRESCRIPTIVE GUIDANCE	Prescriptive guidance based on experience (for commonly used applications where there is good evidence of success over many years); much of BS5250 is of this nature (for example in the section on ventilated roofs). Other relevant prescriptive guidance may be found in documents such as Accredited Details for Part L and Scotland.
MODELLING	Modelling (where there is uncertainty in regard to experience, but sufficient certainty of data and parameters); assessment can then be of two types: **1 Standardised assessment** According to standards ISO 13788 or EN 15026; also for connective effects EN 10211 **2 Non-standardised assessment** This latter type of assessment may be used where existing standards are inadequate (ie. where 2D modelling is required or air flow needs to be incorporated into modelling).
PRINCIPLES-BASED	Principles-based assessment (where there is uncertainty in regard to experience, and data and/or parameters); section 4 in this document outlines the primary principles and the practical measures which result from them. Parts of BS 5250 and Accredited Details for Part L and Scotland also contain useful principles-based guidance. These principles and the resulting practical measures are not the same, however, as prescriptive guidance and require understanding and judgement by the person assessing the building element as well as an acknowledgement of the limits of guidance and the need for on-going care.

1.1 Scope of this document

This document has been prepared primarily because of concerns about negative unintended consequences in regard to moisture issues arising from the practical effects of legislation designed to reduce energy use and carbon emissions in new build and existing buildings. The thermal upgrade of the existing stock and the production of genuinely low energy new buildings are both essential to addressing the major issues of climate change, energy security and fuel poverty. However this must be done in a way that protects and enhances the fabric health of the building and the health of building occupants. Until now the issue of moisture in buildings has been considered secondary to thermal/ energy performance and other issues such as structural stability and access; as such, information about moisture risk and assessment has been split up into different issues and standards and often ignored in design and compliance. However moisture risk has now become a primary concern for regulators due to the considerable potential for harm and cost for owners and users of buildings. This document is therefore an attempt to bring together the different issues in one place and to present a coherent structure and method for moisture risk assessment

and guidance which ensures that moisture risk is properly integrated with other important design and construction issues.
Moisture in buildings is a highly complex subject, about which there are still many unknowns, both in terms of theory and data. This document is an attempt to describe the key mechanisms and relate these to UK building practice in a simple way. It is supported by the Technical Appendices for those who want to understand the issues in more depth. Inevitably both this and the technical document will be incomplete in many aspects. However it is hoped that they will provide sufficient information and guidance to enable the UK construction industry to address the main concerns in a way that reduces risk while also increasing understanding in all parts of design, construction and use.

The level of reader knowledge assumed in this document compares with that assumed for BS5250, BR262 and EN10211. However it can still be read and used by those who are not familiar with some of the modelling protocols and more complex methods of analysis. As identified in Appendix A of this document, many other enabling measures required in order for accurate moisture risk assessment and the actual reduction of moisture risk in buildings to take place. This is a major and important task for the construction industry, building owners and users, and government.

It should be made clear that in regard to standard new build construction, the guidance given in this document is primarily that which is already present and required for compliance. The only partially new factor is the consideration of ABIS effects, which are already partially considered in BR 262, and for which testing and assessment is already available as part of the 30 year durability criteria from certification bodies. Connective and systemic effects are already considered and prescribed in the Accredited Details documents as well as in BS5250 and EN10211. What this document does is to bring all these issues together so that they can be properly understood and integrated in the overall design and construction process.

In regard to work on existing or non-standard buildings the challenges are greater, due to the need for a proper assessment of the existing fabric and services (in existing buildings) and the uncertainties about material properties and construction methods. The avoidance of risk and the mitigation of problems are best handled by using the principles outlined in this document as prescriptive guidance and standardised and non-standardised modelling are less available or accurate. Foremost of the principles is a high quality assessment, design, construction and use process. The development of simple process checks and feedbacks, alongside training and continuing professional development programmes as well as new accredited details for common existing build types, are essential for ensuring that work on existing and non-standard buildings (and also new standard buildings) can proceed without undue testing, bureaucracy or cost and with reduced risk.

2

MOISTURE MECHANISMS AND RISKS

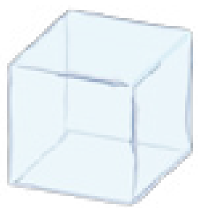
Moisture movement in buildings is highly complex. It occurs not only in building fabric but also in the air within the building shell. It is highly affected by air movement and heat both internally and externally as well as by the materials in the building and the form of construction (as well as its quality). There are also many feedback loops and interactions between the factors involved. For example the temperature distribution through a component is strongly affected by the moisture content of the materials, which is in turn strongly affected by the temperature distribution.

There are also considerable gaps in our data. Many of the material properties, especially those relevant to moisture transport, are difficult to measure and known for only a very limited number of materials. The climate data necessary to model performance are currently available from very few locations in the UK and expensive to obtain.

For this reason a principles based approach, supported by modelling and monitored evidence where possible, is necessary for many types of moisture risk. This kind of approach, however, requires the assessor to understand the principles outlined in Section 4 and to have as full an understanding of moisture mechanisms and risks as possible[4]. This understanding is partly about moisture mechanisms themselves, partly about the interaction of moisture mechanisms with buildings, and partly about the process of design, construction and use which leads to or averts moisture risks. This section briefly outlines moisture mechanisms and the kind of problems that can occur in buildings. Section 4 outlines the principles which are required for low moisture risk in the design, construction and use of buildings.

2.1 Moisture states

It can be helpful to think of water in its different states



As a solid – ice

As a liquid – liquid water

As a gas – water vapour

In simple terms in ice the water molecules are fixed in a structure and relatively static. In liquid water they are linked in chains but not completely linked in a structure and thus fluid,

4 As per Appendix A in this document, training and formal qualifications should be developed to assist in this understanding. This document is only an outline of the issues and a suggested process.

and in water vapour they are individual molecules unattached to other water molecules.

This explains why water as a vapour can go through some materials that water as liquid or solid cannot. Individual water molecules in a gas are much smaller than the linked molecules in water as a liquid, so if a material has a pore size that is larger than an individual water molecule but smaller than that of linked water molecules it can be closed to water passing through it as a liquid but open to water vapour. This is the principle behind many "breathable" roofing membranes.

Water does not need to be at boiling temperature (100ºC) to be a gas. At all temperatures there can be molecules of water vapour in the air, albeit in different quantities and at different degrees of activity according to environmental conditions. However the warmer the environment is, the more activity there is of the water vapour molecules (and other molecules) in the air. This means that warmer air can "carry" more water vapour than colder air without reaching saturation point (which is when the amount of vapour is so high that the water molecules start to coalesce and form liquid water). This saturation point is at 100% relative humidity.

The absolute amount of water in air (absolute humidity) is the amount of water molecules in a given volume of air (ie 1m^3), whatever the temperature. The relative humidity is the ratio of the amount of water present to the total amount that the air can carry at the temperature. If the absolute humidity is constant, then as the temperature goes up the relative humidity goes down and vice versa. This is the reason that condensation can occur in a building element as the temperature reduces towards the outside of the building in cold seasons – as the temperature drops the "space" available for the water vapour reduces thereby bringing molecules together and creating the likelihood that they will coalesce into liquid water. Relative humidity is also important because it determines the moisture content of hygroscopic materials, the growth of moulds and fungi and is the basis of most methods of measuring moisture in the air.

2.2 Moisture mechanisms

The moisture risk in a building - where it is, how severe and in what state - is determined by a number of factors including the type of building materials, the construction type, the quality of the construction work, the use and occupancy of the building, the form and location of the building, and the heating and ventilation of the building. The actual mechanisms by which water in its various states moves and changes is as follows:

Vapour diffusion	Water as gas
Liquid flow through material pores	Water as gas/liquid
Capillary flow	Water as liquid
Hygroscopic buffering	Water as gas/liquid
Air movement	Water as gas

Temperature and vapour pressure gradients through materials, due to heat input from solar gain or the occupancy of the building a) lead to relative humidity gradients, which drive liquid flow, and b) evaporate water from pores causing variations in diffusion. Gravity also affects moisture movement in certain situations.

These mechanisms are explained more fully in the accompanying Technical Appendix 1.

2.3 Moisture risks

The main moisture risks of water in its different forms occur, in most cases, because of **excess** moisture, although very low humidity (or liquid water content) can also cause health problems for building occupants and in limited cases, fabric problems (ie drying out of timber or earth buildings leading to cracking or structural instability). It is important to note therefore that moisture risk assessment is not about trying to keep moisture out of buildings. It is much more about maintaining a healthy balance of moisture for both fabric and building occupants. Human beings require a certain amount of moisture in the air to be healthy; a building with zero relative humidity would be uninhabitable.

It should also be stated that most buildings on the whole cope well with general levels of moisture and even with occasional serious moisture events (such as leaking pipes, flooding or failures in ventilation systems). While we should attempt to avoid moisture risks, events such as minor surface or interstitial condensation are to be expected in many situations. The key question that needs to be asked is not whether they occur, but whether they have a detrimental effect on the fabric of the building or the health of the occupants. The attempt to eliminate all moisture risks entirely may create other problems elsewhere and has always to be balanced against the overall aims and constraints of a project.

The risks of excessive moisture are however the main concern of this document. These are primarily:

- **High humidities** within buildings which will promote surface mould growth and dust mites within houses, which cause distress to occupants as the house is felt to be 'dirty' and are strongly associated with asthma and other respiratory problems.[5]
- **Condensation** on impermeable surfaces which may run or drip onto the surrounding fabric, causing damage and staining. Condensation in cavities can also run and pool leading to fabric structural damage where organic materials (ie timber) are present, or frost damage in masonry (see below).
- **High moisture content** in materials which can promote rot of sensitive materials, leading to structural failure.
- **Frost damage**, such as detached rendering or spalling of brickwork, which can occur due to excess moisture as liquid being held in external surfaces and then turning to ice in freezing conditions.

These relate to the conditions of water as gas, liquid and solid. They are often caused by a combination of moisture mechanisms and can involve phase changes between states of water. The following are examples of these

Indoor air quality and health

Moisture risk levels for human beings relate both to our own biology and to the effect of interactions between moisture and building fabric. Relative humidity levels below 35% can cause a number of bronchial problems as well as shocks from static electricity. High relative humidities can also cause discomfort to the body. Perhaps more importantly at levels of RH over 60% dust mites are able to thrive and moulds are more likely to form on parts of building fabric when the relative humidity at the surface is high[6]. Relative humidity levels therefore which are under 35% and over 60% may be considered to be unhealthy if maintained for long periods. Optimum relative humidities are shown in Figure 1.

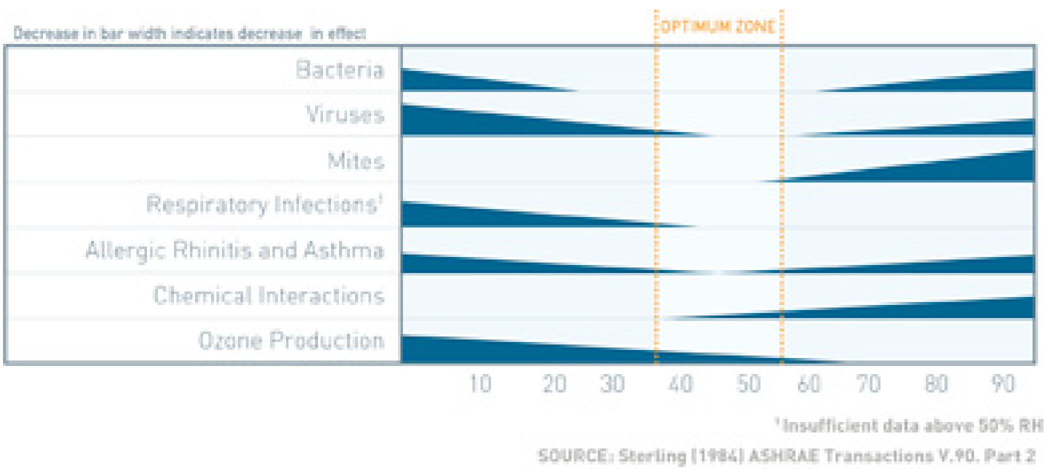


Figure 1 - Optimum relative humidities for various health risks

5 There are many types of moulds, bacteria and insects and these respond to different levels of humidity and temperature. See Sedlebauer thesis for different isopleths.[REF NEEDED]

6 Housing and Asthma by S. Howieson, Spon Press, 2005

However relative humidity levels will often exceed the upper limits in the UK. Often the outdoor relative humidity is 90% or more for extended periods. The question of how long high or low relative humidity levels need to be maintained to be dangerous to health is therefore important. In terms of mould formation at high levels of relative humidity the criteria in Part F (2010) may be taken as a starting point. These are shown in Figure 2.

Indoor air relative humidity

Moving average period	Room air relative humidity
1 month	65%
1 week	75%
1 day	85%

Figure 2 - Moisture criteria from Approved Document F

Condensation (surface and interstitial)

Surface condensation, depositing drops of water on cold surfaces such as window panes (Figure 3) is symptomatic of the high internal humidities caused by high moisture generation and/or low ventilation in combination with internal heating and a poorly insulated thermal envelope, especially if there are areas with higher heat flow and low internal surface temperature (ie. thermal bridges). The water vapour in the air turns to water liquid as it cools at the cold surface.Interstitial condensation is caused by a similar process when

Figure 3 - Severe condensation on a window running onto the sill

within the structure of buildings water condenses on colder usually impermeable surfaces. This can cause structural problems where organic materials such as timber are present, and occasionally freeze thaw problems in masonry.

Absorption by hygroscopic materials

At high relative humidities porous materials absorb water on the surface of buildings or interstitially and can raise the moisture content high enough to promote surface mould growth (Figure 4), rot of sensitive timber based materials and increase the thermal conductivity of insulation. In this situation the water vapour has not necessarily condensed but is sufficiently high within the building fabric material for mould growth to occur. As shown above moulds can start to form with relative humidities of over 60% in the air, or over 70% at a surface.

Figure 4 - Severe surface mould growth in a bathroom

Liquid moisture (not from condensation, but from rain, ground water or other sources)

Large amounts of liquid water can penetrate a structure from rain impact from the outside (Figure 5), rising damp, faulty rainwater goods or leaking pipes. This can move under temperature gradients and raise the moisture content of materials high enough to cause major problems.

Figure 5 - Rain penetration around a poorly installed window frame

2.4 Analysis of moisture problems

In this document we approach moisture risk assessment and guidance in relation to

- **Uniform building elements,** for example wall, floor or roof elements where the construction is the same throughout. This is the standard method of moisture analysis and usually assumes perfect construction and no water penetration. As such vapour diffusion has been considered the main factor in assessment of such elements till now. However with existing buildings and with buildings under ABIS ("as built", "in service") conditions liquid water penetration and air leakage should also be considered.
- **Connective effects** interfaces of different uniform elements with each other (wall, roof and floor junctions and window surrounds) or within itself (for example where a wall construction changes in the same plane due to an extension being built), with openings, with the ground and with all non-elemental materials (such as a balcony, or an external metal fitting on a wall). Liquid moisture leakage, thermal bridge effects, air leakage and trapped moisture are common causes of moisture problems in this regard.
- **Systemic effects** whole house effects such as indoor air quality, or general levels of RH internally which can affect the fabric anywhere in the house through condensation or air leakage into the structure. Typically systemic effects arise from high levels of relative humidity due to poor ventilation and/or changed air permeability or building use.
- A recognition that there are very often significant differences between buildings **as designed or theoretical** (ADT), and those **as built or in service** (ABIS). These differences can arise because of inadequate workmanship on a particular site, but may reflect more fundamental issues of buildability and suitability that should be considered in design. Both the intended use of the building and the external climate will have a major effect on in service performance.

Different types of moisture risk apply to these different approaches. Previous moisture risk assessment has been concerned only or mainly with uniform building elements in "as designed" or theoretical condition. In this approach the connective and systemic effects, along with ABIS conditions, must also be considered as these lead to the majority of moisture problems in buildings.

3

TYPES OF GUIDANCE AND THEIR RELEVANCE

In section 2 the different moisture mechanisms and risks were briefly explained. In this section we outline the different types of guidance and their relevance to the risks identified. As outlined in the introduction this document considers 3 types of assessment and guidance which need to be distinguished:

PRESCRIPTIVE GUIDANCE	Prescriptive guidance based on experience (for commonly used applications where there is good evidence of success over many years); much of BS5250 is of this nature (for example in the section on ventilated roofs). Other relevant prescriptive guidance may be found in documents such as Accredited Details for Part L and Scotland.
MODELLING	Modelling (where there is uncertainty in regard to experience, but sufficient certainty of data and parameters); assessment can then be of two types: **1 Standardised assessment** According to standards ISO 13788 or EN 15026; also for connective effects EN 10211 **2 Non-standardised assessment** This latter type of assessment may be used where existing standards are inadequate (ie. where 2D modelling is required or air flow needs to be incorporated into modelling).
PRINCIPLES-BASED	Principles-based assessment (where there is uncertainty in regard to experience, and data and/or parameters); section 4 in this document outlines the primary principles and the practical measures which result from them. Parts of BS 5250 and Accredited Details for Part L and Scotland also contain useful principles-based guidance. These principles and the resulting practical measures are not the same, however, as prescriptive guidance and require understanding and judgement by the person assessing the building element as well as an acknowledgement of the limits of guidance and the need for on-going care.

The following section briefly describes the first two of these types of guidance and the following section describes the principles based approach.

3.1 Prescriptive guidance

Prescriptive guidance for use in the assessment of moisture risk and the design of low risk buildings should be based upon well documented and robustly evidenced experience over a significant period of time and in a wide number of contexts. This is the nature of good prescriptive guidance which is available in BS5250 and some application and insurance guidance. However as context changes (ie more airtight buildings, new materials, changing climate) such guidance should be reviewed. It should also not be a barrier to innovation or better understanding.

Other sources of guidance may be relevant and are not excluded however as BS5250 is the main reference document for certifications and approvals generally it is the one assessed here.

BS 5250 refers not only to prescriptive guidance, but to modelling and to a principles-based assessment. In regard to prescriptive guidance it is particularly relevant to new build, moisture closed structures (see principles for a fuller description of this distinction), under ADT ("as designed", theoretical) conditions. The prescriptive guidance is primarily aimed at uniform building elements and not the connective or systemic effects. As such it can be useful as guidance in limited applications but cannot be considered a complete moisture risk assessment or guidance document. In one situation, the internal insulation of solid walls (section G3.1.4 of BS5250 (2011)) this prescriptive guidance is now considered not only incomplete but also incorrect. This is explained fully in Appendices 3 and 4 of the Technical Appendices.

The Accredited Details in England and Scotland provide guidance on the design of junction details to minimise **a)** the effects of thermal bridging on the risk of low surface temperatures leading to surface condensation and mould growth, and **b)** air leakage at the junction. They are therefore useful for guidance on connective effects so far as they apply to standard junctions and deal with internal moisture issues. They do not however deal with connective effects due to external conditions, particularly liquid moisture penetration (mainly through rain) at openings and junctions.

3.2 Standardised Modelling

Prescriptive guidance for specific applications, such as ventilated roof spaces, is based upon experience of common applications over many years. The best proof of such guidance is that it is tested and verified in many applications over many years. This is easiest where testing is simple and cheap, such as in viewing a loft space through a loft hatch. It is less easy when testing has to be invasive, and if invasive, usually costly and partial. In such situations and where there is more variability of guidance due to the complexity of application (ie the need for and type of VCL in a wall or floor or flat roof may vary according to the type of wall, location, amount of insulation and occupancy pattern) modelling methods are commonly used. This section examines and compares the two modelling methods available in current standards in order to understand their uses and limitations.

Hygrothermal assessment describes the coupled transfer of heat and moisture through a building material or building element. At present a 'conventional' hygrothermal assessment is generally carried out using a method, known as the 'Glaser' method, developed in the 1950s by a German refrigeration engineer, which is specified in BS EN ISO 13788:2012, and recommended in BS 5250:2011. This is specified as the means of dealing with interstitial condensation problems in all of the Building Regulations in the UK. However, the Glaser method ignores several important factors, including the transport of liquid moisture, diurnal temperature changes, the impact of driving rain and solar gain on the outside surface, and the large variation of material properties with moisture content. After a number of large collaborative research programmes within Europe, more complex methods for hygrothermal assessment were developed. These are specified in BS EN 15026:2007 and software packages for such advanced hygrothermal assessment are available, such as Delphin[7] , MOIST[8] and WUFI[9] .

3.2.1 Hygrothermal assessment using the Glaser method / BS EN ISO 13788

BS EN ISO 13788:2012 specifies procedures for calculating the risk of surface condensation and mould growth and the risk of interstitial condensation.

The Glaser method for interstitial condensation makes a number of important assumptions:

- The analysis is purely one-dimensional, two- or three-dimensional effects are ignored
- Moisture transport is by vapour diffusion alone
- There is no storage of moisture within components
- The transport properties of the materials are not affected by their moisture content
- The internal and external conditions are constant for a month
- Twelve calculations using the monthly mean conditions are carried out and the accumulation and evaporation of any condensate calculated over a year

These limitations are clearly stated in the Scope of BS ISO EN 13788:2012 with the conclusion that "Consequently the method is applicable only where the effects of these phenomena can be considered to be negligible."

7 http://bauklimatik-dresden.de/delphin/index.php?aLa=en or http://bit.ly/1gLtAzL

8 http://www.nist.gov/el/highperformance_buildings/performance/moist.cfm or http://1.usa.gov/1bYBSH8

9 http://www.wufi.de/index_e.html or http://bit.ly/1dcBWl6

The following are the advantages, disadvantages and limitations of the BS EN ISO 13788 method:

Advantages

- Simplicity – the calculations can be carried out on a spreadsheet and there are a number of cheap software packages that allow instantaneous calculation.
- The material property data needed are available for most modern materials and can be measured relatively easily if necessary.
- The climate data needed are available for many locations in the UK and abroad.
- The results from the calculation are easy to interpret.

Disadvantages

- Important processes are not included in the analysis, possibly giving misleading results

Limitations

- The BS EN ISO 13788 method is only appropriate for constructions with limited moisture storage and an impermeable outer layer for example a sheeted metal roof or curtain walling system. It is not appropriate for any construction where there is significant moisture storage or where the outer surface may absorb driving rain.
- It does not deal with "in service conditions" or building faults in or use construction (ABIS conditions) such as moisture or air leakage internally or externally (this applies to both new and existing buildings).
- It does not deal well with traditional materials (due to lack of material data)
- It does not deal well with construction build ups which do not have discreet layers at 90° to the internal-external axis – ie it cannot easily model mixed unlayered material construction build ups such as found in traditional wall construction.
- It does not deal with connective or systemic effects.

All the phenomena excluded from the scope of BS EN ISO 13788 contribute to the performance of many structures especially traditional masonry walls, both before and after insulation and "in service conditions" of all buildings. The moisture transport properties of stone and the thermal conductivity of insulation are strongly dependent on moisture content. Liquid water moves through porous materials, such as sandstone and wood, under moisture concentration gradients, with transport coefficients which are very strongly dependent on moisture content. While air movement through solid stone walls is not likely to be important, air leakage from the interior to locations behind wall lining systems, such a lath and plaster, may transport much more moisture into the system than all other processes combined. All the materials in traditional walling are hygroscopic and take up moisture from the surrounding air, depending on the ambient relative humidity.

BS EN ISO 13788:2012 also takes no account of the diurnal variation of internal and external climate, solar radiation and longwave radiation loss on the outside, and very importantly it does not allow for the impact of wind driven rain on the outside. To remedy these deficiencies, a further standard, BS EN 15026:2007 was developed to cover 'full' modelling of the hygrothermal performance of structures.

3.2.2 The BS EN 15026:2007 methodology

BS EN 15026:2007 specifies a system of equations to allow the calculation of non-steady heat and moisture flows through a structure made up of a number of different materials with complex transport properties. The Scope of BS EN 15026:2007 states:

> This standard specifies the equations to be used in a simulation method for calculating the non steady transfer of heat and moisture through building structures.
>
> It also provides a benchmark example intended to be used for validating a simulation method claiming conformity with this standard, together with the allowed tolerances.
> The equations in this standard take account of the following storage and one-dimensional transport phenomena:
>
> - Heat storage in dry building materials and absorbed water;
> - Heat transport by moisture-dependent thermal conduction;
> - Latent heat transfer by vapour diffusion;
> - Moisture storage by vapour sorption and capillary forces;
> - Moisture transport by vapour diffusion;
> - Moisture transport by liquid transport (surface diffusion and capillary flow).
>
> The equations described in this standard account for the following climatic variables:
>
> - Internal and external temperature;
> - Internal and external humidity;
> - Solar and longwave radiation;
> - Precipitation (normal and driving rain);
> - Wind speed and direction.
>
> The hygrothermal equations described in this standard shall not be applied in cases where:
>
> - Convection takes place through holes and cracks;
> - Two-dimensional effects play an important part (e.g. rising damp, conditions around thermal bridges, effect of gravitational forces);
> - Hydraulic, osmotic, electrophoretic forces are present;
> - Daily mean temperatures in the component exceed 50 °C.

The assessment methods specified in BS EN 15026:2007 are implemented in a number of commercially available software packages, but the definite 'market leader' which is most widely used, is WUFI, an acronym of the German for transient heat and moisture: Wärme und Feuchte instationär.

The advantages, disadvantages and limitations of the BS EN 15026:2007 method are as follows:

Advantages

- The method takes account of important processes including driving rain, liquid water storage and transport and diurnal changes in conditions. It is therefore expected to give a more realistic assessment of the risks of moisture problems.

Disadvantages

- Complexity – the software is complex and needs to be used by someone who understands the issues involved – a week's training course is necessary for WUFI users. A typical run with a model to EN 15026 produces a large amount of complex output which needs to be interpreted.
- The material data needed are not available for many materials and is difficult to measure
- The climate data needed are not available for many locations and are difficult to obtain.

Limitations

Theoretically BS EN 15026 method covers most known material properties, climate issues and moisture mechanisms and as such is appropriate for all constructions and particularly where there is significant moisture storage or where the outer surface may absorb driving rain. However BS EN 15026 does not cover the following:

- Airflow. As such it is not good for assessment of structures in which moisture movement is dominated by airflows eg pitched roofs. Air flow may also be a significant factor when there is unintended air leakage into any building element.
- 2D issues– ie reveals, junctions. As many of the most significant issues require 2D modelling, calculations according to BS EN 15026 cannot be said to cover all or even the most important moisture risks.
- "In service conditions" or building faults in construction internally or externally where unintended moisture ingress occurs (this applies to both new and existing buildings).
- Assessment of the effect of moisture buffering by the fabric on indoor relative humidity (which can affect both the moisture condition of fabric elsewhere as well as human health and comfort)
- There is no clear protocol for the use of BS EN15026, which means that different users of programmes may use different parameters and assumptions and produce widely varying results.

3.2.3 Multidimensional thermal modelling to EN 10211 to determine surface temperatures

Condensation and mould growth on internal surfaces, one of the most common moisture related problems in housing, depends on a combination of low surface temperatures and high internal humidities. Low surface temperatures usually occur at junctions between materials, where the geometry of the junction and often the presence of high conductivity materials, leads to higher heat flows than other areas of the fabric. The effect of these may be analysed with 2- or 3-dimensional thermal calculations using the methods specified in BS EN ISO 10211:2007. Further guidance on these calculations is given the BRE guide, BR497. ISO 13788 specifies a procedure for assessing the risk of surface condensation and mould growth caused by the lowered temperatures at junctions.

The limitations of these models are primarily that they are time consuming and require sufficient skill and knowledge to be undertaken correctly. Furthermore it is often the case that junction details, particularly when complex, are not built on site as they are designed (indeed sometimes they are not practically buildable). The difference between ADT and ABIS conditions is therefore an important consideration.

3.2.4 Non-standardised modelling

While models based upon EN 15026 have additional 2D functions and are also developing protocols for "in service" and building fault conditions (such as the ASHRAE 160 standard which was formalised for the assessment of new timber frame buildings in North America[10]), and while Delphin also contains an air flow function, none of these issues or processes are included in the formal standard BS EN 15026. Furthermore, in the opinion of the authors of this guidance, while such issues and processes can be usefully explored through such models, the more complex the issue and the less accurate the material and other data, the less certain will be the outputs. The use of dynamic hygrothermal modelling in non-standardised procedures therefore requires further work before it can be brought fully into standards, regulations and certification processes. Nonetheless, the issues of airflow, 2D interactions, "in service" conditions, building faults and moisture buffering are significant issues and any moisture assessment of any building should acknowledge their possible impact and take this into account.

How these issues might be addressed:

- Airflow – if there are airflows from the inside of the building into the fabric, the risks cannot be modelled - all that can done is to reduce/eliminate the airflow. This approach is part of the principles approach in section 4.2.3.3 below.

10 The ASHRAE 160 Standard describes the insertion of a moisture source behind the cladding, just before the breather membrane, as a method to include rain penetration, set at 1% of the wind driven rain load. This is a 1D assessment so it does not take account of interface or connective effects and does not currently look at moisture penetration at interfaces.

- "As built" and "in service" conditions and building faults – there must be an understanding of the likely problems that may occur and their effect on moisture risk. This understanding can come from an understanding of moisture mechanisms and of the principles in section 4. Modelling methods such as the ASHRAE 160 method, or modified ISO 13788 may also be helpful in indicating where problems may occur, but should not be used on their own as risk assessment methods.
- 2D interactions – thermal issues can be addressed by modelling to EN 10211, some moisture analysis software has the ability to model in 2D. Where such modelling is not possible, then the principle 4.2.3.2 gives further guidance.
- Moisture buffering can give a degree of protection against short term moisture problems particularly where there is a high degree of airtightness and hygroscopic materials with rapid response are available at or near the inner surface of the room [11].

Finally it should be reiterated that even within the limitations of use laid down in BS EN 15026, there is inevitable uncertainty, as moisture movement, material properties and human behaviour are highly complex and cannot possibly be entirely captured in a model. The dictum "all models are wrong; some models are useful" applies here. With that warning and with acknowledgement of the disadvantages and limitations listed above, it can be said that moisture modelling and particularly BS EN 15026:2007 should be used wherever possible in the assessment of moisture risk in buildings as a guide to what to consider and as part of an overall moisture risk assessment (though not necessarily as proof of risk or safety).

Examples of the different prescriptive and modelling approaches and their relevance and shortcomings are given in Appendix 4 of the accompanying Technical Appendices.

11 Maximising building fabric and furniture hygroscopic materials has no down-side, but further work is required in order to quantify the positive effects. Good evidence exists for archives and museums but not for domestic or commercial buildings. For this reason hygroscopic buffering is not included in the principles section as a material capacity measure. Future research may change this.

4

GUIDANCE BY PRINCIPLES

4.1 A good process of good design, construction and use

This document recommends that the "As Built", "In Service" (ABIS) condition and connective and systemic effects are not only recognised but prioritised in risk assessment and guidance. "As Designed", "Theoretical" (ADT) conditions as assessed for individual building elements are still relevant and can be seen as a baseline or starting point, but are not sufficient in themselves for moisture risk assessment.

The additional moisture risks under ABIS conditions and in regard to connective and systemic effects can be minimised by a higher quality of work and understanding at all levels and in all parts of a project (ie the likely performance gap between ADT and ABIS conditions is relative to quality of process).

This means:

- Good assessment: correct, rigorous and transparent assessment of the project context, including, in renovation, the existing building condition and use.
- Good design which means that which:
  - Incorporates an understanding of the factors that determine the hygrothermal performance of the specific construction type
  - Details all elements correctly
  - Details all connections and interfaces correctly
  - Takes a systemic approach to whole house moisture issues (integrating fabric, heating and ventilation strategies)
  - Integrates moisture strategy with all other requirements and strategies for the building project
  - Is practically buildable according to current building standards and knowledge
- Good quality construction, including effective supervision and inspection of completed work
- Good use, which needs
  - Provision of efficient and useable heating and ventilation systems
  - An understanding by occupants of the effective use of these systems and of the fabric conditions and requirement
- Good maintenance of fabric and services
- Good monitoring and corrective action (where necessary due to uncertainties)
- Good links between all parties in the design, construction and use of the building.

All of these points above indicate that a joined up and holistic process (of design, construction and use) is necessary if good buildings are to be achieved. The following principles and measures for minimising risk in buildings (section 4.2) reiterate many of the issues of quality listed here, but can never replace good quality work and process, which remains the best way to reduce moisture risk. The necessary knowledge and skills for good quality work and process should therefore be identified by all parties (designers, contractors, government etc) as the pre-condition for moisture risk assessment and risk mitigation, and research, training and supervision should be put into place accordingly. See Appendix A in this document for some suggested measures.

4.2 Principles for minimising moisture risk in buildings

The section below spells out the fundamental principles for assessing the risk of moisture problems in buildings and provides practical guidance for implementing these principles.

The key principles are:

6 Ensure a good design and construction **process**

7 Understand the **context** of the building and the building project and ensure **compatibility** of the design with this context

8 Ensure **coherence** in approach and detailing.

9 Build in **capacity** for errors, uncertainties and future challenges

10 Ensure that **caution** is taken where there are uncertainties

The principles identified above are described with short explanations of the different aspects of each of the principles and then practical measures that need to be taken to address the issues raised by each aspect.

The first section reiterates the importance of good **PROCESS** for each specific project, and the following two sections (**CONTEXT AND COMPATIBILITY**, and **COHERENCE**) deal with the primary criteria for a whole building approach. The last two sections (**CAPACITY** and **CAUTION)** are about how to deal with uncertainties in general. In addition the principles of capacity and caution are also included in the practical measures in the first two sections where specific measures to deal with uncertainties are required.

4.2.1 Process

The principles of the design and construction process have been identified above in section 4.1 as essential to reducing moisture risk. In any physical building project, it is usually the connections between professions, trades, and users which cause the most difficulties, not the individual professions, trades or users themselves. There are also systemic effects on projects if the different stages and participants are not communicating or have unresolved differences.

Practical measures

A method for collaboration through all stages and including all participants in a project should be agreed at the start of any project. This can be a Soft Landings approach or any other formalised process which includes proper quality assessment, feedback loops and interaction throughout the project.

4.2.2 Context and Compatibility

General principle

It is essential to understand the context of a building project and then ensure that the project is compatible with this context. Context refers not only to geographical context but to the planned use of a building, the available skills and supply chain, and the financial constraints. In this document the issue of skills, supply chain and finance are covered only briefly under the heading of Capacity as Context is primarily being considered in terms of design.

In relation to the repair, renovation or retrofit of existing buildings, the context is to some extent wider than in new build as it includes all new build contexts and also the existing building itself, its form, construction and condition.

In both new build and retrofit some contexts can vary over time and for this reason sufficient capacity and caution should also be exercised to ensure future changes to context do not introduce new major moisture risks at a later stage.

It should also be said that moisture risk assessment and measures have to be set in the context of other aims of the building project, such as energy efficiency, cost effectiveness, beauty and comfort. Even though health is a major reason for moisture measures, within health there may be conflicts between measures for moisture protection and other measures for the control of toxins (such as radon or traffic pollution for example). Any moisture strategy, therefore, has to be integrated into these other aims and a holistic and whole house strategy adopted.

4.2.2.1 Geographical context: location, orientation, local exposure

Primary principles

Understanding and assessment of location, orientation and local conditions is essential to understanding moisture risks from driven rain, wind and solar drying.

Practical measures

The site should be located on the driving rain map in BR262 or AD C to determine the overall exposure. In critical cases, the detailed driving rain maps and the assessment methodology in BS8104 should be used to allow for local variations in topography, sheltering and orientation; visits to site should be made particularly in adverse conditions.

In particular designers of buildings in DRI Areas 3 or 4 or with local high exposure need to consider the impact of the geographic environment in terms of design, construction and maintenance. Detailing around openings, junctions and at ground level must be appropriate and robust. Roof design in particular needs to be appropriate to location (BRE Guide Roofs and Roofing), as do measures at openings and in terms of rainwater goods and drainage. Solid wall building retrofits in all areas, but particularly in exposed areas, need to minimise the disruption of the equilibrium between the wetting and drying of the walls due to external rain and wind, and the effects of solar driven moisture in walls and solar drying.

Modelling to EN15026, where material and weather data are available, can assist in understanding of the effects of location, orientation and local exposure. Just as importantly, a knowledge of building performance, vernacular design and the monitoring of existing buildings and new projects can assist in identifying risks and appropriate strategies.

Capacity

Maximise weathering capacity (see section 4.2.3.4) for example by increasing overhangs on roofs, increasing rainwater good capacity and ensuring drying capacity of building systems. Use materials with capacity to endure adverse conditions (see 4.2.2.3). Modelling under worst case conditions for an area and with water ingress can be used to test and illuminate moisture risk (but not necessarily to prove the safety of any application).

Caution

Monitor junctions and openings for water ingress. Monitor vulnerable masonry materials for frost damage. Build in regular maintenance activities to deal with vulnerable areas.

4.2.2.2 Form

Primary Principles

The shape of a building, its height and whether it is single or dual aspect are all important considerations for moisture risk (single aspect buildings are nearly always more difficult to ventilate correctly). Complex building forms (in all aspects including external walls, roofs and floors, windows, abutments and all junctions) are often more difficult to detail for weathering, insulation, airtightness or ventilation. This can increase moisture risk in many ways.

Practical measures

In new build design and in alterations and extensions to existing buildings it is essential to keep to a form which is compatible with the geographical context and also with the available skills of contractors and users. Complexity in new and existing buildings should be approached with full detailing coherence (see section 4.3 below).Generally all buildings benefit in relation to moisture risk from simplicity of form.

Capacity

Exercise additional care in detailing and site quality control on complex and non-standard junctions.

Caution

Monitor junctions and openings for water ingress. Build in regular maintenance activities to deal with vulnerable areas.

4.2.2.3 Materials and construction method

Primary Principles

In any area the materials and construction methods used in traditional buildings have evolved to be compatible with the local climate; these can provide guidance for design and construction practice in both new buildings as well as existing (and, in particular, traditional) buildings.

An understanding of the durability of materials under different moisture conditions is essential. Biogenic materials such as timber or straw are more vulnerable to decay from high levels of moisture in comparison with some non-organic materials such as brick and or stone. Somemetals however can be very vulnerable to decay due to moisture problems (through oxidation – rust and also from interactions with substances such as tannic acid from wet oak). With regard to timber it should be noted that there is a significant difference between durable timbers such as oak or sweet chestnut and less durable timber such as fast grown softwood. Within all timbers, there is also a considerable difference between the heart wood and the sap wood. Timber treatment obviously can have a considerable effect, but should never be a substitute for good design. It should be noted that even the most vulnerable materials can be long lasting and healthy if the form of construction and compatibility with all contexts is correct. Furthermore biogenic materials can have positive effects on the durability and health of buildings in regard to their active hygroscopic, capillary and vapour permeability qualities.

Of particular importance is an understanding of the difference between moisture open and moisture closed buildings, materials and systems. This issue is dealt with separately in section 4.3.1.3 below due to its importance.

Practical measures

In work on existing buildings, an understanding of the materials and the construction methods is essential prior to new work being undertaken. Correct assessment of the hygrothermal qualities of walls, floors and roofs is necessary. It is not always apparent from the surface what the actual make up of a traditional wall may be, so a proper and if necessary invasive survey of materials and construction form is essential prior to any work being specified. Testing of materials or expert assessment may be required. For an understanding of traditional materials and construction and the consequences of this, see work by English Heritage, Historic Scotland, SPAB and STBA [refs].

More modern existing buildings can also hold surprises, so an understanding of original construction techniques and materials, as well as past interventions is necessary for all existing building risk assessment and design.

In undertaking new work on existing buildings compatibility of new materials with the existing materials is essential. See below section 4.3.1.3.

Capacity

If the construction is not fully known then assume worst case materials or construction situation. For example if it is not known how porous a brick or a stone type is, assume the worst type of porosity for the situation and design accordingly. Modelling can be used to test and illuminate worst case situations, (but not necessarily to prove the safety of any application).

Caution

Monitor performance of materials and structure for signs of failure due to lack of proper material/ construction assessment. Build in regular maintenance activities to deal with possible failures

4.2.2.4 Condition

Primary Principles

The condition of the fabric and services is an essential part of any moisture risk assessment of an existing building. Buildings in good condition are on the whole much more able to deal with interventions and abnormal events (such as freak flooding) than buildings already under stress or not in equilibrium (ie buildings in good condition have more capacity). Understanding the building condition and moisture performance of a building and, importantly, what constitutes good or poor conditions and the consequences of these, is essential prior to altering a building.

Practical measures

First fully assess the fabric and services condition and performance. Poor fabric condition in wall, roof or floor should be addressed prior to new work being undertaken. In particular where a building is not in equilibrium due to poor weathering, poor drying (internally or externally) or trapped moisture these issues should be addressed and equilibrium restored. In particular roof and wall detailing, mortars and pointing should be addressed, as should ground levels, rainwater goods and drainage. Internally adequate ventilation should be maintained or installed, both in the fabric (ie under suspended floors and in vented roofs) and in the building generally.

Capacity

Where there is uncertainty about building condition due to lack of access or hidden conditions, add additional safety margins in all calculations and work. However this is not a substitute for a proper condition survey or assessment. If no assessment is taken, no design or construction work should proceed.

Caution

Where there is uncertainty, monitor performance of materials and structure for signs of failure. Build in regular maintenance activities to deal with possible failures.

4.2.2.5 Use and occupancy type

Primary Principles

High occupancy and high water usage (particularly in bathing, washing clothes and cooking) can considerably increase moisture risk and push balanced systems into imbalance in some situations. Sufficient capacity of systems and buildings to cope with high or unusual occupancy or use is therefore an important consideration where this is likely to occur. Furthermore it is essential that controls of heating and ventilation systems are adaptable to changed conditions and are usable by occupants or managers.

The main principle here is that designers should understand not only their buildings but the building users and the likely future use of the building.

Practical measures

Capacity

Assess both planned and possible future use and occupancy and model on the basis of the most challenging scenario, where modelling is being used to support principles. Put in sufficient capacity or upgrade facility in ventilation systems, and adequate fabric measures to allow for maximum occupancy.

Caution

Ensure that regular checks are made on the correct operation of key building services such as heating and ventilation.

4.2.3 Coherence

General principle

Having understood the context of a project and made sure that the general project aims and criteria are compatible with this context, the next stage is to ensure that there is coherence in detailing and in the process of design, construction and use. Coherence is about attention to detail and a joined up approach to process. It is an essential concept in the assessment and mitigation of moisture risk.

4.2.3.1 Coherence of moisture approach in materials and systems

Primary Principles

There are two fundamentally different approaches possible to moisture control in regard to the fabric of buildings. These are what may be called moisture closed and moisture open approaches.[12]

A moisture closed approach, which is used in many modern buildings, attempts to eliminate moisture risk in the fabric (particularly external walls, floors and roofs) by excluding moisture as a vapour or liquid by the installation of impermeable materials.

A moisture open approach allows both moisture ingress and egress through the many hygrothermal mechanisms as listed in section 2. The moisture carrying capacity and decay mechanisms of the building materials and systems as well as the use of the building will determine how much moisture ingress is acceptable without detrimental effects to fabric or occupants. A moisture open approach is found in most traditional buildings, which use naturally moisture open materials.

A moisture open approach can also be used in new buildings, particularly if the materials being used in a project are vulnerable to decay (ie. organic materials such as wood and straw), and where there is risk of trapped moisture (for example from the construction process) or from likely ABIS conditions in the future. Moisture open approaches, if designed according to the other principles listed in this section, tend to have greater capacity where there are building faults as they are designed to accommodate some moisture ingress and have physical mechanisms for drying.

While the terms "moisture open" and "moisture closed" broadly characterise two significantly different approaches they are not by any means a complete description of possible approaches to moisture. For example it might be possible to have a capillary closed but vapour open approach, which is indeed common in both new and existing buildings, and also in some parts of traditional buildings. There are also commonly existing buildings which have more than one approach without difficulty, particularly where buildings are not airtight or well insulated. However any attempt in a document like this to further refine the terminology runs into the danger of introducing unnecessary complexity and confusion. The point of making the distinction between moisture open and moisture closed approaches is to strongly flag up the need for awareness of the possibility of radically different fabric moisture control strategies and the importance of a coherent approach in designing and carrying out new work.

Practical measures

Moisture problems often arise where the there is a clash of approach to moisture in the terms laid out above. This can occur in new or existing buildings, so a coherence of

12 this distinction is made in Approved Document L1B sections 3.8 to 3.12 in regard to traditional building construction, but can be applied more generally.

approach is important in all cases, with particular attention to interfaces where approaches are not coherent. Particular difficulties can occur in retrofit in particular if moisture closed approaches are used on moisture open fabric. Certain conditions which are in equilibrium in existing buildings may become problematic when these buildings are repaired or retrofitted, due to changed moisture movement (through for example moisture closed mortar or plasters, increased airtightness, vapour barriers or increased insulation). In order to ascertain the level of risk a proper assessment of the building context (as per section 4.2.2 above) must be undertaken.

A moisture closed approach can be adequate on a moisture open traditional building if there is a low contextual risk (section 4.2.2) or where there is a complete coherence of systems (ie a moisture open fabric is entirely enclosed in moisture closed materials and systems, including at damp course level), but only when there is minimal residual moisture from in-service conditions and where there are no vulnerable materials such as timber. This approach is not recommended unless there is expert design (including assessment) and high quality application. It does not meet the principle of capacity and caution below.

The principle of maintaining the original designed moisture performance of existing buildings is a good starting point for repair and new work, although consequent fabric interventions and change of use should also be borne in mind . Any deviation from original designed performance principles has to fully take account of on-going moisture movement, residual moisture issues, and both connective and systemic effects.

Advice on moisture open building structures and materials in traditional buildings is available from the Society for the Protection of Ancient Buildings, English Heritage, Historic Scotland and other conservation bodies.

Capacity

Where there is an unavoidable junction between a moisture open and a moisture closed approach (for example where a new solid floor with DPM is inserted in a solid wall building without DPC) then particular care should be taken in the detailing, and modelling should assume worse case situation at the junction. Proper site QA processes should be in place.

Where uncertainty exists in relation to the moisture system of existing fabric, a moisture open approach is preferred. If a moisture closed approach is to be used, organic materials should be removed from within the fabric and moisture levels reduced in fabric prior to application.

Caution

Where there is uncertainty, monitor performance of materials and structure for signs of failure . Build in regular maintenance activities to deal with possible failures.

4.2.3.2 Thermal coherence

Primary Principles

The insulated envelope should, as far as possible, be made uniform over the surface of the building to minimise locally depressed internal surface temperatures that can promote surface mould. There will, inevitably, be higher heat flows and lower temperatures at junctions and openings the effects of these can be minimised by effective design and detailing.

Practical Measures

Ensure insulation levels are equal as far as possible around the whole building element, in order to minimise contrasts and creation of possible thermal bridging problems

Ensure thermal bridging at junctions (roof, floor, wall, window and door reveals), lintels and in the frame of buildings is minimised. Use calculations complying with EN 10211 and BR 497 where necessary to see if there is likely to be condensation as a result of thermal bridging.

Ensure that convective bypass is eliminated by detailing to prevent air infiltration through insulation layers and party wall cavities.

Capacity

In new build following the correct conventions is sufficient (EN 10211 and BR497 as well as Accredited Details). If the building is not designed with thermal coherence it will fail any moisture risk assessment. In retrofit where thermal coherence cannot be reasonably achieved, other measures such as additional ventilation should be instituted.

Caution

In retrofit, monitoring of areas where thermal coherence is not possible is essential, as are measures to remove moulds. Access to areas of possible difficulty should be maintained (for example where there is potential convective bypass or in joist ends in external walls where internal insulation is applied). These areas should be monitored and problems addressed if and when they occur by advice from a moisture expert.

4.2.3.3 Airtightness

Primary Principles

Un-designed air infiltration is a major route for energy loss in houses. However ventilation is necessary for good indoor air quality, including the reduction of high internal humidity. Good design of ventilation systems and detailing of the building can achieve an effective balance between these potentially conflicting aims. Air leakage from the interior into the fabric can be the dominant mechanism for transporting water vapour into regions where it can cause problems. This can be minimised by detailing an air tight layer on the warm side of the envelope[13].

Practical Measures

Ensure that airtightness strategy is consistent for the whole building and that airtightness measures are fully linked. In new build there should, as far as possible, be a continuous air barrier (not necessarily a vapour barrier) on the warm side of the building envelope. In design and construction drawings the clear identification of the air barrier is essential, both to ensure that a continuous air barrier is technically possible (if there are areas where fabric elements cut across the air barrier, then this means the barrier is not possible and the design should be altered), and to highlight its importance to site managers and contractors. Where details are complex, 3D modelling and careful site supervision are essential.

In retrofit a completely coherent airtightness layer may not be possible and so a strategy must be defined which minimises air flow into those parts of the external fabric where airtightness measures are possible without increasing air flow into any areas where such measures are difficult or impossible. Such a strategy must also ensure that moisture is not trapped in areas where there is residual moisture. In such situations a moisture open air barrier (including moisture open plasters and renders) may be considered.

13 This section is primarily concerned with airtightness which is related to air and moisture movement from the inside of the building towards the outside. However it should also be noted that air infiltration from outside into the structure and into the building interior is also important in terms of heat loss, comfort and fabric and occupant health. This air infiltration from outside may be known as draught proofing in so far as it affects internal comfort and as wind-tightness in so far as it affects fabric and insulation performance. Both are linked to airtightness. A fully airtight building will be draught-proofed and will not require separate draught proofing measures. However airtightness does not necessarily deal with wind-tightness which requires good detailing and application on the cold side of the structure particularly in suspended floors, roofs, and framed walls. A considerable amount of convected heat loss can occur due to poor wind-tightness (particularly where there are low density insulations in exposed parts of the structure or where convective pathways exist within insulation or internal structures such as party walls). The movement of external air in these situations will also affect moisture content (both positively and negatively).

Capacity

Both designers and site managers/contractors need to be properly trained in airtightness detailing and application. Designs should, wherever possible, keep air barriers separate from service runs and penetrations should be minimised. Design work must prioritise airtightness and ensure that what is drawn is not only technically possible but also buildable. Origami type folds of membranes at complex junctions are usually not achieved on site. Keep it simple.

On site it is worth undertaking air pressure tests at first fix prior in order to address major problems while the structural fabric is still easily accessible. Time for checks, pressure tests and remediation should be built into schedules.

Caution

Where there is uncertainty, air pressure tests, if possible combined with thermographic imaging, should be used to identify air leakage. Where air leakage is unavoidable or irremediable, an assessment should be made of the possible damage of unplanned air infiltration and appropriate measures taken to address risks. These may involve heating and ventilation strategies, or localised treatments.

Areas of identified risk or uncertainty should be monitored.

4.2.3.4 Weathering / waterproofing

Primary Principles

Some degree of damage due to weathering of buildings is inevitable, but can be minimised by good attention to detailing especially taking account of the materials present. The principles of Deflection, Draining, Drying and Decay Resistance[14] are useful. As in section 4.2.3.1 a distinction must be made between moisture open and moisture closed approaches, particularly in regard to capillarity. For example traditional masonry was capillary open, both in brick and stone and in mortar. The application of capillary closed mortars onto capillary open brickwork will cause significant damage to brickwork through freeze-thaw effects and in some cases lead to water penetration to the inside of the building. A coherent approach is essential in this regard, and different approaches must be avoided where possible. If approaches are mixed then the detailing of junctions will require additional care.

Practical Measures

A whole house strategy for rain and drains minimises risk. This means a strategy which fully takes into account the context of the building and then details the rain deflection, drying and drainage accordingly. This can be either a moisture open or a moisture closed approach. The detail must then deal with all materials and junctions in a coherent way. It is important in masonry construction that the mortar (and pointing) is compatible with the brick or stonework.

Weathering is often concentrated in areas affected by run-off from above or severe wind pressures on corner or ridges. The building should be designed and detailed to minimise local affects and to protect more vulnerable materials and areas. Vernacular building design specific to an area is often a good indication of what works, and should be a starting point for designing buildings and renovations.

Water resistant flooring and other surfaces should be provided in areas, such as bathrooms, kitchens and utility rooms, where there is likely to be spillage of water. However this must be integrated with other moisture control systems in a building to ensure that this water proofing does not trap moisture and cause problems in other parts of the structure.

Capacity

Sufficient capacity in Deflection, Draining, Drying and Decay Resistance are essential. Modelling should take account of possible extreme weather events.

Caution

Maintenance and monitoring of weathering details is essential.

14 As developed by the Canadian Mortgage and Houses Corporation in 1999 following the failure of many timber frame houses due to rain penetration.

4.2.3.5 Ventilation, heating and fabric coherence

Primary Principles

A coherent approach is required because many moisture problems are related to fabric, ventilation and heating. Ventilation and heating are not the subject of this document but are an essential component of any moisture strategy.

Practical measures

An efficient, robust and usable ventilation system which is integrated with the heating system, as well as use and occupancy will significantly reduce moisture risk not only to the health of occupants but to fabric as well, as reduced levels of excess humidity (due to effective ventilation) reduces stress on fabric measures.

4.2.4 Capacity

General Principle

Where there is uncertainty about the moisture performance of a building, capacity should be built into the processes of assessment, construction and use. Capacity should take into account not only current but future uncertainties, such as potential building use and occupancy patterns as well as the effects of increased driven rain or wind because of possible climate change.

The principles of capacity and caution have been flagged up already in the sections of context and coherence in relation to specific practical measures required where there is uncertainty in data or for other reasons. This section is more general, and should be integrated into overall approach to moisture risk assessment and guidance.

4.2.4.1 Capacity in design

Don't over-optimise: Building design which pushes the capacity of a building to deal with moisture to the limit is likely to fail.

Practical Measures

Design for the most severe internal and external conditions likely to be experienced by the building. If calculations used to assess the performance of a building suggest that it will 'just pass' reconsider the design. Allow for maximum occupancy in a similar way. Finally allow for the differences that might occur between a building as designed and as built and occupied, and try to minimise these differences by good design and use of appropriate materials.

4.2.4.2 Capacity in process: Skills, supply chain and budget

Primary Principles

It is important that any design for a new building or for the repair or retrofit of an existing building takes into account the availability of contractor skills, types of product and budget necessary for the project being designed. Skills, product knowledge and budget should not be "just enough" as even the best projects will encounter unexpected issues. Sufficiency capacity is essential to avoid real and long term moisture risks.

Practical measures

A thorough understanding of the buildability of designs, of the required skill set, of the availability of adequate products for a particular application, and the cost of all these factors is essential in ensuring a successful approach to a project which does not fall apart during construction process or in use, due to expensive or difficult maintenance requirements. Extra capacity should be added, wherever possible, but particularly if any of these factors is difficult or uncertain.

4.2.5 Caution

General Principle

The many uncertainties, complexities and unknowns in regard to moisture risks, both at the point of design and over the life of the building necessitate caution in design and construction and on-going watchfulness in use in order to mitigate possible problems. In particular many serious moisture problems may be hidden from view for some time prior to their effects being felt (for example when there is moisture build up in the middle of walls, behind linings or in joist or rafter ends). Because of the many complex interactions in walls and the difficulty in understanding fully their consequences, in addition to building in additional capacity, measures of caution should also be built into construction and particularly user information and maintenance programmes.

Practical Measures

USABILITY

Usability of services (particularly ventilation and heating) is essential. The context of user should be prioritised in the specification of services.

MAINTENANCE

Both services and fabric (particularly rainwater goods and drains) must be easily maintained. Maintenance manuals and programmes should be established as part of any project. This will require engagement with users and owners.

MONITORING

Where there is uncertainty allow for simple checks and testing to be undertaken by building users or owners/managers. Leave clear indications as to what is acceptable and what is a moisture risk or problem, with further information as to what to do or who to contact for more information.

FEEDBACK

Ensure that knowledge of problems and concerns is communicated back to all parts of the supply chain including procurers, designers, contractors, and product suppliers. In this way future designs can be improved and risks reduced.

4.2.6 Summary Table

Below is a summary table of the principles. It is suggested that both training modules and checklists can be developed from such a table.

The relevance of different principles varies according to the type of work, the location, building use, condition etc. New buildings of simple form, in unexposed locations, with normal usage and built mainly according to prescriptive guidance, will require less attention to the principles than many other types of work. However it is worth referring to the principles wherever possible in all work as part of good practice.

Main Principle	Sub-principle
Process	
Compatability with context	Geographical
	Form
	Materials and construction method
	Condition
	Use
Coherence	Coherence of moisture approach
	Thermal coherence
	Airtightness
	Weathering / waterproofing
	Ventilation, heating and insulation
Capacity	Design
	Process
Caution	Usability
	Maintenance
	Monitoring
	Feedback

5

HOW TO UNDERTAKE MOISTURE RISK ASSESSMENT AND LOW MOISTURE RISK DESIGN

5.1 Methods of selecting the appropriate approach

The earlier sections of this guide have explained that a number of methods are available to assess the risk of moisture problems in any type of structure. These can be divided into 3 types:

- Prescriptive guidance
- Modelling
- Principles-based assessment

These can be subdivided into the following:

A Prescriptive guidance based on experience contained in BS5250 and other documents targeted at specific building types

B Simplified modelling using the ISO 13788 methodology

C Advanced modelling to EN 15026;

D Multidimensional modelling of temperatures and heat flows to EN 10211 and BR497, to determine the risk of surface condensation and mould growth at junctions

E Non-standardised assessment using modelling which go beyond existing standards to cover issue like 2D or 3D heat and moisture flows or where there are significant air flows through the structure.

F Principles-based assessment (where there is uncertainty in regard to experience, and data and/or parameters). Section 4 outlines the primary principles and the practical measures which result from them

These methods are more or less appropriate for the assessment of moisture risk in a specific situation dependent on the type of construction, the quality of information available and the context. The first 5 methods (A to E) should be regarded as a sequence going from simple/straightforward to complex/sophisticated and require a) more complex information about the structure and b) a better understanding of heat and moisture transport by the user, as we move from A to E. Method F to some extent is required in all the other methods, but becomes particularly important where methods A to E are not relevant or possible. The tables below in section 5.4 give guidance on which method is appropriate for a range of common construction types. These tables also take into account the important factors described in Section 2.4 above as follows:

The differences between buildings as designed (ADT), and those as built or in service (ABIS).

Standardised modelling (B and C) deals with uniform building elements for example wall, floor or roof elements where the construction is the same throughout and assumes perfect construction and no water penetration. There are very often significant differences between buildings as designed or theoretical (ADT), and those as built or in service (ABIS). These differences can arise because of inadequate workmanship on a particular site, but may reflect more fundamental issues of buildability and suitability that should be considered in design. The tables below give an indication of whether the ABIS conditions are likely to differ from ADT in any particular construction. Where prescriptive advice (A) is based on long experience of building performance it may take account of the ABIS conditions, but this cannot be generally assumed. It may be possible to incorporate imperfect materials (eg a VCL with gaps) by changing the material properties in a standardised model, (B or C) or using extreme internal or external conditions however it is virtually impossible to tell how realistic this is, and there is a danger of over designing, to meet a non-existent risk. Non-standard modelling (E) can be used to assess the effect of defects, but this requires complex software, and quantitative information about the defects. Where there are likely to be major differences between ADT and ABIS conditions, it is essential that there is a good understanding of the consequences of these differences on the moisture performance through the principles described in Section 4 (F).

The importance of connective effects at junctions

The connective effects at interfaces of different uniform elements with each other (wall, roof and floor junctions and window surrounds) or within itself (for example where a wall construction changes in the same plane due to an extension being built), with openings, with the ground and with all non-elemental materials (such as a balcony, or an external metal fitting on a wall) can lead to liquid moisture leakage, thermal bridge effects, air leakage and trapped moisture. Prescriptive guidance on minimising surface condensation and mould growth and air leakage is given in the Accredited Details (A). Standardised modelling to ISO 13788 and EN 15026, (B and C) is essentially one-dimensional and does not take account of these effects. Multidimensional thermal modelling to EN 10211 and BR497 can be used in conjunction with the surface condensation procedure in ISO 13788, to assess the risk of surface condensation and mould at junctions (D). Non standardised 2- and 3-D combined heat and moisture models are available (E), but these are very complex to use and require more details of the structure and materials present than are generally available. Where connective effects are likely to be important, it is essential that there is a good understanding of their consequences on the moisture performance through the principles described in Section 4 (F). The tables below indicate which assessment method is likely to be the most appropriate for each common construction type.

Systemic effects due to the interactions between individual elements, the whole structure and the way the building is used.

Systemic effects are due to the interactions between individual elements, the whole structure and the way the building is used. These can affect indoor air quality, or general levels of RH internally which can affect the fabric anywhere in the house through condensation or air leakage into the structure. Typically systemic effects arise from high levels of relative humidity due to poor ventilation and/or changed air permeability or building use. They are not covered by prescriptive advice (A) or standardised modelling (B C). Some non standardised techniques are available (E), such as Computational Fluid Dynamics (CFD), however these are very complex and expensive and rarely justified except in the case of very large, complex buildings. The tables below highlight where systemic effects are likely to be important, and in these cases a good understanding of their consequences on the moisture performance through the principles described in Section 4 (F) is essential.[15]

The important differences between moisture open and moisture closed design.

A moisture closed approach, which is used in many modern buildings, attempts to eliminate moisture risk in by excluding moisture as a vapour or liquid often by the installation of impermeable materials such as membranes. A moisture open approach allows moisture both ingress and egress through the many hygrothermal mechanisms as listed in section 2. A moisture open approach is found in most traditional buildings, which use naturally moisture open materials. Prescriptive advice on moisture open design (A) is available from the agencies that deal with traditional buildings. Where modelling is useful, because the ISO 13788 methodology (B) does not deal with stored moisture or driven rain and therefore does not handle moisture open design effectively, it will be necessary to use the EN 15026 methodology (C). Moisture closed designs in ADT conditions can be assessed with ISO 13788. The tables below provide further details on the most appropriate methodology in individual cases.

The differences between new and existing buildings

There are many differences between a new building, designed and built with modern materials, and an existing building that is being modified to save energy or renovated for a change of use, and these differences become more pronounced in older existing buildings. A modern building should have been designed in the context of current Regulations, including under the provisions of Part C, design to prevent moisture problems. The structure and the materials used will be known. While, as noted above, there are very often significant differences between the ADT and the ABIS condition, if the design, construction and use are carried out well through a good quality process, these differences should be small and have relatively little effect on performance (as noted in section 4.1). In older houses the structure will have achieved equilibrium with the internal and external environment. Adding insulation or changing building use significantly will disturb this equilibrium; for example adding insulation will change the temperature of materials and possibly inhibit evaporation into the interior or exterior. Also measures to save energy by reducing ventilation will increase the internal humidity and therefore the moisture load on the structure. Also, especially in older buildings, the nature of the pre-existing structure and materials may not be known and difficult to determine. This will make realistic assessments using standardised or

15 The recently produced Guidance Wheel for the Responsible Retrofit of Traditional Buildings is a useful way of understanding the connective and systemic effects of particular retrofit measures and an illustration of how these connections may occur both in retrofit of other buildings and in new build as well. See http://responsible-retrofit.org/wheel

non-standardised assessments difficult to achieve. It is, therefore, essential that those concerned with the upgrading of older traditional buildings have a good understanding of the principles of heat and moisture transfer through materials (as explained in section 2 in this document and more fully in Appendix 1) and use a principles based approach (F) in assessment and design supported by appropriate modelling and appropriate prescriptive guidance from relevant organisations. The differences between new and existing buildings (and within this between pre 1919 solid wall and post 1919 buildings) is noted in the text accompanying the tables, where relevant.

5.2 Carrying out moisture risk assessments and low moisture risk design

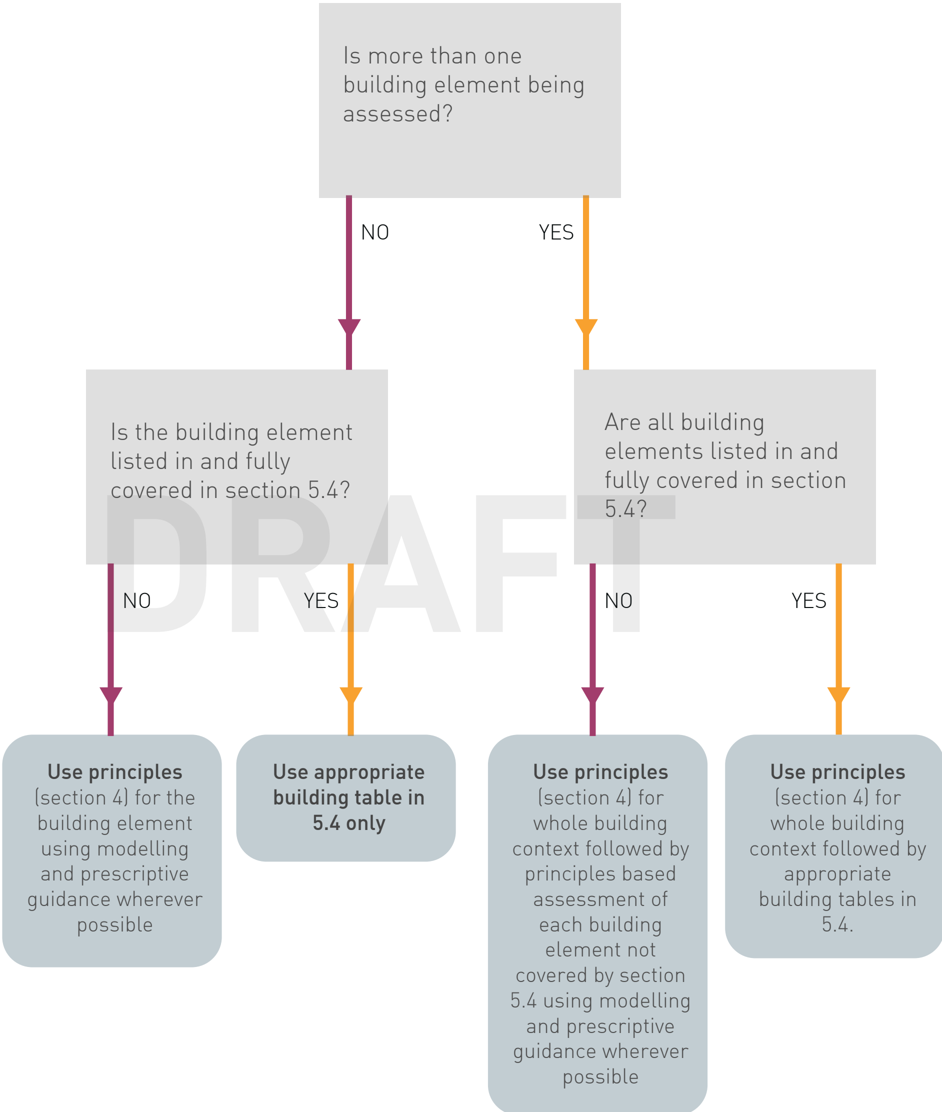
The approach outlined in this document involves a move from a focus on building elements to a whole building approach, and from as designed and theoretical conditions to as built and in service. As such the approach has to be integrated both in regard to the physical whole of the building (including services) and its physical context, and also in regard to the process of design, construction and use. Furthermore, this document has highlighted the much increased risk of moisture problems in buildings due to increased airtightness and the need to retrofit all buildings to high standards of energy efficiency. In order to ensure that an integrated approach is taken which deals effectively with moisture risk the following is recommended for all projects:

- An individual or group should be specifically appointed to each project to be responsible for moisture risk assessment and low moisture risk design[16]. Ideally this person or group integrates not only the elements of the design process but also ensures that low moisture risk design is carried out in construction and communicated properly to the building users. This could be a new professional consultant in the design team, or a new role for an existing part of the design team. In small projects the role will be one of many undertaken by the same person (as designer or builder), but should none the less be identified as a specific task.
- A formal strategy with checklists should be made for design, construction and use phases and kept as part of the building documentation.
- Where a new building is planned, or the repair, renovation or retrofit of the whole of an existing building, then a whole building approach should be followed, starting with principles, and followed by consideration of the building elements tables in section 5.4.
- Where section 5.4 is not applicable the principles in section 4 should be followed, supported by whatever modelling and prescriptive guidance is available and appropriate.
- Where only a single building element is being considered in an existing building project

16 the use of moisture safety experts in design and moisture safety officers on site is now being used in parts of Sweden as part of the ByggaF process. See A Method for Including Moisture Safety in the Building Process Kristina Mjörnell, Jesper Arfvidsson and Eva SikanderIndoor and Built Environment published online 13 November 2011 DOI: 10.1177/1420326X11428340

then the relevant table in section 5.4 may be followed and the principles only considered where relevant.

Suggested flow chart for project assessment



For the non-project based, generic certification of systems and products for particular building element application, the following may apply

- The tables in section 5.4 should be followed for the relevant building element application. Where prescriptive guidance is not available (according to Section 5.4) standardised contexts should be used and testing/ modelling and assessment done according to these contexts. When using certified systems or products, designers of projects will have to assess how far the context under which they have been assessed is relevant to the project and where any further analysis, testing, or capacity/ caution is required.
- Certification of products or systems cannot constitute a risk assessment for a project without the principles in section 4 being taken into account for the project as a whole.

5.3 Judging moisture risk assessment

Moisture risk assessment is not an exact science. Methods of assessment which reduce buildings to their individual construction elements may seem to provide a way to achieve certainty, but ignore the connective and systemic effects as well as the use of the building, which is where the majority of moisture risks occur. In terms of such non-elemental effects, there are a large number of variables, interactions and uncertainties which cannot be reduced or calculated without creating further risks.

The purpose of undertaking moisture risk assessment, therefore, is not to provide definite proof of the safety of a project or part of a project. The function is rather to eliminate definite known risks in defined areas (particularly under ADT conditions) and then to raise awareness of all other risks and their causes, thereby enabling the designer or assessor to form a strategy for addressing these risks. If, in an assessment, a construction is shown to have a risk of moisture failure under certain conditions (ie in severe driven rain areas, or due to complexity of junctions) then this does not mean that it will fail and cannot be permitted. However the strategy for the project must show how such risks are to be managed. This should be in reference to the principles given in section 4. If these principles are not followed then the construction should not be allowed.

5.4 Building Element Assessment and Design Tables

The guidance in the tables below is based upon building elements as in previous moisture risk guidance[17], but this does not mean that a whole building approach is not intrinsic to the whole assessment process. At all times the building should be considered as a whole (including its services and use). However in our current state of knowledge and process (including design and certification) it is still easiest, in the first instance, to classify risk and approach according to building element.

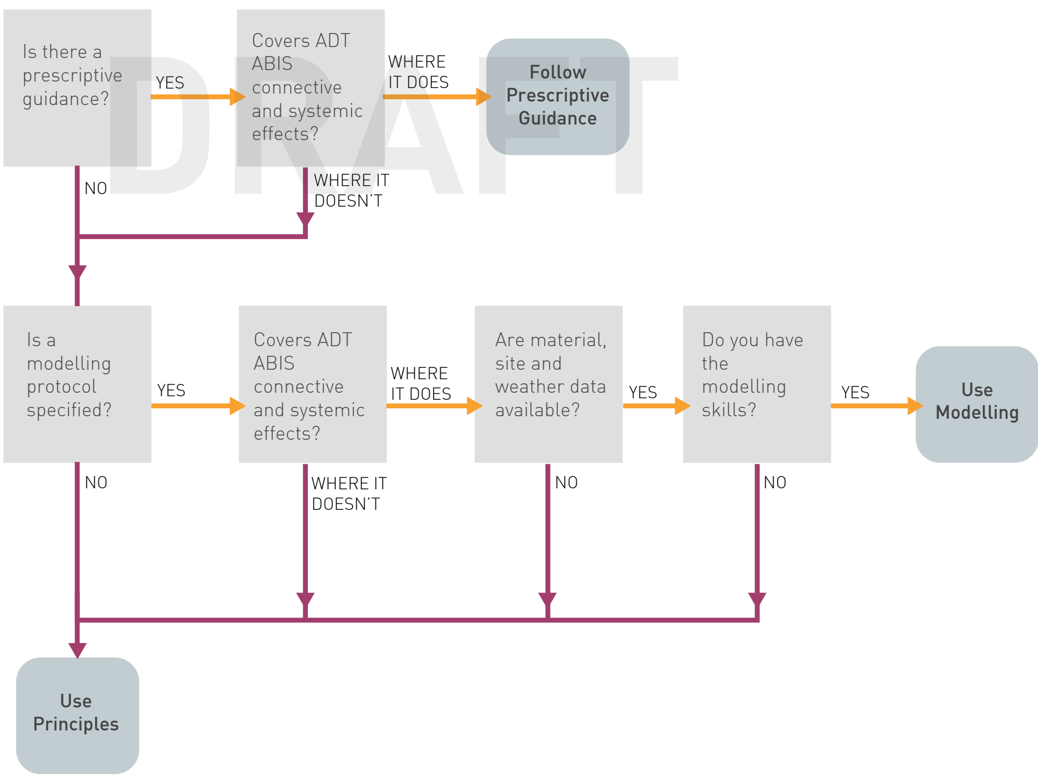
This section only covers the most common building element constructions; all other constructions should be assessed by using the principles in section 4 and by utilising modelling and other guidance wherever relevant and possible. ADT and ABIS conditions as well as connective and systemic effects should be considered in all cases. Guidance for non-standard construction should be taken from authoritative or specialist bodies, but this guidance must be viewed critically in the light of this document taking into account all the hygrothermal mechanisms, and the limitations of current standards and knowledge.

17 for example BS EN 5250: 2011

Where prescriptive guidance or modelling is recommended, this only applies where this is relevant to the particular application and where sufficient data is available. It will be a common occurrence (particularly in existing buildings) that prescriptive guidance is not exactly suited to the particular project or that exact data is either not available or is difficult to obtain without great cost. In such situations a principles based approach should be used supported by prescriptive guidance or modelling which is as near as possible to the reality of the project being assessed.

As noted in section 4.1 the importance of good quality assessment, design, construction and use in a joined up and holistic process will close the gap between ADT and ABIS conditions, as well as dealing with connective and systemic effects. The quality and integrity of the design and construction process should therefore be an important factor in moisture risk assessment.

Flow chart for use of tables in section 5.4



This flow chart is designed as a logical way to use the tables in section 5.4. It should be used as a subsidiary process within the flowchart in section 5.2. As will be evident, in many situations, particularly in retrofit and in non-standard new buildings, the use of Principles is both the beginning and the end of the process. This does not mean reduplication of work, but does indicate that understanding and assessing buildings and building elements according to the Principles is an essential part of moisture risk assessment and should be undertaken properly in the first instance in order to save extra work and avoid confused outcomes.

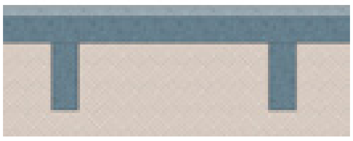
5.4.1 Ground floors

Ground floors are protected from the external climate, and are not affected by the impacts of driving rain and solar gain however they can be significantly affected by:

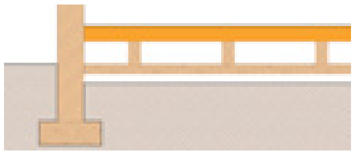
- Ground moisture;
- Water incorporated in construction which may take many months to dry
- Moisture generated by the occupants and their activities
- Leaks and spillage within the building

There are two types of ground floors

Ground bearing



Suspended



Furthermore there are two conditions: moisture-closed, which contain a DPM and moisture-open which do not. Moisture-closed floors are usually specified where there is a DPC in the walls to which the DPM can be linked. Moisture-open floors, which are more difficult as they have to take account of the water table level, ground conditions and site drainage, may be required in traditional buildings where the insertion of a DPC is difficult or undesirable, or where new extensions abut old walls. It is a common problem that the insertion of a new moisture-closed floor into a building without DPCs can increase the moisture in the bottom of the walls and cause both damp and salt damage.

In moisture-closed new build and retrofit the following moisture closed constructions and issues are common

Ground bearing

Floors of concrete which are cast on a prepared base. These should incorporate a damp proof membrane (DPM) to protect against moisture from the ground. The risk of condensation is affected by the position of the DPM relative to the insulation. Surface condensation may form, particularly at the junction with external walls and at external corners; that risk may be reduced by providing thermal insulation to the edges of the slab and providing adequate heating and ventilation.

Suspended

Floors of structural concrete or timber with a void beneath them that should be ventilated to remove moisture. It will be important to consider the relative vapour resistance of the different layers in the floor above the void, using the ISO 13788 procedure, to reduce the risk of surface and interstitial condensation.

In moisture-open new build and renovation the following moisture-open constructions are used

Ground bearing

Floors made of flagstones or brick bedded on lime mortars directly onto subsoil were common in the past, particularly prior to 1919. Such floors work adequately provided that the ground has a low water table and is well drained, and that the mortars and flagstones/ bricks are suitable. Floor coverings or furniture on top of such floors should not inhibit the evaporation of moisture from the floor. New moisture open groundbearing floors are rare, but technically possible using a number of inert vapour open insulation materials and moisture open mortars, stones, bricks and materials such as "limecrete"

Suspended

Floors in traditional buildings are moisture open. They are usually of timber construction and unheated, though (un)insulated radiator pipes often run through the voids and may condition the floor void to some extent. If insulation is added then great care needs to be taken to ensure that this does not increase the risk of surface or interstitial condensation due to trapped moisture and thermal bridging. It is conventionally considered that condensation risk is avoided by adequate ventilation of the below-floor void, although minimal research exists on this subject. Air tightness is important both in terms of moisture transfer and heat loss, so an air barrier is essential. Making traditional building floors airtight can also considerably effect indoor air quality and air flow to chimneys (systemic effect).[18]

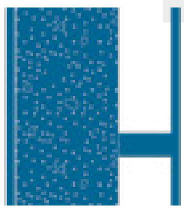
Moisture-closed	ADT	ABIS	Connective/ systemic
Ground bearing floors of concrete	Prescriptive Guidance: Annex F of BS5250	Prescriptive Guidance: Annex F of BS5250	Prescriptive Guidance (Accredited Details) for connective effects.
Suspended concrete floor Suspended timber floor	Prescriptive Guidance: Annex F of BS5250	Prescriptive Guidance: Annex F of BS5250	Prescriptive Guidance (Accredited Details) for connective effects.

18 The STBA Guidance Wheel illustrates these connections here and in regard to other building elements for the retrofit of traditional buildings. see http://responsible-retrofit.org/wheel

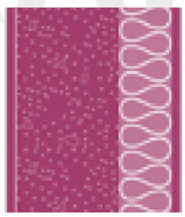
Moisture-open	ADT	ABIS	Connective/ systemic
Ground bearing floors	EH Energy Efficiency in Historic Buildings: Insulating Solid Ground Floors	Principles based approach	Principles based approach. Refer EH Energy Efficiency in Historic Buildings: Insulating Solid Ground Floors
Suspended floors	EH Energy Efficiency in Historic Buildings: Insulation of Suspended Timber Floors	Principles based approach	Principles based approach. Connective Effects should be considered particularly in retrofit. Systemic effects should be considered particularly in retrofit

5.4.2 Solid Walls with and without additional insulation

Solid wall without insulation



Solid wall with additional insulation



New build solid walls can be either moisture-closed (for example concrete with external insulation systems) or moisture-open (for example systems such as aircrete, aerated clay, hemp or straw walling). Sometimes these also have additional external or internal insulation. Most common systems currently have render finishes but it is possible for there also to be vented facades such as timber, brick or stone.

Existing solid masonry walls are extremely common and comprise about 25% of the building stock of the UK. Many are entirely moisture-open and have few moisture problems, if they are maintained in good condition. They may be of brickwork, stone or flint, with mortar joints between the elements, or of monolithic earth. The thickness may be as little as 215mm or as much as 600mm or more. Older walls may consist of thin inner and outer skins of stone or brick separated by a core of rubble and voids, in a matrix of mortar. Brick and sandstone walls have a considerable capacity to absorb water, which can move under temperature gradients. Granite walls typically will absorb little water, but leakage through mortar joints may be a problem. Earth walls are nearly always covered with a lime based render. Brick and earth walls are commonly plastered internally while older stone walls may have a lining of lath and plaster, separated from the masonry by a cavity.

Adding internal or external insulation to an existing solid wall will disrupt the long term equilibrium that will have developed between the masonry and the ambient conditions, by changing the temperatures through the wall and inhibiting evaporation from surfaces. Care needs to be taken therefore that the Principles in section 4 are followed and that a proper assessment using EN 15026 is undertaken. In particular information about residual moisture (related to the building condition section 4.2.2.4) and materials and construction method (section 4.2.2.3) from actual site inspection and analysis are essential to the usefulness of any modelling. Complexity of form (section 4.2.2.2), use and occupancy (section 4.2.2.5) and ventilation (section 4.2.3.5) are also essential factors in assessing risk.

Both moisture-open and moisture-closed approaches are possible in retrofit of existing solid walls, but please note Principle 4.2.3.1 and the need for capacity and caution, as there is still much uncertainty about the effects of solid wall retrofit and the long term implications of many measures.[19]

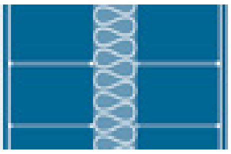
Moisture-closed	ADT	ABIS	Connective/systemic
Solid masonry walls with and without insulation	Standardised modelling to EN15026	Principles based approach supported by standardised modelling to EN15026 Non-standardised modelling (ie ASHRAE 160 method)	Principles based approach supported by modelling to test for connective effects (ie 2D or 3D analysis of junctions to EN 10211) For solid masonry with external insulation prescriptive guidance in Accredited Details for thermal bridging and air leakage connective effects. Systemic effects should be considered particularly in retrofit

Moisture-open	ADT	ABIS	Connective/ systemic
Solid masonry walls with and without insulation	Standardised Modelling: EN15026	Principles based approach supported by standardised modelling to EN15026 Non-standardised modelling (ie ASHRAE 160 method)	Principles based approach supported by modelling to test for connective effects (ie 2D or 3D analysis of junctions to EN 10211 to test for thermal bridging connective effects) Systemic effects should be considered particularly in retrofit.

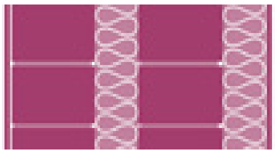
19 For further information about these issues as well as access to a substantial body of peer reviewed research papers, please see the STBA Guidance Wheel and Knowledge Centre at http://responsible-retrofit.org/

5.4.3 Cavity masonry walls with cavity insulation or additional EWI or IWI

With cavity insulation



With additional EWI



After the First World War solid masonry walls were increasingly replaced by walls with a cavity between two leaves of brick; this was designed to reduce rain penetration through the wall into the interior.

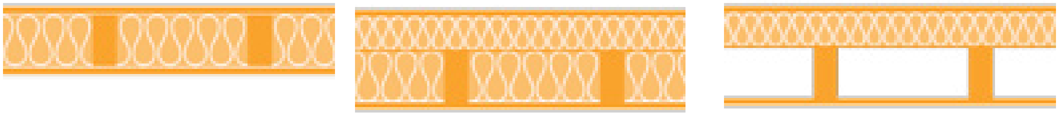
It is now common practice to fill the cavity with thermal insulation to reduce heat loss from the house. This will make the outer leaf colder, increasing the chance of frost damage to the masonry. There is also the possibility that the insulation will bridge the cavity allowing moisture from driving rain to penetrate to the inner leaf. However if the outer leaf is in good repair and the insulation has been properly installed, this risk is negligible, except in conditions of extreme driven rain. The context of geographical location and orientation, as well as building condition and maintenance, is therefore important particularly in ABIS conditions.

As with solid walls, adding external or internal insulation to existing cavity masonry walls will disturb the previous hygrothermal equilibrium by altering the temperatures and inhibiting evaporation. No distinction is necessary in terms of moisture open or moisture closed approaches, as cavity walls are primarily designed to be moisture-closed. However application of EWI or IWI systems can be on a moisture-closed or moisture-open basis and as such will require different modelling and may achieve different outcomes.

Table 7 - Appropriate methods for analysing cavity walls

Cavity masonry walls	ADT	ABIS	Connective/ systemic
Cavity masonry wall with insulated cavity	Prescriptive guidance: Section G.3.2.3 of BS5250:2011	Principles based approach supported by Non-standardised modelling (ie ASHRAE 160 method) in areas of high driven rain	Principles based approach supported by Prescriptive Guidance (Accredited Details) for thermal bridging and airtightness connective effects or modelling (ie 2D or 3D analysis of junctions to EN 10211)
Masonry wall with cavity with additional EWI or IWI	Standardised Modelling: EN15026	Principles based approach supported by Non-standardised modelling (ie ASHRAE 160 method) in areas of high driven rain	Principles based approach supported by Prescriptive Guidance (Accredited Details) for thermal bridging and airtightness connective effects or modelling (ie 2D or 3D analysis of junctions to EN 10211)

5.4.4 Framed walls with any insulation system



Modern framed walls, with either timber or steel framing, usually incorporate a 'sheathing' layer on the frame to provide racking resistance to the structure. It is typically a moisture-closed material and if it is outside the insulation layer may provide a barrier to vapour diffusion; this will lead to a risk of interstitial condensation which will require an AVCL internally. Moisture-open constructions often have the sheathing layer on the inside of the insulation and use moisture open insulations and membranes.[20]

Many modern framed walls also have vented cladding systems externally. However this is not necessary in all situations; systems without vented cladding (for example systems with insulation and render directly onto the frame) can operate with low moisture risk provided they are designed, built and maintained correctly. In all framed systems the main risk is under ABIS and connective conditions and consequently quality of work (from design through to construction and maintenance) as identified in section 4.1 is the best protection against moisture problems.

Traditional (ie pre-20th century) timber frame walls are moisture open. They often do not have a sheathing layer as the frame itself provides sufficient racking. Materials for infill of the frame were traditionally wattle and daub (earth) or brick. Externally frames were either left bare, or more commonly, particularly in areas of driven rain, rendered or clad. These frames survived without moisture risk to the structure because of the moisture open construction which drew moisture away from timbers (due to the capillary and hygroscopic qualities of the infill materials) and also encouraged drying. Principles of deflection, drainage and durability (as identified in section 4.2.3.4) were also essential (as in all wall and roof constructions, but particularly here). However walls were also often thin (sometimes as thin as 100mm) and so liquid water penetration into buildings was not uncommon. This problem can and will be exacerbated by changing weather patterns.

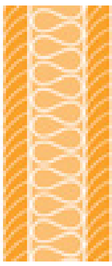
Any changes to the original construction design or materials including the addition of claddings, linings, insulation or different infill materials will disturb the previous hygrothermal equilibrium, by altering the temperatures and inhibiting evaporation. Particular care should be taken to follow a principles based approach in traditional timber frame buildings.

20 This is considered a safer method in German Building Regulations DIN 68-800, and in regard to timber frame means that preservative treatment is required only in sill beams.

Table 8 – Assessment methods for framed walls

Moisture-closed	ADT	ABIS	Connective/ systemic
Framed wall with insulation externally, in between members, internally and other combinations	Standardised Modelling: ISO 13788 or EN15026	Principles based approach supported by non-standardised modelling to test for ABIS conditions (ie increased rain – ie ASHRAE 160 method - increased occupancy)	Principles based approach supported by Prescriptive Guidance (Accredited Details) for thermal bridging and airtightness connective effects or modelling (ie 2D or 3D analysis of junctions to EN 10211) Systemic effects should be considered particularly in retrofit.
Moisture-open	**ADT**	**ABIS**	**Connective/ systemic**
Framed wall with insulation externally, in between members, internally and other combinations. Also all traditional timber frame construction.	Standardised Modelling: EN15026	Principles based approach supported by Non-standardised modelling to test for ABIS conditions (ie increased rain – ie ASHRAE 160 method - increased occupancy)	Principles based approach supported by Modelling to test for thermal bridging connective effects (ie 2D or 3D analysis of junctions to EN 10211) Systemic effects should be considered particularly in retrofit.

5.4.5 Cladding systems - Composite insulated panels, Built in situ, SIPS



There is a risk of condensation occurring on the inside of the external sheet. To avoid that, all site-assembled sheet metal walls should incorporate an AVCL on the warm side of the thermal insulation; a breather membrane may be required immediately beneath the outer sheet. The internal metal liner may constitute an AVCL provided all joints between trays and all penetrations are fully sealed.

Provided the insulation fully fills the space between the metal facings in preformed insulated panels, the impermeable metal internal lining prevents water vapour diffusing into the interior of the panel, eliminating any risk of interstitial condensation. However, water vapour diffusion is still possible at panel edges. Condensation can form in any spaces near the cold facing.

Table 9 - Methods for assessing cladding systems

Cladding systems (moisture-closed)	ADT	ABIS	Connective/ systemic
Cladding systems – Composite insulated panels, SIPS and built in situ	Standardised Modelling: ISO 13788	Standardised Modelling: ISO 13788, modified to take account of estimated defects, such as a gap in the inner sheet or VCL	Principles based approach supported by modelling to test for thermal bridging connective effects (ie 2D or 3D analysis of junctions to EN 10211)

5.4.6 Pitched roofs

There are three types of pitched roof:

Cold | **Warm** | **Hybrid**

Cold or warm refers to whether the rafters of the roof are outside the insulation layer or within it. Hybrid roofs have rafters both outside and within.

Cold pitched roofs

The most common type of domestic roof in the UK has a cold ventilated loft above a horizontal insulated ceiling. Because substantial amounts of air pass from the occupied rooms through gaps in the ceiling, heat and especially moisture movement are dominated by air transport. There are therefore no methods available for modelling the condensation risk. Practical methods for minimising condensation risk have therefore been developed.

Warm pitched roofs

The insulation follows the line of the roof, with a sloping ceiling beneath. If the roof structure incorporates air cavities above the insulation layer, these should be ventilated as specified in BS5250:2011. If there are no cavities, the risk of condensation can be assessed with ISO 13788 or EN 15026 calculations and the materials specified accordingly.

Hybrid pitched roofs

Designers should be aware that this form of construction is less efficient and more difficult to form than warm pitched construction. However it is frequently adopted in the adaptation and renovation of existing buildings. Great care and attention to detail is recommended to achieve continuity of the insulation and the AVCL in a hybrid pitched roof. However it might not be possible to achieve an airtight ceiling.

Moisture risks in all roofs increase with complexity of form, penetrations and openings. In existing buildings there are particular moisture challenges in regard to brick chimneys. Moisture risks are also increased considerably if excess humidity from inside the house is allowed into the roof due to poor AVCLs and openings such as loft hatches.

As identified in BS5250:2011 a different approach is required depending on whether there is a high or a low resistance membrane or other material (such as a sarking board) on the outside of the rafters. The calculation method and approach however is the same in both cases, although the resulting specification will often be different. Moisture open or closed approaches apply only to warm and hybrid roofs. In all cases it is assumed that the roof covering is capillary closed and keeps out rain. Thatched and other non-standard pitched roofs should be treated separately and require specialist knowledge, based upon a thorough understanding of hygrothermal mechanisms.

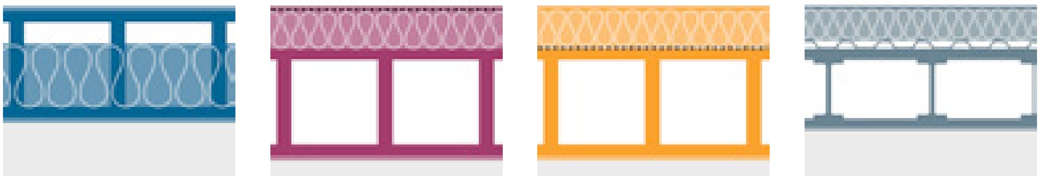
Table 10 – Methods for assessing pitched roofs

Pitched Roofs	ADT	ABIS	Connective/ systemic
Cold pitched roof with underlay	Prescriptive Guidance: Section H.4 of BS5250:2011	Prescriptive Guidance: Section H.4 of BS5250:2011	Principles based approach. Connective effects should be considered particularly in retrofit Systemic effects should be considered particularly in retrofit
Warm pitched roof with underlay	Standardised Modelling: ISO 13788 or EN15026	Principles based approach supported by Non-standardised modelling to test for ABIS conditions (ie excess moisture ingress into insulation layer from inside).	Principles based approach supported by Non-standardised modelling to test for thermal bridging connective effects (ie 2D or 3D analysis of junctions to EN 10211) Systemic effects should be considered particularly in retrofit
Hybrid pitched roofs	Prescriptive Guidance: Section H.6 of BS5250:2011	Principles based approach supported by Non-standardised modelling to test for ABIS conditions (ie excess moisture ingress into insulation layer from inside).	Principles based approach supported by Non-standardised modelling to test for thermal bridging connective effects (ie 2D or 3D analysis of junctions to EN 10211) Systemic effects should be considered particularly in retrofit

5.4.7 Flat roofs

There are four main types of flat roof

Cold deck | **Warm deck** | **Inverted** | **Metal deck**



All flat roofs incur a higher moisture risk than pitched roofs due to the fact that they do not shed water as effectively and rely on continuous membranes or other materials. These factors do not meet the principles of Deflection, Drainage and Drying (see section 4.2.3.4) as well as pitched roofs. ABIS conditions cannot allow for any deterioration in the roof finish, or connective effects without complete failure. Consideration of the location, use and maintenance regime is critical for ABIS assessment

Cold deck roofs require considerable care in the design and construction as the ventilation to the underside of the decking is critical.

With all warm flat roofs there is a risk of interstitial condensation forming between the thermal insulation and the waterproof covering; to avoid that risk, an AVCL with vapour resistance at least equal to that of the waterproof covering, should be provided immediately above the supporting structure. The AVCL should be wrapped around the edges of the insulation and sealed to the waterproof finish at the perimeter and all penetrations.
As the thermal insulation in an inverted roof is above the waterproof layer, there is no risk of interstitial condensation. It is essential that the insulation resists the absorption of water and is strong enough to support the load of any protective finish of ballast or slabs.

Connective effects (from openings, penetrations etc)v in all flat roofs should be kept to a minimum as they considerably increase risk.

Green roofs can increase the durability and capacity of a flat roof, but also bring their own risks and may require additional maintenance.

Table 11 - Methods for assessing flat roofs

<table>
<tr><th>Flat roofs</th><th>ADT</th><th>ABIS</th><th>Connective/ systemic</th></tr>
<tr><td>Cold deck</td><td>Prescriptive Guidance: BS5250: H7.1</td><td rowspan="4">Standardised Modelling: ISO 13788, modified to take account of estimated defects, such as a gap in the inner sheet or VCL</td><td rowspan="4">Principles based approach supported by modelling to test for connective effects (ie 2D or 3D analysis of junctions to EN 10211)</td></tr>
<tr><td>Metal deck</td><td>Prescriptive Guidance: BS5250: H7.2</td></tr>
<tr><td>Warm deck</td><td>Prescriptive Guidance: BS5250: H8</td></tr>
<tr><td>Inverted</td><td>Prescriptive Guidance: BS5250:H9</td></tr>
</table>

5.4.8 Sheeted metal roofs

There is a risk of condensation occurring on the underside of the external sheet and dripping into the thermal insulation thereby reducing overall thermal performance. To avoid that, all site-assembled sheet metal roofs should incorporate an AVCL on the warm side of the thermal insulation; a breather membrane may be required immediately beneath the outer sheet. The internal metal liner tray may constitute an AVCL provided all joints between trays and all penetrations are fully sealed.

Provided the insulation fully fills the space between the metal facings in preformed insulated panels, the impermeable metal internal lining prevents water vapour diffusing into the interior of the panel, eliminating any risk of interstitial condensation. However, water vapour diffusion is still possible at panel edges. Condensation can form in any spaces near the cold facing.

Table 12 – Methods for assessing sheeted metal roofs

Sheeted metal roofs	ADT	ABIS	Connective/ systemic
Site-assembled sheet metal roofs pre-formed (composite) insulated roof panels with underlay	Standardised Modelling: ISO 13788	Standardised Modelling: ISO 13788, modified to take account of estimated defects, such as a gap in the inner sheet or VCL	Principles based approach supported by modelling to test for connective effects (ie 2D or 3D analysis of junctions to EN 10211)

APPENDIX

Appendix A: Supporting Measures

The new method of moisture risk assessment in this document is necessarily more complex and involved than previously because of the changes to our buildings and our understanding of moisture mechanisms and risks. It is not sensible or acceptable in terms of liability and responsibility to continue to ignore changed circumstances and the body of evidence about moisture risks. However this new approach must be practicable if it is not to create further unintended consequences. In order to make this practicable it will be necessary for government and industry to work together in the following areas:

- Training for designers and contractors (where relevant)
- Protocols for use of EN 15026
- Protocols for non-standardised modelling for ABIS conditions and connective effects
- Protocols for product and system certification
- Harmonised and coherent methods for undertaking risk analysis
- The production of better material data for modelling
- The accessibility of better weather data for modelling
- Improved and extended Accredited Details
- The integration of new research into moisture into moisture risk assessment on an ongoing basis, particularly in the area of retrofit where multiple uncertainties exist.

References & sources of further information

List of applicable standards + other design guidance. Important research papers. Relevant organisations. Etc.

Standards

BS5250 2011, British Standard Code of Practice for control of condensation in buildings, BSI 2011

BS EN ISO 12572: 2001, Hygrothermal performance of building materials and products — Determination of water vapour transmission properties, BSI 2001

BS EN ISO 13788: 2012: Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation. Calculation methods (London: British Standards Institution) (2012)

BS EN 15026: 2007: Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation. (London: British Standards Institution) (2007)

ISO 10456, Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values

BS EN ISO 10211: 2007, Thermal bridges in building construction – heat flows and surface temperatures – detailed calculations (BSI 2007)

ANSI & ASHRAE, 2009. ANSI/ASHRAE Standard 160-2009 Criteria for Moisture-Control Design Analysis in Buildings. Atlanta, GA, USA: ASHRAE, & Washington, D.C., USA: ANSI.

CIBSE Guide A.7 Moisture

Regulations

Approved Document C - Site preparation and resistance to contaminates and moisture, http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partc/documentc

Approved Document F 'Ventilation' http://www.planningportal.gov.uk/uploads/br/BR_PDF_ADF_2010.pdf

Technical Handbook - Domestic Scottish Building Standards 2013 http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/pubtech/th2013domcomp

Software

Delphin software: http://bauklimatik-dresden.de/delphin/index.php?aLa=en

Moist Software : http://www.nist.gov/el/highperformance_buildings/performance/moist.cfm
WUFI Software: http://www.wufi.de/index_e.html

BRE Publications

The BRE Stone List: on line database http://projects.bre.co.uk/ConDiv/stonelist/stonelist.html
BRE IP 4/06, Airtightness of ceilings, Energy loss and condensation risk, BRE 2006
BR 262 : Thermal insulation avoiding risks, BRE 2002
BR 497: Conventions for calculating linear thermal transmittance and temperature factors, BRE 2007
BR 443 : Conventions for U-value calculations, BRE 2006

Background papers

Glaser, H., 1959. Graphisches Verfahren zur Untersuchung von Diffusionsvorgängen. Kältetechnik, 10, pp. 345-9.
IEA Annex 24, Heat , Air and Moisture Transfer in Highly Insulated Building Envelopes, Technical Synthesis Report: http://www.ecbcs.org/docs/annex_24_tsr_web.pdf
Low Carbon Construction report, Green Deal Provider Guidance http://gdorb.decc.gov.uk/admin/documents/6975-green-deal-provider-guidance.pdf
H. Jansssen, S. Roels, Qualitative and quantitative assessment of interior moisture buffering by enclosures. Energy and Buildings 41 (2009), 382 - 394
Responsible Retrofit of Traditional Buildings;2012; N May and C Rye;
Survey of Building Envelope Failures in the Coastal Climate of British Columbia', (MHL 1996), http://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/98102.htm

Sources of Information

The following organisations can provide further information on performance of buildings and moisture problems:
English Heritage: http://www.english-heritage.org.uk/professional/
Historic Scotland: http://www.historic-scotland.gov.uk/index/learning.htm
CADW: http://cadw.wales.gov.uk/?lang=en
BRE: http://www.bre.co.uk/page.jsp?id=1849
STBA : http:// www.stbauk.org
Protection of Ancient Buildings: http://www.spab.org.uk

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