Health and Moisture in Buildings

A REPORT FROM THE UK CENTRE FOR MOISTURE IN BUILDINGS ABOUT THE HEALTH IMPACT OF BUILDINGS WHICH ARE TOO DRY OR TOO DAMP

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SAINT-GOBAIN

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It is based upon an academic report, which was researched and written by C. McGilligan, overseen by M. Ucci. This academic report is available on request to the UKCMB.

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[1] Neil May and Marcella Ucci are members of the Institute for Environmental Design and Engineering (IEDE) at University College London. Charles McGilligan (PhD) was contracted as the main researcher for the project, with Marcella Ucci being the Principal Investigator. This public report was based upon this work and was written primarily by Neil May. IEDE is one of the Core Knowledge Partners of the UK Centre for Moisture in Buildings, see www.ukcmb.org

Health and Moisture in Buildings

Executive summary

Buildings which are too damp or too dry can be bad for occupants' health. This fact has been well established by many reports including those of the World Health Organisation[1] and the Institute of Medicine[2]. Yet precisely how bad such buildings are to what kinds of occupants at what level of dampness or dryness is much more difficult to define, as are the agents of illness, such as the many types of mould, bacteria, other irritants and toxins that can result from imbalances of moisture in buildings.

This UK-based report seeks to identify the issues that prevent progress towards a better outcome for occupants, both now and in the future, and to suggest a constructive way forward.

The academic research into this project covered several hundred articles and books, and references almost 200 separate studies. From this research we can conclude not only that there is a significant link between moisture levels in buildings and occupant health, but that it is highly likely that we are increasing the risk of illness in this country through the current changes to building form, construction, occupation patterns and use.

However, as we show, the evidence necessary to provide proof of causality is not sufficiently strong to drive policy makers, industry or financial organisations to demand changes in legislation or practice, or to penalise wrongdoing. This is primarily because of the complexity of interactions between agents of illness, human health, and building condition. This complexity is compounded by a lack of robust methodologies and metrics, and by the fact that in each specific context there are multiple variables.

Consequently, it is difficult not only to identify causes with certainty, but also to calculate how much illness is caused by buildings which are too damp or too dry. For example, the Energy Savings Trust recently stated that around a third of the UK population report that they have mould in their homes[3] ie, over 8 million properties and 20 million people—a figure which is wildly out of line with the English Housing Survey reports (of 4% of buildings with mould)[4]. Nonetheless, even using these most cautious estimates, there are over 1 million damp properties in the UK, with around 2.5 million people potentially affected by exposure to dampness in buildings[5] in England alone, and the costs of this to the National Health Service and the economy may run into many tens, if not hundreds of millions of pounds each year[6]. It is therefore essential to be able to identify more clearly the actual level of this problem and to move forward towards robust evidence which will enable policy makers, industry and financial organisations, as well as building occupants, to act positively and promptly.

[1] World Health Organization, editor. *WHO guidelines for indoor air quality: dampness and mould*. Copenhagen: WHO; 2009. 228 p

[2] Institute of Medicine (U.S.), editor. *Damp indoor spaces and health*. Washington, DC: National Academies Press; 2004. 355 p

[3] This information comes from the APPG on Healthy Homes and Buildings report *Building our Future*. The reference is from Energy Saving Trust. *Cold, draughty, mouldy, damp: What the UK public think about their homes*. 2014: http://www. energysavingtrust.org.uk/about-us/news/ colddraughty-mouldy-damp-what-uk-public-thinkabout-their-homes.

[4] English Housing Survey Headline Report 2015-6; DCLG

[5] The English Housing Survey shows that there is a higher proportion of damp buildings within the private rental and social housing sector, where there is greater density of population than the average household size of 2.3 (as per the Office for National Statistics figures 2011).

[6] The potential costs are set out on pages 6 and 12 of the main report.

Our research makes the following recommendations for a way forward:

1 Where possible, within the current conventional knowledge framework in the UK, we should *develop robust methodologies and metrics for the testing and collection of relevant data about moisture and health in buildings*. In particular we need to have methods to assess more accurately the levels of dampness and mould in buildings, as well as building ventilation rates, and benchmarks for what is safe or unsafe.

2 *We should develop a research methodology which integrates the complex interactions of health, moisture and buildings and takes full account of contextual conditions.* We believe that this requires a new approach in research with an emphasis on multiple detailed holistic case studies, which, *en masse* and combined with quantitative data (as in point 1 above), will enable a new understanding of influential factors and of their causality.

3 *A new way of thinking about moisture and health in buildings is required*, based upon firstly, an informed understanding of the multiple factors which affect building performance and human health, and secondly, an understanding of the complex interactions of these factors in the context of specific buildings and their occupants. This would enable more accurate risk-based assessment, and the implementation of specific measures to address the moisture-based health risks of a particular building and occupancy, without the need to establish precise medical causality. We call this a **balanced** approach or model.

4 *It is important to ensure that this approach gains acceptance by the medical establishment*, and that medical, building science and building use researchers and experts work together.

The development of this knowledge base must happen before new policies and regulation in government, industry and the finance sector can be instituted. Therefore our short-term recommendations are that:

i *Moisture risks should become a priority of building safety* and be fully integrated into regulations, and all building policy (including, especially, energy focused measures).

ii *A Whole Building approach to both new and existing building work must be taken*, which integrates people, building fabric and services within the context of the building. In particular, ventilation and building use should be integrated with fabric measures such as airtightness and insulation.

iii *Additional attention should be given where there is particularly strong evidence of moisture risk*. This applies to parts of the private rental sector, to temporary accommodation, and wherever there is overcrowding or high levels of poverty. Government should address these cases with urgency.

iv *All moisture safe design must also deal with unavoidable uncertainty* and integrate sufficient capacity and caution into design, construction and use in order to mitigate unknown risks.

v *Engagement with the public in general and with building occupants during work is essential*. More information and clearer communication about a balanced approach to moisture in buildings can help to reduce risk immediately.

vi *Funding for the research programme and for a public communication strategy should be forthcoming*. This should become a priority for government and industry now.

The risks to health of excessive or too little moisture in buildings have been acknowledged and discussed for many years, but without identifying a clear way forward. We argue that this is no longer acceptable, given the increasing risks from ongoing changes to buildings and their use, and the well-known and better evidenced risks to the fabric and value of buildings from unbalanced moisture levels. We believe that we have identified a way forward for the study and assessment of health and moisture in buildings, and look forward to working collaboratively to develop it, and the solutions that will arise from it, for the health and benefit of buildings' occupants and the UK.

Health and Moisture in Buildings

1 Introduction

Buildings which are too damp or too dry can be bad for occupants' health. This fact has been well established by many reports including those of the World Health Organisation[1] and the Institute of Medicine[2]. Yet precisely how bad such buildings are, to what kinds of occupants, at what level of dampness or dryness, is much more difficult to define, as are the agents of illness, such as the many types of mould, bacteria, other irritants and toxins that can result from imbalances of moisture in buildings.

This UK based public report seeks to identify the issues that prevent progress towards a better outcome for occupants, highlights the risks of not addressing these issues in a timely way, and suggests a constructive way forward.

It is the result of an examination of the academic and expert research literature in this subject undertaken over the past year, 2016 – 2017. This research covered several hundred articles and books, and references almost 200 separate studies. From our research we have drawn the following conclusions:

1. **There is a significant link between moisture levels in buildings and occupant health. While there is good evidence of the dangers to health from excessively damp or dry buildings—and of moderately damp or dry buildings when measured against particularly vulnerable people such as the very young or very old, pregnant women and very sick people—there is currently less robust evidence of the health risks to the general population.**
2. **This is not necessarily because there is no evidence of health impacts, but because we do not have the right methodological tools and metrics to gather appropriate data in order to adequately assess the effects of building moisture on human health. Consequently, much of the data that is being gathered is inconsistent, incomplete or non-comparable.**
3. **It is highly likely that, through the current changes to building form, construction, occupation patterns and use, we will increase the risk and incidence of illness in the UK. These changes to our buildings may make their moisture condition much more hazardous over the next few years.**

Such potentially detrimental changes include:

- the increasing airtightness of buildings, as demanded in building regulations and energy retrofit measures;
- the frequent failure of ventilation systems;
- the fabric retrofit of existing building stock, which often leadings to increased ventilation requirements and problems of cold bridging and trapped moisture;
- the reduction in room sizes and house volumes, making ventilation and air movement more difficult;
- increasing water use and consequent leaks from the ever increasing numbers of appliances;
- increased moisture production in housing from lifestyle changes, thereby increasing moisture pressure;
- overcrowding of buildings, particularly in the rental sector, again increasing moisture levels and often reducing air movement;
- the changing climate in the UK, leading possibly to increased flooding and wind driven rain, as well as increased use of air conditioning in hot weather.

The levels of illnesses such as asthma in the UK are some of the highest in the world and cost over £1bn to the NHS alone[3], and there is evidence that these cases are directly related to the moisture condition of buildings. There are also many illnesses with less well-proven links to dampness or excessive dryness. These include many respiratory and skin diseases as well as auto-immune conditions and mental health challenges, which may be exacerbated by the moisture environment in a large number of buildings in the UK.

The current estimates for the number of houses affected by dampness (but not excessive dryness) range from 4% to over 25%[4], which equates to between 1.1 and 6.75 million properties, affecting somewhere between 2.6 million and 16 million people. Even the lower figures suggest that this is a problem of considerable magnitude and importance to the UK. These figures do not include non-domestic buildings, or problems of excessive dryness which are often more common in commercial buildings.

All these factors have been shown to be of real concern in particular situations, but are currently ignored in

[1] World Health Organization, editor. *WHO guidelines for indoor air quality: dampness and mould*. Copenhagen: WHO; 2009. 228 p
[2] Institute of Medicine (U.S.), editor. *Damp indoor spaces and health*. Washington, DC: National Academies Press; 2004. 355 p

[3] Asthma UK. *Asthma UK | Asthma facts and statistics* [Internet]. Asthma UK. [cited 2016 Dec 2]. Available from: https://www.asthma.org.uk/about/media/facts-and-statistics/
[4] This range of figures relates to the estimates in the English Housing Survey (2015-16) and the figures given by the WHO (in 2009) as an estimate for the number of houses affected by dampness in Europe.

government, industry and financial sectors. The primary reasons for this are as follows:

1. the complex relationship between multiple agents of disease, human health and buildings;
2. the physical, geographical, social, economic, and cultural context of specific buildings and their occupants; and
3. the uncertainty inherent in this area of research and practice.

As will be illustrated in the following pages, the approach to standard medical causality cannot work in this area of study and so we need a new approach to causality and proof. This must include an epistemology (ie, a way of thinking and analysing) that meets the reality of this situation, and a consequential research methodology which will deal with this complexity, context and uncertainty.

To say, however, that this is too difficult a subject to study and address may be a serious derogation of responsibility, particularly at this time, when we are changing our building conditions and how we live in buildings so radically.

This report focuses therefore on how we move forward in this situation, asking what new research programmes might look like, and just as importantly, what policy consequences would flow from taking the potential health effects of moisture in buildings seriously. In both cases, we suggest that much of the thinking for a new approach already exists, and that what is required is not necessarily huge funding or policy changes, but a willingness to engage with uncertainty, complexity and context, and to drive this thinking into an often reluctant academic, industrial, medical and policy environment. It means change, but it also opens up huge opportunities for new understanding and engagement, and ultimately, for healthier and better buildings.

2 What do we know?

Moisture and its effects on us and our environment are everywhere. Too little moisture can be difficult, and ultimately fatal, to most living things whether large or microscopic. However, excessive moisture can also be problematic, and in extreme cases can cause decay, illness and even death. To survive and thrive, we humans need a balance of moisture in our environment, and this moisture balance is also beneficial for other living things, such as plants and animals, and also for the preservation of many non-organic objects, like buildings.

Agents of illness

Moulds also require moisture to live and thrive. We know that there are tens of thousands of mould spores per cubic metre in many outdoor and sometimes indoor environments; there are over 100,000 identified mould species, and over a million species in total. Outside, these spores increase considerably during the spring and autumn when there is the right combination of moisture and temperature. But there are also moulds in our food, on our bodies, and in our guts. Some of these are beneficial and some not so. Similarly all bacteria and viruses need moisture to live and thrive.

Buildings, and particularly homes, provide protective and controlled environments where moisture imbalances can be managed and a healthy environment can be created and maintained. However this has largely occurred without planning or monitoring. so there is a risk that imbalances will occur, particularly when we are making changes in our built environment and in the way we live. This risk has largely been ignored over the past decades, so there is a paucity of research and evidence in this area. However, there is now a growing concern over moisture in buildings and its effects on human health.

The poor health outcomes which have been most thoroughly studied so far are respiratory illnesses as a result of dampness and mould. A range of respiratory diseases and symptoms, such as cough and wheeze, have been reported as being associated with dampness by the Institute of Medicine of the National Academy of Sciences (IOM) and by the World Health Organization following a review of the epidemiological evidence. A 30-50% increase in the likelihood of poor respiratory health for people living in homes with signs of dampness or mould has been reported[5], and both the World Health Organization[6] and the National Health Service (NHS) advise upon the removal of dampness and associated microbial agents from within buildings[7].

Asthma in particular is associated with an elevated dampness level. This is of especial significance in the UK, given its prevalence and cost to the economy. 5.4 million people in the UK are currently receiving treatment for asthma, with the UK having one of the highest rates in the world: there were 1,216 asthma related deaths in 2014 alone. Costs incurred from treatment are estimated as £1bn to the NHS, and over 20 million working days are lost to asthma each year, estimated as costing the economy

[5] Fisk WJ, Lei-Gomez Q, Mendell MJ. *Meta-analyses of the associations of respiratory health effects with dampness and mold in homes.* Indoor Air. 2007 Aug;17(4):284–96

[6] WHO op cit

[7] National Health Service. *Can damp and mould affect my health? - Health Questions - NHS Choices* [Internet]. 2015 [cited 2016 Dec 2]. Available from: http://www.nhs.uk/chq/Pages/Can-damp-and-mould-affect-my-health.aspx?CategoryID=87

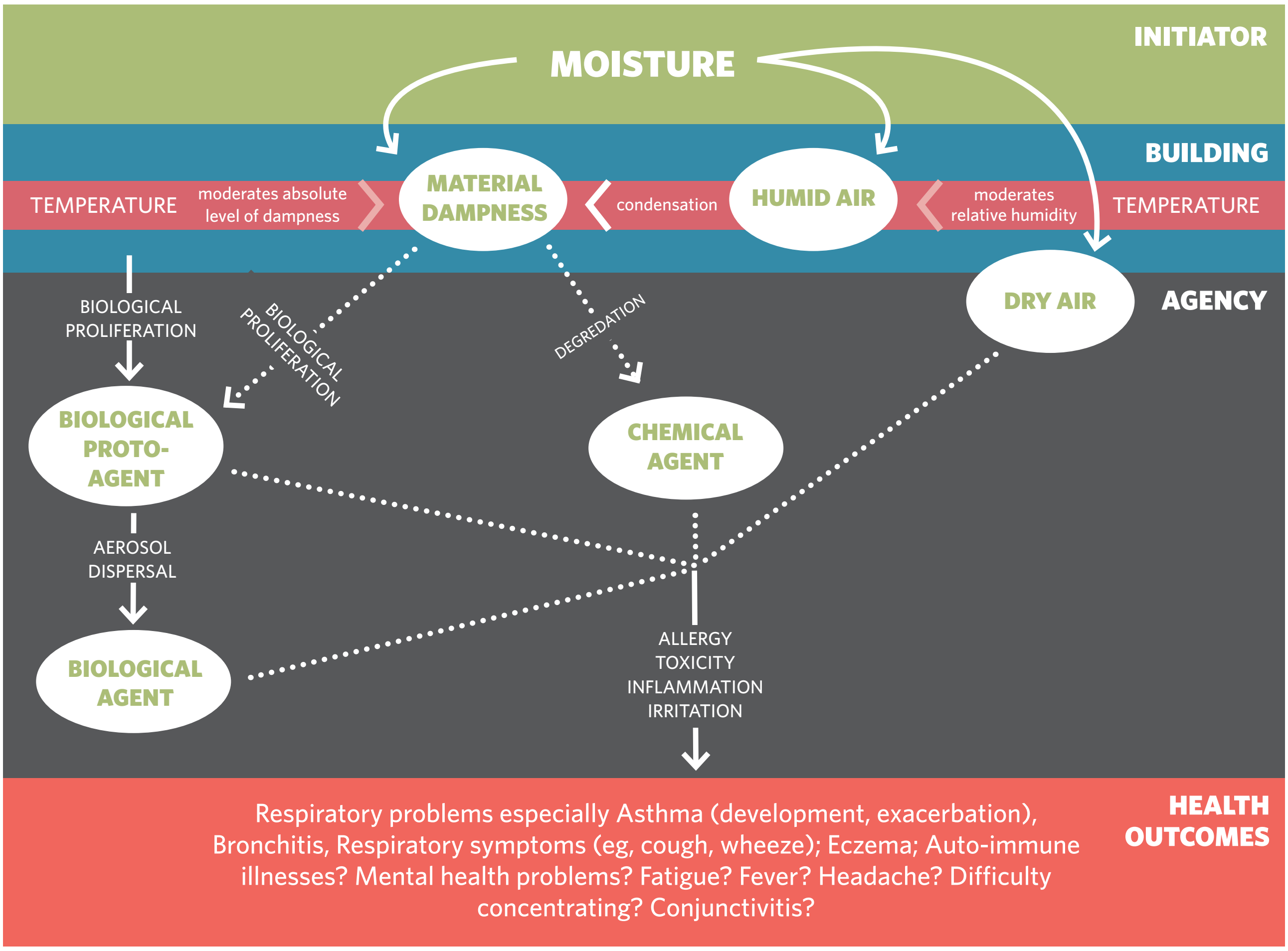
£2.5 billion. A proportion of this cost is almost certainly attributable to dampness in buildings[8].

In addition to asthma, the literature reports a wide range of health effects related to exposure to moisture or moisture-associated agents in buildings. These include other respiratory problems such as rhinitis, coughs, wheeze, dyspnoea, sinusitis, pneumonitis and alveolitis. Non-respiratory problems include throat, eye and skin irritations, nausea, fever, tiredness and mental health problems.

Such health problems as listed above are not always the result of dampness; some can occur in buildings which are too dry. Health problems can also result from interactions between moisture and other (non-fungi based) biological and chemical agents such as dust mites, bacteria and VOCs in building materials (which can be released when certain materials become damp). Interactions are sometimes complex and involve several stages. Many possible health outcomes are difficult to assess as a result of this complexity.

A map of the means of interaction between moisture and illness, which summarises the research evidence, is given below.

Below: The causal and contributory factors between high or low moisture levels and health outcomes, via agents and the physical context of the building.



[8] Using a methodology outlined in the WHO's guide on the quantification of health effects from housing risks, our academic report calculates a cost to the NHS (out of a total of £1bn spent on asthma) of between £13m and £201m. This huge variation is due to inconsistency in the data on exposure, resulting from the lack of standardised methodologies, as well as the complexity of asthma as a disease.

Below is a summary table of known causal and associational effects of moisture on health. This has been compiled from our extensive search of peer reviewed academic and medical papers.

	Dampness/ Mould	House ust Mite	VOCs (formalde-hyde)<	Endotoxin	Ergosterol	(1-3)-β-D-glucan	Dry Air
Rhinitis	Red (good evidence)	Red (good evidence)					
Cough	Red (good evidence)						
Wheeze	Red (good evidence)		Green (limited evidence)	Green (limited evidence)			
Respiratory infections	Red (good evidence)						
Respiratory symptoms	Red (good evidence)		Green (limited evidence)				
Asthma development	Red (good evidence)	Crimson (causal relationship)					
Asthma exacerbation	Crimson (causal relationship)	Crimson (causal relationship)	Green (limited evidence)	Red (good evidence)	Green (limited evidence)	Green (limited evidence)	
Dyspnoea	Red (good evidence)						
Hypersensitivity pneumonitis (allergic alvelolitis)	Red (good evidence)						
Bronchitis	Red (good evidence)						
Common cold	Green (limited evidence)						
Sinusitis	Teal (possible association)						
Inhalation fever, Humidifier fever	Red (good evidence)						
Throat symptoms	Teal (possible association)						
Eye symptoms							Teal (possible association)
Malaise (nausea, vomiting, stomach ache, diarrhoea, fever, chills, fatigue)	Teal (possible association)						
Skin symptoms, eczema	Red (good evidence)	Red (good evidence)					Teal (possible association)
Mental health problems (incl. headache, difficulties concentrating)	Teal (possible association)						

- Teal: Literature reveals evidence of a possible association but more evidence is required
- Green: Limited evidence of an association exists
- Red: Good evidence of an association exists
- Crimson: Evidence of a causal relationship exists

Note that the associations relating to formaldehyde may or may not relate to the presence of dampness; the literature merely reports an association.

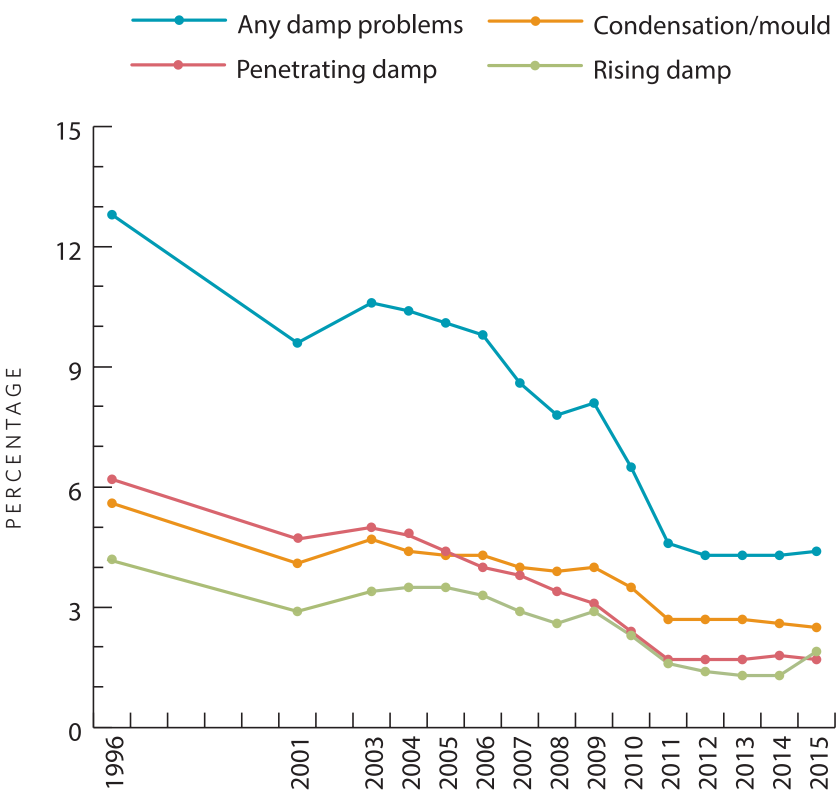
It is important to note that a blank cell in the table above, ie, absence of an association between a given agent and given health outcome, does not necessarily mean that there is no association. In some cases possible associations may not have been examined, and in other cases there may be insufficient evidence at the present time to positively assert the existence of an association, especially with respect to moisture in buildings. For example, VOCs in general have been implicated with a great many poor health outcomes, but there is only sufficient data to state that there is limited evidence of an association between formaldehyde and asthma exacerbation. The table represents the state of knowledge at the present time. As more evidence is accumulated, some associations and gaps may be upgraded in the future.

Buildings

In a review of published data from buildings in Europe and North America, it was estimated that at least 20% of all buildings had one or more signs of dampness[9]. Elsewhere, it has been reported that more than 47% of buildings in the United States showed signs of dampness[10]. A study of dwellings in northern European countries reported that 18% of the occupants lived in damp housing[11]. A later review of European dwellings from 31 countries estimated that 16.5% of the stock had sign of dampness[12]. Reviewing levels of dampness in European countries with climates similar to that of the UK, the World Health Organization[13] estimated the number of homes with dampness at 10 – 25%[14].

This would mean between 2.7million and 6.75 million homes out of a total of 27 million dwellings in the UK, or between approximately 6.6 million and 16.5 million people[15], are potentially affected by dampness in their homes.

However, these figures stand in contrast to figures for England from the English Housing Survey (EHS), which is the main study of housing conditions in the UK[16]. The EHS undertakes a physical survey of 6000 houses each year, with 13000 households also answering questionnaires. This is a randomly selected sample categorised to be representative of the whole of the UK. In the 2015 survey, it was estimated that only 4% of the UK housing stock had dampness problems[17]. See the graph below.



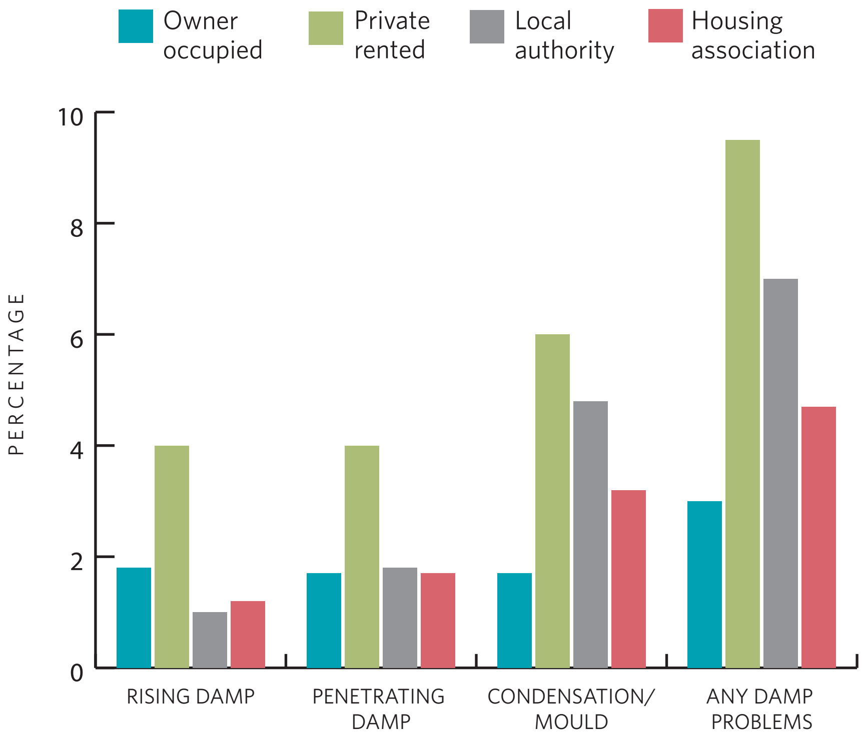
Damp Problems 1996 to 2015
Source: English Housing Survey

[9] Institute of Medicine (U.S.), editor. *Damp indoor spaces and health*. Washington, DC: National Academies Press; 2004. 355 p.
[10] Mudarri D, Fisk WJ. *Public health and economic impact of dampness and mold*. Indoor Air. 2007 Jun 1;17(3):226–35
[11] Gunnbjörnsdóttir MI, Franklin KA, Norbäck D, Björnsson E, Gislason D, Lindberg E, et al. *Prevalence and incidence of respiratory symptoms in relation to indoor dampness: the RHINE study*. Thorax. 2006 Mar 1;61(3):221–5
[12] : Haverinen-Shaughnessy U. *Prevalence of dampness and mold in European housing stock*. J Expo Sci Environ Epidemiol. 2012;22(5):461–467
[13] World Health Organization. *Environmental burden of disease associated with inadequate housing*. Copenhagen; 2011. The WHO classify countries as falling into one of two groups, "cold climate" and "moderate/warm climate"; it recognises the UK as having a moderate/warm climate
[14] The equivalent figures for mould in homes are 5 - 25%, with a central estimate of 10%.
[15] Statistics from Gov.UK table 101 shows approximately 28 million houses (including vacants) in the UK https://www.gov.uk/government/statistical-data-sets/live-tables-on-dwelling-stock-including-vacants. Vacants are estimated at over 600,000 in England https://www.gov.uk/government/news/empty-homes-reach-10-year-low and allowing for vacant properties in the rest of the UK we estimate approx. 27 million houses are occupied. Total population according to gov. uk (2016 report released on 22/06/17) is 65.648 million in the UK https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/population estimates
[16] There are also housing surveys in Wales and Scotland but at much less frequency and scale
[17] Although the graph shows almost 6% of buildings with "any damp problems". It is assumed that some of these have more than one problem.

As reported in the survey, "The most common damp problems were condensation and mould, affecting 586,000 (2%) of the homes. Fewer homes were affected by rising damp (439,000, also 2%) or by penetrating damp (393,000, 2%)...

Owner-occupied dwellings were less likely to have any damp problems than private or social rented dwellings. Some 9% of private rented dwellings had some type of damp problem, compared with 5% of social rented dwellings and 3% of owner occupied dwellings...".

Below: Damp problems by tenure, 2015
Source: English Housing Survey



Looking more closely, this chart shows a significant inequality of moisture risk between different tenures, with the greatest risk falling on the poorest in society. Private rental and local council tenures are also shown to have the greatest degree of overcrowding, with owner occupiers having the highest level of under-occupation[18].

However, as pointed out by Möller, there are considerable differences between the levels of dampness reported by the EHS surveyors and the occupants themselves[19] with self-reported levels of dampness reaching 20% according to figures from the 2009-10 English Housing Survey[20].

This compares with the surveyor-reported figure of 8% reported in the 2009-10 EHS dwelling sample.

The contrast between different assessments of the prevalence of dampness raises significant questions about the definitions and methodologies currently used to characterise dampness.

Nonetheless, if the EHS figures are correct the number of houses in England alone suffering from dampness in buildings is over 1 million properties, with around 2.5 million people potentially affected by exposure to damp conditions[21].

It appears from fig 2.7 that damp problems have significantly reduced in English housing stock over this period, from about 13% to 5% of the stock. On this basis, government and industry might argue that moisture risk is

[18] See sections 1.62 to 1.71 pages 19-21 in the EHS
[19] Möller, H, Harwood C, Kinsella T. *Quantification of the impact of indoor dampness and mould on asthma onset in children and hospital spells due to respiratory problems in children and adults in Wirral PCT* [Internet]. 2012 [cited 2016 Dec 5]. Available from: http://info.wirral.nhs.uk/document_uploads/Short-Reports/Damp-housing-report-V7-13-08-12.pdf
[20] Note that the EHS no longer collects dampness data from interview of householders, relying solely upon surveyor estimates.

[21] Based on the Office for National Statistics figures of average household size of 2.3

being addressed through mechanisms such as improved building regulations and programmes such as Decent Homes, as well as the increased availability and use of central heating.

However, if this is the case, why is concern increasing among occupiers, government and in industry?

Evidence outside the EHS includes reports of many houses now suffering from damp due to incorrect cavity wall insulation, significant increases in the remediation costs of dampness in social housing, notable moisture failures in retrofit schemes and in new housing, and an ever increasing number of people with moisture-related health complaints, such as asthma. The Energy Savings Trust recently stated that around one third of the population reported in 2014 that they have mould in their homes[22]. This means that 8 million properties and 20 million people are affected. The EHS Figures also contradict all the European and American studies referenced above.

The disparity between the EHS and other evidence may be due to:

- differences between international methods for reporting of damp and the methods of the EHS. This illustrates the fundamental problem of not having accepted and consistent methodologies which would allow proper comparison of data from different studies.
- greater awareness of the effects of damp on health, leading to increases in reporting and concern in general but not in the EHS
- new trends in specific housing conditions which have not yet become apparent in the EHS (for example, in retrofitted houses or in airtight new houses)
- a reduction in visible mould and condensation due to increased use of central heating, but an increase in moisture in the indoor air, and in dust mites, and types of bacteria and other pathogens, which thrive in moist and warm environments, rather than in moist and cold ones.

It is noticeable from the English Housing Survey that the highest recorded dampness is in the private rental sector, which is also where the highest levels of over-occupancy occurs. The increase in private rental and of occupancy in poor housing are picked up in section 4, as key pressures for increased moisture risk in our buildings.

[22] This information comes from the recent APPG on Healthy Homes and Buildings report *Building our Future*. The reference is from Energy Saving Trust. *Cold, draughty, mouldy, damp: What the UK public think about their homes*. 2014. Accessed 2017: http://www.energysavingtrust.org.uk/about-us/news/colddraughty-mouldy-damp-what-uk-public-thinkabout-their-homes

Toxic mould

It is worth briefly mentioning the issue of 'toxic mould' as this subject is often raised in discussions of health and moisture in houses. There is currently no clear evidence for a link between mould in homes and dangerous levels of toxicity leading to poisoning, or to autoimmune illnesses such as cancer. The main conclusion of a major medical study of mould and health is: *'The occurrence of mold-related toxicity (mycotoxicosis) from exposure to inhaled mycotoxins in non-occupational settings is not supported by the current data, and its occurrence is improbable.*[23]'

Fungi can no doubt be toxic if ingested. The fungi Death Cap and Destroying Angel are both lethal to human beings if ingested even in very small quantities, for example. Furthermore in certain industrial and agricultural environments high levels of mycotoxins from mould spores, fungal bodies and fragments can be present in animal and plant products, and are highly toxic to humans when exposed for long periods or in very high quantities. However mould levels in all domestic and most industrial buildings remain far below what is considered toxicological. The highly publicised report by the Centre for Disease Control in Cleveland in 1993-4, which concluded that the mould spores of the fungi *stachybotrus chartarum* (common in buildings) was the cause of pulmonary haemorrhage in young children, was thoroughly reviewed in 2000 and the conclusions were overturned: there is no causal or associational link between the mould and the disease in this case.[24]

However, research into *stachybotrus chartarum* continues to throw up possible connections between the fungus and many possible health effects. These are dependent upon multiple interactions between parts of the fungus and 'other natural and anthropogenic contaminants present in damp building indoor air.'[25] Their possible effect is also dependent upon the age and health of the exposed individual.

Particular groups in certain contexts may therefore be vulnerable to mycotoxicity. As reported in the WHO report "there is no epidemiological evidence for an association between exposure in damp buildings and cancer....It has been shown, however, that microbial isolates from damp buildings have genotoxic activity in vitro [ie in a test tube or culture dish or elsewhere outside of living organism][26]." Other reports also issue warnings about vulnerable groups and reports of auto-immune diseases have been reported in several studies[27]. However causality has not been established.

[23] Bush RK, Portnoy JM, Saxon A, Terr AI, Wood RA. *The medical effects of mold exposure*. J Allergy Clin Immunol. 2006 Feb;117(2):326–33

[24] See https://www.cdc.gov/Mmwr/preview/mmwrhtml/mm4909a3.htm

[25] See https://academic.oup.com/toxsci/article/104/1/4/1717327/Stachybotrys-chartarum-Trichothecene-Mycotoxins

[26] Op cit

[27] See Myllykangas-Luosujärvi et al., 2002; Luosujärvi et al., 2003

Summary of what we know

While it is important not to scaremonger about the effects of excessive or too little moisture in buildings on human health, the research clearly shows that there can be negative impacts of clinical significance. In particular the impact of high moisture levels in buildings (and the presence of dust mites, which thrive in conditions of high relative humidity) on respiratory illness, and specifically on exacerbation of asthma, is proven[28].

However, with regard to all moisture impacts and to mould in particular, there is still a considerable uncertainty about their overall effects on health, due to the complexity of Agents and interactions, different Building Contexts, different Occupant Conditions and different types of resulting illnesses. This remains a significant challenge to research which we address in section 4.

3 Why aren't moisture risks to health taken seriously in the UK in policy, medicine, and law?

There are several reasons why risks are usually taken seriously by governments, industry and professionals, with resulting actions such as legislation or funding to address the risks, and ultimately changes in industry practice and public understanding and behaviour. These reasons include: the potential or real cost; the possible liability; the degree of certainty about the risks; and the availability of proven and deliverable solutions. These are, to a large extent, linked. We examine each of these areas:

The costs of too much or too little moisture in buildings

In the midst of the uncertainty and lack of evidence about moisture levels in buildings and the effects on human health, it is not surprising that there is a huge variation in the possible financial costs of doing something about it.

Moisture damage-related repair was estimated to cost approximately 9 billion Euros a year to the European Union in 2004[29]. The majority of this was flooding or escape of water. With regard to indoor health, as detailed in the WHO report, "Pirinen et al. (2005) estimated that the cost of repairing microbiological damage [ie, the cost of the building repairs] that resulted in adverse health effects in Finland was €10,000–€40,000 per case.[30]"

The WHO report continues, "A review of studies in several European countries, Canada and the United States in 2004 indicated that at least 20% of buildings had one or more signs of dampness (Institute of Medicine, 2004).... From several studies conducted in the United States, Mudarri and Fisk (2007) estimated the prevalence of dampness or mould in houses to be approximately 50%".[31]

It would be easy to use these figures to show a potential remediation cost in the UK running into billions of pounds, ie, 20% of UK housing stock = 5.4 million multiplied by the Finnish figure for remediation of say €20,000 = €108 billion. If we take the 50% figure then the cost would be a stunning €270 billion. Even if we accept the 4% figure given in the English Housing Survey, this would equate to a cost of €21.6 billion for the whole of the UK. None of these estimates take into account the cost to the country of ill health, lost working days or medical treatment. However, the difference between 4% and 50% of the housing stock is considerable and the costs of the Finnish remediation model may not apply in the UK.

Ultimately, the effects of adverse moisture levels and all their associated costs depend entirely upon the accurate and academically validated diagnosis of moisture levels in buildings, and the establishment of robust benchmarks for safe and unsafe levels. But these methods and metrics, as pointed out in the UKCMB academic review, and indeed in the WHO report, have not been established in theory or in practice, and consequently vary hugely between different research projects and from country to country. No government will pay any attention to costs under such circumstances.

Liability and certainty

The liabilities of government, owners, insurance companies or industry are based upon proven causalities which are in the public domain with sufficient presence and authority to the extent that negligence can be proved and the cost of negligence determined.

At present there is very little possibility of proving the causal effect or costs of moisture levels on health for two main reasons: problems with measurement, and the challenge of complex interactions:

1 Problems of measurement

The contrast between differing assessments of the prevalence of dampness raises significant questions about the definitions and methodologies currently used to characterise dampness. Since all buildings contain moisture, and since there is no standardised way of

[28] Kanchongkittiphon W, Mendell MJ, Gaffin JM, Wang G, Phipatanakul W. Indoor Environmental Exposures and Exacerbation of Asthma: An Update to the 2000 Review by the Institute of Medicine. Environ Health Perspect. 2015 Jan;123(1):6–20.

[29] Adan,2004,p.254

[30] Op cit p34

[31] Op cit section 2.1 p 7

measuring dampness, when does an increasing level of moisture in a building actually becomes problematic and associated with poor health? Can one really attach the label 'damp' to one building and 'dry' to another, given that there is no clear demarcation line? Do increasing levels of dampness tend to result in increasingly levels of poor health outcomes in a proportionate way? What are the threshold levels of moisture which would serve to classify a building as suffering from a dampness problem in terms of:

- quantity, such as relative humity/surface moisture reading
- period—how long it has been going on
- place, for example bedroom/living room/kitchen/ bathroom,
- building use, for example domestic, commercial, museum, nursing home, relative to levels of occupancy and volume
- building form, type and condition, for example solid wall, cavity wall
- time, for example winter/spring/summer/autumn, daytime/nighttime
- geographical location and orientation?

Can these elements realistically be married together into a single catch-all term universally recognised as 'damp'? Whether or not, for example, an intermittent patch of moisture in a wall is reported as dampness may depend upon whether or not the patch is visible or not at the time of the inspection. It may not be visible if the patch is behind wallpaper or the assessment is made in summer. It should also be pointed out that all buildings will have condensation and high relative humidity (RH) at some point and place, and should not necessarily always be deemed as unhealthy or unacceptable. In such instances, for example, where an intermittent patch of dampness appears following use of a shower, would the householder or a surveyor be best placed to make a judgement? Whilst the householder may be best placed to make an evaluation on occasion given his/her familiarity with his/her home, an experienced surveyor may be more aware of the potential for and presence of elevated RH levels in some modern tightly-sealed dwellings and may report it as such, in contrast with the occupants.

While the measurement of moisture in buildings has improved in the past few years, there are still considerable shortcomings in this area, particularly with regard to indoor atmosphere (as opposed to moisture in fabric). There are also some significant gaps in the measurement of other factors:

- Ventilation rates: how to measure these simply and what are the benchmarks for 'safe' ventilation rates or acceptable risk?
- Mould levels in buildings: what should we measure and how? How do we create meaningful benchmarks?
- Indoor Air Quality levels more generally: how do we measure these to capture the interactions of moisture-related toxins and agents of harm with those not related to moisture?

Consequently liability and proof of causality are not yet possible in most situations. As Tischer and Heinrich concluded in their review[32] assessing exposures of mould, fungi and microbial components on children's health, there is no standardised exposure assessment method which would allow one to better compare results from different studies or inform dose–response curves.

2 The challenge of complex interactions

In order to prove causality in medicine or law, a direct and testable connection must be made between an input and a resulting output. However, as we made clear in Section 2 above, there are many possible factors involved in the interactions between moisture and health. These can be reduced to three variables as identified earlier Agents (or Exposures), Human Health, and Buildings. The problems may be assessed as follows:

1 Agents

- There are many different types of Agent, including chemical toxins from degradation of building materials due to excess moisture. Regarding mould, there are thousands of different species, and, in each one, at least four parts which may affect human health: spores, fungal fragments, β-D-glucans, and mycotoxins.
- Agents arising as a result of moisture imbalance in buildings also include volatile organic compounds (VOCs), bacteria, protozoa, viruses and house dust mites.
- There is no clear understanding of the effects of most of these Agents on human health.
- There are many possible interactions between Agents, including beneficial effects.
- There are also many possible interactions both in air and in the human body with other non-moisture-related agents, such as indoor and outdoor pollutants.

[32] Tischer CG, Heinrich J. *Exposure assessment of residential mould, fungi and microbial components in relation to children's health: Achievements and challenges.* Int J Hyg Environ Health. 2013 Mar;216(2):109–14

2 Human Health

- The measurement of impacts of multiple moisture-related agents on Human Health is very difficult. It is difficult to separate out different agents, to measure actual exposure, to understand multiple responses; there are ethical problems with experimenting on humans, which make testing difficult. Consequently there is no clear relationship between exposure of most moisture-related agents and specific health effects.
- Human Health is an interaction between physical, mental and social factors. It is apparent that the mental impacts of mould and other moisture-related effects in buildings can be considerable and can impact on both physical and social health[33].
- Research shows that there is not always a straightforward linear dose-response relationship. For example, the hygiene hypothesis might be used to show that the immune system benefits from a certain level of challenge from moulds to increase resistance to infection.
- A person or group's *Individual Context* has a huge effect on their susceptibility to the effects of moisture in buildings, for example, their stage of life, genetic background, diet, medical history, social relationships and work situation.

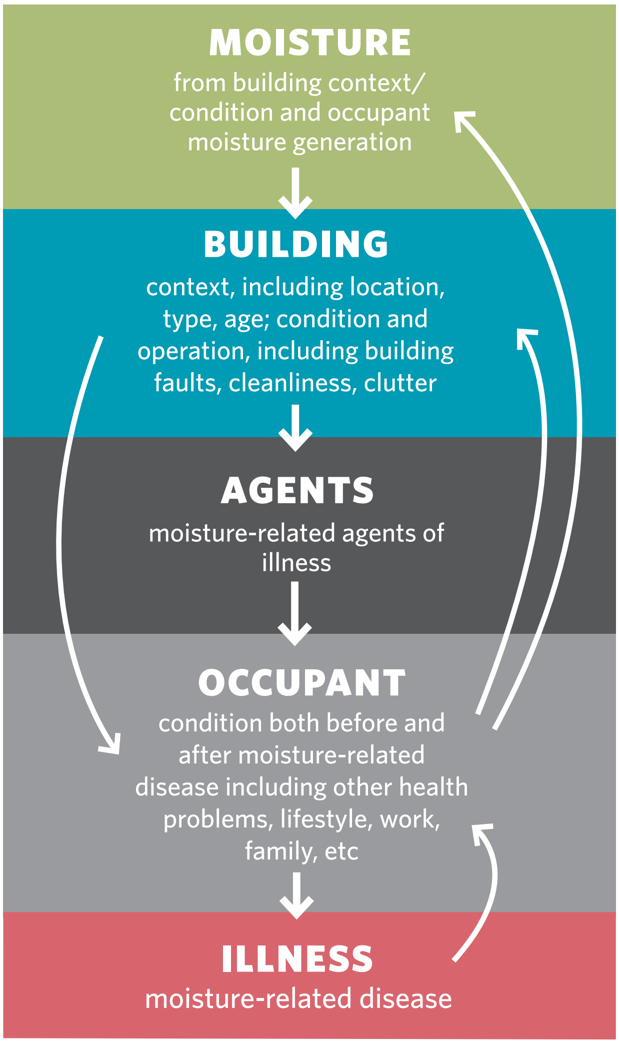
3 Complexity of Buildings

- Building performance is influenced by a combination of people, fabric and services, and these interact in complex ways, which require proper consideration, particularly of the way the building is used by occupants.
- Building performance is also highly influenced by the *context of the building* (location, form, condition, occupation level, use)
- The challenges of testing Indoor Air Quality, mould presence, ventilation rates, moisture in fabric, for example damp, are considerable, as are the relationship to other non-moisture agents.
- Many of the methodologies required for testing have not yet been fully developed, are prohibitively expensive, and require multi-disciplinary teams and understanding.

[33] There are several reports covering the mental and social impacts of dampness and flooding. Please refer to the UKCMB academic report page 25 for more information and references.

Thus we have the complexities of Agents, Human Health and Buildings interacting with each other within specific, unique contexts. In addition there are many possible feedback loops whereby for example the effect of a moisture-related illness on an individual affects the way that they use a building, or generate moisture (for example a sick person is likely to spend more time at home thereby increasing moisture generation). This means that our model of causality has to be changed from that which we showed earlier.

> The model for moisture-related illnesses given in section 2 fails to account for the condition of the building occupant and for the many feedback mechanisms between Occupants, Moisture Generation and Building Performance. A fuller model is shown below:



This situation is made worse by the lack of robust data and tools and methodologies for measurement. Consequently, it is very difficult to define at what level dampness, dryness or a moisture-related agent becomes a health hazard in any individual or group,and it requires considerable effort and detail to characterise the relationship of moisture to a specific building.

Intervention studies

As mentioned above, for policy makers to be able to fund programmes or enact legislation to reduce or eliminate risks, there must be appropriate solutions available which can be shown to be successful. As such, intervention studies can provide good quality evidence that something can be done about risks, and can quantify costs or difficulties.

In our research analysis of six meta-studies covering a total of 107 intervention programmes, the evidence for the effectiveness of a number of different measures – which ranged from cleaning houses and removing soft furnishings, to energy efficient retrofit, improved ventilation, dehumidification and changes to behaviour – was very mixed. Although there was some evidence that building remediation and removal of moulds led to some improvements in asthma, there were very few examples of interventions which could be said to ensure improvements to health. In fact, in the case of some energy efficient retrofits, asthma increased[34]. This was diagnosed as probably a result of failure to remove Agents and a decrease in ventilation, possibly coupled with under-heating of the buildings due to fuel poverty, which arguably shows the need for a more detailed and holistic analysis using case studies.

However, many of the meta-studies commented on the poor quality of data, and the fact that many assessments of the condition of the buildings and people studied were not comparable.

This is due to the lack of accepted metrics and methodologies for assessment of moisture levels, building condition, and agents of illness or disease. In addition many of the studies were only looking at particular symptoms of ill health in the occupants and not at the whole health picture, nor of the health of people over time. It may well be the case that the effects (both positive and negative) of many interventions will take several years to manifest themselves, which is outside the scope of most research projects.

One notable exception to the overall failure of intervention studies is some research in north Wales on a collaborative programme between the National Health Service (which provided data on health) and local government (which was responsible for the installation of the housing improvements). Woodfine and Edwards' study investigated the effect of a tailored package of housing improvements[35] on the health children in north Wales with moderate or severe asthma, as well as the health care and intervention costs[36]. It was shown that 29% of children with severe asthma improved to an extent that they could be re-classified as suffering from moderate asthma within 12 months. Furthermore, as shown in other studies, interventions may have impacts beyond clinical health outcomes, with Liddell and Morris suggesting that accrued benefits could be extended to cover measures reflecting quality of life, social engagement and impacts on mental wellbeing[37], so the advantage afforded may have extended beyond any mere cost-effect analysis of the use of public resources.

[34] Sharpe RA, Thornton CR, Nikolaou V, Osborne NJ. *Higher energy efficient homes are associated with increased risk of doctor diagnosed asthma in a UK subpopulation.* Environ Int. 2015 Feb;75:234–44.

[35] Ventilation systems were installed in roof spaces and central heating was either updated or installed.

[36] Edwards RT, Neal RD, Linck P, Bruce N, Mullock L, Nelhans N, et al. *Enhancing ventilation in homes of children with asthma: cost-effectiveness study alongside randomised controlled trial.* Br J Gen Pract J R Coll Gen Pract. 2011 Nov;61(592):e733-741.

Woodfine L, Neal RD, Bruce N, Edwards RT, Linck P, Mullock L, et al. *Enhancing ventilation in homes of children with asthma: pragmatic randomised controlled trial.* Br J Gen Pract J R Coll Gen Pract. 2011 Nov;61(592):e724-732.

[37] Liddell C, Morris C. *Fuel poverty and human health: A review of recent evidence.* Energy Policy. 2010 Jun;38(6):2987–97

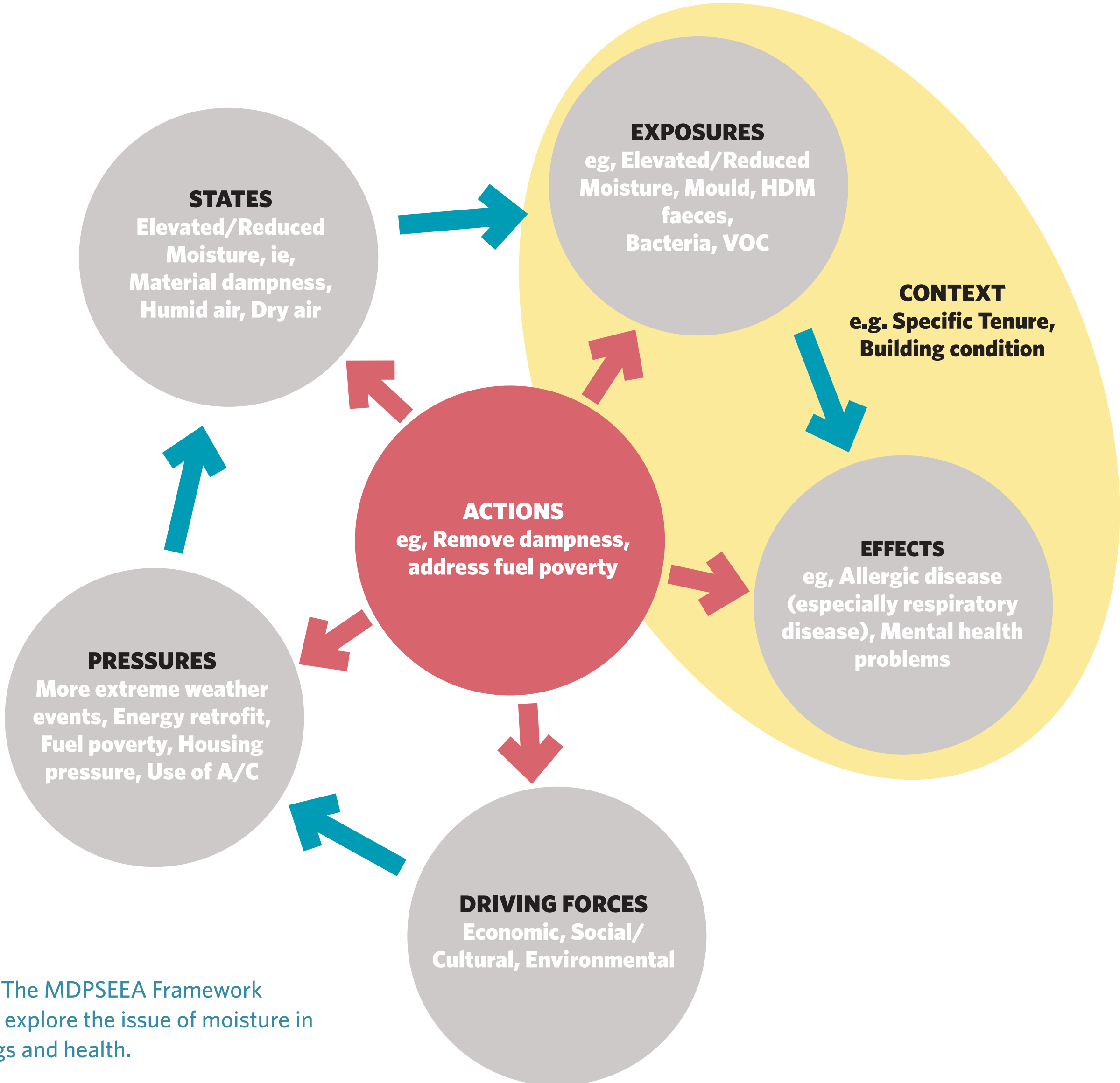
4 Complexity and change

Environments are constantly changing around us and this must be taken into account when understanding health and moisture in buildings. The built environment is continually being added to, adapted, renewed and degraded, while our lifestyles, expectations, pressures of work and family, and our prosperity and use of technologies are also changing, perhaps more rapidly at the present time than in any other era. Consequently our health, the illnesses which affect us and our physical, emotional and mental condition are also undergoing significant change.

In order to understand change in the UK, we used the following model, called the Modified DPSEEA Framework, to help us understand the interactions between **Agents** (called Exposures in this model), **Human Health** impacts (Effects) and **Building Condition**/performance (States).

Context refers to the individual context of a particular person in a particular building. The green circle in the centre refers to the Actions which might be taken to address some of the other factors and hopefully reduce the effects on the health of building's occupants. The large-scale factors which drive change in the detail of Exposures, States and Effects are represented by the Driving Forces and the Pressures[38].

Buildings, particularly homes, have changed considerably with regard to moisture over the past 150 years, with evolving material form and design, the introduction of toilets, baths and showers and now washing machines, tumble driers and many other appliances. Moreover, the way we inhabit buildings and the time we spend in them has changed radically. Furthermore in the UK we are about to embark on an ambitious programme of energy efficiency upgrade for the whole stock, which will have considerable consequences for building performance and lifestyles.



Above: The MDPSEEA Framework used to explore the issue of moisture in buildings and health.

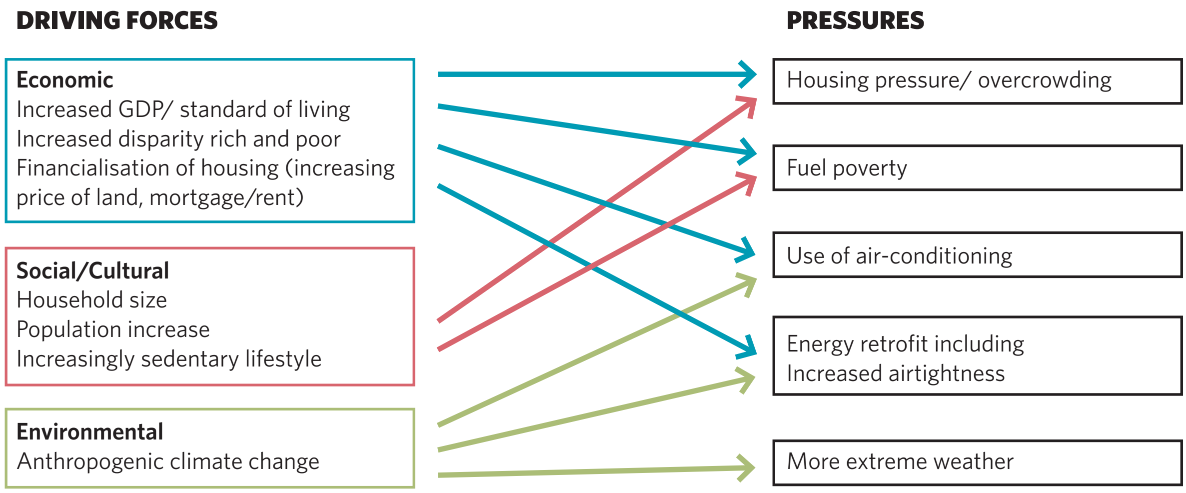
38 The MDPSEEA model has been developed by Morris GP, Beck SA, Hanlon P, Robertson R. *Getting strategic about the environment and health.* Public Health. 2006 Oct 1;120(10):889-903

At the same time, climate, demographic, social and economic conditions are all changing in ways that affect the state of our buildings with regard to moisture. These changes also often affect and interact with other things that may threaten our health, particularly toxins from new building and decorating materials, NO_2 from gas appliances, radon from the ground—particularly dangerous when retrofit is undertaken without increasing ventilation—VOCs and other possible toxic or irritant compounds from cosmetics, furnishings and consumer goods.

However, with regard to the direct risks to the moisture condition of buildings in the UK, the following are some of the Pressures which are of particular concern within the research and expert community:

- Increasing airtightness of new buildings combined with the frequent failure of ventilation systems. Recent research shows the failure to meet required air changes in over 95% of new homes[39];
- The fabric retrofit of existing building stock, often leading to increased but unmet ventilation requirements and condensation problems from cold bridging and trapped moisture;
- The reduction in room sizes and house volumes, making ventilation and air movement more difficult;[40]
- Increased moisture production in housing, due to levels of occupancy and increases in washing, bathing, etc, thereby increasing moisture pressure;
- Increasing water use from ever increasing number of appliances and consequent leaks;
- Overcrowding of buildings, particularly in the private rental sector, again increasing moisture levels and often reducing air movement;
- The changing climate in the UK, possibly leading to increased flooding and wind driven rain;
- Increased use of air-conditioning due to hotter summers, poor overheating control and cheap availability of the technologies. Incorrectly used this can lead to buildings being excessively dry, as well as moisture problems and pathogens in duct work;
- Increasing gap between rich and poor[41], leaving up one in three people, or almost 15 million, in poor housing conditions , potentially in fuel poverty—unable to heat their homes adequately. This can lead to increased condensation and damp.

As shown in the MDPSEEA diagram above, these changing pressures are to a large extent the result of more general Driving Forces, which often lead to multiple effects or combine to reinforce a particular effect. Simplifying this down, we have divided these Driving Forces into Economic, Social/Cultural and Environmental and related them to the Pressures in the following diagram:



[39] From as yet unpublished research for the Zero Carbon Hub and DCLG

[40] Average house size has reduced from 102m2 in 1919 to 92m2 in 2012, the smallest average house size in Europe see http://www.savills.co.uk/research_articles/186866/188035-0. But as LSE points out "New houses are about 40% smaller than in similarly densely populated European countries" and this is particularly the case in London and areas of high population. http://cep.lse.ac.uk/pubs/download/EA033.pdf

[41] Office for National Statistics UK wages over the past four decades – 2014 3 July 2014

The MDPSEEA framework helps to show how very long-term largescale changes can affect the built environment through particular issues and impacts, which in turn give rise to specific, often microscopic agents and their impacts on Human Health in specific Contexts.

A justifiable concern is that many of the current changes are leading to significant and new pressures on the built environment, which may vastly increase the States in buildings that in turn lead to the moisture risks and effects that we have identified. Many of these changes are due to economic and social factors which are beyond the remit of most built environment professionals and medical practitioners to address, but which must be taken into account and mitigated where possible in built environment policy. To be absolutely clear about this:

It is a conclusion of this research that, with regard to moisture levels in buildings, we are significantly increasing the risk of illness in this country through the current changes to building form, construction, occupation patterns and use.

This risk is already unacceptably high in the UK, and yet is largely ignored. The risks in particular affect a certain portion of the population, those subject to poverty and overcrowding, often living in private rented accommodation of poor quality. These risks have been highlighted by the English Housing Survey, but are not yet fully understood or investigated.

Moisture effects on health are not as dramatic or as sudden as other risks, such as fire or poisoning, but they may be far greater in total, both in the number of people affected and in the seriousness of their impacts on the social and economic life of our society.

5 A way forward

In exploring the links between health and moisture in buildings, we now find ourselves in a difficult situation where we are aware that there may be real risks but cannot clearly define them or identify causes. In addition there is the anxiety of considerably increased risks due to new pressures, arising from economic and social changes.

Some of these risks could be addressed technically, but we currently have no clear justification for action. As discussed in section 3 this is primarily because we are faced with the interactions of multiple complex systems which change according to context, in a situation where there is already great uncertainty and lack of good data. This cannot be captured by our current ways of assessing causality and risk, which are primarily based upon mono-causal and reductionist principles where identifiable agents have proven causal effects in a particular part of the body, largely independent of context.

With regard to the risks of excessive or too little moisture in buildings, except in a few cases (ie, with regard to the proven effect of over-dry buildings on mucous membranes and skin or the effect of dust mites on exacerbation of asthma), we cannot pretend that we exist in a world that can ever be so reduced or simplified. Furthermore, we cannot, morally and financially, ignore the associational evidence of existing problems and the very likely effect of current trends on real health risks in the near future. We must therefore move forward quickly to address both the research and the policy consequences of this situation.

The following is our proposal for how we should address the issue of moisture and health in buildings with regard to research and causality:

I *Where possible within the current conventional epistemological (knowledge and research) framework, we should develop robust and academically acceptable methodologies and metrics for the testing and collection of relevant data.*

Some of the key actions are identified in section 3 above, namely, to develop effective methods and benchmarks for determining moisture levels in buildings, mould levels and ventilation rates. In addition we need more data on the moisture qualities of materials, particularly traditional and vernacular materials, and on the moisture effects of flooding and escape of water in buildings.

The use of these methodologies should be validated academically and then used in research programmes at a statistically relevant sample size to provide epidemiological data of relevance to the UK. In this way built environment policy and guidance can be directed with more certainty and with the support of hard evidence.

However this will not deal with the multiple complexities, context or inevitable and on-going uncertainties in most areas. So we also need to:

II *Develop a research epistemology and methodology which grapples with non-physical as well as physical health, with complex system interactions, with context and with uncertainty.*

We have to accept in particular that Context is an integral part of causality and is not just a confounding factor. There is no such thing as a context-less agent or person.

This drives us towards research based upon open-ended, detailed case studies and the use of multiple case study comparisons, as well as intervention studies which test out the complex and contextual factors in a systematic way. These can and should take account of subjective feedback and evidence, as health effects are often the result of a combination of physical, mental and social pressures and impacts. There is no reason however why this approach cannot be combined with the more conventional testing and epidemiological approach (as in point 1 above). Hard data can be combined with contextual information and subjective feedback to give a more complete and realistic understanding of the links between moisture risk and health.[42]

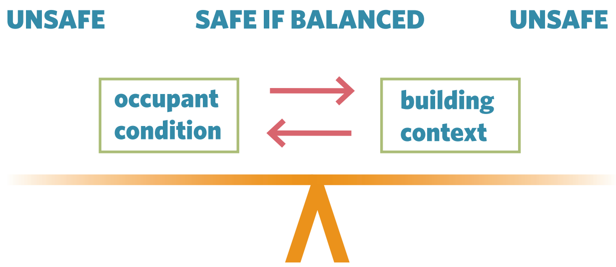
III We suspect that a *new approach to moisture and health in buildings is required*.

This will take into account the fact that extreme conditions (too wet or too dry) are known to be bad for health in all people. There is a healthier area between the very dry and very wet. However the thresholds for safety might be very broad or hard to define.

Furthermore these thresholds also depend on an Occupant's Condition and the Building Context. As we have identified, very old people, babies, pregnant women and the sick, as well as the mentally ill, bereaved or stressed are all examples of different Occupant Conditions, while the ventilation, heating, building maintenance and cleanliness of a building, as well as its location and construction type, are examples of building context. Some of these Conditions or Contexts can be improved or changed more easily than others.

[42] For examples of the use of case studies for determining statistically valid impacts and causality, see the Probe (Post-occupancy Review Of Builidings and their Engineering) case studies and BUS (Building Use Studies) on building performance, now adopted by Innovate UK for Building Performance Evaluation programmes. The Probe studies were called "The best piece of research of the decade" by Prof T. Oreszcyn. Also see the work of B.Flyvbjerg on case studies, showing their use and relevance, and often superiority to epidemiological approaches.

The following is a diagrammatic way of explaining how the Occupants of a building and its Context are part of a balanced or unbalanced situation between too wet and too dry. If both Context and Occupants are exacerbating the situation, the solution lies in rebalancing, either by changing the Building Context, or where possible the Occupant's Condition, to ensure that the combination not only does not make their health worse, but helps to improve it.



This may be called a 'balanced' approach or model. It could be developed by identifying the main factors within Building Context that are responsible for moisture imbalance, and the main factors in each Occupant's Condition. This is slightly different from the MDPSEEA system in that, although the States and Context in this model relate to some extent to the Building Context here, there is no place really for the Occupant's Condition. The MDPSEEA model seems to assume that Agents do things to individuals and that Occupant's Condition doesn't have such an important role in illness or in cure. That seems both to go against evidence and also to disempower building occupants.

A list of Building Contexts and Occupant Conditions could be easily drawn up, with weightings for the degree of severity and the potential for improvement. Building Conditions would include factors such as relative humidity and temperature, mould levels in buildings (if these could be robustly measured), ventilation rates and air tightness (all of which could also be enhanced by assessment of building condition, building age, exposure facilities such as outdoor drying space for laundry etc); Occupant's Condition would include factors such as age, physical fitness, other health conditions, exercise taken, time spent in home, family context, levels of occupancy and moisture generation in the home, type of work, stress levels and mental health. These factors could be put into a simple spreadsheet or IT Tool and actions and outputs recorded in order to build up the evidence base for the approach and to assist with further adjustments to the categories and weightings in the approach, as well as the analysis of causality.

This holistic approach would require building as well as human skills, but could quickly start to identify those issues which were most affecting the moisture balance of the building and the health of the occupant, and which could be most easily addressed for most impact. Sometimes improving just one factor might make a substantial difference, in other cases multiple factors might have to be addressed to achieve any improvement. Of course the act of engaging positively and holistically with the sick occupant may also have considerable health benefits.

This approach can be tested through case studies and other research. Assessments can then be made to identify which factors can and should be addressed to restore a better balance to the overall situation for each Occupant's Optimum Health.

It should be noted that while two of the three variables—Occupant Condition and Building Context—are essential to this 'balanced' approach, the third variable, the Agents of illness (ie, the moulds, dryness, bacteria), is not. This is for two reasons: firstly the number of Agents and their parts, coupled with their interactions with other Agents and with Human Health makes most research into the effects of specific agents very difficult if not impossible.

Secondly, even if researchers or doctors are able to identify particular moisture-related Agents as causing a specific health problem, in most cases there is very little we can do, specifically, about the presence of the Agent itself, particularly if it is abundant in our environment, which nearly all moisture-related agents are. There are over a million known types of fungi for example, and each cubic metre can contain tens of thousands of different spores, even within normal conditions. However, all the Agents that concern us are more, or less, active and reach excessive levels as a result of specific building conditions, and are clearly linked to levels of moisture and other conditions, such as temperature within the building and its environment. While we cannot change the outdoor environment or the normal levels of mould or other biological Agents within buildings, we can more easily do something about abnormal levels of moulds and other moisture-related Agents within the indoor environment by changing the Building Contex; just as we can, to a greater or lesser extent, also change some aspects of the Occupant's Condition with regard to factors which may make him or her more or less vulnerable to Agents of illness.

This does not mean that we should not be testing for mould levels, or for VOCs, bacteria or other Agents of possible ill health in buildings. They are important indicators of moisture imbalance, and as we understand more about them we may be able to attribute specific health conditions more exactly to them (though this has so far proved extremely difficult). Furthermore, they may be important evidence in establishing liability for the provision of substandard housing. However, the 'balanced' approach is not concerned with them *per se*, but with the way that the Building Context and Occupant's Condition can be addressed more robustly in order ultimately to reduce health problems, whatever the exact causality.

Finally, it should be noted that this 'balanced' approach is not a counsel of perfection, but a way forward which accepts some uncertainty and sometimes failure to improve health outcomes. We have to accept these because of the complexity of all contexts and the limited means we have to address this complexity. The attempt to eliminate moisture linked illness in buildings altogether could easily create multiple unintended consequences as well as huge costs, all for little benefit, since we have to live in the world, and unless we seal ourselves entirely from the outside world and other people, we will always have to face some risks. Indeed, there is also evidence that our bodies need some such risks and challenges in order to be healthy in the first place.

IV *It is important to ensure that this approach gains acceptance by the medical establishment*.

A new understanding of medical causality (or at least medical 'effect') based upon probability and multiple interactions, should be discussed and developed with doctors, medical researchers and public health bodies in this field. This is highly challenging, not only because of the uncertainty, but because of the complexity and time scale of chronic illnesses. Nonetheless engagement with medical research, including exchange of methods of research and verification and validity of causal proofs, is essential to move forward the whole subject area of moisture risk and health in buildings, both at a research and at a policy and liability level.

6 Consequences for Policy and Industry

While there is a considerable need for a major long-term research programme focused on health and moisture in buildings, this does not mean there are not policy actions which should be taken now, based on the evidence we have, on the principle of pre-caution and in view of the considerable possible consequences of the known risks.

This precautionary principle in situations of considerable risk, but also uncertainty, is a key recommendation of the Wanless report on health for the Treasury (2004)[43] where it is stated that "The very poor information base has been a major disappointment.... There is a need for significant and continuous improvement if evidence is going to be used to drive decisions. The lack of conclusive evidence for action should not, where there is serious risk to the nation's health, block action proportionate to that risk..." [44]

Furthermore it should be noted that these risks to occupant health are in addition to the better documented and understood risks to building fabric of damp or over-dry buildings, which add considerable additional cost and liability to negligence of this area.

The following are the logical conclusions of this research for policy and industry practice:

i *Moisture risks should become a priority of building safety.*

They should be identified clearly in building regulations, advisory documents, and in all policies and initiatives by government with regard to buildings. The long-term and chronic health risks of moisture imbalance should be integrated with programmes for energy efficiency, as well as other programmes and regulations.

ii *A Whole Building (or Whole House) approach to both new and existing building work must be taken.*

This means taking account of people, fabric and services within the specific context of the house in question. In particular, the integration of fabric measures such as insulation and airtightness with ventilation strategies and with occupant behaviour and use are essential.

This approach is now embedded in the recent British Standards Institute (BSi) White Paper on Moisture Risk in Buildings (which may well be the basis for the new BS5250 standard), as well as in the Each Home Counts programme (formerly the Bonfield Review), and also in the aims of the current BSi Retrofit Standards Task Group. This report brings a new emphasis to the consideration and integration of the mental/social/ physical health of occupants within this whole building approach.

iii *Additional attention to moisture safety in buildings should be given where there is particularly strong evidence of moisture imbalance.*

This applies to parts of the private rental sector, to temporary accommodation, and wherever there is overcrowding or high levels of poverty. Council officers, health and safety officials and others in positions of authority, should work to address the worst cases of poor and overcrowded housing as a matter of urgency.

iv *All moisture safe design must also deal with unavoidable uncertainty.*

Capacity and caution must therefore be built into all programmes, as identified in the BSi White Paper. This means designing for peaks and extremes, not only average conditions, ensuring maintenance and upkeep is undertaken, and integrating monitoring and feedback into building contracts and activities, particularly where risks are considered greatest (such as in fabric retrofit).

v *Engagement with the public in general, and with building occupants during work, is essential.*

Moisture issues should be conveyed in simple language and in ways which encourage understanding of how balance can be maintained or restored by the occupant, as well as where there are issues which require expertise. This engagement is essential to enable building occupants to meet the specific challenges of their own health and their individual homes.

vi *Funding for the research programme and for communication with the public should be forthcoming.*

There has been almost no funding for understanding moisture risk in buildings over the past decades, whereas energy and innovation have received continual and generous support. This should change, not only because of the health risks incurred, but because moisture safety can be a driver for a radical improvement in the overall quality of design, construction and use of buildings in all areas.

[43] Wanless D. *Securing Good Health for the Whole Population* [Internet]. London: Her Majesty's Stationery Office; 2004 Feb [cited 2017 Jan 26]. Available from: http://webarchive.nationalarchives.gov.uk/20111011031323/http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4076134.pdf
[44] p5 op cit

7 Conclusion

Moisture and health in buildings may seem a very complex and confused subject. However in essence it is very simple. We know for certain that very high levels and very low levels of moisture in buildings, either directly or as mediated through biological or chemical agents, are bad for health and can lead to both acute and, more commonly, chronic illnesses and, in extreme cases, fatalities. What we do not know at the present time are the exact mechanisms for this process, nor the boundaries of what is safe or not safe.

In this report, we have tried to explain the state of existing knowledge with regard to health and moisture in buildings. For further and more detailed information, please contact the UKCMB for the full academic report. On the basis of this study, we have concluded that there are real risks and costs now for buildings with a moisture imbalance, and that certain forces and pressures are likely to make this situation worse in the future. As researchers, government or industry, we cannot therefore ignore the issue and hope it will go away. Even if the risks are less than we fear, we should identify them more clearly and use this knowledge to ensure risks do not re-emerge in future. We cannot and should not gamble with the health of the nation now or in the future. The risks are too high.

Moreover these risks combine with the other more clearly defined risks to the durability and value of the building fabric. It is relatively easy to see and to cost the damage done to buildings where moisture imbalance occurs. It is estimated that perhaps 70 to 80% of all building damage is due to excessive or trapped moisture[45]. In addressing the moisture risks to building fabric we will also improve the overall quality of the building and its performance, and this alone would be a sufficient justification for focusing on moisture in regulation, research, training and guidance.

Nonetheless, the risks to human health—to our comfort, well-being and long-term fitness and human potential—should be at least as important to us in research, policy and practice in this matter of moisture in buildings. We should not ignore this issue just because it is difficult to understand or define. In order to protect our country and its health in this regard, a properly conceived and funded programme of research, public information and supportive policy must be put in place as soon as is possible. This will be to the benefit of many individuals suffering from moisture-related illness, to the quality and performance our built environment, and to our society, financially, socially and culturally, as a whole.

[45] This figure is a key insight on the website of the internationally renowned Swedish Centre for Moisture in Buildings. see http://www.fuktcentrum.lth.se/english/vision/. The scale of this problem is backed up by many organisations in the UK both with regard to new and existing buildings.

Water connects everything and is the basis of all life. Life relies on growth and decay in equal measure and all such processes are dependent on water in some way. The health of our buildings as well as their decay is primarily connected with water.

Many substantial building problems (including health problems) are caused by excessive or insufficient moisture. And yet we have very little research in the UK on moisture in buildings, a lack of focus and coherence in regulation, policy and guidance, and minimal public and industry understanding of moisture risks and how to deal with them.

The **UK Centre for Moisture in Buildings** has been set up to help address these issues.

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