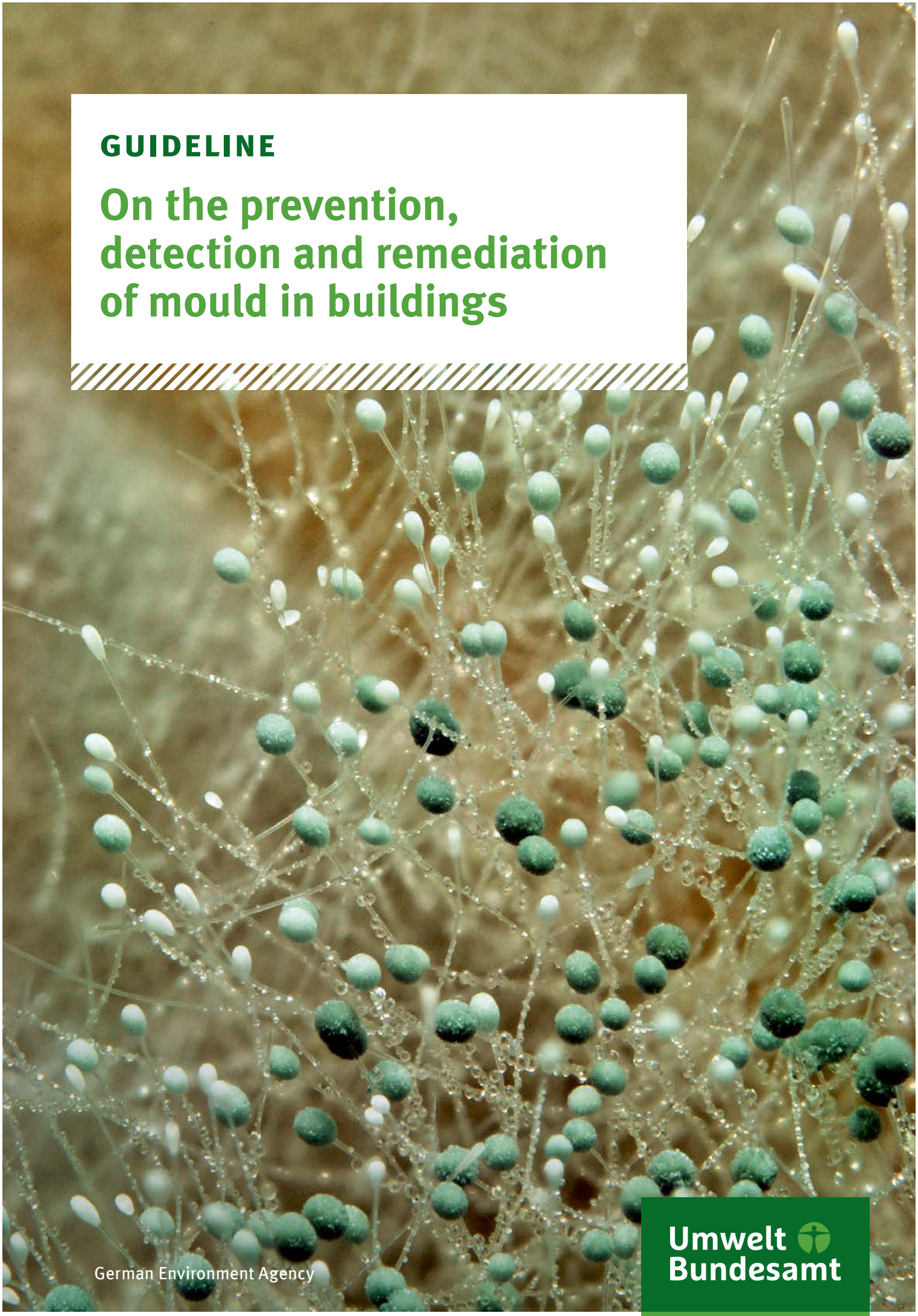

GUIDELINE

On the prevention, detection and remediation of mould in buildings

German Environment Agency

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On the prevention, detection and remediation of mould in buildings

COMPILED BY THE INDOOR AIR HYGIENE COMMISSION OF THE GERMAN ENVIRONMENT AGENCYS

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Contents

1 Introduction

The German Environment Agency (UBA) published “Guidelines for the prevention, examination, evaluation and remediation of mould infestation in indoor spaces” which was amplified by the Indoor Air Hygiene Commission in 2002 and “Guidelines on cause search and remediation of mould infestation in indoor spaces” in 2005. For the first time, these documents enabled the establishment of uniform nationwide recommendations for the search causes, detection, assessment and remediation of indoor mould infestation. Both documents have attracted great interest up to now.

However, the current guidelines have become ‘outdated’. Legislative requirements for the construction of new buildings and the remediation of existing ones have significantly changed and have become more stringent with regard to energy savings in recent years. The building envelope has become increasingly airtight due to current Energy Saving Ordinance (EnEV) requirements, while improper or inadequate ventilation has increased the risk of moisture accumulation and mould infestation. It has therefore become necessary to update the findings and recommendations with regard to the building stock and the advantages and disadvantages of ventilation equipment in connection with the emergence of mould infestation, especially in energy-efficient buildings. The methods for detecting and assessing mould infestation have been adapted to the latest scientific findings.

Not only will this guideline describe accepted rules of technology, but the current state-of-the-art science and technology in certain areas will also be clearly explained in the text. Technical rules are considered to be accepted rules of technology if they are recognised by science as theoretically correct in accordance with the prevailing view of experts and have been tried and tested in practice. This is true for most of the standards and directives cited in the guideline. It can also be generally accepted that buildings remain free of mould if the provisions and recommendations in this guideline for avoiding mould with regard to moisture avoidance, ventilation, heating and building regulations are observed. Methods that have not yet generally proved themselves such as the detection of bacteria in materials or MVOC in indoor air fall under state-of-the-art. This guideline also presents state-of-the-art science and technology in connection with conclusions and procedures that are currently being discussed in the scientific community or are still in their trial phase but are neither yet generally accepted nor applied by the majority of professionals. These also include the use of mould detection dogs and molecular biological detection methods as well as decisions about health-related effects of metabolic products and cell constituents in the case of mould infestation.

The guideline recommendations do not constitute legal regulations and do not replace them.

In recent years it became clear that not only mould fungi but also bacteria such as actinomycetes are present when moisture damage occurs. The new guideline therefore generally uses the term ‘mould’ for microbial infestation in connection with moisture damage caused by mould fungi, yeast and bacteria. Mould fungi continue to be considered as indicators of mould infestation as they are always present in mould infestation, with just a few exceptions.

Not every material used on and in buildings is mould-infested just because mould spores or bacteria have been detected on or in them. The new guideline clarifies this and makes a clearer distinction between contamination and infestation and presents background values for mould fungi and bacteria for different materials.

“Old” mould guidelines were often criticised for applying recommendations to all interiors without making any differentiation. Practical interpretation has often been interpreted as having the same requirements in living rooms as in adjoining rooms outside the home or even in garages. Therefore, utilisation classes with different requirements for assessment and above all, for remediation of mould infestation, will be introduced in the future. This guideline explains in detail the individual utilisation classes and their requirements. Since distinct approaches primarily have an effect on the remediation of mould infestation, in the case of damage, the description of each utilisation class is given at the beginning of the chapter on Measures (Section 6.1). Individual remediation recommendations generally apply to utilisation class II and the text explains where distinct approaches can be applied (Utilisation class III).

This guideline applies to offices, schools, kindergartens, theatres and other public spaces as well as to all living and other spaces – i.e. within the utilisation level – with permanent or restricted use (utilisation class II). The guideline does not apply to canteen kitchens, restaurants, food companies and working places contaminated by production-related microorganisms. In hospitals and similar facilities, special hygienic requirements apply which are not dealt with in this guideline (see Section 6.1, utilisation class I). Utilisation class III describes areas outside the utilisation level (see Section 6.1).

In the past, the recommendation as to when infested components must be removed. The new guideline deals with this issue in a more differentiated way and with regard to utilisation classes.

Biocide applications (often mistakenly referred to as disinfectant measures) are in most cases inappropriate for mould remediation and are used far too frequently in practice. Therefore, the new guideline gives clear recommendations to individual cases where the use of biocides makes sense and where it should be avoided.

Finally, guideline recommendations, occupational health and safety requirements and some other formal aspects have been updated.

The new guideline – like the previous ones – claims to set the framework for uniform nationwide procedures in Germany and, as a new feature, also in Austria in consultation with their state institutions, and adapted to Austrian conditions. Switzerland has also been interested in adopting parts of the guideline. The guideline is not aimed at describing every single case and giving detailed recommendations – this cannot be done by a general "guideline". It was agreed in advance with various associations active in mould detection and assessment that special leaflets or instruction manuals e.g. with practical measures for drying and moisture assessment in materials are to be released by competent external specialist associations. Instruction manuals about occupational safety are to be released by the Employers Liability Insurance Covering Occupational Illness or Injury (BG BAU). The recommendations there should be based on the UBA guidelines and give detailed recommendations on specific areas or occupational groups.

The current guideline addresses experts' offices, craft enterprises, microbiological laboratories and all those who detect and assess moulds and develop remediation concepts. Remediation companies will find important pieces of information but will have to refer to recommendations from their associations for further details. The guideline also provides assistance to local authorities and housing companies that accompany or supervise mould remediation. Finally, affected building users will find valuable information within the guideline.

The guideline takes into account health, building physics, metrological and general indoor air hygiene issues. Contractual and other legal aspects that may give rise to different interpretations are not included.

Provisions from labour law (Workplaces Ordinance) and aspects of occupational health and safety law beyond mould remediation are also not dealt with in this guideline. Information on the legal situation is provided by appropriate bodies such as local representatives of the German Tenants' Association (DMB), the Home Owners' Associations, the Federation of German Consumer Organisations (vzbv) and the advice centres of Consumer Organisations (e.g. Guide of the North Rhine-Westphalia Consumer Centre[1]) and the insurance industry.

1 Moisture and mould – Detect, eliminate, prevent. NRW Consumer Centre. Düsseldorf 2016 (www.ratgeber-verbraucherzentrale.de/ratgeber)

The guideline is structured as follows:

Chapter 1 "Mould, mould infestation and mould fungi". In this chapter, the terms used in the guideline are defined and the principles of mould fungi and their growth conditions are described. The growth of bacteria and other microorganisms in the case of indoor moisture damage will also be discussed.

Chapter 2 "Effects of indoor mould on human health". This chapter describes the potential health effects and risks of indoor mould.

Chapter 3 "Causes of mould infestation in buildings". The chapter describes the relevant parameters for mould growth, in particular humidity and temperature. The interaction of humidity, temperature, building conditions and ventilation is explained in detail.

Chapter 4 "Preventative measures against mould infestation". In addition to structural factors that are described, the room user can contribute a lot to mould avoidance. This will be discussed in this chapter. In particular, ventilation and heating recommendations are given. Mechanical ventilation equipment and their advantages and disadvantages are discussed.

Chapter 5 "Recognise, detect and assess mould infestation" describes important points of site inspection and the detection of mould fungi in the air and in materials. Reference is made to standards and guidelines for details of verification procedures.

Chapter 6 "Measures in the event of damage" explains what to do if mould infestation has occurred. A distinction is made between measures that room users can take and measures that are reserved for specialist companies. The different utilisation classes in buildings are described and a utilisation class reference is made for remediation recommendations and measures. It also describes precautionary measures to be observed from the occupational safety point of view and briefly discusses individual remediation procedures. References to recommendations by associations are given where the reader can receive further information in detail on remediation procedures.

The guide concludes with a glossary briefly explaining the most important technical terms.

This mould guideline now being published replaces the German Environment Agency's former mould guidelines of 2002 and 2005, which are losing their validity.

1

Mould, mould infestation and mould fungi

The German term ‘Schimmel’ for mould comes from the Middle High German and has been documented since the 9th century (at that time in the form of ‘Schimmel’). Historically, long before mould fungi were identified, the term ‘mould’ was used to refer to visible stains on moisture-affected materials that, inexplicably at that time, kept developing almost on their own. See “Conservandae Sanitatis Praecepta”, anno 1545, by Johannes Curio (the Medicine Doctor): *“Choking with its rotting constituents, it (the air) is similar to that trapped in some houses where much dirt and mould accumulate due to rot and deficient ventilation.”*

When it was discovered that this mould is caused by fungi with microscopic structures, the fungi causing mould were called ‘mould fungi’ (see Section 1.2). Mould needs a lot of moisture to grow (see Section 1.1). Over time, it was recognised that there were also “fungi” that looked a bit different, in particular they were smaller by an order of magnitude and were referred to as ray fungi or actinomycetes (from the Greek aktis = ray and mykes = fungi). Later it was found that actinomycetes are not fungi but bacteria. Therefore, these organisms are today called actinobacteria (see Section1.3).

The growth of microorganisms on furnishings, on or in walls and other components is commonly called mould (German: Schimmel). Mould infestation is caused by mould fungi, yeast and bacteria. Mould fungi are the lead organisms in the detection of mould.

Mould fungi and bacteria can grow if sufficient moisture is present in most organic materials or materials with organic contaminants. Mould fungi can only be recognised by the naked eye as mould stains if a sufficient amount of conidiophores with coloured spores have developed on a visible surface. Both mould fungi and some actinobacteria among others can contribute to indoor pollution by producing spores. Therefore, the guideline’s focus is directed towards these two groups of microorganisms (see Sections 1.2 and 1.4).

In addition to mould fungi (Section 1.2) and bacteria (Section 1.4), unicellular fungi (yeasts, see Section 1.3) and protozoa (in particular amoeba) also occur in mould infestation. With regard to protozoa, there are no indications that they can cause health problems to room users in the case of mould infestation. Therefore, neither measurements nor assessment of mould infestation will further consider protozoa.

In addition, mites can occur in damaged areas, especially in older mould infestations. Mites belong to a subclass of arachnids. The most common mites are the two common house dust mites *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae*. They feed on dander and mould fungi. Mites faeces can trigger an allergic reaction and thus contribute to the occupants' health problems observed in the case of moisture and mould damage.

Mites are a problem in indoor rooms regardless of mould infestation. Therefore, they must be considered and assessed independently of these guideline recommendations.

All organisms mentioned are microscopic (see Table 1).

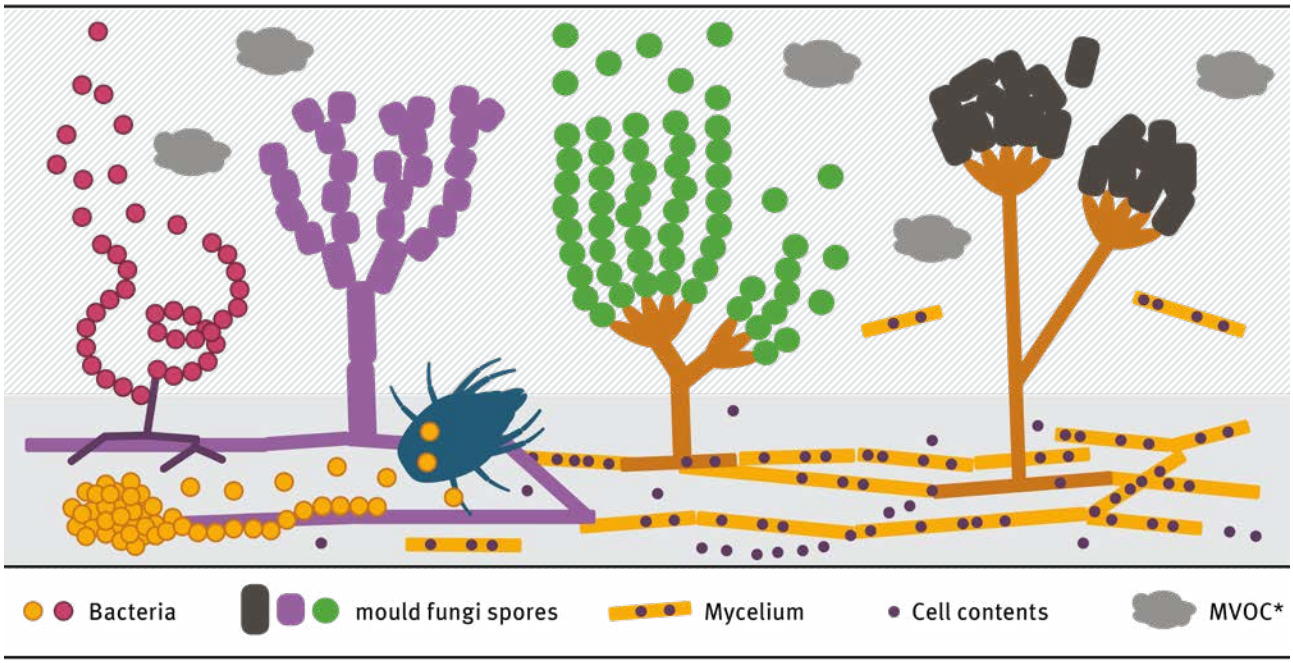
Table 1

Size of different (micro)organisms compared to human hair

	Magnitude in µm
Hair [Ø]	100
House dust mite	100–500
Amoeba	100–300
Mould spores	2–30
Mould hypha [Ø]	4–10
Actinobacterium hypha [Ø]	1

Figure 1

In the case of mould infestation, a diverse life community can be found on or in the material. Various microorganisms (mould fungi, yeasts, (actino)bacteria) as well as protozoa and mites can occur.



MVOC = microbiological volatile organic compounds.

Source: Trautmann, Environmental Mycology GmbH, Berlin

1.1 Mould infestation

Mould infestation occurs when microorganisms are proliferating or have proliferated on or in a material. The most important prerequisite for proliferation is a sufficiently high moisture content. Temperature and nutrients also play a role (see Section 1.2).

To be differentiated from mould infestations is contamination from other mould sources that accumulate loosely on surfaces due to sedimentation. Contamination can be caused by spores or other microbial particles that enter the interior from outside, are released by mould or originate from other sources inside the room (potting soil, food, building dust).

Distinction between mould infestation and contamination

Mould-infested materials are building materials or furnishings inhabited by mould fungi, bacteria or other microorganisms, regardless of whether the organisms are vigorously/actively growing, have grown or have already perished. Conceptually, one also speaks of **mould damage.**

Contamination is a surface or materials' impurity caused by microorganisms or biogenic particles and substances through direct contact with infested materials or air and exceeding the background load.

Microscopic analyses can help distinguish mould from contamination (see Section 5.1.2.1).

In principle, all materials containing organic matter (nutrients) and moisture available to microorganisms can be colonised (infested). The growth of microorganisms in materials results in a firmer anchoring of the microorganisms in the material as opposed to contamination. These microorganisms actively release metabolites and spores into the air due to their metabolic activity. In addition, cells (mycelial fragments) and cell components may spread around.

Microorganisms cannot grow in high density materials such as glass, metals and ceramics. Growth of moulds and bacteria on surfaces is only possible when nutrients and moisture accumulate on smooth materials. Visible infestation on such materials is always due to an adhering dust or dirt layer, as this layer can both store moisture and contain nutrients.

Figure 2

Examples of hidden mould damage

Source: left: Lorenz, Institute for Indoor Diagnosis; right: Betz, Experts Office for Building and Interior Analysis

When there is moisture damage, wallpaper, plasterboard walls and objects made of paper or leather can be colonised relatively quickly by mould. Prolonged exposure to moisture may result in damp components and microbial colonisation of wood materials, plasters and insulation material (e.g. mineral wool, polystyrene). Low-nutrient, strongly alkaline materials such as cement screed, concrete and solid wood are hard to colonise. However, "specialists" among fungi are capable of colonising wood, although these so-called "wood-destroying fungi", with few exceptions, do not belong to the mould fungi.

Mould fungi need a high moisture content to grow (see Section 1.2). They not only grow in places that immediately catch the eye but are often concealed in poorly ventilated areas such as behind skirting boards, wardrobes, wallpaper or linings (see Figure 2).

If the surface is dry but the materials themselves are moist, they can still be infested. Infestation can occur below the visible surface in the pores of materials as such insulation materials or wall plaster or at the interface between different materials. These cases of damage may contain large amounts of microbial biomass and infestation is only detectable microscopically or by cultivation in the laboratory. This is especially true for polystyrene footfall sound insulation (underlay) when it has been infested microbially. Polystyrene underlay very often looks unremarkable at first and it is only microbiological analysis that can show a massive growth of mould fungi and bacteria. The infestation of a wall plaster on a moist wall is sometimes not visually recognisable but can cause musty odour.

Mould can lead to stains, odours (see below) and damage to materials. Also, the emission of spores, microbial substances and cell fragments can cause health problems for room users (see Chapter 2).

Mould is not always visible

Only a part of microbial damage can be perceived as mould stains to the naked eye. Mould often occurs in hidden places or under the surface of materials and is thus not recognisable.

Visible and invisible mould may, but need not, occur together.

Visible stains are usually more of a concern, even if they are just small areas. However, hidden infestation often contains large amounts of microbial biomass and must therefore be included in further damage assessment.

Whether and what odours occur depends on the mould fungi and bacteria present and on the substrate material. It is known from practice that the genus *Bacillus* bacteria or some actinobacteria produce a very concentrated smell. The musty odour in old and damp cellars is often caused by bacteria of the genus *Streptomyces* and other actinobacteria: they can almost always be detected in large quantities in the case of long-lasting mould infestations. Moist, microbially populated chipboards smell particularly musty while polystyrene or mineral wool, with comparable contamination, usually does not smell or produces a different odour.

In addition to microbial emissions, chemical emissions from wet materials can also cause odour nuisance.

1.2 Mould fungi

"Mould fungi" is an umbrella term for fungi that produce typical fungal threads (hyphae) and spores. They can be perceived with the naked eye as mould stains with a coloured surface (see Figure 3). They are not a uniform systematic group of fungi, the term "mould fungi" covers so-called hyphomycetes from different taxonomic groups (ascomycetes, zygomycetes) and their anamorphic stages (formerly called deuteromycetes or fungi imperfecti).

Individual species of mould fungi are denoted by double Latin names. The first part of the name specifies the parent fungus genus (e.g. *Aspergillus, Penicillium*) and the second part of the name is the individual fungus species (synonym fungus species; e.g. *Aspergillus fumigatus, Penicillium chrysogenum*).

Many mould fungus species have been given new names due to new taxonomic findings. Molecular biology studies have shown that some mould fungi exist in two forms: sexual and asexual forms. Both forms are created by the same mould fungus and have been described as separate species. The dual nomenclature for the sexual (teleomorphic) and asexual (anamorphic) forms of fungi was abolished in 01.01.2013 (one fungus – one name). This changed some genus and species names of mould fungi (see table in Annex 1). Important aspects of the molecular biological identification of mould fungi are summarised in Annex 2.

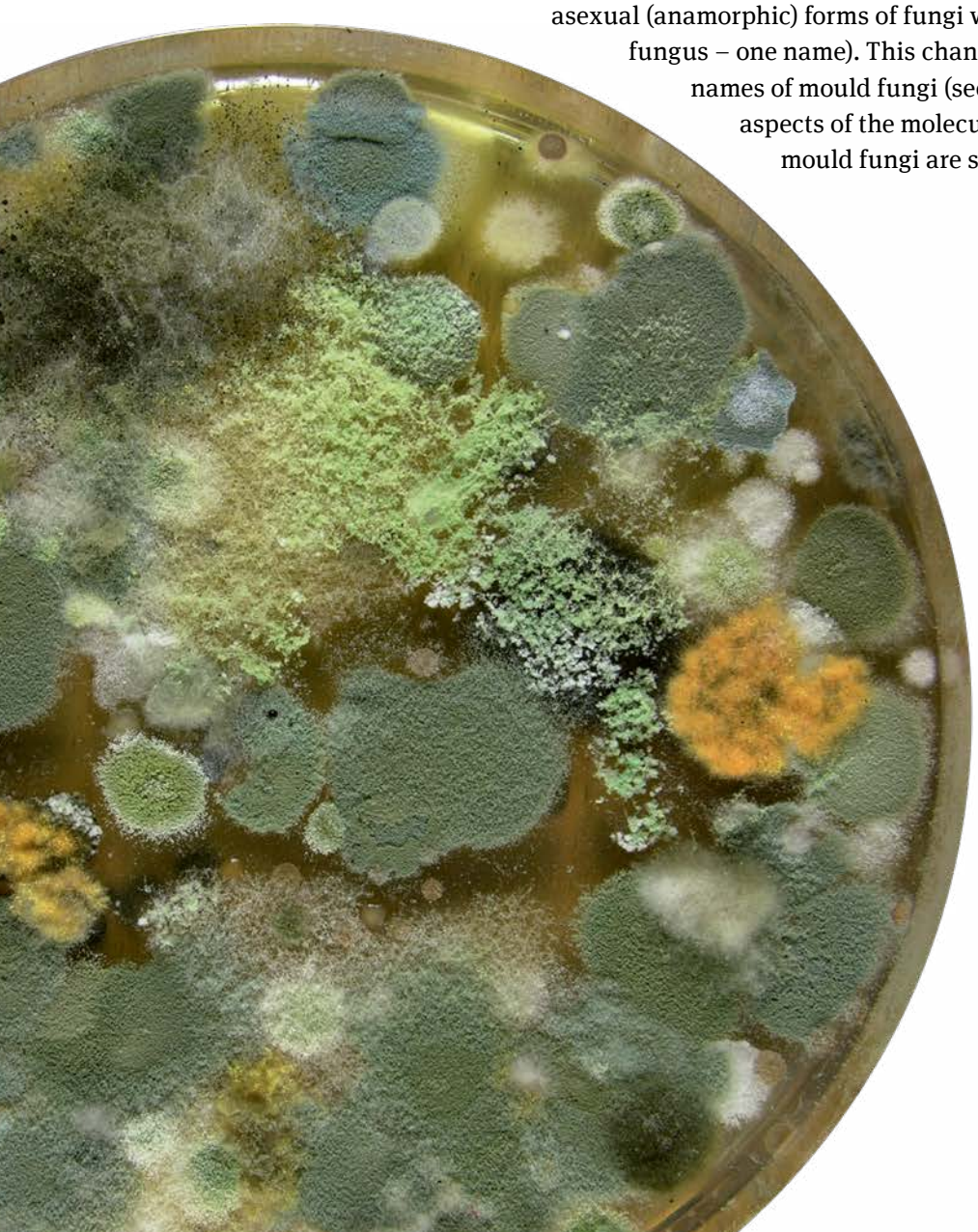


Figure 3

Various species of mould fungi growing on nutrient medium in a Petri dish and creating spores

Source: Szewzyk, German Environment Agency

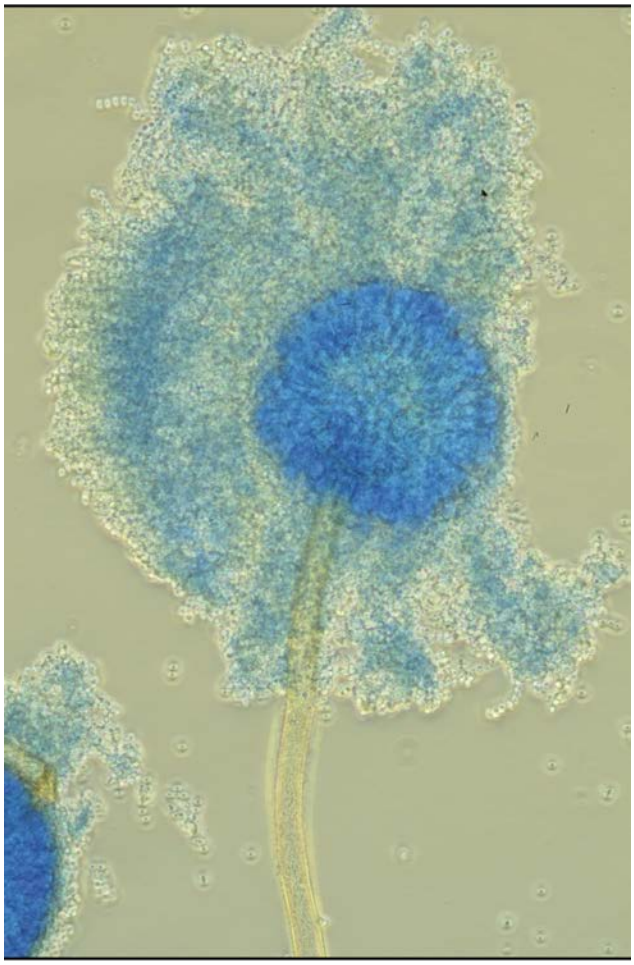
1.2.1 Properties of mould fungi

In the growth phase, mould fungi produce multicellular filaments (hyphae, see Figure 1) whose interconnected network is called a **mycelium**. Mould fungi are barely visible to the naked eye at this stage since these threads are often whitish in colour. For proliferation and distribution, mould fungi produce asexual dispersal propagules (sporangiospores and conidia, see Figures 1, 4 and 5) and, much less frequently, sexual dispersal propagules (zygospores, ascospores). All dispersal propagules will be summarised hereafter under the term **'spores'**. Since the asexual spores are usually produced in large numbers and are often coloured, the naked eye can perceive mould infestation during and after spore formation (e.g. as mould stains).

Mould fungal spores come in sizes from 2 µm to 30 µm (maximum range 1 µm to 100 µm) with few exceptions. Most spores have a diameter less than 10 µm. They are inhalable, can float in the air over long distances and be transported by the wind.

Figure 4

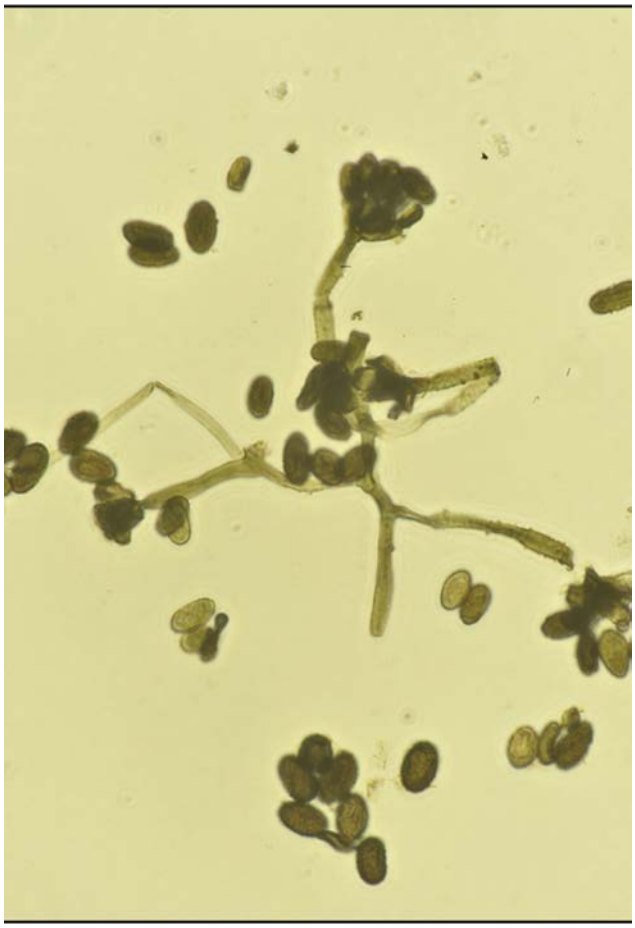
***Aspergillus* sp. under the microscope**
(400 x magnification)



Source: Valtanen, German Environment Agency

Figure 5

***Stachybotrys* sp. under the microscope (from a dried-out damage on plasterboard)**
(400 x magnification)



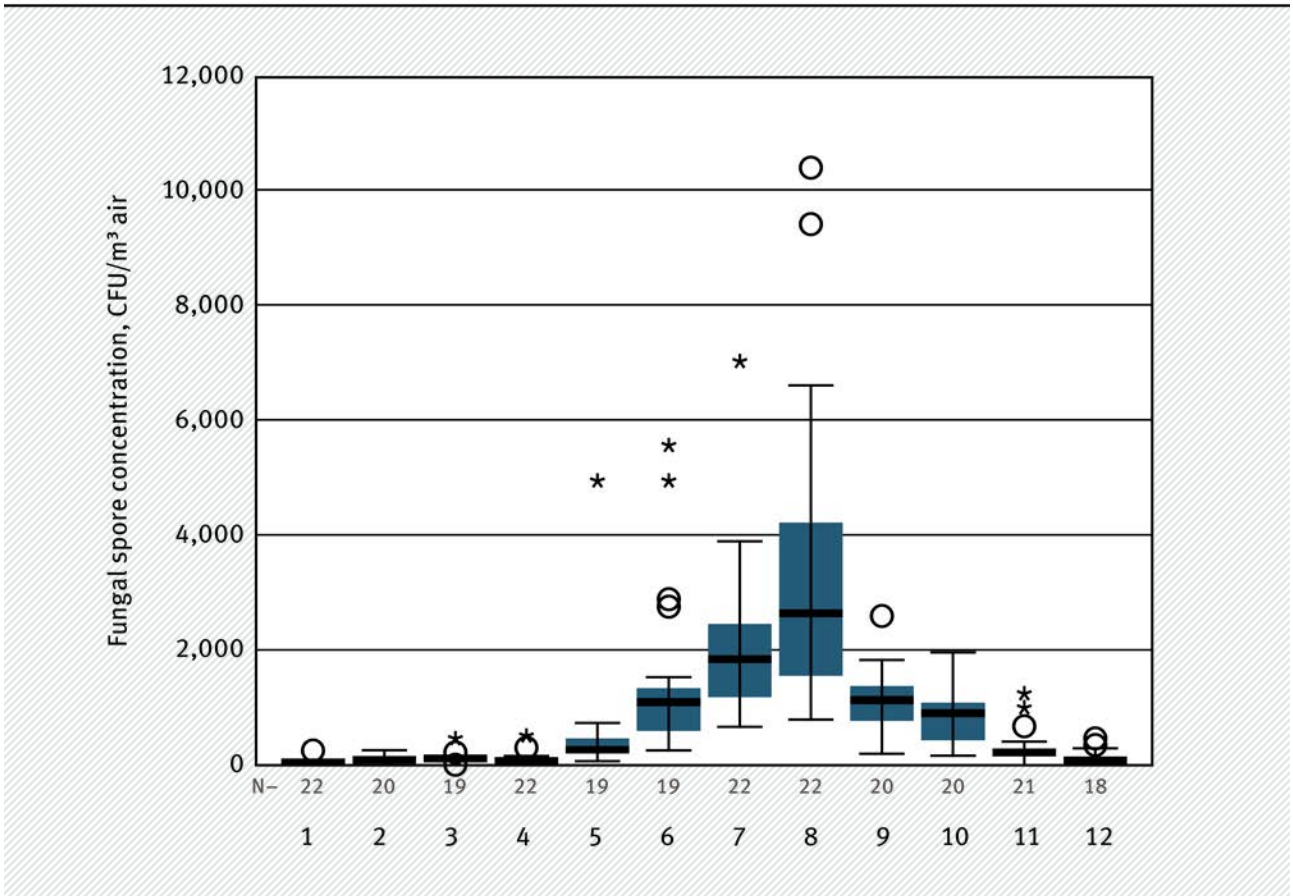
Source: Valtanen, German Environment Agency

Mould fungi are common in nature. They are involved in the decomposition of organic matter and play an important role in nature's carbon cycle. Mould fungal spores are therefore a normal part of outdoor air and are always present in indoor air. As a rule, a number of different genera and species occur together.

The concentration of mould fungi air is subject to a large fluctuation, depending on location, climate, time of day and season (see Figure 6). This fluctuation is caused by natural influences, for example by changes in temperature and humidity during the year and by dependence on geographical location, accumulation of rotting material or dust devils. Mould fungi can also be released by human activities such as in compost plants, recyclables sorting plants, livestock farms or grain processing.

Figure 6

Typical seasonal trend of mould fungus concentration in the outdoor air in Germany



The box plots show the median (thick black line), the 25th and 75th percentiles (blue area limits), the 5th and 95th percentiles, outliers (O) and maximum values (*).

Source: Koch et al.: Indoor viable mold spores – a comparison between two cities, Erfurt (eastern Germany) and Hamburg (western Germany). Allergy 55: 176–180

1.2.2 Indoor mould fungi

Mould fungi are a natural part of our living environment and their spores are therefore present in all indoor areas.

Mould fungi that occur in indoor air can come from a variety of sources. They enter indoor areas from outdoor air due to ventilation and are transported by dust and dirt on clothing and shoes into buildings. Fungi of the genera *Cladosporium* or *Penicillium* are often found in house dust and usually in indoor air for example.

Mould fungi can grow indoors due to increased moisture on materials and also develop in indoor air. Mould infestation caused by indoor mould growth poses a hygienic problem, especially since different mould fungal species dominate in cases of building damage than in the natural environment.

Mould fungi are a natural part of our living environment and therefore also available indoors.

However, an increase of mould fungi concentration indoors due to mould growth must be avoided. The concentration of mould fungi in the outdoor air is subject to strong fluctuation. This must be taken into accountin the assessment of indoor air concentrations (see Chapter 5).

Some mould fungus species do not occur in outdoor air and in dust or only at a low concentration but are regularly found in moisture damage for example *Aspergillus versicolor* (see Figure on page 22) and fungi of the genus *Chaetomium*. Such species are therefore also referred to as moisture indicators (see Table 2). If such mould fungi are detected in the room air at noticeable concentrations exceeding the background concentration, there is or has been a high probability of increased moisture content.

Aspergillus niger is often mentioned as a typical indoor mould fungus. However, this fungus is relatively uncommon in damp building materials, but often occurs in house dust and in the soil of indoor plants.

It is important that investigations of indoor air include a comparative measurement of the outdoor air or in a reference room (comparable room without mould infestation) in order to be able to distinguish between contamination and mould infestation (exception: remediation control, see Chapter 5).

Table 2

Mould fungi with high indication for moisture damage (moisture indicators)

Mould fungus species
Acremonium spp.
Aspergillus penicillioides, Aspergillus restrictus, Aspergillus versicolor
Chaetomium spp.
Phialophora spp.
Penicillium chrysogenum
Penicillium brevicompactum
Scopulariopsis brevicaulis, Scopulariopsis fusca,
Scopulariopsis brumtii, Scopulariopsis chartarum
Stachybotrys chartarum
Tritirachium (Engyodontium) album
Trichoderma spp.

From: Leitfaden des Landesgesundheitsamtes Baden-Württemberg, „Schimmelpilze in Innenräumen – Nachweis, Bewertung, Qualitätsmanagement“ (Guidelines of the Baden-Württemberg State Health Office, “Indoor mould – detection, assessment, quality management”), Stuttgart 2001+ amended in 2005

There is a great diversity of species among mould fungi and new species are being discovered all the time. However, the diversity of frequently occurring mould fungi is manageable in the case of mould on building materials: mainly *Penicillium* spp. (in 80 % of the samples), *Aspergillus versicolor* (50 %), *Cladosporium* spp. (46 %), *Acremonium* spp. (31 %), *Aspergillus restrictus* group (26 %) and 18 other genera (in 1 % to 10 % of the samples) have been detected on and in mineral building materials (cement screed, wall plaster or concrete).

1.2.3 Factors influencing mould growth

Mould fungi need nutrients and moisture to grow. Since nutrients are present in buildings in a more or less readily available form, moisture is of crucial importance. Temperature and pH also play a role although mould fungi can grow in comparatively wide ranges of temperature and pH. Fungal growth can be slower or faster depending on nutrients, temperature and pH (see Sections 1.2.3.1 and 1.2.3.2).

Moisture

In addition to biological and physical factors of influence, availability of moisture (see Chapter 3) is a decisive cause for the growth of mould fungi and other microorganisms.

Increased humidity is the **most important cause of mould fungi growth** in buildings.

Moisture content at a material surface is often described by its so-called water activity (a_W value), where a_W value of a damp material (under equilibrium conditions) corresponds to the numerical value of the relative percentage air humidity present at the outer and inner material surface divided by 100. In practice, equilibrium conditions can only approximately be achieved; an a_W value of 0.8 therefore corresponds to approximately 80 % relative humidity at the material surface. In order to establish room climatic boundary conditions where mould fungi are expected to emerge, one must know that fungi can absorb water or water vapour both from the substrate and from air.

It is believed that spores absorb moisture from their immediate environment during germination. Mycelium produced after germination can absorb moisture from the building material by penetrating into the pore structure of a building material.

A relative humidity of 70 % to 80 % on the surface of materials is sufficient for mould fungal growth if it prevails over a longer period of time. Materials do not have to be visibly wet. Particularly favourable growth conditions are always available when condensation occurs on or in the material. Different water activities encourage fungi to produce different metabolic functions. Thus, the minimum required and optimum a_W values for spore germination, growth and mycotoxin production are different.

Table 3

Minimum water activity values required for the growth of various mould fungi (minimum a_W values)

Mould fungus species	Minimum a_W value
Wallemia sebi	0.69–0,75
Aspergillus restrictus	0.71–0,75
Aspergillus versicolor	0.78
Penicillium chrysogenum	0.78–0.81
Aspergillus fumigatus	0.85–0.94
Cladosporium cladosporioides	0.86–0.88
Fusarium solani	0.87–0.90
Rhizopus stolonifer	0.93
Stachybotrys chartarum	0.94

Source: Northolt, Frisvad, Samson (1995): Occurrence of food-borne fungi and factors for growth. In: Samsonetal. (ed.) Introduction to food-borne fungi., CBS, Baarn, NL

Each fungus species grows in a characteristic moisture range that determines the intensity of growth (see Table 3). Xerophilic species such as *Aspergillus restrictus* can grow from an a_W value of 0.70 to 0.75, but most mould fungi need a_W values of at least 0.80 to 0.85 for their growth. *Stachybotrys chartarum* needs much more moisture to grow (minimum a_W value of 0.94) and therefore only occurs when the material is heavily soaked, for example due to water damage. Most mould fungi can usually colonise drier areas than bacteria, almost all of which require a_W values above 0.9 to grow.

The moisture limit, below which no growth of mould fungi takes place on materials, is under otherwise optimal conditions at about 70 % relative humidity at the surface.

As the moisture content of the material increases, the probability of mould fungi growth increases.

At 80 % relative moisture at the surface, growth conditions are reached for many indoor mould fungus species when the surface temperature is sufficiently high (well in the plus-degree range). When surface moisture content exceeds 80 %, almost all species of mould and bacteria can grow. Bacteria can grow in stagnant water (100 % moisture) but mould fungi usually cannot.

Temperature

Mould fungi can grow in a wide range of temperatures.

Fungal species showing optimal growth in a medium temperature range are called mesophilic. Species that are able to grow well even at high temperatures are called thermotolerant. Fungi with a growth optimum at high temperatures are referred to as thermophilic fungi (see Table 4).

In outdoor spaces, mesophilic mould fungi are most likely to find optimal temperature conditions in our latitudes. This group includes the most important members of the *Penicillium* genus. *Aspergillus* species prefer higher temperatures and are therefore among the most thermotolerant mould fungi. In contrast, thermophilic mould fungi such as *Aspergillus fumigatus* occur in low concentrations in moderate temperate regions, except for composting plants and certain agricultural activities.

Table 4

Growth temperatures of mesophilic, thermotolerant and thermophilic mould fungi

Description	Temperatures		
	Minimum	Optimal	Maximum
mesophilic mould fungi	0–5	25–35	ca. 40
thermotolerant mould fungi	0–5	30–40	ca. 50
thermophilic mould fungi	20–25	35–55	ca. 60

Source after Mücke M, Lemmen Ch (1999): Mould fungi, occurrence, health hazard, protective measures. Ecomed Publishing Landsberg.

Nutrients

Mould fungi can use nutrients from building materials as well as nutrients that are spread by house dust such as fibres, pollen, bacteria, hair and dander.

The following are examples of materials that mould fungi can grow on:

- wood, wood-based materials (e.g. hardboard, OSB or chipboard)
- paper, paperboard, cardboard (including plasterboard)
- wallpaper, wallpaper paste
- rubber, plastics (e.g. polystyrene, silicone, foils)
- wall-to-wallcarpet, floor covering adhesive, mineral wool
- paints, varnishes
- leather, textiles

Materials such as cement and concrete may also contain nutrients for mould fungi. Mould fungi can also grow on materials that do not contain nutrients themselves (e.g. glass) if organic particles and dusts have settled on them.

In addition to humidity and temperature, the nutrient content of the substrate is also an important factor for the growth of mould fungi.

Mould fungi can use a variety of materials as nutrient sources.

Generally speaking, indoor surfaces have sufficient nutrients.

Even though humidity is the most important factor, the three essential growth conditions – humidity, temperature and nutrients – must be present simultaneously in a favourable area over a certain period of time so that mould fungi spores can germinate and the mycelium can subsequently grow (see Sections 1.2.3.1 and 1.2.3.2).

pH value

The extent to which mould fungi can use a substrate for growth also depends on the pH value.

Many mould fungi species can grow well in a range between pH 3 and 9. Individual mould fungi species tolerate pH values between 2 and 11.

Mould fungi can grow in a wide pH range.
Mould fungi almost never grow above pH 11 which is why infrequently used rooms (storage rooms outside the home or permanently damp cellar rooms [utilisation class III]) can be coated with strongly alkaline paint to temporarily suppress mould fungi growth (see Chapter 6).

For example, wallpaper and paints often have a pH between 5 (e.g. woodchip wallpaper) and 8 (e.g. synthetic resin dispersion paint). Lime-containing building materials such as lime-based plaster or concrete may have pH values higher than 12. Over time, however, the carbon dioxide contained in the air leads to carbonation thus lowering the pH, which is why whitewash only has a temporary effect against mould fungi growth. In addition, mould fungi growth can also be favoured by organic deposits on such material surfaces.

1.2.3.1 Interaction between temperature and humidity

Germination or mycelium growth only occurs at the minimum levels of relative air humidity in the presence of optimal temperatures and a good nutrient supply. If the temperatures are not optimal, germination or mycelium growth will only take place in greater humidity.

In practice, the requirements for growth – humidity and temperature – cannot be considered separately since the value of relative humidity changes with the temperature at uniform absolute humidity.

A superposition of the two influences (temperature and humidity) is illustrated in a diagram by lines of the same germination time or the same growth (so-called isopleths). Depending on the mould fungi species, different isopleth systems apply. Figure 7 shows, by way of example, the isopleths for the mycelium growth of two mould fungi species of genus *Aspergillus*. As such, *Aspergillus versicolor* can only grow 0.01 mm per day at a relative surface humidity of 85 % at 10 °C, but can grow 0.5 mm per day at 25 °C. The outermost curves indicate the conditions under which no growth is detectable.

These isopleths are based on literature data and individual selected tests. They serve as an indication for estimating the likelihood of mould fungi growth but cannot represent all individual situations occurring in practice.

1.2.3.2 Interaction between temperature, humidity and nutrient content

The **nutrient content** in the material also exerts an influence on the growth of mould fungi. Tests have shown that, depending on surface moisture and temperature, different time periods are required for specific materials in the development of mould fungi. These periods can span a few days to a few weeks.

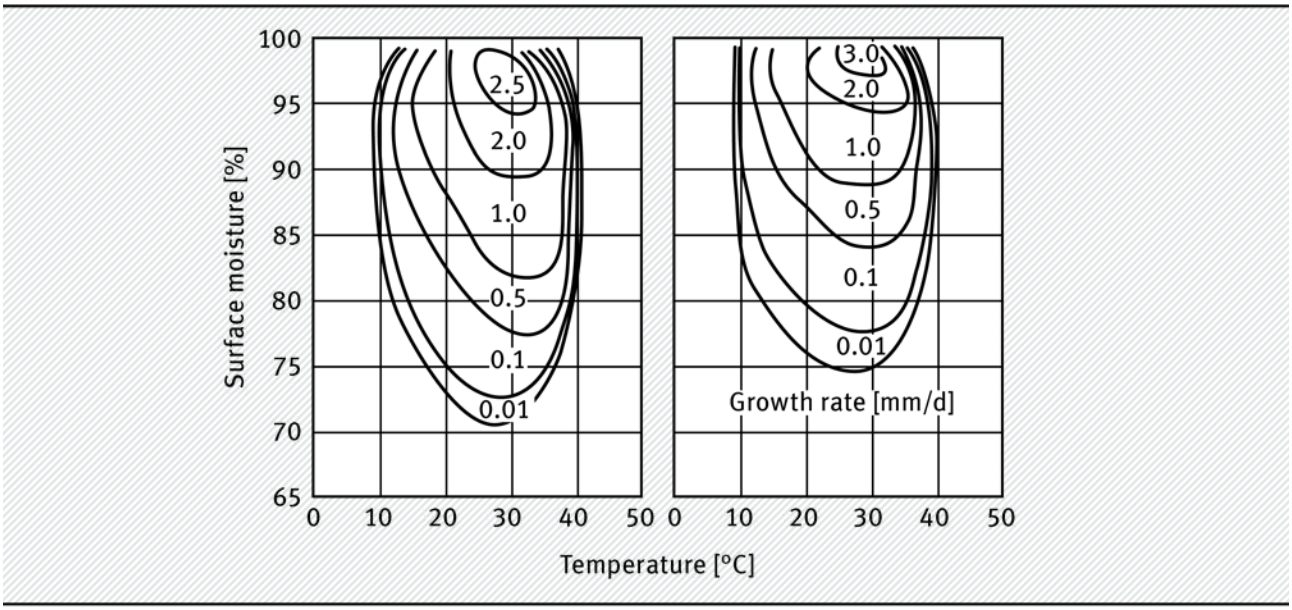
By considering the surface moisture, the temperature and nutrient content, generalised isopleth systems can be established (see Infobox 1). These isopleth systems help estimate and model the probability of mould infestation for certain temperatures and relative humidity values.

An isopleth map offers a simplified graphic representation of the susceptibility of building materials to mould infestation. It is based on laboratory studies for mould growth at different combinations of relative humidity and temperature. These tests show that straw is relatively susceptible to mould growth, while untreated cellulose blown-insulation is found to be less susceptible to mould infestation (Figure 8). The isopleths provide growth indications but in practice cannot represent all conditions.

The temperatures and nutrients necessary for the growth of mould fungi are usually present in residential indoor spaces which is why the reduction of moisture in the material or on its surface is of decisive importance for the prevention of mould infestation (see Chapters 3 and 4). Long-term success in the remediation of mould-infested living spaces can only be achieved if the causes of the increased humidity are identified and eliminated (see Chapter 6).

Figure 7

Isopleth systems for the mycelium growth of the mould fungi *Aspergillus restrictus* (left) and *Aspergillus versicolor* (right) depending on relative surface moisture and temperature according to Smith et al. (1982)

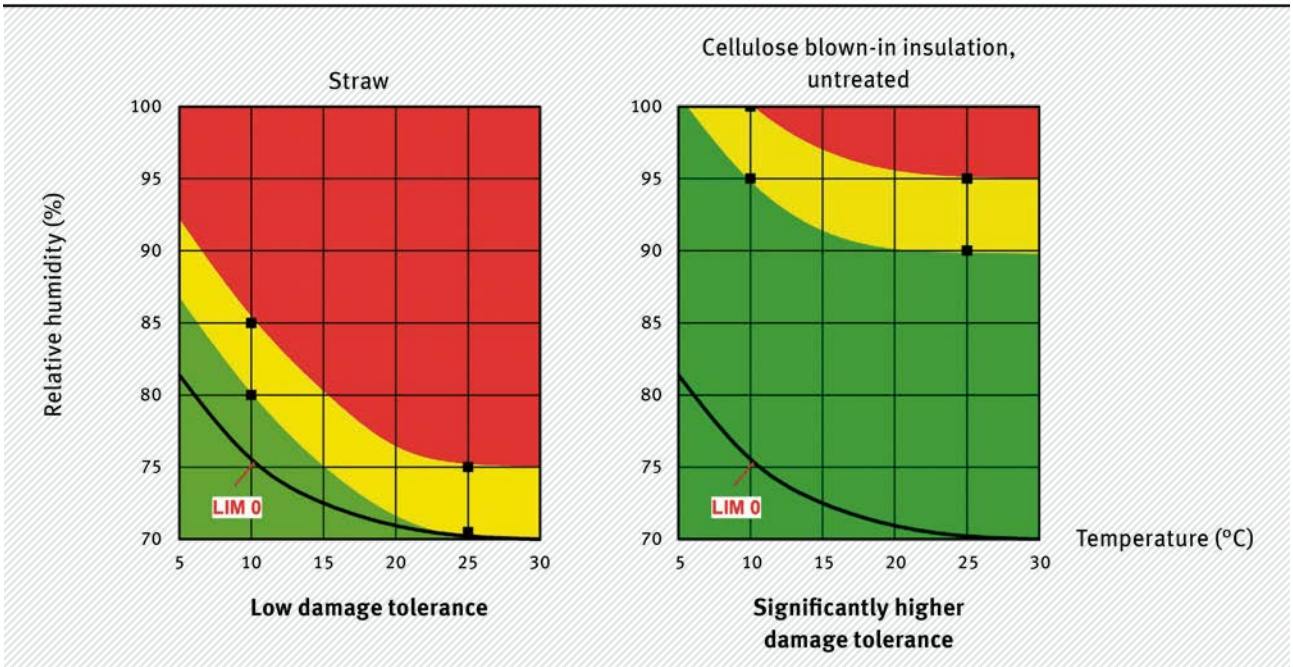


The figures near the isopleths indicate the growth rates in millimetres per day (mm/d)

Source: Sedlbauer, IBP

Figure 8

Measured isopleth areas of straw (left) and of a cellulose blown insulation (right)



Mould growth is very likely in the red areas, while it is not expected in the green areas. The yellow zones indicate a transitional area where mould growth cannot be completely ruled out. LIM-0 marks the so-called 'Lowest isopleth for mould' which was determined in the laboratory for a large selection of mould fungi in building materials using optimal nutrient conditions on agar plates (full nutrient medium).

Source: Sedlbauer 2001: Prediction of mould growth on and in building materials

INFOBOX 1

Isopleth systems

Isopleth systems illustrate the interdependence between the three factors – humidity, temperature and nutrient content (substrate).

Since there are significant differences between the growth conditions of individual fungal species, the following isopleth systems only consider data from mould fungi that can occur in buildings damaged by moisture.

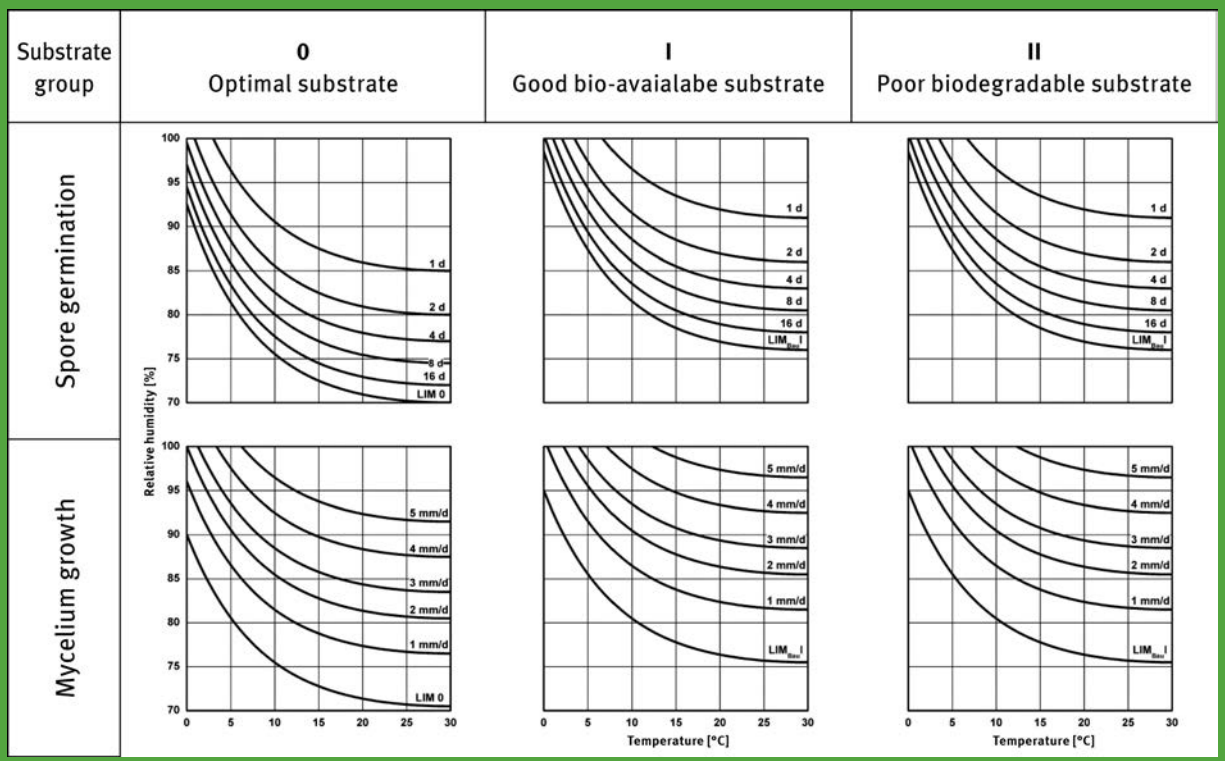
To account for the influence of nutrients, isopleth systems were established for various substrate groups (Sedlbauer 2001):

Substrate group 0: Optimal nutrient medium (e.g. full media); these isopleth systems form the lower growth limit for all mould fungi occurring in buildings.

Substrate group I: Biodegradable substrates such as wallpaper, plasterboard, building products made of readily degradable raw materials, materials for permanently elastic joints, heavily soiled material.

Substrate group II: Building materials with a porous structure such as plasters, mineral building materials, some woods and insulating materials that do not fall under Substrate group I.

In the case of severe soiling, the assessment should always be based on Substrate Group I.



Generalised isopleth systems for spore germination (top) and mycelium growth (bottom), which apply to fungi that occur in building components (according to Sedlbauer 2001); for optimal substrate (left), for Substrate group I (centre) and for Substrate group II (right). The values indicated characterise the timespan in days after which germination is complete or the expected growth in mm/day. LIM (Lowest isopleth for mould) indicates the lowest limit of spore germination or mycelium growth.

1.3 Yeasts

The term ‘yeasts’ refers to different families of unicellular, non-mycelial fungi that proliferate through budding (see Figure 9). There are currently more than 1500 known species.

Yeasts are very common in the environment and can occur in the summer in concentrations of several thousand CFU/m³ in the outdoor air. The detection of yeasts, especially ‘red yeasts’ such as *Rodotorula* spp. and *Sporobolomyces* spp. is therefore also considered to be normal in indoor spaces. Higher concentrations in indoor spaces may be due to an abundance of plants (e.g. in conservatories). Even in such cases, there is no need for action.

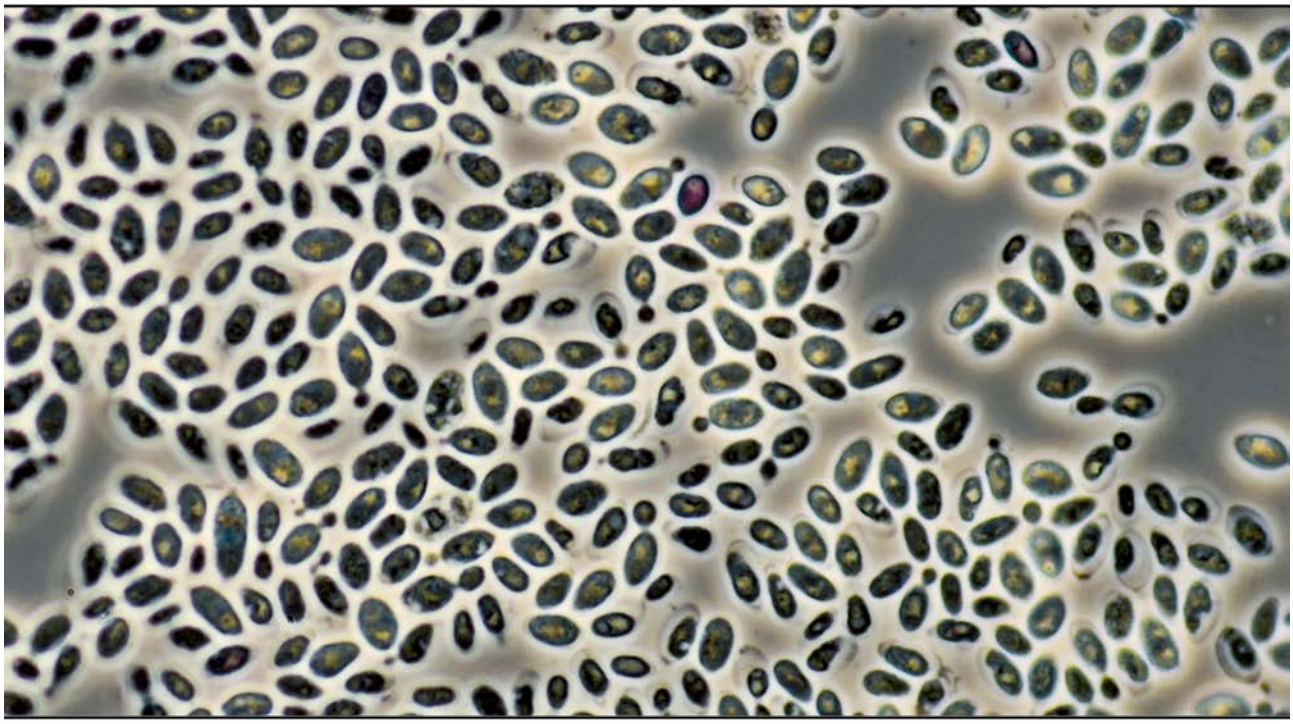
The appearance of yeasts in connection with mould indicates a greatly increased humidity. Yeast growth requires a_W values of at least 0.9 (for an explanation of the a_W value, see also Section 1.2). However, according to the current understanding of moisture damage, they play a subordinate role in terms of health aspects. There is no point in determining the species or genera of the yeasts in laboratory analyses, which are therefore not included in the following recommendations of the Guideline.

There is one exception: yeasts of the *Cryptococcus neoformans* species can occur in case of indoor pollution caused by pigeon droppings, which can trigger meningitis and pulmonary diseases in people with severe underlying diseases or dispositions.

Figure 9

Yeast under the microscope

(1000 x magnification)



Source: Valtanen, German Environment Agency

1.4 Bacteria and actinobacteria

Bacteria often occur together with mould fungi in the case of mould damage. Studies on moisture damage showed that approximately 15 % of the material samples exhibited only fungi and no bacteria in noticeable concentrations. It is not uncommon for the concentrations of bacteria in materials to range higher than those of mould fungi.

Since mould infestation can usually be recognised by detecting mould fungi, it is usually not necessary to examine air or material samples for bacteria. Bacteria should nevertheless be examined in the case of noticeably musty-smelling materials paired with negative mould fungi findings (see Sections 5.1.2.1 and 5.1.2.4). In practice, such materials are often directly examined for bacteria to obtain a timely result.

Knowledge about the bacteria species that occur in buildings is incomplete, particularly due to the difficulties in taxonomic determination. The most common distinction is made between mycelial actinobacteria, possibly Bacillus species and other bacteria. Mycelial actinobacteria are particularly important, since their spores, similar to the spores of mould fungi, are airborne and can cause health problems for room occupants (see Section 1.4.1).

Bacteria often occur in high concentrations in **musty-smelling materials.** If the examination of such materials finds no elevated levels of mould fungi, bacteria (especially actinobacteria) should also be searched for. In practice, such materials are often directly examined for bacteria to obtain a timely result.

Similar to the spores of mould fungi, **actinobacteria** spores are also airborne.

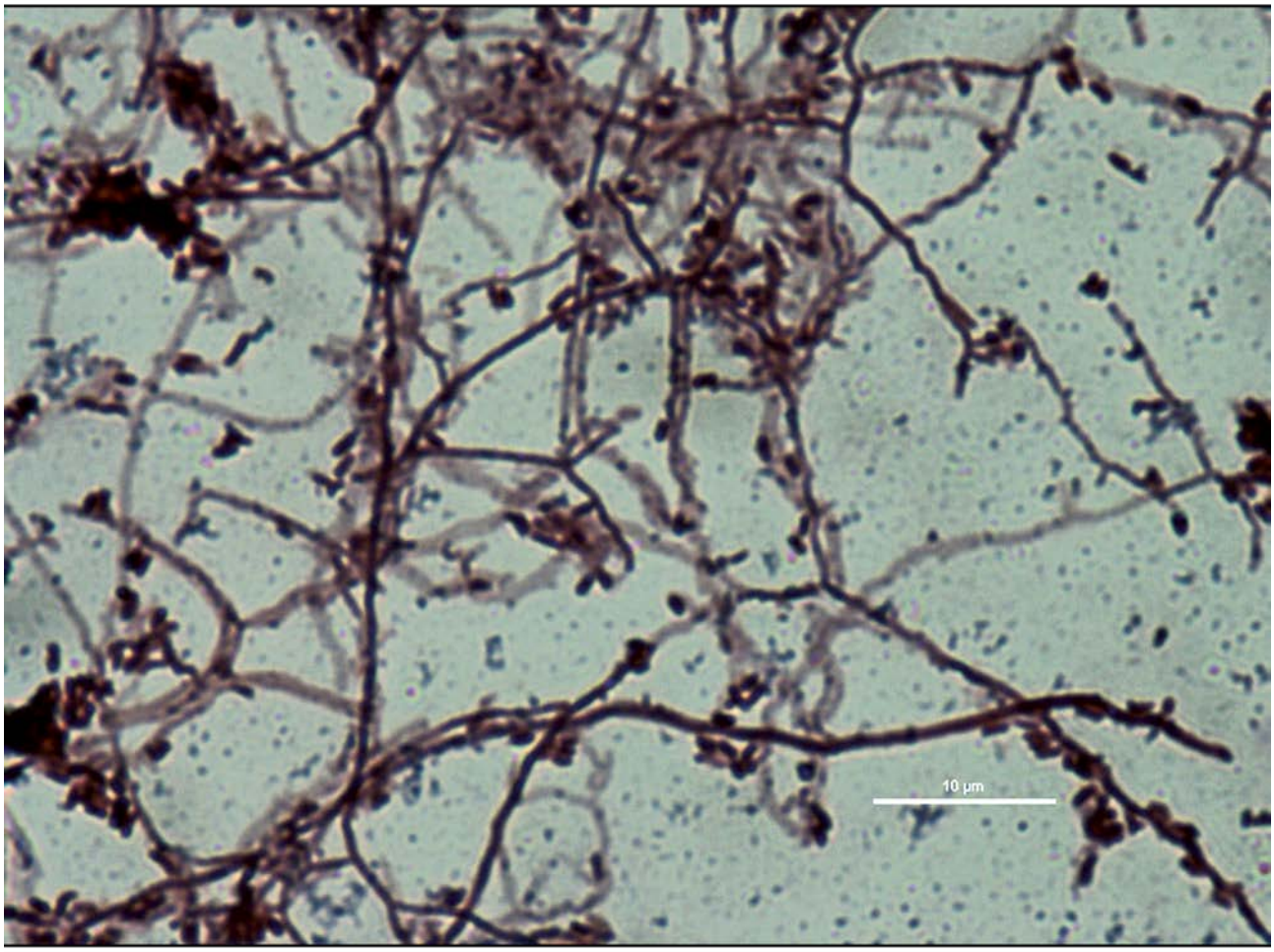
1.4.1. Properties of actinobacteria

'Aktinobakterien' (actinobacteria) was the German term proposed in 1997 for the *Actinobacteria* class in order to account for the great morphological diversity of the bacterial group, thus far also known as 'actinomycetes'.

Actinobacteria are heterotrophic, predominantly aerobic bacteria that vary widely in their morphological, physiological and cytochemical properties. The very large morphological diversity of actinobacteria ranges from cocci or coccoid cells to complex mycelial structures (hence the former name 'actinomycetes', which often causes a confusion with 'real' fungi).

Figure 10

Mycelium of an actinobacterium (Nocardiopsis alba) under the microscope after Gram staining
(1000 x magnification)



Quelle: Plaschkies, Mycolabor Dresden

Characteristic of many actinobacteria is the ability to form a mycelium (substrate mycelium). The hyphae are significantly thinner compared to fungal hyphae (about 1 µm, see Table 1). In many species, free mycelial strands are recognisable from the surface colonies extending into airspace (aerial mycelium), giving them a characteristic powdery or velvety colony morphological picture. Many actinobacteria can form spores and thereby spread and multiply. Here, the vegetative hyphae grow into long filaments which are transformed into sporophors, where spores mature by differentiation of the fragments – these are then released into the air (see Figure 10).

Some representatives of the actinobacteria form specific secondary metabolites such as volatile organic compounds, which are in part odoriferous. Furthermore, it is known that some actinobacteria produce toxins as metabolites. In particular, numerous *Streptomycetes species* are among the most well-known potential producers of antibiotic and/or toxic active substances. With regard to the formation of toxic substances and

pathogenic properties, the German Commission for Occupational Health and Safety and Standardisation identifies the genera *Actinomyces, Mycobacterium, Frankia, Dermatophillus, Nocardia, Rhodococcus, Streptomyces, Micromonospora, Gordona, Tsukamurella* and *Actinomadura* as relevant to health. In line with the increase in indoor areas with moisture damage and the associated human exposure, and taking into account the cytochemical characteristics, actinobacteria have long been the subject of clinical scientific interest (see Chapter 2).

Actinobacteria are an important component of the microbial community in indoor spaces with moisture damage. In particular, *Streptomyces, Amycalotopsis, Pseudonocardia, Nocardia* and *Promicromonospora* have been detected.

The growth conditions of actinobacteria are not understood as well as those for mould fungi. However, it can be assumed that they tolerate or favour similar growth conditions as the mould fungi associated with them. Because of their relatively slow growth, they tend to be more likely to occur in cases of old damage and, like other bacteria, usually at high a_W levels.

1.4.2 Detection and identification of actinomycetes

Many actinobacteria cannot be detected easily through cultivation as some have very specific growth requirements and cannot be distinguished from other bacterial colonies.

In practice, it therefore makes sense to detect only mycelium-forming actinobacteria, since they form relatively recognisable morphological colonies on agar. It is therefore proposed to use the term actinomycetes for the mycelium-forming actinobacteria recognisable on agar plates.

The detection and identification of actinomycetes is more difficult than that of mould fungi.

When standard media are used, actinomycetes are frequently overgrown by the mould fungi associated with them and thus overlooked. The isolation of actinomycetes from damp indoor materials is also difficult because the actinomycetes group contains bacteria with very different growth requirements. In order to take these into account and to record all actinomycetes, different nutrient media should be used.

A general examination of actinomycetes in cases of moisture damage does not make sense. For certain issues in the case of moisture damage (see Chapter 5), it may be important to investigate whether an actinomycete infestation is present in the material. For such cases, it is recommended to isolate the actinomycetes on mineral agar according to Gauze (see Chapter 5).

The species identification of actinomycetes within a genus is not possible or only to a very limited degree using morphological and biochemical methods, due to the relatively low morphological differences and the ever-increasing number of known species. Only with molecular biological methods can actinomycete isolates be differentiated relatively efficiently, at least at the genus level. These investigations should only be carried out in specialised and qualified laboratories.

2

Effects of indoor mould on human health

Mould growth in indoor areas is considered a health risk; even without establishing a quantitative and causal relationship between the occurrence of individual mould fungi or certain biogenic pollutants and health problems[1].

Scientific findings on health effects and related issues due to mould infestation/damp in indoor areas, are available for a number of symptoms but for other complaints they are currently scarce (see Table 5).

When assessing the effect of mould infestation on the occupants' health, their health status (predisposition) plus the extent of mould infestation with the release of bioaerosols (exposure) must be taken into account. The AWMF mould fungi guideline[1] provides important information for medical diagnostics in cases of mould infestation.

Population-based studies have adequately shown that people exposed to indoor damp/mould infestation are at an increased risk of multiple respiratory diseases (see Table 5).

The study results indicate an overall adverse development in the health of the affected children, particularly in the case of children growing up in accommodation with visible mould infestation and fungi/damp. In children with existing asthma, recent studies indicate a causal relationship between mould infestation and worsening of the disease (see Table 5). A connection between damp indoor areas and/or mould infestation and the onset of asthma, especially in children, can be considered a certainty. In addition, there are relationships with the development of asthma and exacerbation of adult asthma, with respiratory infections as well as with symptoms such as cough, wheezing and dyspnoea (see Table 5). Indoor mould also appears to be associated with bronchitis and allergic rhinitis (hay fever) but evidence for hay fever is not yet clear and there are only few studies on bronchitis (WHO Guidelines 2009).

It should be noted that prolonged or intermittent damp indoors, even without visible mould growth, is associated with an increased risk of respiratory disease, respiratory tract infection or the enhancement of existing asthma. It is also important to note that in rooms that are constantly damp there is a higher probability of hidden mould damage or invisible mould growth occurring. Table 5 gives an overview of the relationships between damp/mould infestation and health problems.

1 AWMF Mould Fungi Guideline "Medical-Clinical Diagnostics for Mould Exposure indoors" AWMF Register No. 161-001 – Final Version

Table 5

Strength of correlation between indoor moisture levels/mould infestation and health problems observed in epidemiological studies

Strength of correlation	Symptoms
Sufficient evidence for a causal relationship	· Aggravation and worsening of symptoms of existing childhood asthma
Sufficient evidence for a relationship *(Data make relationship appear likely)*	· Aggravation and worsening of symptoms of an existing asthma disease · Upper respiratory symptoms · Cough · Wheezing · Development of asthma disease · Shortness of breath · Currently existing asthma · Respiratory infections
Limited evidence for a relationship *(Data allows a relationship as possible but not secured)*	· Occurrence of bronchitis · Symptoms of allergic rhinitis (hay fever)
Insufficient evidence for a relationship *(Data has been checked but is not sufficient to prove any relationship)*	· Altered lung function · Occurrence of allergy or atopy · Occurrence of asthma throughout life (does not need to be present and to cause symptoms)

Source: According to WHO Guidelines for Indoor Air Quality: Dampness and Mould, 2009, supplemented by Kanchongkittiphonetal., 2015: In-door Environmental Exposures and Exacerbation of Asthma: An Update to the 2000 Review by the Institute of Medicine, Env. Health Perspectives 123: 6–20.

So far, only a few studies have been conducted that examine the effect of reducing indoor damp and mould infestation. However, these show that reducing indoor moisture levels can reduce adverse health effects (asthma and respiratory allergies).

Occupants of rooms with moisture damage and mould infestation are also prone to nonspecific symptoms such as irritation of the conjunctiva, throat and nasal mucous membranes as well as coughing, headaches or tiredness. Eye irritation of the conjunctiva or nasal irritation may be associated with both allergic and irritant effects; the other symptoms are mainly associated with irritant effects.

Scientifically substantiated conclusions about dose-impact relationships between indoor mould exposure and occupants' health complaints are currently not possible. This is because the exposure to mould in population-based studies is usually only qualitatively based on a few indicators, for example,the detection of visible damp, known water damage, visible mould or a mouldy odour. Only a few mould fungi have been identified in the available quantitative measurements, although other factors such as (actino)bacteria, mites and cell constituents and biogenic substances remain largely unconsidered although they can also contribute to health problems.

Indoor damp and mould infestation are associated with an **increased risk of respiratory disease** as well as development and exacerbation of asthma symptoms,for those who live in such conditions.

In individual cases (patients), it is not possible to attribute health effects to the mould infestation in a particular indoor space as in principle, there are a large number of causes that may be responsible for the disease and sensitisation.

In individual cases, it is not possible to attribute health effects to the indoor mould infestation as a large number of causes may be responsible for disease, also there is hardly any definite proof for the causes (see Chapter 5). This means that the health effects of indoor moulds cannot be attributed to a particular triggering agent and/or concentration of mould fungi and/or bacteria associated therewith. According to the current state of knowledge, in the case of mould growth indoors, an increase in risk for certain health complaints is generally assumed.

Particular risk groups needing protection include patients with certain immunosuppression and people with cystic fibrosis or bronchial asthma. The risk of developing asthma is increased in patients with allergic rhinoconjunctivitis or rhinosinusitis and in patients with atopy[2].

In the following, the various health effects (allergic, irritant effects and infections) in the case of exposure to mould are presented in principle and then evaluated with regard to the occurrence of indoor damp and mould. While allergic and irritant effects may be due to a variety of living as well as dead mould fungi (or their components), the ability to trigger infections is limited to a few mould fungi.

2 AWMF Mould Guideline "Medical-Clinical Diagnosis for Mould Fungus Exposure indoors" AWMF Registry No. 161-001 – Final Version

Actinobacteria (see Section 1.4), like mould fungi, can cause irritative reactions in addition to allergies and infections in severely immunocompromised individuals. In addition, they sometimes produce very strong “mouldy” or musty smelling odours. To detect mould infestation, it is sufficient just to investigate mould fungi as an indicator organism. However, if actinobacteria are investigated for specific issues and detected in higher concentrations (see Chapter 5), there is no reason to neglect actinobacteria in the evaluation or classify them as harmless compared to mould fungi.

In contrast, high concentrations of total bacteria in the air indicate contaminated or heavily occupied indoor areas without any relevance to health.

Health effects after exposure to very high mould fungi concentrations (around 10^6 to 10^{10} spores/m^3), for example the Organic Dust Toxic Syndrome (ODTS) or exogenous allergic alveolitis, usually only occur in certain workplaces and generally do not occur in homes or offices.

2.1 Allergic reaction

Mould fungi can have a sensitising effect and trigger allergic reactions as a result.

Detection of specific antibodies (IgE) in the blood does not allow conclusions to be drawn about the place of exposure to mould fungi (indoors or outdoors) nor about the severity of the allergic reaction.

One of the possible reactions of the body when inhaling mould fungi (spores or mycelial fragments) is the occurrence of allergies. Currently, extracts for allergy testing are only available for a few types of mould fungi, it is possible that a mould fungus allergy is not recognised as such. So far, only a few mould fungi can be routinely tested. Some tests only record typical outdoor varieties. With such tests, allergies to indoor mould fungi cannot be detected.

In addition, allergy tests are not performed with pure single allergens,- thus different results can be achieved by different manufacturers using combinations of different single allergens in their test systems.

Allergies caused by mould fungi outdoors and indoors were detected in the total population throughout Europe at a frequency between 3 % and 10 %. Most of the affected persons were already sensitised to several allergens. According to the results of the German Environment Agency's Child Environmental Survey from 2003 to 2006[3], around 6 % of the 1,790 children tested between the ages of three and fourteen had antibodies to at least one of the indoor mould fungi tested. Sensitisation rate was highest at 5 % for *Penicillium chrysogenum*, followed by *Aspergillus versicolor* (2.3 %). Compared to the mould fungi occurring in high concentrations outdoors, *Alternaria alternata* and *Cladosporium herbarum*, 4.8 % and 2.1 % of the children were sensitised, while for *Aspergillus fumigatus*, which is present in low concentrations both outdoors and indoors, 2.6 % of the children were sensitised.

3 Children's Environmental Survey (KUS) 2003/2006, Sensitisation to indoor mould fungi. German Environment Agency, Series Environment and Health 05/2011. https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4176.pdf

In a survey of 490 schoolchildren conducted by the Baden-Württemberg State Health Office, 3.7 % were sensitised to mould fungi predominantly found outdoors *(Cladosporium herbarum, Aspergillus fumigatus, Alternaria alternata)*. The rate of sensitisation was significantly lower than for typical indoor mould fungi (e.g. 1.2 % for *Penicilium chrysogenum* and 0.2 % for *Aspergillus versicolor*).

Among the allergic symptoms that can be triggered by inhaled air containing mould fungi from outdoors or indoors are rhinitis (hay fever-like symptoms) or asthma. Rhinitis and asthma attacks can occur within a few minutes of the inhalation of aerosols containing mould fungi and thus belong to the Type I allergy. In persons already sensitised, even mild mould fungi concentrations in the air from outdoors or indoors (e.g. 10^2 *Alternaria alternata* spores/m^3 or 10^3 *Cladosporium herbarum* spores/m^3) may be sufficient to trigger allergic reactions.

As there is always an exposure to mould fungi outdoors, it cannot be proven in individual cases that an allergy was caused by exposure to indoor mould fungi.

The determination of specific IgG antibodies with respect to mould fungi allergens in the blood is not useful for the diagnosis of exposure to indoor mould fungi as it does not allow for the presence of sensitisation or the severity of an allergic reaction. Evidence of this antibody only shows that the person was exposed to these mould fungi at some point, e.g. in the open air, at work or at home.

INFOBOX 2

What is sensitisation; how does an allergy develop and what is an atopy?

When allergies occur, the body's adaptive immune system reacts to so-called antigens (foreign substances such as pollen, food components, mould fungi spores). The first contact with the antigen leads to the formation of defensive components (antibodies). The so-called Type I allergy is mediated by immunoglobulin E antibodies (IgE) and occurs shortly after contact with the antigen (immediate type allergy). The body's contact with one or more mould fungi allergens may result in the formation of specific IgE antibodies. This process is called sensitisation.

Sensitisation itself does not constitute an illness – only renewed contact with the antigen can trigger reactions in the body, leading to typical symptoms of illness such as a runny nose, sneezing, red eyes, rash, etc.

The tendency to exhibit an immediate allergic reaction (Type I allergy) from contact with otherwise harmless substances in the environment is called atopy. Atopy refers to a hereditary hypersensitivity reaction of the body with a pathologically increased formation of IgE antibodies.

2.2 Irritating, toxic and odorous effects

In vivo and in vitro studies of bioaerosols from damp buildings also observed inflammatory reactions as well as toxic, immunosuppressive and immunomodulatory effects.

Irritating and toxic effects of mould fungi have so far been detected almost exclusively in workplaces where manufacturing technology has caused very high concentrations of mould fungi.

The extent and importance of irritating, toxic or odorous effects of mould infestation in indoor spaces are not well known.

The lack of standardised methods and assessment criteria means that substances suspected of contributing to the non-specific health effects of indoor mould fungi and bacteria are not routinely tested in the case of mould infestation.

Indoor mould can cause nonspecific irritation of the mucous membranes of the eyes (e.g. burning sensation, tears), the nose (sneezing, a runny or blocked nose) and throat (e.g. dryness, coughing). They are particularly widespread among workers as a possible consequence of several weeks of exposure to average mould concentrations (> 10^3 spores/m^3) in the workplace. However, population-based studies related to elevated levels of indoor mould described such symptoms even in 'normally' used indoor spaces. It is assumed that bacterial components (e.g. endotoxins) and mould fungi components (e.g. 1,3-ß-D-glucan) as well as different substances produced by mould fungi, possibly also through synergistic effects, can cause irritation of the mucous membrane.

The lack of standardised methods and assessment criteria means that substances suspected of contributing to nonspecific adverse health effects triggered by mould infestation such as endotoxins, mycotoxins, MVOC, PAMP (see Infobox 3) are not routinely tested in the case of mould infestation. As a precaution, however, the selection of suitable remediation measures (see Chapter 6) should consider that mould infestation may create such small, very mobile particles or substances.

INFOBOX 3

Important substances that occur in bioaerosols in the case of mould infestation (routinely not investigated)

ENDOTOXINS

Endotoxins are cell wall components of gram-negative bacteria.
In high concentrations, they can cause various toxic effects that most commonly have an inflammatory effect on the conjunctiva, the skin, more rarely on the nasal mucosa, upper respiratory tract, and even less frequently on the deep respiratory tract.

1,3-ß-D-Glucan

1,3-ß-D-glucan is a cell wall component of fungi. Comparable with the endotoxins released from gram-negative bacteria, 1,3-ß-D-glucan causes an inflammatory effect. Studies in office buildings with poor indoor air quality have associated the substance with irritation of the mucous membrane and fatigue.

MYCOTOXINS

Mycotoxins are metabolic products of mould fungi. The mycotoxins levels thus measured in indoor spaces are so low that they do not cause acute toxic effects. However, there are indications of immunomodulatory effects as well as synergistic effects with other biogenic substances. To date, there are no findings on the health effects of long-term exposure.

MVOC

Microbial volatile organic compounds (MVOCs) such as alcohols, terpenes, ketones, esters and aldehydes are produced by mould fungi or bacteria. They cause the characteristic smell of mould. The odour perception thresholds of some MVOCs are very low (ng/m³ range) and can lead to nuisance reactions. The low concentrations of MVOCs in mould infestation do not produce expectations of acute health effects. To this date, there are no findings on the health effects of long-term exposure.

PATHOGEN ASSOCIATED MOLECULAR PATTERNS

Pathogen Associated Molecular Patterns (PAMPs) are characteristic structural patterns, microorganism molecules or viruses that can be recognised by the innate immune system. In the case of mould fungi, certain cell wall components (e.g. ß-glucans, phospholipomannans) are expressly recognised as PAMPs. They trigger immune responses that can lead to irritating or inflammatory reactions. It is believed that such reactions may contribute to the nonspecific illness symptoms triggered by exposure to mould fungi. This area of study is in need of further research.

2.3 Infections

Infections caused by mould fungi (mould fungi mycoses) or actinobacteria are **extremely rare** and only occur in particularly susceptible, highly immunocompromised patients.

Highly immunocompromised patients who are treated on an outpatient basis should definitely be advised about the risks of infections caused by mould fungi and actinobacteria by their doctors.

Infections caused by mould fungi (mould fungi mycoses) very rarely occur in indoor spaces and only in highly immunocompromised patients. Mycoses are usually caused by only a few types of mould fungi (e.g. fungi of the genus *Aspergillus*). The most common is aspergillosis caused by *Aspergillus fumigatus*. The areas susceptible to infection are the skin, the nasal cavities, the ears and the lungs. The lungs are most commonly affected by pulmonary mycosis. Like mould fungi, actinobacteria can also cause infections.

In addition to rare cases in older patients with a higher susceptibility to respiratory tract infections, immunocompromised people (e.g. post-chemotherapy cancer patients and transplant patients) are affected almost exclusively. As a precaution, highly immunocompromised patients who are treated on an outpatient basis should definitely be advised about the risks of infection caused by mould fungi and actinobacteria by their doctors. Such patients should avoid rooms with mould infestation and other mould fungi sources such as biowaste or indoor plants after being discharged from the clinic. In addition, immunosuppressed patients are generally advised to avoid rooms with moisture damage or basements due to the possibility of mould contamination.

3

Causes of mould infestation in buildings

Mould fungi and other microorganisms that occur in the case of mould infestation above all require humidity to grow (see Chapter 1). Increased humidity can be caused by construction defects, water damage or by the room's occupants. The following section discusses these causes in more detail. It describes the influencing factors for moisture damage which can lead to mould infestation (see Section 3.1) and subsequently tackles damage due to improper remediation (see Section 3.2). One way of quickly determining the causes of the infestation is through the application of the 'cause tree' (see Section 3.3 and Annex 3).

Normative information on mould problems in buildings can be found in current regulations for heat and moisture protection in building construction. There are currently no standards in Germany specifically designed for mould problems in the construction sector. Annex 4 contains a compilation of current standards for moulds.

3.1 Construction, usage and other influencing factors

When it comes to mould infestation, a distinction should be made between the following:

a) constructional influencing factors such as insufficient or inadequate thermal insulation, thermal bridges, poor moisture buffering of materials, damaging water-permeable areas in the building envelope, other leaks, moisture in a new building and rising moisture due to insufficient damp course or soil moisture sealing;

b) usage-related influencing factors such as insufficient or improper heating and ventilation and

c) other influencing factors such as water ingress through accidents or flooding.

Moisture damage is often caused by an unfavourable combination of different influencing factors.

A basic prerequisite for understanding the mechanisms taking place is the knowledge of the relationship between the surface temperature and the surface moisture in relation to indoor air climatic conditions (see Infobox 4). The phase diagram of air explains the processes occurring on a cool wall in more detail.

In order to assess the causes of moisture damage and mould infestation, it is very important to establish the room climate situation through the professional determination of surface temperature and surface moisture (see Infobox 5).

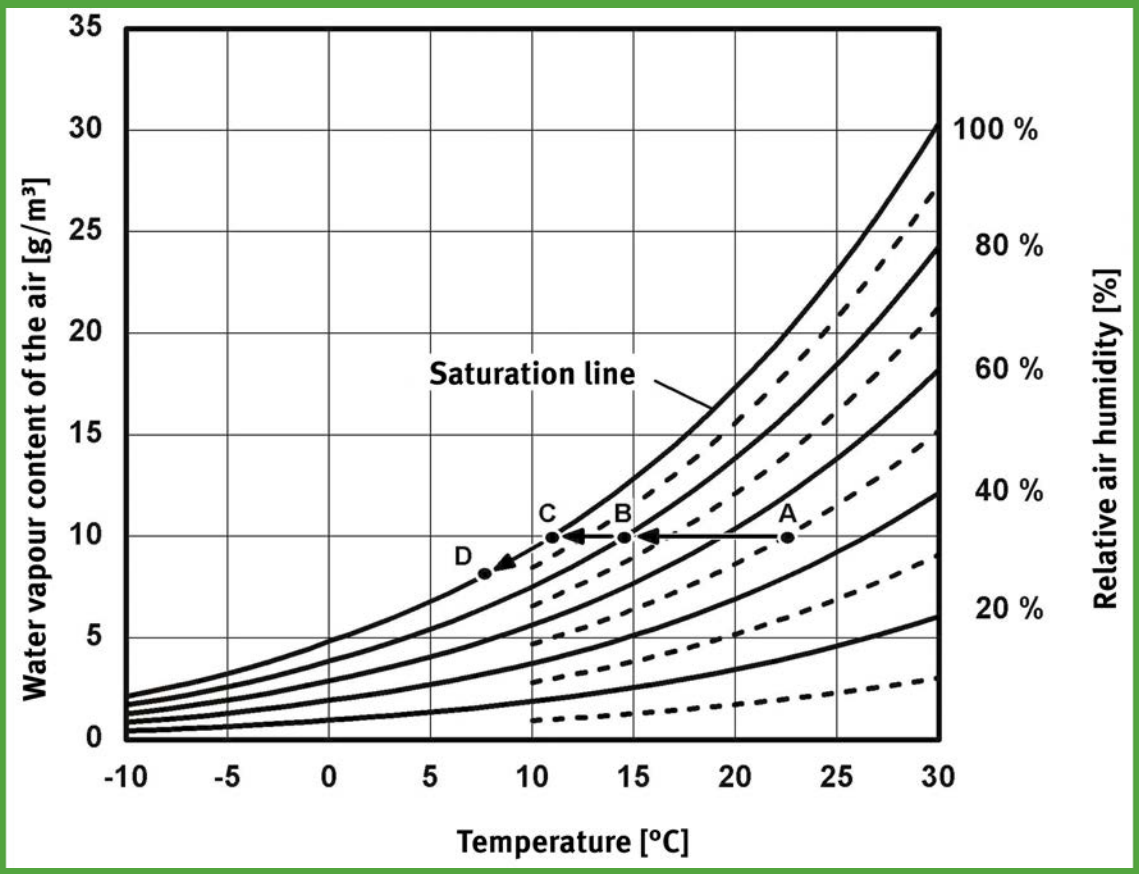
INFOBOX 4

Air phase diagram

The figure shows the relative indoor air humidity (in %) as a function of the room air temperature (x-axis) and the water vapour content of the air (y-axis). Graph according to Willis Haviland Carrier.

For example, indoor air at 22 °C and a water content of 10 g/m³ has a relative humidity of 50 % (point A). If the surface temperature of the inner wall is also 22 °C, its air humidity will also measure 50 %. During winter, however, the low outside air temperatures mean that the inner surface temperature of the outer walls are lower (assuming a surface temperature of 14.5 °C by way of example), whereas the indoor air temperature is kept constant at 22 °C through indoor heating.

In the proximity of the wall surface, the absolute water content of indoor air remains the same as in the middle of the room (in this example 10 g/m³). However, indoor air cools down when approaching the wall. This means that the air condition changes when approaching the wall, as shown in the figure, parallel to the abscissa up to point B. Thus a higher relative humidity of 80 % prevails in the proximity of the wall which favours mould growth. A further cooling of the inner wall surface under these conditions would mean further cooling of the air thus reaching the dew point (at about 11 °C, point C). When the temperature drops below 11 °C, the state of the air follows the saturation line (up to point D). The result is water vapour condensation on the cool surface.



INFOBOX 5

Determining the indoor climate situation

The surface temperature and moisture are decisive in assessing the possibility of mould infestation.

The **SURFACE TEMPERATURE** of the walls should be measured at various locations and potentially at different times. A single measurement only indicates potential thermal bridges under certain conditions (significant inside/outside temperature difference). Long-term measurements provide more meaningful results. These should be carried out by professionals who have the necessary equipment and experience for the evaluation.

Additional information can be obtained from knowledge of the structure of the building (thermohygrometric calculations).

The **SURFACE MOISTURE** on the inside of external walls due to hygrothermal effects is generally not determined by humidity measurements but calculated from the indoor air humidity and the measured room air and surface temperatures.

The room occupant can easily check the temperature as well as the relative humidity in the room and in critical areas such as corners and in the immediate vicinity of the outer walls. A simple electro-thermo-hygrometer that is cheaply available in DIY warehouses are perfectly adequate to check whether the room temperature is sufficiently high and has been sufficiently ventilated. However, their measurements only provide a rough estimate.

The WTA leaflet 'Measurement of water content or moisture of mineral building materials' contains information on the measurement of the equilibrium moisture content of materials (WTA leaflet 4-11, 2016).

3.1.1 Inadequate thermal insulation

Inadequate thermal insulation means that the inside of external walls cools down at low outdoor temperatures and increased surface moisture forms due to condensation of indoor air humidity.

The appearance of mould growth on the inside of exterior walls and ceilings depends on their surface temperature and moisture. These in turn are influenced by the heat transfer coefficients (U value) of the exterior wall and the heat transfer resistance (R_{si} value) on the inside of the external wall (see also Section 3.1.3) as well as the room air temperature and humidity.

Under steady-state conditions – in practice only approximately achievable – the surface temperature can be calculated as follows:

$$\Theta_{si} = \Theta_i - U\, R_{si}\, (\Theta_i - \Theta_e)$$

Θ_{si}	[°C]	Interior surface temperature
Θ_i	[°C]	Room air temperature
Θ_e	[°C]	Outdoor air temperature
U	[W/(m² K)]*	Heat transfer coefficient
R_{si}	[(m² K)/W]*	Interior heat transfer resistance

*W = Watt, K = Kelvin

The U value characterises the insulation level of a building component of the outer envelope, e.g. the external wall. A high U value means high heat transfer, i. e. poor insulation.

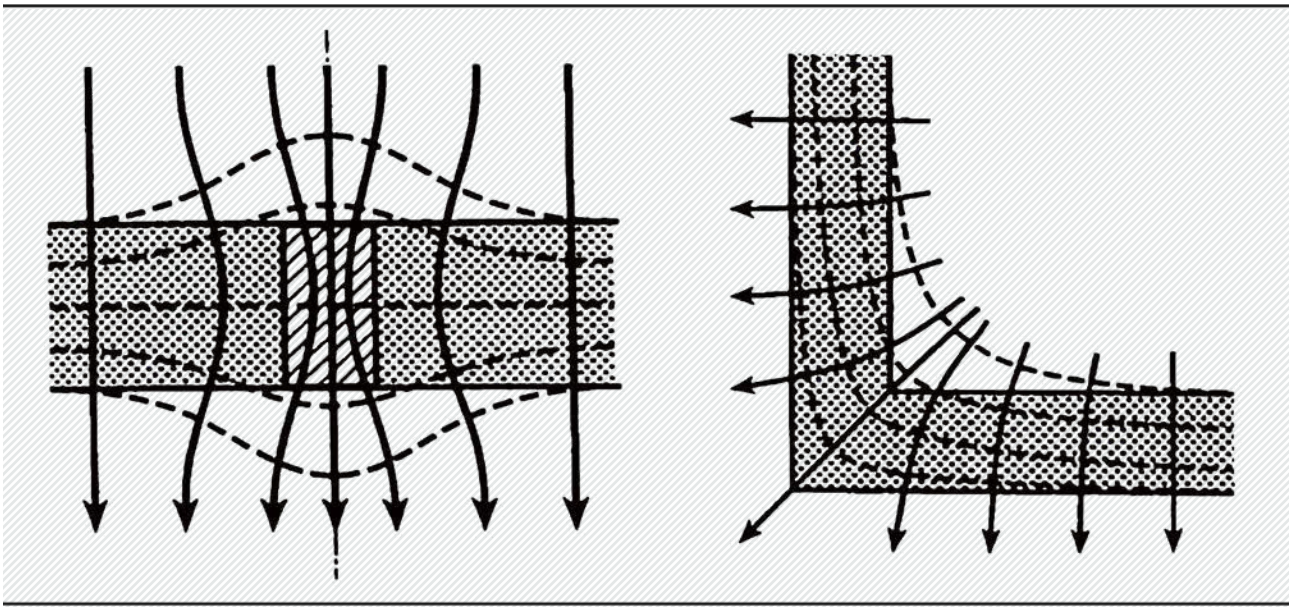
Thermal insulation must not be confused with heat storage. The higher heat storage capacity of heavy building materials used for walls (solid walls) has a higher chance of compensating for temperature fluctuation than lightweight building structures and thus also ensures better buffering of the room air temperature (see Section 3.1.7). In addition, solid structures can improve summer heat protection (avoiding excessive room heating). In the case of mould prevention, however, the thermal insulation of the outer envelope as well as sufficient ventilation and heating are the decisive factors, not the heat storage.

3.1.2 Thermal bridges

Thermal bridges are localised areas in the enclosing surfaces (walls, ceilings, floors) of a building which enable an increased heat loss to outdoor or unheated spaces. They lead to a reduction of the interior surface temperature of building components. Thermal bridges may be due to the spatial (geometrical) conditions (e.g. corners, see Figure 11 right and Figure 12) or the use of building materials with very different thermal conductivity (e.g. supporting pillars in a wall, wooden beams in a converted attic, etc., see Figure 11 left). The consequences of thermal bridges during the cooler seasons cause – in addition to heat energy losses – a lower interior surface temperature of the affected building components, an increased surface moisture and thus an increased risk of condensation and mould infestation along the wall.

Figure 11

Schematic illustration of two thermal bridges with an indication of heat flows: adiabats (solid lines) and isotherms (dashed lines)



Thermal bridges are physically characterised by an increased heat flow with the adiabats getting closer to each other and a curvature in the isotherms.

Source: after Gertis, Fraunhofer Institute for Building Physics

3.1.3 Increased resistance to heat transfer

The free flow of air (convection) is obstructed in corners within a building generating an increased resistance to heat transfer. Warm indoor air does not reach the corners in a room sufficiently well. In addition to the thermal bridge effect, this leads to an additional reduction in the surface temperature, especially in corners of external walls and thus to an increase in surface moisture within the wall corner. For this reason, mould growth is fairly often observed in the corners of external walls.

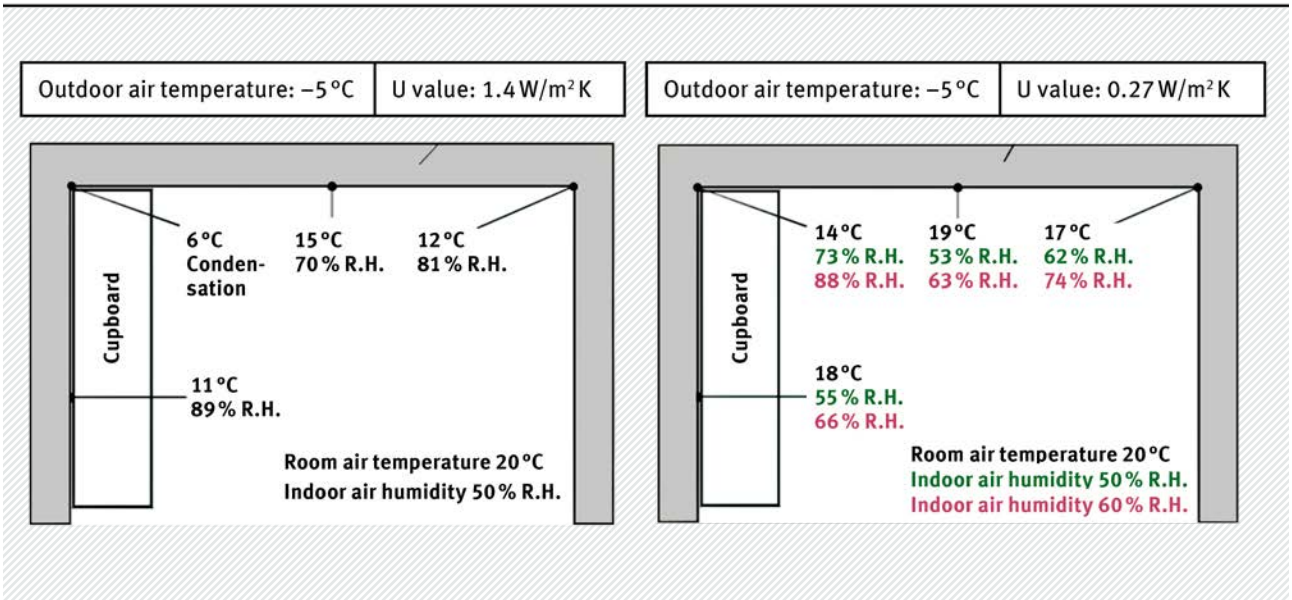
Furniture, curtains and the like do not represent much resistance to indoor air humidity, thus it progresses to the walls behind furniture. At the same time, however, the heat in the room – due to reduced convection and radiation heat transfer – is very inefficient at getting behind the furniture and curtains. Furniture and curtains thus cause an increased resistance to heat transfer. The combination of these two effects further increases the relative humidity on the wall behind the furniture (see Figure 12). This can lead to mould growth.

Furniture, curtains and other furnishings should always be arranged or installed a few centimetres away from the wall if the external walls are insufficiently well insulated so that the warm indoor air can flow unobstructed behind these furnishings and thus heat up the cold wall. The air flow also removes moisture from the wall surface. It is also helpful to put furniture on feet so that an improved ventilation is maintained. In planning home furnishings more attention should be paid to the fact that built-in wardrobes (or kitchen cupboards) are not installed directly on poorly insulated external walls without a sufficient air gap to the room. The arrangement of furniture on external walls is usually unproblematic in well-insulated, low-energy and passive houses of modern design with sufficient ventilation.

Additional resistance to heat transfer is problematic especially in poorly insulated old buildings (see Figure 12, left). While only 70 % surface moisture occurs at the surface of an unfurnished external wall with a surface temperature of 15 °C, the reduction in temperature of 11 °C behind a cupboard causes 89 % of surface moisture on the outside wall and condensation water at the external corner at 6 °C (see Figure 12, left).

Figure 12

Summary of the consequences of increased resistance to heat transfer (e.g. because of furniture standing in front of the wall), high heat transfer coefficient (upper part) and of thermal bridges (external corners) on wall temperature and relative humidity (R.H.) at the surface (surface moisture) of the internal side of external walls



Left: Building with low thermal insulation standard (U value = 1.4 W/m²K).
Right: Building with high thermal insulation standard (U value = 0.27 W/m²K).

Source: Fraunhofer Institute for Building Physics, Holzkirchen

Furniture on the external wall/corner is not critical in well-insulated buildings (see Figure 12, right), unless there is an additional increase in indoor humidity caused, for example, by insufficient ventilation (60 % relative humidity in the example of Figure 12). At 20 °C room air temperature and 50 % relative indoor humidity, a surface humidity of only 73 % occurs even in the external corner behind the cupboard. However, an increased indoor humidity of 60 % already leads to a surface moisture of 88 %, which allows mould growth. Figure 12 shows the theoretically calculated values under steady-state conditions. In practice, these specifications do not always apply precisely.

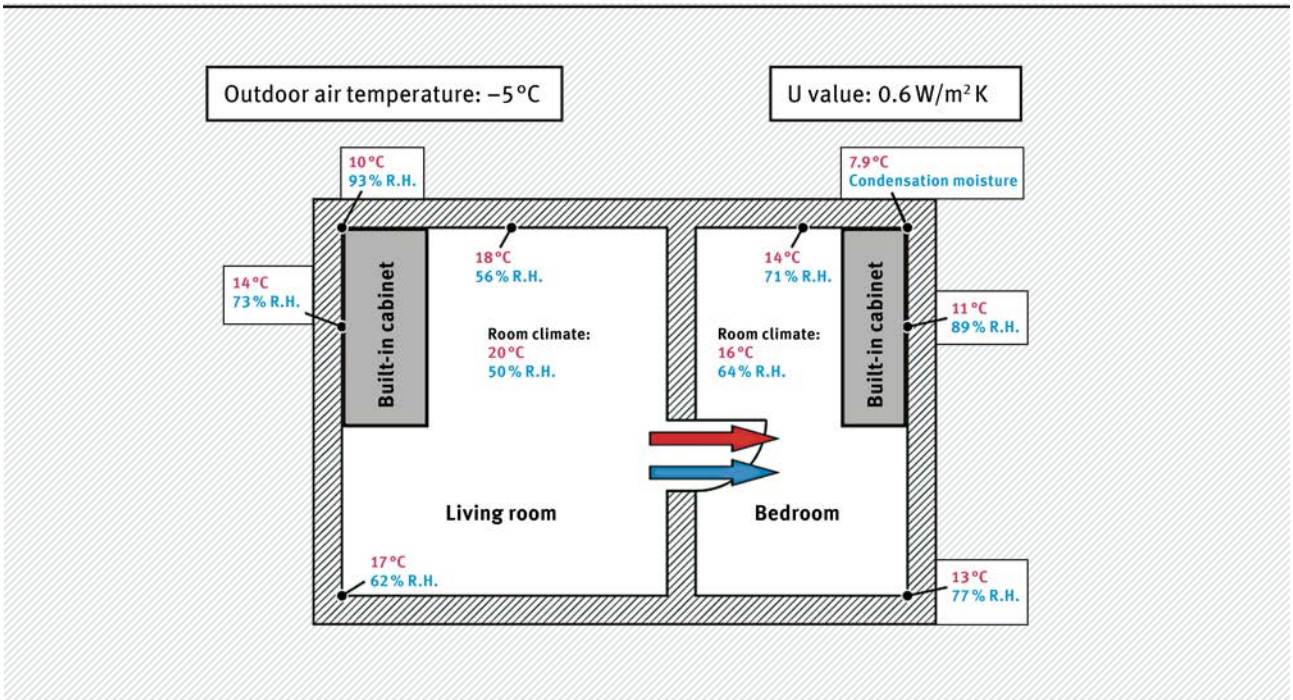
3.1.4 Inadequate or improper heating

Heating causes an increase in room air temperature and thus reduces the relative water content of the air at the same absolute water content. In addition, heating the room also increases the surface temperature of the internal wall surface. Both effects contribute to avoiding mould growth.

If individual rooms such as bedrooms, guest rooms or storage rooms are heated just a little or not at all, the risk of mould growth increases in reverse. Reduced room air temperature not only ensures an increased relative room humidity, but also lower surface temperatures (see Figure 13). In bedrooms, additional moisture is released through breathing and sweating

Figure 13

Illustration of the effects of external corners (thermal bridges) and furniture on wall temperature and relative humidity (R.H.) at the surface of the internal wall of an insufficiently heated bedroom that is in air exchange with the rest of the flat with a relative humidity of 50 % in the centre of the living room



Source: Fraunhofer Institute for Building Physics, Holzkirchen

(transpiration). This increases humidity and the possibility of water vapour condensation on cool walls. Bedrooms especially are often ventilated insufficiently or incorrectly (for proper heating and ventilation, see explanations and information boxes 9 and 10 in Chapter 4).

3.1.5 Increased indoor moisture production

High moisture production through cooking, washing, etc. leads to higher absolute indoor humidity and thus to higher surface moisture.

Table 6 gives an overview of the quantities of moisture produced by various indoor activities and furnishings. These are empirical values and moisture levels can vary significantly upwards and downwards in individual cases.

The amount of moisture produced by room users can be as high as 6 to 12 litres a day for an average 3-person household (see Figure 14).

Table 6

Moisture production by activities of room users or by furnishings in rooms at a room air temperature of 20 °C

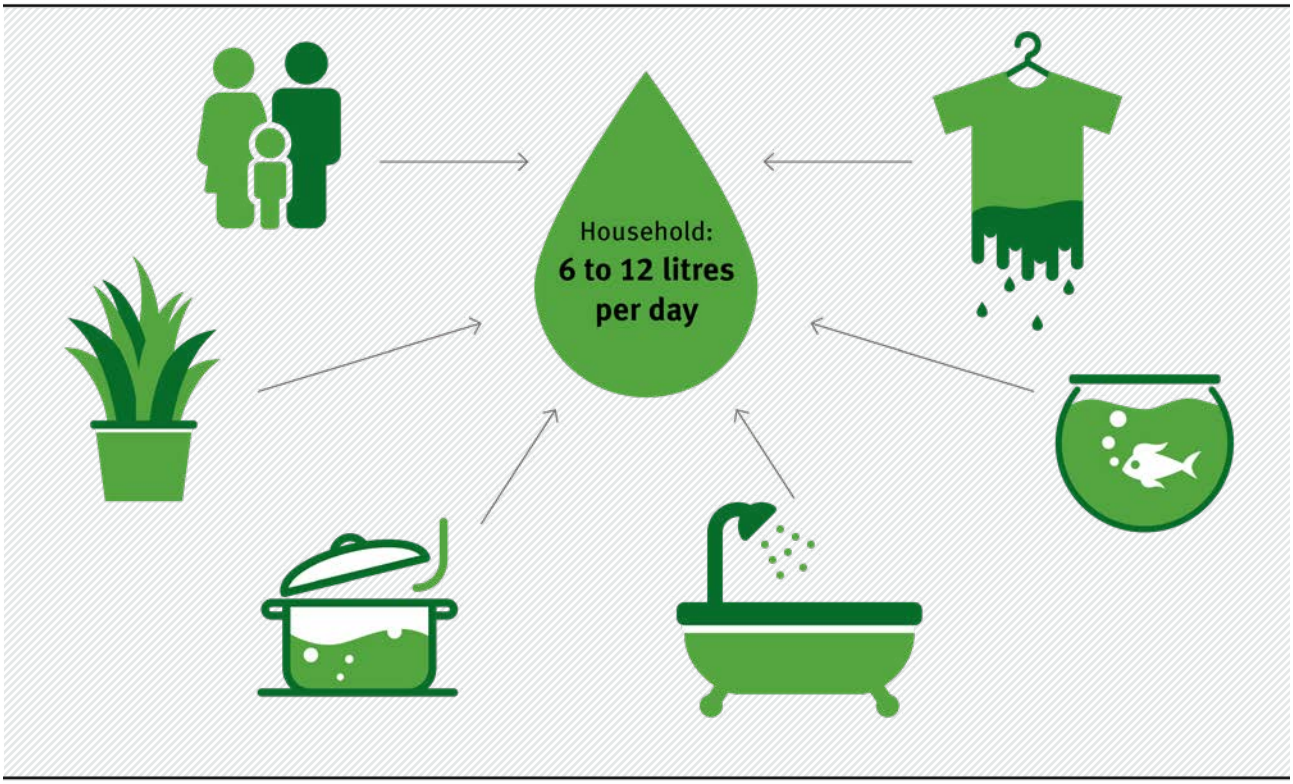
Humidity source	Moisture production per hour or day or per m² per hour
Humans, light activity	30–40 g/h
Drying laundry (4.5 kg drum)	Spin-dry: 50–200 g/h Dripping wet: 100–500 g/h
Cooking/showers per person	270 g/d each
Indoor plants	1–5 g/h*
Water surface	Open aquarium: approx. 40 g/m²/h ** Covered aquarium: approx. 2 g/m²/h

* Can also be significantly higher according to the number and type of houseplants
** Grams per square metre per hour, depending on environmental conditions.

Source: Fraunhofer Institute for Building Physics, Holzkirchen, amended

Figure 14

Humidity sources in apartments



Additional sources of moisture such as drying laundry, many indoor plants or a indoor water fountain should be avoided especially with a high relative humidity indoors (see Figure 15) in the cold season. **If there is an increased indoor humidity level, relative humidity must be reduced by increased ventilation and, if necessary, heating** (see notes in Chapter 4).

Figure 15 shows indoor air humidity values common in buildings over the year. Data were collected for normally used, non-mould infested rooms. It shows a typical trend over the year with indoor air humidity lower in winter and higher in summer. In order to avoid mould, indoor air humidity should not exceed the stipulated common values permanently, especially in poorly insulated buildings in winter. In our latitudes however, with the exception of alpine regions, winter situations where the indoor air is very dry (less than 20 %) over a longer period of time is only the exception. If a humidifier is used in such cases, the relative humidity should be checked with a hygrometer so that it does not reach elevated values (see Figure 15) otherwise the risk of mould growth increases. Humidifiers should be cleaned regularly.

3.1.6 Inadequate or improper ventilation

Chapter 4 gives a detailed description of ventilation.

Ventilation is the most effective way to remove moisture from the home.

The efficiency of ventilation has long been expressed by the air exchange rate. It indicates the volume of air exchanged and replaced by outdoor air per hour in relation to the volume of a room. Today, user- and area-specific outdoor air volume rates are used instead of the air exchange rate to calculate the air exchange for ventilation systems in particular.

Especially at low temperatures in winter, the outdoor air has a low absolute humidity even at a high relative humidity (e.g. rainfall) (see Table 7). If ventilation takes place at –10 °C outdoor temperature and the cold outdoor air is heated up to 20 °C indoors, the relative humidity of the outdoor air is reduced by the heating originally from 80 % to only 9 % (see Table 7). This provides a large capacity for absorbing the moisture stored in indoor materials which is released to the now dry indoor air and transported by ventilation back outside. In practice, however, indoor air humidity levels below 20 % relative humidity are only rarely achieved over a longer period of time since moisture-buffering materials release moisture into the indoor air during the ventilation process (moisture buffering by desorption).

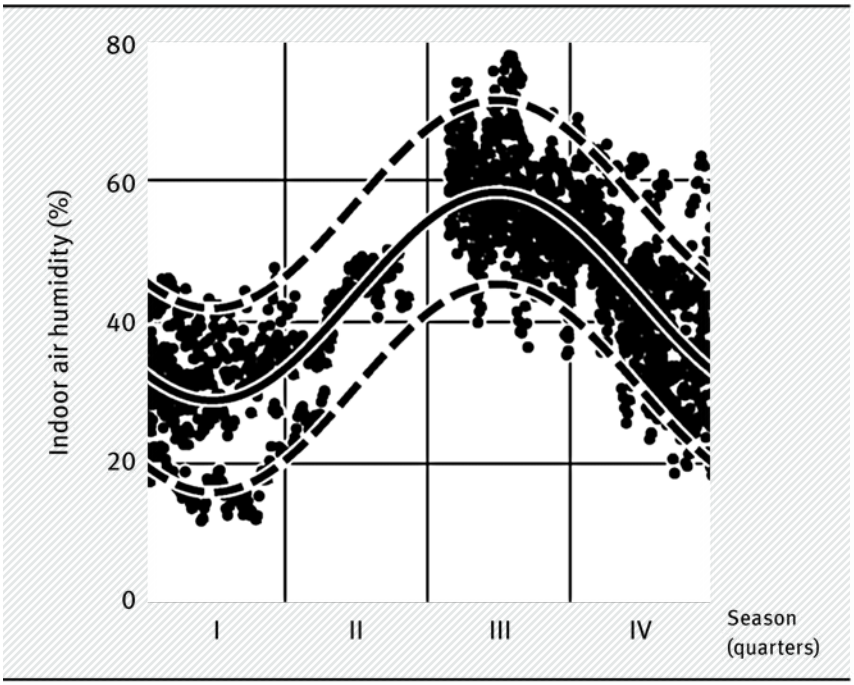
Table 7

Theoretical relative indoor air humidity at different outdoor air temperatures by heating outdoor air of 80 % humidity to 20 °C indoor temperature at a constant absolute humidity (ignoring moisture buffering)

Outdoor air temperature [°C]	Relative outdoor humidity [%]	Absolute humidity [g/m³]	Theoretical relative indoor air humidity at 20 C [%]
–10	80	1.7	9
0		3.9	21
10		7.5	42
20		13.5	80

Figure 15

Typical annual cycle of relative indoor air humidity in buildings in Germany



The solid line is a sine curve adjusted to the measuring points. The dashed lines represent the spread of the measuring points: 90 % of the measuring points lie between these two lines.

Source: Fraunhofer Institute for Building Physics, Holzkirchen

Time and again, one hears the assertion that walls "breathe" and an air exchange takes place through them. But this is physically not possible, unless the walls have leaks and cracks.

There is no air exchange from indoors to outdoors through structurally intact walls. Also, the amount of moisture transported through the walls by vapour diffusion is negligible compared to the amount removed by ventilation. Vapour-tightness of a wall structure therefore has only minimum influence on indoor air humidity and quality. The term "breathing" walls, which is often used in this context, can only be seen in connection with moisture buffering (see Chapter 3.1.7), but not supporting air exchange in the building.

3.1.7 Moisture buffering of building materials

Different amounts of humidity are released through the use of indoor spaces throughout the day. Part of this humidity is absorbed, stored and released by the building materials in the room. This is called moisture buffering or humidity regulation. When the relative humidity is increased, the material adsorbs ambient humidity (adsorption) and transports a part by diffusion into deeper, drier layers of the component. When ambient humidity is reduced, moisture from the interior of the building material is emitted to the surrounding air (desorption). Since indoor conditions constantly change, so do humidity regulation and temperature of the material. How quickly a material can adsorb or release moisture depends on the material properties (e.g. sorption capacity and diffusion resistance).

The buffering effect of materials is usually limited to a depth of a few millimetres of the component, only those material parts close to the indoor space contribute significantly to buffering. Furniture (uncoated wood furniture, upholstery) also has an influence on indoor air humidity.

Humidity buffering of building materials reduces daily humidity variations, depending on the buffering capacity of the material (see also Infobox 6).

The humidity-buffering effect of all these materials together leads to a reduction of humidity fluctuations from which the indoor climate and comfort can benefit. It cannot be concluded directly from this as to what extent this also has an influence on mould growth. If damp peaks are buffered by the sorptive effect of the walls, which would have led to condensation or increased surface moisture without buffering, mould growth can be prevented.

Sorption properties of the wall material primarily compensate humidity peaks. The mean humidity content of the air remains largely unchanged and can only be reduced by active ventilation (see Chapter 4).

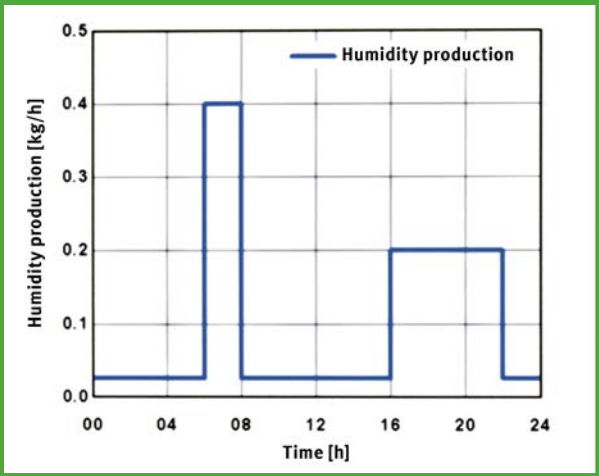
INFOBOX 6

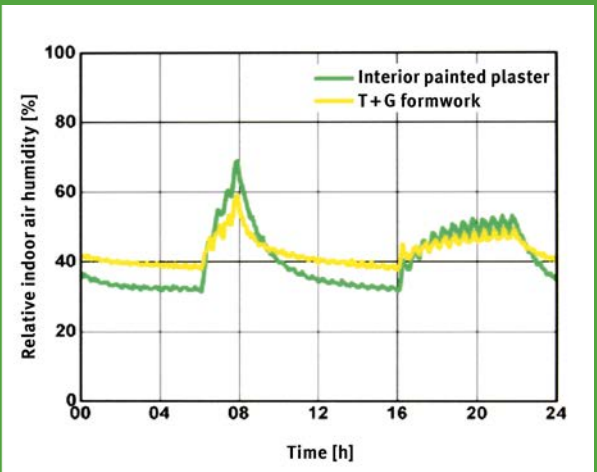
Example of moisture buffering

The effect of moisture buffering can be measured by introducing a typical daily humidity load into a defined room with different wall coatings (diagram left) and determining the relative indoor humidity (diagram right).

The case study simulated the humidity production of a family of two adults and two children in a 65 m² apartment. It observed a particularly high humidity production between 6 and 8 am due to cooking and showering and once again in the evening between 6 and 10 pm. This high humidity load increased even further due to washing, cooking and the production of humidity by the occupants. Observations further concluded that the timber lining in the chosen example reduced the relative indoor humidity from approx. 60 % to approx. 40 % due to the buffering of the timber lining. Painted plaster would have reduced the relative humidity even further, albeit with a higher fluctuation range.

These are just examples. In individual cases, the buffer effect depends largely on the type and structure of the wall surface materials and on the type of paint (breathable, sealing) etc.





Daily trend of humidity production (left) and the resulting changes in indoor air humidity (right) of a room with a paint coated wall, typical interior plaster (green line) and a room with timber lining (tongue and groove, T+G formwork, yellow line); (Image source: Fraunhofer Institute for Building Physics, Holzkirchen)

3.1.8 Moisture in the building structure due to leaks and rising damp

Moisture finds its way into the building structure in various ways.

Moisture can penetrate the building from the outside. Driving rain can force moisture into the structure via outer walls that are insufficiently protected against rainwater ingress. Typical cases of damage to buildings that allow water ingress are leaky connecting joints – in window reveals and frames etc. – or leaks in the roof area. Rising and laterally penetrating moisture can arise through masonry, foundations and basement walls that have been insufficiently sealed from the ground.

Large amounts of water from damaged household water pipes, leaking heating pipes, burst hose connections or poorly sealed fittings in showers or bathtubs can be released and enter the building structure. Increasingly recurring floods in individual regions repeatedly lead to a significant moisture accumulation in buildings.

All **moisture damage to the building structure** requires immediate action to **eliminate the causes** of the moisture input and to **dry** the affected building areas in order to avoid the occurrence of visible and hidden mould infestation (see Chapter 6).

3.1.9 Trapped moisture

The content of humidity in building materials during constructing process (trapped moisture) poses a problem if occupants move into newly built homes or existing buildings after large-scale refurbishment too soon, especially, if they have not been adequately ventilated after completion. Components (predominantly concrete and screeds, but also plastered walls and ceilings) often contain large amounts of water immediately after construction.

Trapped moisture has a negative effect on thermal insulation properties and thus on energy consumption. However, its influence on the indoor air humidity (which is often significantly increased by trapped moisture over a longer period) is even more important.

New buildings or buildings that underwent large-scale refurbishment require intensive ventilation because of the increased trapped moisture, but also because of the chemical substances potentially emitted by the building materials. An indoor space with trapped moisture should definitely be subject to a long intensive ventilation before occupants move in. Depending on the construction and structure, the drying phase can take up to several years. Intensive heating can be a supporting factor.

3.1.10 Flood damage

Buildings situated near the water are repeatedly exposed to flood damage. The frequency and extent have been increasing for years due to climate change and missing flood plain areas in nature. Water ingress often leads not only to mould growth, but also to microbial and chemical contamination by correspondingly polluted water.

For further details see Chapter 6.

3.2 Moisture damage due to improper energy modernisation

In addition to the intended reduction in energy demand, every energy-efficient remediation always influences the moisture balance of the indoor air and building materials.

Properly installed external thermal insulation reduces the possibility of mould growth through the associated higher temperatures on the inside of the external walls and the reduction of thermal bridges in the structure.

Replacing only the windows is usually insufficient to improve the energy demand of the building and facilitates the occurrence of moisture and mould damage (see Section 3.2.1).

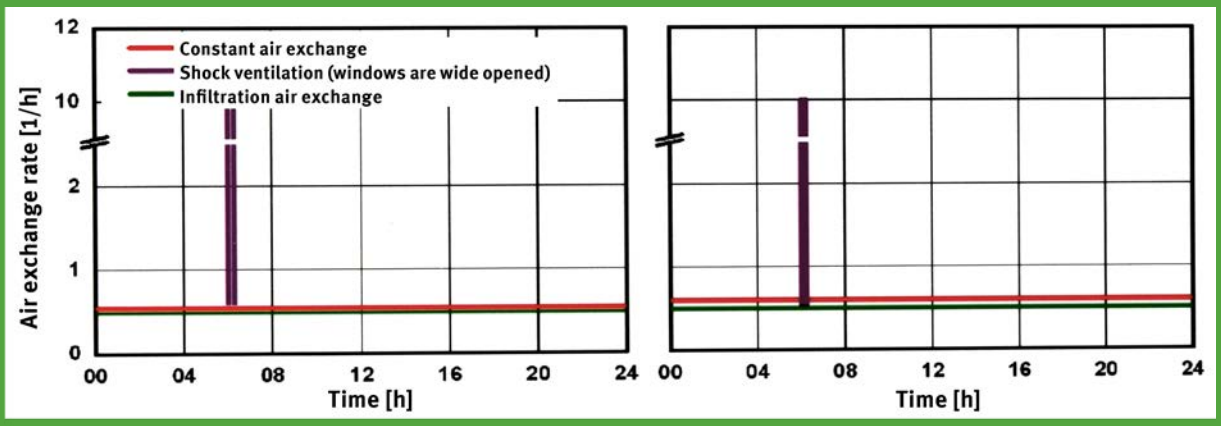
Properly installed internal insulation can also increase the surface temperatures of the walls. Unfortunately, this is an area where mistakes are often made which increase the risk of mould growth even more (see Section 3.2.2).

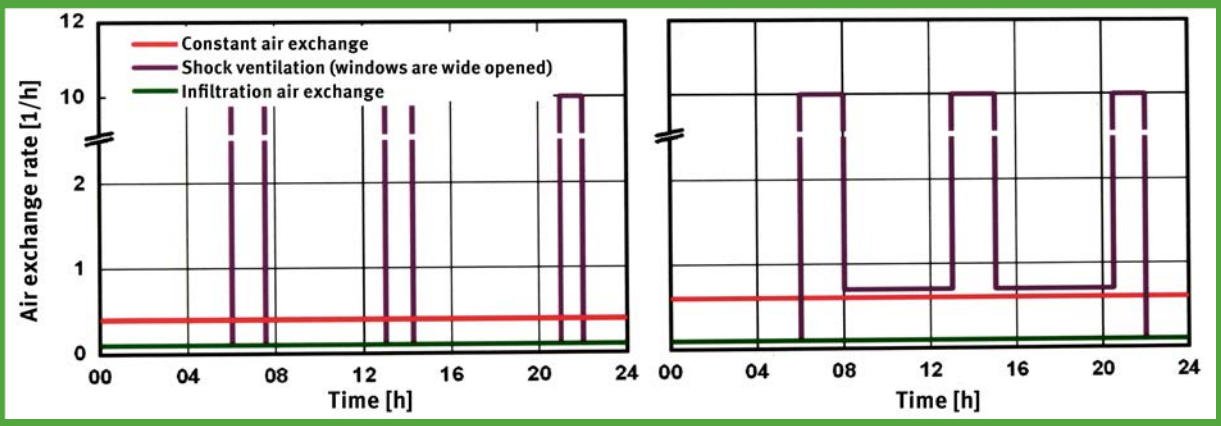
Improperly installed sealing in energy-efficient buildings can also promote mould infestation (see Section 3.2.3).

INFOBOX 7

Calculation results of the influence of different ventilation options on the room climate

The two figures show the ventilation time-span required to avoid mould growth in the model apartment in the non-remediated bedroom (top) and in the bedroom with newly installed tight-fitting windows (bottom). The figures show the frequency and duration of the necessary active shock ventilations (open windows marked with purple) or, alternatively, the necessary constant air exchanges (e.g. via ventilation systems marked in red or infiltration, marked in green) which eliminate the possibility of mould growth in even the most unfavourable places in the room (outer edges and corners). This calculation also considers the infiltration air exchange rate via leaks (green), which is high for non-renovated old windows (top) (in this example 0.5 h^{-1}) and very low for new, tight-fitting windows (bottom) (0.1 h^{-1} in this example).





Due to the high infiltration rate (green line) through the leaky windows, the non-renovated old apartment (top left image) only requires a one-time shock ventilation in the morning. Although the increased moisture load from laundry drying has a visible impact on the ventilation (top right image), further window ventilation is not necessary. With continuous ventilation (e.g. with an exhaust fan), a small additional air exchange is sufficient.

A completely different picture emerges due to the installation of tight-fitting windows without additional insulation measures in the old building (bottom). The necessary frequency of shock ventilation (bottom left image) is barely achievable in practice. This is even more true if laundry is dried in the flat (bottom right image). In such cases, ventilation via mechanical ventilation devices is an advantage (red line).

The calculation was based on a typical 3-room flat in an old building with brick masonry and minimal thermal insulation (U value 1.4 W/m²K). Calculation: Fraunhofer Institute for Building Physics, Holzkirchen.

3.2.1 Installation of tight-fitting windows in poorly insulated old buildings

Leaky windows in non-refurbished and non-energy saving old buildings ('old buildings' are buildings built until the 1960s and 70s as well as later that do not comply with the current thermal insulation standards) facilitate a certain air exchange (infiltration air exchange) through windows and doors even without active ventilation. As a result, some of the moisture produced indoors is already being transferred outside.

The installation of tight-fitting windows, usually required by increased heat protection regulations, largely eliminates air exchange by infiltration making more frequent active ventilation necessary to remove moisture (see Infobox 7). Tight-fitting windows are particularly problematic when walls and other critical components (e.g. window reveals) are not improved according to thermal standards at the same time so the exterior walls in the building remain cold. Inadequate ventilation can subsequently lead to increased indoor air humidity, which leads to an increased surface moisture or water vapour condensation on the cold walls.

A calculation model helps illustrate the influence of different ventilation options on the room climate (see Infobox 8). The calculations show that the installation of new tight-fitting windows in buildings with low insulation standards and without additional insulation measures leads to moisture problems. For this reason, the establishment of a ventilation model is recommended when installing new tight-fitting windows. According to DIN 1946-6, sufficient air exchange for moisture protection must be provided independently from the occupant. Mechanical ventilation devices can support moisture removal.

3.2.2 Incorrectly installed internal insulation

The internal insulation of exterior walls has become a proven method of rapidly improving the low thermal insulation standard of exterior walls in old buildings. However, proper planning and execution is important, since internal insulation measures may even increase the occurrence of mould infestation. **Internal insulation measures should therefore preferably be carried out by specialist firms.** Based on the RAL Quality Label No. 964 'Interior Insulation', a model was developed and implemented which provides for the qualification of specialist firms that undertake the installation of RAL-certified internal insulation.

Figure 16

Mould infestation due to the improper installation of internal insulation

Source: Betz, Experts Office for Building and Interior Analysis, Hellertshausen

Internal insulation measures are thus the preferred method if the exterior façade cannot be changed for reasons of historical preservation or aesthetics. Under no circumstances can internal insulation be used to conceal damp walls (e.g. due to rising or laterally penetrating moisture or leaks). In the case of wet exterior walls, wall battens on the room-side pose a risk of mould infestation – even with active ventilation. Therefore, wall battens should not be used in damp cellar and basement rooms or on other damp walls.

The installation of later internal wall insulation entails various risks and can result in considerable damage to the existing building within a short period of time if not installed correctly (Figure 16). Typical problems include humid air flow behind the internal insulation, condensation inside the component due to vapour diffusion as well as imperfections in the internal insulation (see Infobox 8). Significantly fewer problems arise from breathable, fully-bonded insulating materials or the incorporation of installation levels. Experts should be consulted for the installation of internal insulation since the potential subsequent problems are usually not recognisable to the layman.

Frequently, moisture can also reach behind the insulation façade through wall penetrations and sockets. Wall penetrations must therefore be carried out very carefully. Installation of panels arranged in front of the internal insulation on the room side can help avoid penetration points in the insulation layer.

Driving rain may also be a problem since it causes the moisture to penetrate the outer wall reaching the inside where it cannot dry because of the internal wall insulation. The centuries-long proven additional cladding of exterior walls on the weather side with rain-proof materials such as slate shingles can also be an adequate solution to avoid these problems in the remediation of old buildings using internal insulation to improve energy efficiency.

INFOBOX 8

Avoiding the problems of internal insulation

FLOW BEHIND INTERNAL INSULATION

The installation of insulation can cause the temperature behind the insulation to drop below the dew point of the indoor air. Air from the occupied space, which passes behind the insulation via convection leads to moisture increase in this area. Insulation boards should therefore always be glued over their entire surface of the external wall in order to avoid humidification through indoor air flow behind the insulation.

CONDENSATION DUE TO VAPOUR DIFFUSION

The surface temperature behind the internal insulation occasionally lowers to well below the temperature of the indoor air's dew point due to the increasing insulation value. This is why breathable but low capillary-active standard insulation materials such as mineral wool for internal insulation are suitable only if the insulation value it is lower than the insulation value of the underlying wall structure or if an additional suitable vapour barrier is applied on the room-side. Breathable but capillary-active insulating materials (e.g. calcium silicate boards, mineral foam boards, spray-on cellulose) are more suitable.

DEFECTS IN INTERNAL INSULATION

Manufacture faults can lead to the construction eventually having a continuous open convection gap due to the internal coating and insulation. Not even the proper building technology can always prevent the occurrence of such defects because of movements in the masonry or shrinkage and expansion processes. The capillary activity of the insulation is again advantageous. In the case of an internal insulation system with a vapour barrier, it is very important for the film to be properly glued and not damaged (e.g. by subsequently installed sockets or wall-plug holes in the wall). Such damage can be prevented by using specially prepared cavity socket outlets or applying installation panels.

INTEGRATED CEILINGS AND INTERIOR WALLS

Before applying internal insulation, it is particularly important to check whether mould problems have occurred in the transitional area from the (existing) external wall to the ceiling. If so, the causes must be clarified and eliminated before applying the subsequent internal insulation.
If, following the thermal remediation, there is a change in use with a higher moisture load or altered ventilation conditions (e.g. due to the installation of new tight-fitting windows), the possibility for later mould infestation must also be reassessed.

WINDOW REVEALS

Installing internal insulation without insulating the window reveal leads to lower temperatures in the reveal area. Maintaining the existing windows severely limits the possibilities of insulation application because of the lack of space in the window frame. This area must therefore be given special consideration and often requires separate insulation solutions with possibly different insulation materials having a lower thermal conductivity than the internal insulation.

Further information on internal insulation can be found in WTA leaflet 6-4 (2016) "Internal insulation according to WTA 1: Planning Guidelines" and in WTA leaflet 6-5 (2014) "Internal insulation according to WTA 2: Proof of internal insulation systems using numerical calculation processes".

3.2.3 Improperly executed seals on energy-efficient buildings

Airtightness is an important quality feature in modern buildings. Imperfections in the seals can cause humid indoor air to enter the structure, especially in the case of wood-framed walls and lightweight constructions where it can lead to large-scale mould infestation and infestation by wood-destroying fungi. Special attention must therefore be paid to the professional planning and building at the seals level. Cold seasons are usually characterised by a high vapour pressure gradient from the inside to outside. The resulting water vapour diffusion can cause moisture transfer from the higher to the lower potential (usually from the inside to the outside).

3.3 Determining the causes of infestation

The search for mould infestation causes should first determine the reasons for an excessive moisture content in the infested area. The possible causes are shown schematically in a 'causes tree' (see Annex 3).

The cause tree is also aimed at home occupants and owners who either find the initial cause of a mould infestation or want to take measures to prevent it. The application of the cause tree does not replace the involvement of qualified independent experts in serious or more complicated cases.

It is often the case that mould cannot be traced back to one situation, but is the result of several, overlapping causes. For example, an unfavourable combination of thermal bridges in the structure, low indoor air temperature, low building component temperature and high air humidity lead to mould infestation, while none of the individual factors alone would have caused this effect.

A precise determination of mould infestation causes often requires a greater investigative effort with regard to the constructive situation and occupant behaviour. Clearly identifiable causes should be immediately remedied without further investigation, since the effort of additional investigations is disproportionate to their benefits.

4

Preventative measures against mould infestation

Preventing mould infestation first implies making an effort to effectively avoid or promptly eliminate increased humidity (in the building or in indoor air).

Many frequently occurring cases of damage can be avoided by observing technical and (building) physical aspects (see Section 4.1) and by proper use with sufficient ventilation (see Sections 4.2 and 4.3) and heating (see Section 4.4).

4.1 Preventative construction measures

The basic requirement for a building without moisture problems and mould infestation is its construction in accordance with the applicable regulations (recognised rules of technology, building regulations of the Länder (German federal states), model building regulations of the German government). These in particular include the avoidance of thermal bridges and leaks in the building envelope, moisture barriers for components that come into contact with the soil, potential special structural protection measures in flood areas, and structural requirements for use (ventilation, ventilation systems, heating systems). It is recommended that the building envelope and water-carrying installations are inspected for potential leaks prior to use.

Likewise, the heat protection of the outer envelope must be verified to avoid thermal bridges. Thus, a check of the insulation in the first winter using thermographic analysis of the indoor space can show where there may be thermo-technical weak spots.

During construction, it must be especially ensured that the existing trapped moisture is adequately dried and/or flashed out (see Section 4.1.1) and that no damp building materials are used (see Section 4.1.2).

If existing buildings are renovated, additional aspects must be taken into account (see Section 4.1.3). In addition, regular inspections of buildings also help prevent problems (see Section 4.1.4).

4.1.1 Prevention of mould infestation caused by trapped moisture

Building materials containing water as an essential component are built in or used in new and extensively refurbished buildings. For example, a solidly built detached house consisting of masonry walls, cement plaster, basement walls and concrete floors contains several thousand litres of water 'incorporated' into the structure. Drying processes and long-term intensive ventilation must be applied to transfer some of this water to the outdoors (see also Section 3.1.9). Final drying may take up to several years depending on the structure and building technology used.

There has been a tendency over the years to shorten the building process and move occupants into buildings as quickly as possible in all seasons for economic reasons. In the past, care was taken to allow rough buildings to dry over the winter months before commencing internal finishing work. Previously less water was used (brickwork and beamed ceilings instead of concrete) and buildings were less airtight. Air exchange was more efficient due to the frequent use of open fireplaces, thus drying generally proceeded more quickly. Today, however, drying-out houses is much more difficult and time-consuming due to wide-spread central heating and the building regulations requiring airtight designs.

Trapped moisture, which mainly occurs using monolithic construction methods and poured screed (see Section 4.1.1), **must be properly flashed out** before the internal finishing work takes place.

It is inappropriate to place dividing walls and facing form works on still damp screed because moisture is absorbed by the materials and is difficult to remove.

Complete drying of the components can take up to several years (see Section 3.1.9.).

When constructing a building, care should be taken that the internal finishing work only takes place when the building moisture has been sufficiently removed. A detailed ventilation and heating plan must be prepared for the construction phase, particularly when building takes place in the winter.

Special problems occur in connection with screed laying in buildings with drywalls, where (partially hidden) mould often grows on the plasterboard. The introduction of internal plaster and floor screed after the installation of windows is a common cause of mould in new buildings. If the moisture has not been sufficiently released from the building material to the outside, mould can grow (see Figure 17). In addition

Figure 17

Mould damage due to moisture in a new building

Source: Betz, Experts Office for Building and Interior Analysis, Hellertshausen

to plasterboard panels, this often affects wooden components in the roof area. Specified ventilation must be applied during screed laying. Excessive ventilation may weaken the screed drying process while too feeble ventilation can lead to mould growth risk.

4.1.2 Avoid damp building materials

Building materials should be stored dry and installed in a dry condition. Building practice shows, however, that building materials are often stored outdoors unprotected (also in the rain) and installed while still wet.

Special care has to be taken on building construction. **Materials** delivered to the building site **should be stored dry and installed in a dry condition.** Unprotected storage and wet installation of insulation materials, dry construction elements and wood-based panelsare particularly problematic. Materials installed in a wet condition are difficult to dry off later and can lead to concealed mould infestation.

4.1.3 Avoiding moisture and mould during refurbishment

If existing utility rooms are converted into living spaces or for a different purpose of use, it must be checked how, and to what extent this affects the building physics. A basement or extension room used as a storage room in an old building and built accordingly can cause significant problems if the internal finishing work is restricted to installing wall coverings and new floor coverings without checking and, if necessary, reducing the permeability of the external walls and the underfloor membrane to moisture ingress. In addition, layered structures must also be checked from a building physics point of view. Rooms in old buildings comprising a concrete floor slab and masonry walls can easily tolerate the penetration of small amounts of moisture because the existing non-airtight doors and windows and wall openings enable sufficient air exchange. However, if the originally uncoated or lime plaster coated brick walls are clad with dry components and the floor is covered with a floating screed and relatively impervious surfacing, the moisture penetration through the soil into the walls and underfloor cannot be released into the indoor air to the same extent as before. This can lead to damp accumulation and plasterboard walls: wall plaster or the insulation in the floor can be microbially colonised.

When installing rooms or components such as stairs, it must be ensured that the building envelope is protected against water penetration (driving rain, ground water pressure) or soil moisture. Gaps often occur in the building seal, in particular in the joints between old and new components, which can cause significant damage. The problem may become fatal when the seal cannot be easily improved after building an extension, e.g. when a garage is attached to an existing building directly and the damp proof seal in contact with the earth is damaged. In this case, the site needing repair lies directly under the garage and is not accessible from the outside without demolishing the new building.

Specialist planners should be consulted when such conversion measures are undertaken to account for the complexity of building physics issues and the different structures.

4.1.4 Building inspection in everyday use

Technical products exposed to environmental conditions are usually inspected regularly. This is mandatory for vehicles and commercial installations. Regular inspection is also helpful in buildings to avoid problems cause by dampness and mould. In addition to structural inspections (see preliminary remark in Section 4.1), inspections play an important role in everyday use.

Pipes in houses should be checked regularly. However, this is technically complicated and difficult with water pipes laid under the plaster. Rust particles in, or the corresponding discoloration of the water may be clear indications of the need to renew pipes.

Often, damage is caused by easily removed causes such as rain gutters clogged with foliage. If the gutter gets clogged (see Figure 18), water runs down the façade, it can penetrate the walls and cool outer parts of the building envelope. In winter, additional frost damage may be the result into which driving rain can later penetrate.

Silicone joints are 'maintenance joints' in wet areas and must be replaced after a certain period of use as they will lose their sealing function. Water from the shower can then easily penetrate into the wall behind the bathtub or shower tray through leaky silicone joints and cause substantial damage, mostly invisible, especially to permeable and wooden structures.

Figure 18

Clogged gutter

Source: Lorenz, Institute for Indoor Diagnostics

TIPS for the prevention of water damage on and in buildings:

- Regularly check gutters and façade.
- After a storm, have the roof inspected.
- Check whether old water pipes need to be replaced as part of a refurbishment.
- Pay attention to possible water leakage from heating systems (pressure drop, check water consumption).
- Pay attention to peeling and leakage of silicone seals in the bathroom area (shower, bath tub).
- Further information can be found in the “Instructions for use for houses” of the Aachener Institut für Bauschadensforschung[1].

4.2 Proper ventilation

Room users can usually help keep the indoor space free from mould growth because sufficient ventilation (see Infobox 9) can “dispose of” the moisture released towards the outdoors during use. Heating (see Section 4.4) counteracts low surface temperatures of fabrications (see Chapter 3) and supports moisture removal during ventilation. However, measures taken by room occupants are not sufficient in cases where buildings have structural defects such as insufficient thermal insulation or inadequate ventilation options.

Old, non-airtight buildings have a greater air exchange with closed windows and doors than new or refurbished airtight houses. Ventilation is equally important in old and new airtight buildings. However, ventilation frequency in airtight buildings must be significantly increased depending on usage or, alternatively, ventilation equipment (see Section 4.3.3) can be installed.

1 Schnapauff, V. Richter-Engel, S.: Gebrauchsanweisung für Häuser (Instructions for use for houses), Fraunhofer IRB-Verlag, Stuttgart 1997

INFOBOX 9

TIPS for proper ventilation

The following tips apply to buildings that are ventilated by windows and have no ventilation equipment.

Moisture-enriched air should be transferred from rooms with high levels of moisture release, especially bathrooms and kitchens, to the outdoor space by airing as quickly as possible after use! Prevent entry of moist air into other rooms, d. h. do not use cross-flow ventilation, but ventilate with the window (or several windows) completely open and the door closed!

Also ventilate rooms that are occasionally or hardly ever used such as corridors, guest rooms or storage rooms! Moisture will inevitably get into these spaces from the other rooms in use and it must be flushed out before it reaches a critical moisture content.

When drying laundry or damp towels in closed rooms, ensure adequate, timely ventilation! Alternatively, the use of spin dryers can be useful with the moist exhaust air transported directly out to the open air (exhaust air dryers) or the condensate is directed into the sewage system or collected in a container (condenser dryer).

Use a wiper to remove 'residual moisture' from wall tiles after bathing or showering! Indoor baths should be ventilated by a fan-operated exhaust air system. In the absence of ventilation options, it is highly recommended to retro-fit an exhaust fan ventilator system controlled by the light switch or better still, by humidity sensors especially in small bathrooms without windows.

Exhaust ducts (with or without a fan) must be regularly checked for proper functioning! They can be easily tested by holding a piece of toilet paper up to the ventilation grille. If the paper is not sucked in and does not stick to the grille, ventilation is likely to be inadequate or the filter in front of the fan needs to be cleaned or replaced. If this does not help, the exhaust fan must be inspected by a specialist. The outlet must not be closed or fan operation stopped under any circumstances.

Extractor hoods removing the exhaust air to the outside have proved efficient in reducing the moisture load in kitchens. However, many extractor hoods are built as recirculation systems that only reduce odours but fail to remove the moisture released during cooking. Kitchens lacking ventilation systems must be 'dehumidified' during and after use through adequate ventilation.

Room occupants should be told about special features of their building and given recommendations for action tailored to their current situation especially if first time buyers or after renovation. Help can be obtained from the consumer centres' energy consultation sponsored by the federal government: www.verbraucherzentrale-energieberatung.de.

Building ventilation systems generally remove adequate amounts of moisture in houses or flats equipped with controlled domestic ventilation systems.

When ventilating **cool cellar rooms** at high outdoor temperatures, there is the problem that summer air, which is often very humid, flows into the cellar where it cools down and causes 'summer condensation'. This can also occur in basement rooms. In the case of a warm and therefore humid outdoor climate, ventilation should only be provided if the outdoor temperature is no higher than the cellar temperature, i.e. possibly at night or early in the morning. Basement windows should remain closed during the day. If adequately adapted ventilation is not sufficient to prevent critical humidity, technical items such as ventilation systems controlled by the absolute humidity are required (see Section 4.3.3). Additional dehumidifiers can also help in cool cellar rooms. The collected water must be regularly removed if the equipment is not connected to the drainage system.

4.3 Ventilation options

Adequate ventilation is a prerequisite for preventing increased humidity and mould.

The following chapters will describe the options of free ventilation (see Section 4.3.1).

If manual ventilation through windows or passive ventilation openings is not sufficient to achieve adequate moisture removal, installation of ventilation equipment is recommended. Their advantage is that they can be operated independently of user intervention (see Sections 4.3.2 and 4.3.3).

Ground-source heat pumps, which are however, not without risks (see Section 4.3.4), are used to pre-cool the outdoor air (in summer) or pre-heat it (in winter).

Proper maintenance is important for all technical systems (see Section 4.3.5).

4.3.1 Free ventilation

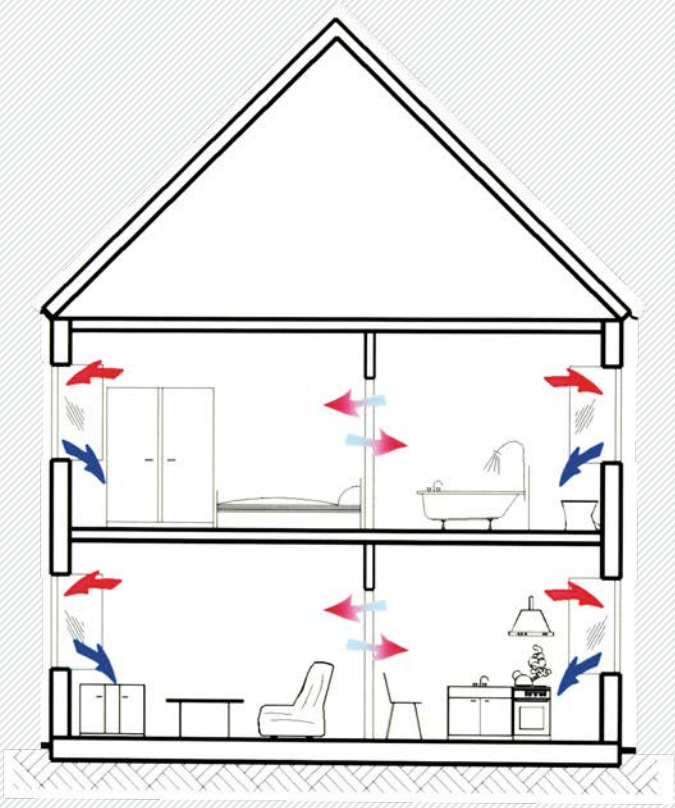
Air transport resulting from the utilisation of natural pressure differences due to wind and thermal (temperature differences) is called 'free ventilation'. Free ventilation can be done manually via open windows or structurally via exhaust ducts. However, different weather and wind conditions (windward/leeward) can lead to uncontrolled air exchange.

Manual window ventilation

High ventilation rates can be achieved by completely opening the windows in the room to be ventilated (shock ventilation, see Figure 19). Window ventilation is most effective when opposite windows are simultaneously opened ('cross-ventilation') since this is how outdoor air can most quickly replace room air.

Figure 19

Free ventilation – window ventilation (red = exhaust air, blue = supply air from outside)



Outdoor air enters and leaves the room through window and door clearances. Air exchange depends on wind pressure, temperature and other parameters and can be controlled by opening the windows.

Source: Fraunhofer Institute for Building Physics (IBP) 2001

Shock and cross-flow ventilation are the means of choice! Ventilation using tilted windows is much less effective and should be carried out over a much longer period of time. Long-lasting airing through tilted windows can also severely cool the window reveal and lintel are ain the cold season creating cold surfaces that can trigger condensation and possibly mould. Also, tilt ventilation is not recommended over long periods in the cold season as too much heat energy is wasted. Window ventilation may not always be adequate depending on usage and utilisation of airtight buildings and may need to be supported or replaced by mechanical ventilation equipment.

Pipe ventilation and passive ventilation openings

In particular older multi-family houses with bathrooms or toilets without windows usually have **exhaust ducts** (ventilation through closed pipe systems) lacking fan assistance. These types of baths and kitchens can be ventilated by natural air movement through a ventilation duct that exits above the roof.

Passive **ventilation openings** such as louvers or openings in windows and possibly doors enable a certain amount of air exchange (usually insufficient) and contribute to the dehumidification of the rooms.

Duct ventilation and passive ventilation openings do not enable the volume of fresh air to be controlled. As a result, too much air is exchanged in winter and too little in summer. Therefore, humidity is only removed for short periods of time, much energy is lost unnecessarily, and air flow is not controlled properly. Targeted air extraction by a fan can directly remove the necessary amount of moisture more efficiently. Ventilation specialists must check whether existing ducts are suitable for a fan-assisted ventilation (see 4.3.2) prior to installation.

Duct ventilation without fan support and passive ventilation openings e.g. in bathrooms can ensure air exchange to some extent but they are not suitable for targeted moisture removal.

4.3.2 Simple mechanical ventilation devices

Simple mechanical ventilation systems such as fan-operated exhaust air systems can normally ensure adequate dehumidification of rooms (if outdoor air humidity is not too high). However, when operated in airtight buildings, standalone devices usually cannot guarantee an air exchange rate required by hygiene aspects. They are therefore not a substitute for air supply and exhaust systems with heat recovery. They can only be considered for cost or structural reasons when air supply and exhaust systems cannot be installed within a reasonable period of time.

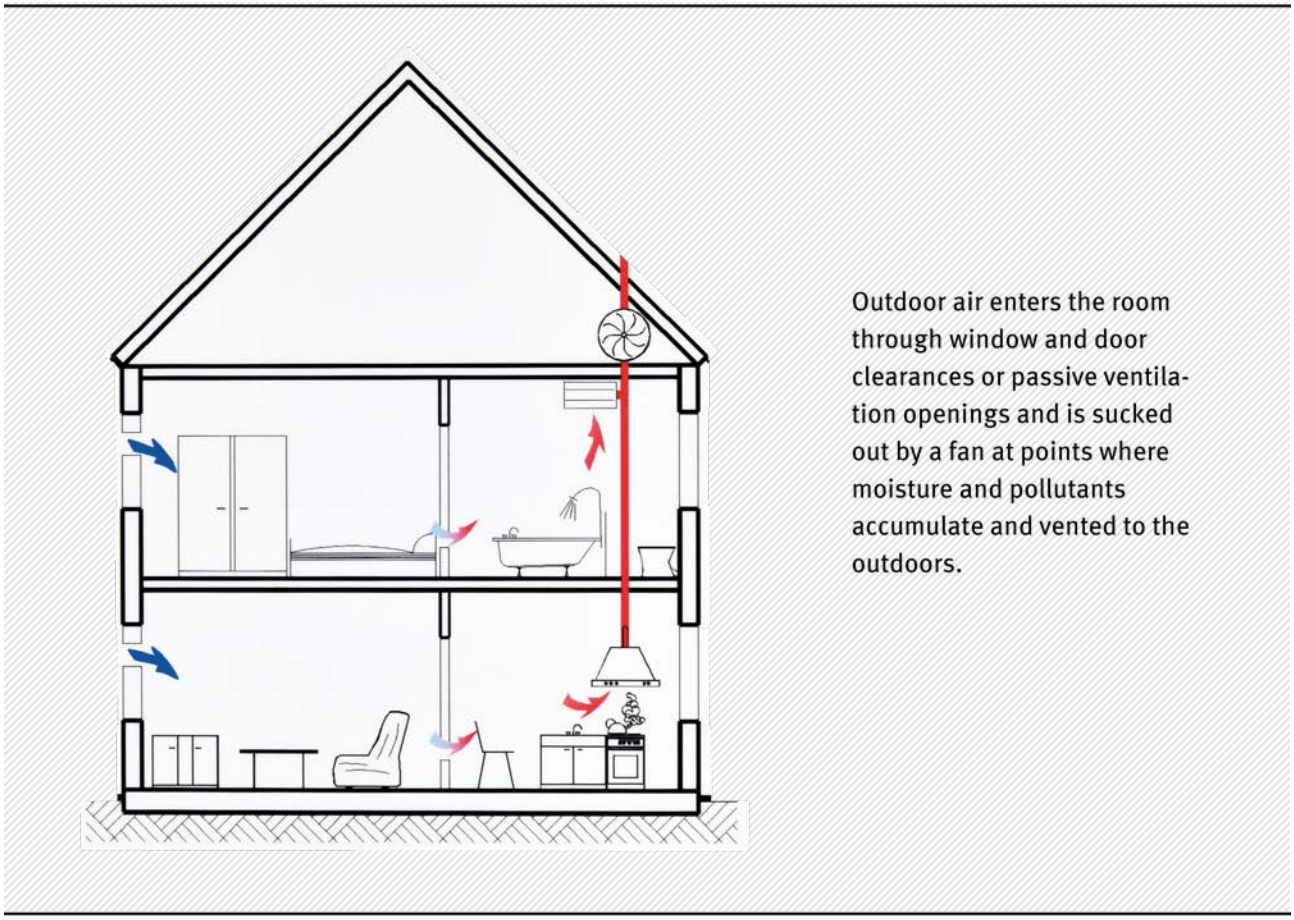
Fan-operated exhaust air systems

Exhaust air systems can be characterised by the extraction of air from the most heavily used rooms (kitchens, bathrooms, toilets) by a fan and transported to the outdoors via an air duct (usually beyond the roof) (Figure 20). When air is sucked from the kitchen and bathroom of a home, air must also be able to flow into the building. In older, leaky buildings, outside air can flow into the building through leaks. However, outdoor air apertures (OAA) must be installed in refurbished energy-saving airtight buildings to enable an air flow.

Dirty exhaust filters in air extraction systems in wet rooms impair or obstruct air flow and are therefore among the common causes of high humidity in these rooms. Filters must therefore be regularly checked and, if necessary, cleaned or replaced.

Figure 20

Fan-assisted ventilation of a building: outdoor air apertures (OAA) and exhaust air system (red: exhaust air, blue: supply air from outside)



Source: Fraunhofer Institute for Building Physics (IBP) 2001

Fan-assisted exhaust systems combined with outdoor air apertures offer an easy option to achieve targeted dehumidification. Combined supply and exhaust air systems are better suited to achieve an air exchange required by hygiene. Exhaust air systems are the easiest to operate when they are coupled with a caster action light switch, e.g. in bathrooms with no windows. However this is sometimes not sufficient for effective dehumidification.

For high humidity, controllers with humidity and temperature sensors can be installed both inside and outside and they switch on a fan when there is a set inside/outside absolute humidity difference. Simple arrangements, which are only switched by indoor hygrostats, can exacerbate the humidity problems, by causing summer condensation in cool rooms especially in the summer months when the absolute outdoor humidity is high.

Filters, fans and ceiling outlets of exhaust fans and extractor units must be regularly cleaned or changed.

Landlords should tell the tenants what maintenance work (e.g. filter change) is the tenants' responsibility.

Demand-related mechanical window ventilation

Demand-based mechanical window ventilation is a simple targeted ventilation method. In the event of elevated air humidity, high temperatures or high CO_2 values, the windows are automatically opened and closed by small motors if the desired values are reached. Rain and wind sensors prevent opening in adverse weather conditions.

The advantage of such a solution is the relatively simple installation (especially in roof windows) and the possibility of automated night ventilation in the summer. In comparison to controlled domestic ventilation systems (see Sections 4.3.3 and 4.3.4), disadvantages may arise from increased heat losses due to ventilation and a difficult-to-calculate air intake, which can lead to drafts in certain circumstances.

4.3.3 Building ventilation systems with supply and exhaust air control

Systems with supply and exhaust air control (building ventilation systems or BVS for short), usually equipped with heat recovery today, are more complex than pure ventilation systems. These ventilation devices have the advantage that they can provide air exchange regardless of usage, e.g. in the absence of room occupants.

The air flow rate (and thus the ventilation result) depends not only on the inside/outside air pressure differences but also on the use of the rooms. A disadvantage of these systems is that regular maintenance and control is required.

If the air is only transported and maybe its temperature kept constant, the systems are referred to as 'ventilation systems', possibly with a heating function (see DIN EN 13779). Systems with additional humidification and/or dehumidification or cooling are called 'air conditioning systems'.

Efficient ventilation systems provide the most reliable solutions to remove moisture, odours, carbon dioxide and other undesirable indoor air contents.

In its Guideline on Indoor Hygiene in School Buildings (German Environment Agency 2009) and in the recommendations of the UBA Ventilation Working Group (German Environment Agency 2017), the German Environment Agency recommends such ventilation systems as preferred principle of ventilation. Building ventilation systems are currently relatively the exception in tenement and private housing in Germany, while they are often the rule in new buildings in neighbouring countries such as Switzerland and Austria or in Scandinavia.

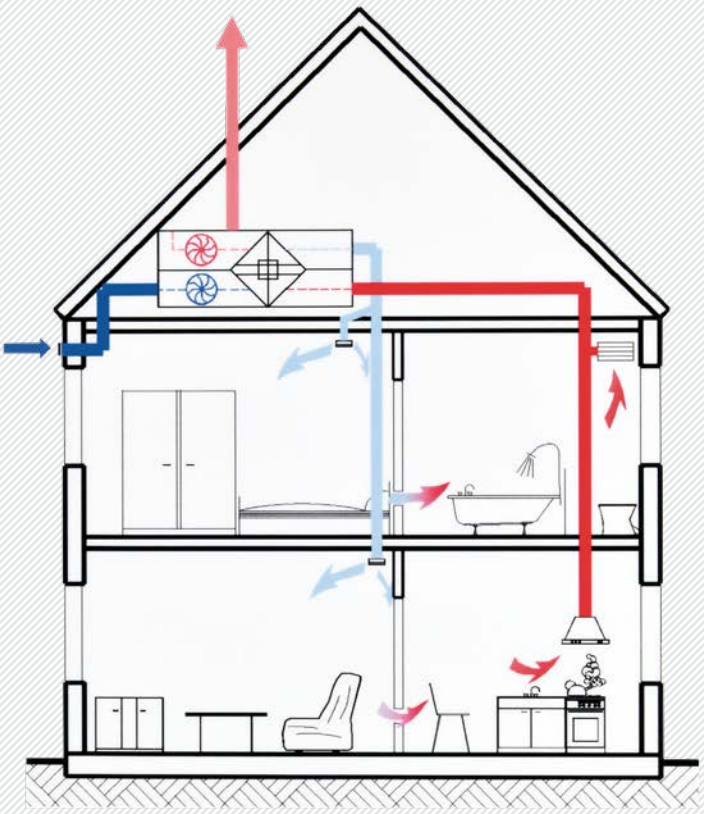
Ventilation systems

Ventilation systems are available as central systems for entire buildings, *for individual flats or offices*, and as decentralised standalone devices for individual rooms.

In central ventilation systems – also called "Controlled Living Room Ventilation" in residential buildings – (see Figure 21), room air is extracted from humidified rooms (e.g. kitchens, bathrooms and toilets) by a fan. Supply air is transported by a second fan through air ducts into the flat or office area. Heat recovery takes place during the heating season, which improves the overall energy balance of the building. Ventilation systems with increased demands on efficiency, hygiene and comfort are also called 'comfort ventilation' (www.komfortlüftung.at).

Figure 21

Central ventilation system with supply and exhaust air control and heat recovery (red: exhaust air, blue: supply air)



Outdoor air is sucked into the building by a fan through an external air intake and blown into the supply air areas via a heat exchanger and pipe system. Humidified exhaust air (toilet, bath, kitchen etc.) is sucked out and transported back to the outdoors through a heat exchanger by a fan.

Source: Fraunhofer Institute for Building Physics (IBP) 2001

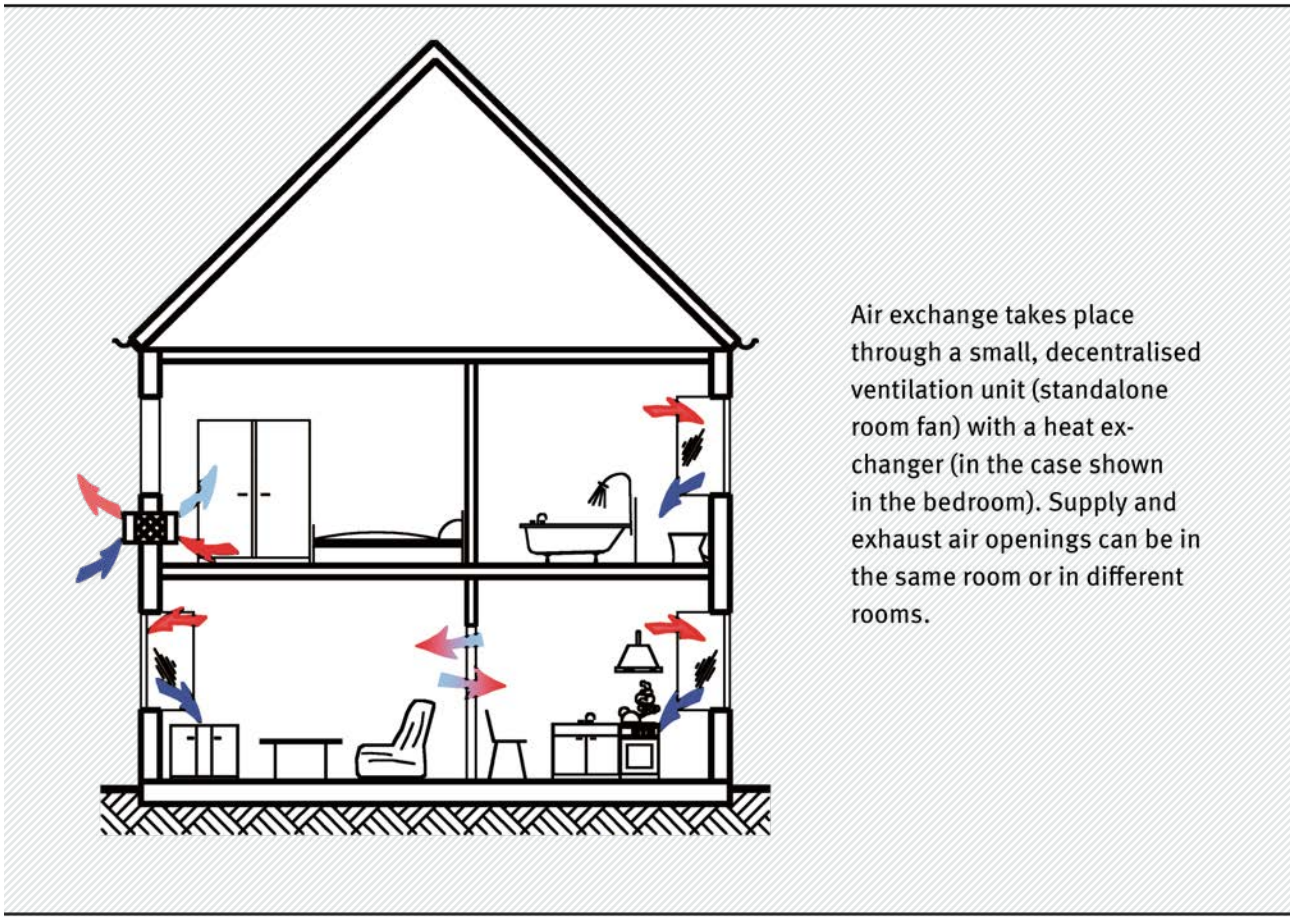
Passive or zero-energy houses and “plus-energy houses” definitely require supply and exhaust air systems that are combined with highly efficient heat recovery (comfort ventilation standard).

Some of the newer equipment apply moisture recovery and demand-based control via sensors so that indoor air does not get too dry during the winter months. Some systems also take into account the absolute outdoor air humidity and reduce the air volume when outdoor air humidity is high.

In addition to centralised (building or flat) ventilation systems, decentralised ventilation units (also called standalone room fans) are becoming increasingly popular (see Figure 22). These devices are preferably mounted on the external wall next to the windows or in the area of the windowsill. Another alternative is a combination of the ventilation unit with a radiator under the window. Apart from some special solutions, these are air supply and exhaust units. As with the central supply and exhaust air systems, a heat exchanger is now the standard.

Figure 22

Decentralised (room-wide) ventilation unit with heat recovery in the bedroom (red: exhaust air, blue: supply air)



Source: Fraunhofer Institute for Building Physics (IBP) 2001

Standalone room fans can do without the long ventilation ducts (see Figure 22). Ventilation can be easily adapted to room use, often using a time programme or sensors. Silent fans are very important as ventilation noise is particularly annoying in bedrooms. Disadvantages of decentralised solutions stem from the often too low air flow rates of such devices that fail to properly remove anthropogenic air pollutants.

Standalone room fans are particularly suitable for the refurbishment of old buildings where it is structurally almost impossible to install central supply and exhaust air systems for a whole building or a flat, or only at a high cost. They can provide suitable solutions for particularly difficult or unfavourably located spaces such as living rooms and bedrooms facing busy roads.

Ventilation units usually require openings in the external walls which impairs the appearance of the building's façade – and in some cases its stability too. Architectural concerns often complicate installation, especially in listed buildings. Recently, there are standalone ventilation devices available that can be fully integrated into the window frame and do not require openings in the wall.

Air conditioning systems

Central building ventilation systems are referred to as 'air-conditioning systems' when the supply air can also be humidified, dehumidified or cooled. The advantage of such systems lies in the exact setting of the desired indoor climate. Disadvantages are an energy- and cost-intensive operation and an increased maintenance.

'Air conditioning systems' are building ventilation systems that not only allow temperature control of the air through heat recovery, but also have **additional components for cooling/heating and/or humidifying and dehumidifying the air.** High demands are placed on the installation and maintenance of such systems (VDI 6022 Sheet 1). Air conditioners usually use two filter systems that filter out contaminants from the intake air.

"Air improvement" methods such as ozonation or ionisation of the supply air are also being offered, but they are neither necessary nor useful for hygienic reasons; even harmful as far as ozone is concerned.

Air conditioning systems are rather the exception in homes, and they are not even necessary when mould infestation should be avoided.

The VDI 6022 Sheet 1 provides advice about hygienic risk assessment, maintenance, checking and inspection of building ventilation systems. This includes all building ventilation systems and devices and their central and decentralised components. It also provides advice about testing the building ventilation systems (checklist) and training.

4.3.4 Ground-coupled heat exchangers

Ground-coupled heat exchangers (ground source heat pumps) are used to pre-cool (in summer) or preheat (in winter) the outdoor air before it enters the building.

The supply air whose temperature is to be modified is either led directly via underground pipes (air ground-coupled heat exchanger) or via an in-ground brine circuit (brine ground-coupled heat exchanger) without direct earth contact.

Similar to cold cellar walls in the warm season, the wall temperature of air ground-coupled heat exchangers is briefly lower than the dew point temperature of the air. Therefore, high relative humidity or even condensation occurs on the walls, and microbial infestation can be the consequence. Even if moisture is correctly removed and supply air filters are good, the supply air can be expected to transport smaller microbial constituents such as endotoxins or mycotoxins (see Section 2.2) into the indoors when the ground-coupled heat exchanger is microbially infested. For this reason and for reasons of easy control, the air ground-coupled heat exchanger should no longer be used, rather brine ground-coupled heat exchanger or heat pumps should be preferred.

4.3.5 Maintenance of mechanical ventilation equipment

Mechanical ventilation equipment must be regularly inspected and, if necessary, cleaned. Details are regulated in the VDI 6022 guideline series. Supply and exhaust air filters must be changed regularly. High-quality supply air filters help prevent contamination in the system and significantly reduce the entry of pollen, spores and particulate matter from the outdoor air.

Existing air ground-coupled heat exchangers must be regularly checked and cleaned as increased condensation and thus microbial infestation may occur.

If mechanical ventilation systems have been installed, careful building construction, adjusted supply air flows and the proper function must be checked immediately after installation.

Specifically, the requirements for dimensioning, function and sound insulation must be controlled and recorded. Detailed information can be found in the DIN EN 13779, the DIN 1946-6 and the VDI guideline 6022 Sheet 1 (hygiene inspection).

Suitable filtering of the supply air ensures that significantly lower airborne bacterial concentrations are supplied from the outdoors to the room air than in the case of pure window ventilation. The prerequisite for the minimisation of microorganisms is the proper use of adequately suitable air filters (see VDI 6022 Sheet 1).

Filter loading must be regularly checked provided it is not automatically displayed by the devices. The filters must be cleaned or replaced if necessary.

4.4 Adequate heating

Chapter 3 has already presented a few discussions about the relationship between heating, indoor air and surface temperatures. Adequate heating combined with proper ventilation can prevent mould.

INFOBOX 10

TIPS for proper heating

Heat all rooms sufficiently!
Cool air will absorb less water than warm air!

Bedrooms:
Each person releases about ¼ litre of water as vapour into the room air every night. Therefore, room air temperature in bedrooms should not sink too low, the doors to warmer rooms should be closed and sufficient ventilation should be provided. In general, temperatures in the range of 16 °C and 18 °C suffice to avoid damp and mould problems. Due to lower room air temperatures, furniture should preferably be placed against the internal walls in poorly insulated buildings, in particular in bedrooms. For external walls a few centimetres distance must be maintained (see Chapter 3).

Unused rooms:
Even rooms used occasionally or not at all over long periods should be heated to some extent.

Keep doors closed to less well heated rooms!
It does not make any sense to heat cool rooms with air from warmer rooms because not only heat but humidity is also transferred into the cooler room. When warm air cools down at the wall surfaces, relative surface humidity increases and mould can develop.

Heating can be reduced during night or for a prolonged absence.
By reducing the room air temperature – which usually happens at night via the central heating boiler system of the house – energy can be saved. However, the relationship with room humidity must be taken into account. When indoor humidity is high, room air temperature should only be reduced if this does not result in excessive relative humidity at cold surfaces.

Do not obstruct heat emission from radiators!
It is very unfavourable if radiators are surrounded by incorrectly mounted panels or oversized windowsills or partially covered by curtains. In the worst case, the desired room air temperature cannot be achieved and energy consumption increases.

5

Recognise, detect and assess mould infestation

The general recommendations for site inspections and detection of mould infestation apply to all utilisation classes (for the definition of utilisation classes see Section 6.1).

In the case of a suspected mould infestation, the affected rooms are inspected by experts specialised in building physics and microbiology in order to determine the causes of the increased humidity and the extent of the damage (see Section 5.1.1). Damage identification is carried out with the aim of localising relevant damage from moisture and to detect possible microbial infestation against the normal basic load. The site inspection also aims to determine whether further investigations (see Section 5.1.2) are necessary to clarify the cause and extent of the infestation.

INFOBOX 11

Who can I contact if I suspect mould infestation in my flat?

If you would like to know who is carrying out site inspections and, if necessary, further measurements in your area, then you can receive advice from consumer centres, tenant or homeowner associations, your local health authority or one of the mould consultancy networks in Germany: https://www.umweltbundesamt.de/en/themen/gesundheit/umwelteinfluesse-auf-den-menschen/schimmel/netzwerk-schimmelpilzberatung.

The chambers of industry and commerce can also help. Some major cities provide the option of special authority advice ('housing protection').

When ordering a mould inspection, make sure that the measuring institute is sufficiently qualified to perform the task (see Section 5.1.3).

Who can I contact if I am afraid of getting ill from the mould in my flat?

If you are ill or suffering from medical conditions and suspect a possible association with mould in your living space, then consult your GP who may refer you to a specialist, e.g. to a pulmonologist or an allergist. You can also inquire at your local health authority, your consumer advice centre or mould networks about an environmental epidemiologist.

If the result of the medical examination indicates any problems with indoor hygiene in your home, you should have your home examined for possible mould sources (see above). If you are a tenant, clarify the further course of action with your landlord.

Evaluation of the site inspection results and potential further investigations in the overall context make it possible to determine whether a mould source is present in the indoor space (see Section 5.2). In the case of mould infestation in the indoor space, the causes of the increased humidity must be eliminated, and the affected area must be remediated under consideration of the utilisation class (see Chapter 6).

All results and evaluations should be summarised in a detailed report (see Section 5.3).

5.1 Site inspection and damage assessment

A thorough site inspection carried out by professionals is the foundation of the detection and assessment of visible or suspected mould damage. A professional assessment of mould infestation is generally not possible without a site inspection – for example, based only on DIY measurements carried out by the occupant (quick test kits for mould that don't require special expertise to be interpreted).

The issues to be examined in the damage assessment should be agreed upon between the parties prior to the inspection. The investigation must be performed without any fixed expectations regarding the results. Inspections of suspected mould infestation are carried out for example when there is no visible mould infestation, but moisture damage, structural defects or odour indicate possible mould growth or in the case of health problems that are suspected to be due to mould infestation.

The site inspection (see Section 5.1.1) clarifies the possible causes of increased moisture or mould infestation and records them in an inspection report. Depending on the result and the nature of the issue, further physical and microbiological examination may be necessary (see Section 5.1.2).

The information obtained from the inspection and, if applicable, the results from the further investigations (see Section 5.1.2) usually make it possible to determine whether there is a source of mould in the indoor space. Since there are no generally applicable assessment criteria, the overall assessment requires a high degree of expertise and a mandatory case-by-case assessment (see Section 5.2).

The site inspection, the additional investigations and the assessment should only be carried out by persons, laboratories or institutions that meet certain quality criteria (see Section 5.1.3).

5.1.1 Conducting the site inspection

The site inspection clarifies whether and to what extent there is mould infestation and determines the possible causes (see Chapter 3). Important building physics parameters such as room temperature, indoor air humidity, material moisture and surface temperature are collected as well as constructional boundary conditions, information on the affected space and its use and possible building-independent sources of mould (e.g. biowaste, animals kept in cages, terrariums). The DIN EN ISO 16000-32 (2014) "Examination of buildings for pollutants" provides valuable information.

An important indicator of mould infestation are odours that are typical of mould and indicate moisture. The site inspection also provides the possibility to localise odour sources. Any odour determination should be based on the relevant guidelines (AGÖF Guidelines for Odour, DIN ISO 16000-30 "Odour Test of Indoor Air" and VDI 4302 Sheets 1 and 2 "Odour test of indoor air and emissions from indoor materials").

Building physics and room climate investigations can be used to determine whether the effects of use or construction are at the root of increased humidity and mould growth (see Chapter 3).

The aim of **site inspection** ist to collect and record physics data (e.g. temperature, humiditiy) and general information about the affected rooms in an **inspection report**. Interviewing the room occupants regarding the type of room use and their perception of the indoor situation also serves the purpose.

The site inspection should also carry out an optical and sensory evaluation of the affected rooms and of the materials an objects in the rooms.

The aim of the site inspection ist to clarify whether mould infestation is present and to what extent.

This information establishes whether an, if so, what additional further investigations are required for clarification.

Further measurements are generally not required if the mould infestation is visible (Category 2 and 3, see Table 8) and has a clarified cause. However, the affected area should be remediated in a timely manner under consideration of the utilisation class.

Climate records (temperature and relative humidity) using data loggers have proven to be very useful in facilitating the evaluation of the different influences on the emergence of infestations. These measurements are usually useful in the cold season and should take place in important areas (assumed cool surfaces, indoor air, possibly outdoor air). Since the results of individual measurements are subject to strong fluctuation, long-term measurements over several weeks (e.g. using data loggers) are best suited to provide useful results, and they also can characterise ventilation behaviour. This helps identify whether and over what periods or in which activities critical constellations of temperature and humidity may occur.

In addition, building physics investigations (e.g. room-side building thermography or airtightness tests) can also be applied. Room-side thermography is a non-contact measurement of the surface temperature that reveals temperature differences and may indicate thermal bridges or moisture in the building materials. A site inspection can provide adhesive film samples from areas of microbial infestation and examine them for active infestation (mycelium growth/sporophors) at short notice. Since building thermography can be influenced by many factors (e.g. material properties, construction method, weather conditions, solar radiation, furnishings), taking and evaluating the records is the responsibility of experienced specialists.

Thermography reveals differences in the temperature of component surfaces in the form of a colour pattern. **Room-side thermography enables the clarification of thermal bridges and damp areas** and can therefore also be used to locate problem areas for mould growth (cooler areas).

Mould often finds optimal growth conditions behind pieces of furniture next to exterior walls because the circulation of warm air is prevented and a significantly increased surface moisture is possible because of the cool walls.

That is why indoor site inspections should also check for mould growth behind shelves, cupboards and upholstered furniture, especially if the furniture is close to cool exterior walls (see explanations in Sections 3.1.3 and 3.1.4). If possible, separated cavities, storage spaces and partitioned areas – especially in occupied attics – should also be inspected. In the case of water damage in lightweight constructions, interspaces in the construction (behind gypsum plasterboard) must also be opened and checked.

During the site inspection, the expert should also collect relevant information about the indoor space regarding mould infestation in addition to the building physics parameters (see also DIN EN ISO 16000-19). The

collection of general information on the indoor space and its use as well as any known sources of mould is indispensable for a clear interpretation of the measurement results about mould infestation in the indoor space (see Section 5.2) and, if applicable, for the remediation of mould infestation (see Chapter 6).

The following are examples of important information in the inspection report:

Indoor space
- General information (location and size, age of the building,structural features, wet rooms, building materials, basement, attic, insulation, type of windows)
- Indoor features (floors, walls, furniture, curtains, pot plants, air humidifiers)
- Building ventilation systems
- Heating system
- Type of room use
- Number of occupants
- Heating and ventilation behaviour
- Thermal insulation measures
- Odour: type and intensity

Indications of mould infestation and/or moisture damage in the indoor space
- Visible mould infestation, damp patches and other moisture damage
- Earlier or current occurrence of moisture and/or mould problems (including measures taken so far)
- Water damage, heating leaks
- Materials with moisture damage (e.g. masonry, furniture, insulation materials, books)
- Building measures with moisture input

Other possible mould or moisture sources in the indoor space:
- Biowaste collection or 'green dot waste' bin in the indoor space
- Potting soil of indoor plants
- Pets kept in cages
- Greenhouse in connection with the indoor space
- Air humidifier, indoor water fountain
- Aquarium in the indoor space
- Damp firewood

Possible mould sources in the surrounding area
- Emitting operations in the area such as compost plants, garden centres
- Recyclable material sorting plants, agricultural facilities
- Biowaste bins, compost heaps

It is reasonable to record this information in a standardised inspection report which contains all information, including any photographic documentation. Such an inspection report serves as a checklist for the site inspection and should facilitate a comparable and comprehensible documentation. For laboratory investigations, all data must be included to allow unambiguous assignment and characterisation of the samples (sampling record). When creating the inspection report, it should be borne in mind that it may serve as a reference document for other experts (e.g. architects, environmental epidemiologists). Comprehensibility and transparency are therefore key issues.

The results of the site inspection show the direction of further procedures. In many cases, the site inspection has already provided specific recommendations for remediation measures without further investigation being needed. Further measurements are unnecessary particularly when mould infestation can clearly be recognised visually and the cause of damage identified. Rather, prompt remediation steps should be taken (see Chapter 6). Adhesive film samples (see Section 5.1.2.1) may provide evidence that the issue is mould infestation indeed.

Further investigations are necessary if the site inspection and building physics investigations cannot clearly determine if there is a mould problem or where the mould infestation is precisely located (see Section 5.1.2).

5.1.2 Further investigations

Before commissioning further investigations, the objective of the examination must be precisely specified. Before accepting a commission, the expert must present an investigation strategy adapted to the objective of the investigation, whereby it should also be clear what conclusions are possible from the proposed methods.

There is no procedure for sampling and detecting mould fungi and bacteria that is applicable to all problems. A summary of the measurement strategy for mould infestation can be found in DIN EN ISO 16000-19, which was compiled based on the earlier VDI 4300 Sheet 10.

Measurements of mould fungi serve to detect whether mould infestation is present in the room and, if necessary, to what extent.

Mould infestation is determined by the presence of mould fungi as a leading organism. An investigation of other microorganisms that occur during mould infestation is therefore generally not necessary.

Only in exceptional cases (strong odours despite negative mould fungi findings, extensive moisture penetration) is it advisable to investigate materials for bacteria (see Section 5.1.2.4).

A quantitative assessment of mould exposure for the evaluation of individual health risks is **not possible** using mould fungi measurements.

The following sampling and verification procedures for mould fungi in the indoor space have been standardised in the form of DIN standards (see also Annex 4):

- DIN ISO 16000-16 (2009): Detection and enumeration of moulds – sampling by filtration
- DIN ISO 16000-17 (2010): Detection and enumeration of moulds – culture-based method
- DIN ISO 16000-18 (2012): Detection and enumeration of moulds – sampling by impaction
- DIN EN ISO 16000-19 (2014): Sampling strategy for moulds
- DIN ISO 16000-20 (2015): Detection and enumeration of moulds – determination of total spore count
- DIN ISO 16000-21 (2014): Detection and enumeration of moulds – sampling from materials

Materials can be tested directly to determine the extent of infestation (see Section 5.1.2.1).

If the site inspection failed to detect visible mould growth or construction-related abnormalities and if odour problems, moisture damage or health complaints among the room occupants suggesting mould persist, the use of a mould detection dog to find and localise covert infestations can be useful (see Section 5.1.2.2).

Measurements of cultivable mould fungi in the indoor air can provide indications of the probability of mould infestation and allow species or genus determination of the occurring mould fungi (see Section 5.1.2.1). This provides additional information on moisture damage (moisture indicators, see Chapter 1), on the causes of potential contamination and, in individual cases, on potential health effects caused by particular mould fungi (e.g. *Aspergillus fumigatus*, see Chapter 2).

In some cases, the investigation of dust samples can provide information about a potential continuous mould contamination in the indoor space because mould fungi accumulate in dust over a longer period of time ('passive collector'). However, due to difficulties in collecting sufficient amounts of specified sediment dust, the different composition of household dust and the low survivability of some fungal spores, it has not yet been possible to develop a standardised method for the analysis and evaluation of dust samples. Therefore, results of dust investigations cannot be interpreted unambiguously.

Since usually only a part of the available mould spores can be cultivated, but allergic or toxic effects can also originate from non-cultivable microorganisms and their components (see Chapter 2), methods have been developed to determine the total spore count of mould fungi (see Section 5.1.2.5) without cultivation.

INFOBOX 12

Summary of further investigations

A. ESTABLISHED RULES OF TECHNOLOGY
Procedures that are unequivocally accepted among experts and applied by the majority of professionals in practice.

- Measurement of mould fungi in the air (DIN ISO 16000-16 to -18)
- Measurement of cultivable mould fungi in the material (DIN ISO 16000-21)
- Measurement of the total spore count in the air (DIN ISO 16000-20)

B. STATE OF THE ART
Procedures that although extensively used, are not yet widely accepted by experts.

- Direct microscopy including adhesive film samples (not yet standardised)
- Measurement of cultivable (Actino)bacteria in/on materials (not standardised)
- MVOC measurements (VDI 4254 Blatt 1)

C. THE LATEST STATE OF SCIENCE AND TECHNOLOGY
Procedures currently used in scientific research projects or in the experimental phase, but not yet suitable for routine indoor measurements since there are no standardised measurement methods and/or generally accepted assessment criteria.

- Mould detection dogs
- Molecular biological detection methods of microorganisms
- Detection of mycotoxins and other secondary metabolites
- Detection of endotoxins, ß-glucans, PAMPs and other cell components
- Quick processes for detecting mould growth (e.g. ATP)
- Total cell count in the material through microscopy
- Total cell count in the air through filtration and microscopy
- Measurement of actinomycetes in the air

D. NON-RECOMMENDED MEASURING PROCEDURES

- contact plate samples (except in clean rooms and ventilation systems)
- Measurement of cultivable mould fungi in the air using sedimentation plates
- Measurement of mould fungi in household dust
- Measurement of the total bacteria in the indoor air

In the case of odour problems, the determination of MVOCs may, under certain conditions, provide indications of the cause of the odour or hidden mould infestation (see Section 5.1.2.6).

Methods for quick detection of mould growth such as ATP detection, enzyme activity, special antigens or cell components were developed on a biochemical or molecular biological basis (see Section 5.1.2.7). However, these methods are currently not sufficiently validated for practical application.

In practice, such procedures are considered to be the generally accepted rules of technology or state of the art and should form the basis of assessment (see Infobox 12). Procedures according to the latest state of science

and technology can be used in individual cases in order to obtain further information about hidden infestation damage or the occurrence of cell fragments. However, infestation assessments and remediation decisions must not be based solely on such methods.

Further investigations should only be carried out by experienced specialists and institutions that carry out internal quality management and regularly participate in external quality assurance measures (see Section 5.1.3).

5.1.2.1 Measurement of cultivable mould fungi and bacteria in the material and on its on surfaces

Material samples (such as plaster, wallpaper, wooden items, screed, also potting soil and insulation materials) are tested to obtain information on the type and extent of the mould infestation.

The investigation of mould fungi and possibly bacteria on or in materials provides information on the type and extent of the mould infestation. Material samples can be examined through microscopy and cultivation.

The investigation of materials is carried out with the following objectives:
- Confirmation that the material discoloration is caused by mould
- Distinction between an infestation and contamination
- Determination of the type and extent of infestation in the area
- Determination of type and extent of the infestation in the body of the material

Adhesive film samples enable the quick and easy confirmation of whether discoloration on the wall or on other materials is caused by mould. This is made by sampling the conspicuous areas with adhesive film. The detection of microorganisms is subsequently microscopic. In addition, the detection of a mycelium can confirm the growth of mould fungi or actinomycetes on the material.

Contact plate samples, as used to verify the cleanliness of surfaces, in building ventilation systems (see VDI 6022), are not suitable for the assessment of mould fungi growth on component and material surfaces indoors since contamination caused by sedimented mould spores on the nutrient medium can cause strong growth and therefore lead to false positive results regarding mould infestation.

To investigate mould fungi within the infested material, a sample is taken, crushed and examined both microscopically and using the dilution method by cultivation. In the dilution method, the crushed material is suspended in an aqueous medium and a specified portion of this suspension is applied to nutrient media (DG18 and malt extract agar for mould fungi).

Cultivation allows informed conclusions to be made on the concentration of cultivable mould fungi per gram of material. In recent years, a procedure for material investigation has been developed, validated and standardised (DIN ISO 16000-21). In addition to determining the concentration, the identification of the existing species or genera of mould fungi is also important. The occurrence of typical moisture indicators (see Chapter 1) is a clear indication of elevated moisture and mould growth in the material.

Direct microscopy can distinguish between mould fungi growth in the material (infestation) or contamination with spores from another mould source (see Section 5.2). The evaluation of a material through direct microscopy requires a lot of experience and can lead to false negative results since only very small areas of material can be examined. Therefore, it makes sense to examine the material in parallel using the more sensitive cultivation method. If direct microscopy has already detected extensive mould fungi growth, cultivation can be dispensed with (see also Annex 6).

When **examining materials,** it should be noted that there is always a certain number of fungal spores in all material samples. This should not lead to the conclusion that the material is infested.

Sedimented dust can also be used to detect higher concentrations of 'non-native' mould fungi in the material. This should be precluded by careful sampling ensuring it is as free of contamination as possible and by avoiding dust-laden samples.

In direct microscopic examination, the detection of relevant amounts of mycelium in the material provides a good indication of mould growth occurrence in the material (see Section 5.2).

In recent years, comparative values for the normal occurrence of mould fungi in certain building materials (background load) have been derived by examining materials without known moisture damage. Comparing the measured values obtained with such comparative values in the case of suspected mould damage can assess whether relevant mould growth has taken place in the material (see Section 5.2.2).

Bacteria in materials are not routinely investigated in mould infestations since existing microbial infestation can usually be proved by the measurement of mould fungi.

However, bacteria often have a growth advantage in very wet materials where there are hardly any mould fungi. Therefore, for certain suspected problems of mould infestation without abnormal mould fungi concentrations, investigations should also be carried out for bacteria (especially if the material is very wet or there are musty odours) and/or actinomycetes (especially in the case of older damage) (for the detection of bacteria see Section 5.1.2.4).

5.1.2.2 Mould detection dogs

Mould detection dogs can be used in suspected cases of hidden mould in buildings to obtain information on the presence and localisation of the mould infestation. In recent years, validation investigations have been carried out and quality assurance measures have been established (see Section 5.1.3).

Mould detection dogs can help pinpoint hidden mould infestation because they are able to smell MVOCs (microbially induced volatile organic compounds), even at low concentrations.

The decision to remediate the affected indoor spaces should not be derived solely from the response of the mould detection dog but should rely on further investigations such as opening components at suspected infestation sites and possibly microbiological examinations. The decision to remediate should only follow such investigations.

Remediation decisions must not be based solely on mould infestation detected and indicated by a mould detection dog. It should be noted that the location indicated by the dog in the indoor space is not necessarily the place of infestation. For example, this is the case when the MVOCs picked up by the dog do not leak out directly at the point of infestation due to air

flow. In such cases, the interpretation of the mould detection dog's marks can be difficult. Therefore, it is important that the dog's handler knows how building physics relationships can affect the drifting of odours.

5.1.2.3 Measurement of cultivable mould fungi in indoor air

The method for determining cultivable airborne mould fungi spores in indoor air is the most widely used method of detecting mould infestation in buildings. It provides a snapshot of the mould fungi concentration in the indoor air and enables informed conclusions to be made on whether a mould source is likely or not. However, especially in the case of hidden infestations, it is possible that only insignificant mould fungi concentrations can be detected in the indoor air although extensive infestation is present.

The method is based on growing the cultivable mould fungi spores after appropriate collection on two different nutrient media (DG18 and malt extract agar) (DIN ISO 16000-17). Through cultivation, the spores collected on the nutrient media grow into individual colonies and can be counted and reported as the total number of colony forming units per volume of air (total CFU/m³) (see Chapter 1). The advantage of this method is

that it enables not only a determination of the total number of colonies, but also a differentiation (distinction) of the individual species or genera of mould fungi present. The disadvantage of the method is that not all mould fungi can be cultivated because sampling puts spores under stress which decreases their germinability and, moreover, some species of fungi, including typical moisture indicators, are generally not readily cultivable.

Suitable methods for collecting mould fungi from the air are filtration (DIN ISO 16000-16) and impaction (DIN ISO 16000-18). Specified air quantities are sucked in with a pump and the mould fungi spores contained in the air are separated on a filter (filtration) or directly on the nutrient medium (impaction).

The mail-order business also provides mould testing kits that can be set up around the flat by the occupant and sent back to a laboratory for evaluation. However, these DIY measurements of cultivable mould fungi by sedimentation (open Petri dishes over a certain period of time) do not yield reproducible results and are therefore not recommended.

In order to be able to distinguish whether the detected mould fungi are due to a source located inside or outside the indoor space, the outdoor air is usually examined immediately after measuring the indoor air. From the comparison of the measured values obtained from the indoor and outdoor air, it can be deduced how high the probability of a mould infestation in the indoor space is. A mould source is to be assumed in the indoor space if the concentration of mould fungi in the indoor space is significantly higher than the concentration in the outside air and/or the composition of species in indoor air differs significantly from the composition of the species in the outdoor air (see Section 5.2.3). As an alternative to the outdoor air sample, it is also possible to sample rooms in the same building that do not show signs of mould infestation (so-called reference rooms). Reference rooms are primarily measured in buildings where outdoor air cannot be used as a reference (e.g. buildings with ventilation systems).

In addition to measuring the concentration of mould fungi in indoor and outdoor air, the determination of the relevant genera or species of mould fungi is an important indication of the possible cause of increased mould fungi concentrations.

The results of the mould measurement alone cannot provide an overall assessment of the situation. A remediation decision must also consider the results of site inspections and building physics investigations.

The active measurement of the concentration of cultivable mould fungi in indoor air (total CFU mould fungi) provides a snapshot of the mould fungi concentration in the indoor air.

An identification of the mould species or genera (differences to outdoor air, indicator types) can provide important indications about the presence of mould infestation in the indoor space.

Parallel measurements are necessary in order to take into account the temporal and spatial variations in mould fungi concentrations.

The comparison of the results of the indoor air investigationss usually enables the deduction of whether a mould source is probable or not in the indoor space (see Section 5.2).

Adjacent non-contaminated rooms can also be used as a reference (especially useful in buildings with ventillation systems).

DIY measurements by sedimentation (Petri dishes open for a certain period of time) do not provide reproducible results and are not recommended for indoor spaces.

Answering the question of whether a mould source is likely in the indoor space is often difficult in practice since:

- microbiological determinations are subject to a high degree of scattering. Mould fungi spores are not uniformly distributed in the air as their distribution depends on a wide variety of parameters (e.g. spore size, spore shape, air circulation, movements in the room, dust load, relative humidity). Therefore, individual mould fungi measurements are subject to a large uncertainty factor. It is recommended to carry out several measurements (e.g. two different volumes in duplicate).

- unlike many chemical pollutants, biogenic pollutants are not stable but can constantly change in terms of their properties, size and composition. An infestation detected at a particular time may change within a week in terms of its dominant species composition and extent.

- not all existing mould fungi are cultivable.

- some mould fungi grow very poorly on the nutrient media, especially if they have to survive under stress conditions (e.g. prolonged drying out). Depending on the composition of the mould fungi population, significantly fewer cultured mould fungi can be detected on nutrient media than are actually available. The determination of the total spore concentration, which is independent of the growth on nutrient media, can take this problem into account (see Section 5.1.2.5).

- the commonly used reference value for an indoor space load is the outdoor air load, which in turn is subject to very strong local, weather-related and seasonal influences. In the case of high mould fungi concentrations in the outdoor air (especially in the summer, see Section 1.2), it is often difficult to detect mould growth in the indoor space. In the winter, especially in snowy conditions, outdoor concentrations are extremely low at times. In addition, local mould fungi sources such as biowaste bins or compost can contribute to an increased mould fungi concentration in the outdoor air. A purely numerical comparison with these external air values as a reference can lead to misinterpretation. Therefore, it may be helpful to use empirical values in outdoor air that are typical for the season and the residential area in the assessment.

5.1.2.4 Measurement of cultivable bacteria

Bacteria are not routinely investigated for mould infestation as the concentration of bacteria in the air fluctuates greatly and can be influenced by exfoliation of the large number of bacteria present on the skin of the sampler and the occupants of the room alone. The total concentration of bacteria in the air is not meaningful either in terms of health effects or in terms of mould infestation. Neither is the detection of actinomycetes in indoor air useful, since there is no standardised method and no evaluation criteria for the results.

The measurement of bacteria in room air is not useful.

In exceptional cases (strong odours despite negative findings for mould, severe damp) **it may be useful to investigate materials for bacteria.**

The investigation of bacteria (especially actinomycetes) in materials may be useful in individual cases. If no elevated levels of mould fungus are detected in odoriferous material, tests should be carried out for bacteria (especially actinomycetes). In practice, such materials are often tested directly for bacteria in order to obtain a result in a timely manner. For some old damage and for saturated moisture damage, the bacteria or actinomycetes may dominate and only a few mould fungi are detectable. Thus investigations into actinomycetes should still be carried out, even in cases of suspected problems with mould where there is no noticeable mould fungus concentration (particularly in the case of old damage).

Total bacteria in (construction) materials are detected on CASO agar but so far there is no standardised detection method.

It is not possible to specify a general routine method for the detection of all actinobacteria. The recommendation is therefore to isolate the genus *Actinomycetales* filamentous bacteria on mineral agar according to Gauze (see Annex 5), to report the results as CFU actinomycetes and to point out in the interpretation that only part of the actinomycetes can be detected in this study.

5.1.2.5 Measurement of the total spore count in the air

Irritant, toxic and sensitising effects of airborne fungal spores can arise from cultivable as well as non-cultivable spores (see Chapter 1). Therefore, the determination of total spore count of the moulds by non-cultivable methods makes sense in many cases. So, for example, *Stachybotrys chartarum,* a species of mould fungi that is capable of forming mycotoxins, is often not detected by cultivation but by the direct determination of the total spore count.

The total spore count is determined according to DIN ISO 16000-20 by slot nozzle impaction on coated slides. With a particle collector airborne spores are fixed on a coated slide and evaluated microscopically after staining. Bacteria are not detected by this method.

A big advantage of this cultivable independent method is the faster evaluation, since the time-consuming cultivation is eliminated. The disadvantage is that it is not possible to differentiate between living and dead microorganisms and that a determination of the mould fungi genus and species is only possible to a very limited extent.

The determination of total spore count is particularly important for the review of remediation success if biocides were used during the remediation. In this case, the determination of the total spore count can be used to check whether the mould fungi were not only killed but also effectively removed after biocide application.

Determination of the **total spore count covers both cultivable and non-cultivable mould fungi.** Differentiation of the genera and species is limited.

5.1.2.6 MVOC measurements

Mould infestation microorganisms can form a variety of volatile organic compounds as they grow. Analogous to volatile organic compounds, commonly referred to as VOCs (Volatile Organic Compounds), the term MVOC (Microbial Volatile Organic Compounds) was coined for VOCs produced by microorganisms. The MVOCs cover a broad spectrum of different chemical classes, e.g. aldehydes, alkanols, alkenols, esters, ethers, carboxylic acids, ketones, sulphur-containing compounds, terpenes, terpene alcohols and sesquiterpenes. So far, about 30 such compounds have been identified that can be produced by moulds. Some MVOCs are already noticeable in very low concentrations (nanograms per cubic metre).

The presence of MVOC can be an indicator of mould infestation. When interpreting the results, it must be borne in mind that some of these substances can also be released into the room by construction products, cleaning products, paints etc. as well as certain activities (e.g. smoking, baking). Especially in new buildings or after major refurbishment of existing buildings, MVOC measurements can lead to false positive results.

Certain chemicals (e.g. chloranisols, chloronaphthalenes) have a mouldy odour. In case of odour problems, it is therefore possible in individual cases to obtain information on the type of odour source (caused chemically or microbially) by determining the (M)VOCs.

3-methylfuran, dimethyl disulfide, 1-octene-3-ol, 3-octanone and 3-methyl-1-butanol are considered as clear indicators of microbial damage. Less specific indicators are hexanone, heptanone, 1-butanol and isobutanol.

A uniform evaluation scheme for the concentrations measured is not yet available.

Mould can form a whole range of volatile organic compounds **(MVOCs)** during growth. In the case of odour problems, the detection of characteristic (M)VOCs in indoor air can give an indication of the odour source. An estimation of the exposure to mould or an assessment of health risk cannot be derived from evidence of MVOC.

The measurement of MVOCs can be done in two ways: by sampling with activated charcoal and subsequent elution and by sampling with Tenax followed by thermodesorption (see VDI 4254 Page 1, draft).

5.1.2.7 Rapid tests for the detection of mould growth

Biochemical (e.g. detection of ATP, enzyme activity, special antigens or cell components) and molecular biology (Q-PCR) rapid tests for the detection of mould growth in general or of certain mould fungi, are not yet sufficiently validated in practice nor standardised.

Some of these tests do not work at all or only to a limited extent after disinfection or thermal treatment and at low pH values, e.g. in older mould infestation. There is a need for further research.

5.1.3 Quality assurance

Proper identification of mould infestation and its causes is a complex task. It therefore makes sense that the appropriate investigations and assessment of the results – depending on the issue – are carried out with the involvement of people from different disciplines. These include in particular the areas of construction (sampling, measurement of buildings' physical conditions, sampling protocol, determination of structural causes), mycology (sampling, detection of mould fungi) and hygiene. For health questions environmental epidemiologists, infectiologists, allergists or pulmonologists should be consulted.

Before the contract is awarded to a measuring institute to carry out further investigations (see Section 5.1.2), the client should confirm that the necessary quality assurance has been carried out at the institution or in a laboratory and that the necessary experience is available (see Section 5.1.3.3).

5.1.3.1 Quality requirements for specialists conducting site inspections and sampling

Specialists for sampling and evaluating indoor pollutants usually have a university or college degree in biology, chemistry or engineering or a technical qualification in a relevant field of work. In addition, specialist training in the subject of 'mould' is required.

UBA's website summarises the requirements for specialists, remediation companies, doctors, lawyers, etc. (https://www.umweltbundesamt.de/en/topics/health/environmental-impact-on-people/mould).

A working group at Landesnetzwerk Schimmelberatung NRW (NRW Mould Advice Network) has come up with proposals for standardising trade qualifications for the remediation of moulds and has defined the term for it: "Expertise for the detection, evaluation and remedying of mould damage" (http//www.schimmelnetz-nrw.de).

5.1.3.2 Quality requirements for mould detection dogs

For a successful job, it is imperative that a well-trained dog handler leads the mould detection dog.

For dog training, it is helpful if the dog handler completes the training with his dog as a team. The dog handler must have a close bond with his mould detection dog in order to correctly interpret the behaviour and signals from the dog. Regular training with suitable odour samples is required to ensure the quality of the mould detection dog's work.

Training the dog team is an ongoing process and requires regular quality reviews. The dog is trained to mark the areas that have a notable mould odour by displaying particular behaviour (e.g. display with the paw or nose) and thus to signal to the handler that mould is present.

Judgement of whether a dog/dog handler team is well-trained, is very difficult for the client to investigate. An important pointer is a certificate of successfully completed further education and testing of the respective dog/dog handler team. Exams must be carried out by independent institutions on the basis of standardised examination regulations.

Guidelines from relevant associations provide the requirements for dog behaviour tests and tests to find mould samples.

5.1.3.3 Quality requirements for test laboratories

For most investigations on indoor moulds there are standardised procedures (see Section 5.1.2). Preference should be given to test institutes that are accredited for these procedures in accordance with DIN EN ISO/IEC 17025 (see DAkkS database for accredited test centres) or have performed comparable analytical quality assurance.

For external quality assurance, the mycological laboratory must be able to demonstrate that it regularly and successfully participates in interlaboratory tests for the detection of mould fungi. For example, the Baden-Württemberg State Health Office regularly offers interlaboratory tests for the identification of mould fungi. In addition, individual associations regularly offer interlaboratory tests for air sampling and individual interlaboratory tests for the determination of total spore count.

As stated, there is no binding procedure prescribed to determine bacterial load in buildings; also there are no standardised detection methods so far. So it is frequently impossible to compare results from different test institutes. Thus the information given in the relevant reports with regard to the applied detection methods, evaluation criteria used and interpretation and evaluation of the results, is of particular importance.

5.2 Evaluation of the results

The procedures and investigations described in Section 5.1 and the evaluations described in Section 5.2 are intended to ascertain whether there is a mould source in the indoor area and where to locate it. To assess whether there is an indoor mould source, information in the site inspection protocol should be evaluated together with the results of further investigations if available in the overall context.

The health assessment of pollutants in indoor air is carried out in toxicology and environmental medicine usually with the help of health-related limiting, guideline or leading values. This approach is not so applicable to indoor moulds, as there are no health-related limiting or guideline values for mould fungi concentrations in indoor air, house dust or materials.

This is mainly due to the fact that to date no reliable exposure-response relationship has been determined between the occurrence of mould fungi in indoor air or in the indoor area and health (see Chapter 2). A quantitative assessment of longer-term exposure to mould using measurements of mould fungi concentration in indoor air is made more difficult by:

- mould fungus measurements are usually only performed once and only for relatively short periods (minutes to hours),
- the concentration of mould fungi in indoor air fluctuates substantially in terms of time and space,
- the spore formation in mould fungi species is vastly different – it is possible in large-scale mould infestations that inconspicuous spore concentrations occur in the room air,
- concealed infestation is not correlated to increased spore concentrations in indoor air,
- some species occur predominantly in the outdoor air,
- often only the cultivable mould fungi can be determined in indoor air,
- the influence of components and metabolic products (mycotoxins, MVOCs, cell components such as ß-glucans, ergosterol) is not sufficiently understood so generally they cannot be determined, and
- the health significance of other influencing factors (bacteria, endotoxins, allergens, house dust mites, etc.) in the case of mould infestation in indoor air and their synergistic effects are currently unknown.

The purpose of the measurement is therefore not a quantitative exposure estimation, but the location of mould sources indoors. If the assessment indicates that there is an indoor mould source, then location of the infestation and as a rule, remediation should take place (see Chapter 6). Indoor mould sources must be eliminated for health protection reasons, depending on utilisation class.

The following evaluation schemes help to detect the presence of a mould source and to assess the severity of the load from a hygiene point of view. They are not intended to derive a quantitative assessment of the risk of disease.

For clarification of the health complaints that arise and for which a connection with mould load is suspected, the doctor carries out a targeted medical history. The description of the procedure necessary for a medical evaluation is not part of this guideline. Information on medical diagnostics in case of mould infestation can be found in the AWMF guidelines[1].

The identification of an indoor mould source must not be equated with an acute health risk for the occupants. The extent of health risks posed by indoor moulds depends partly on the sensitivity and exposure of the occupants and partly on the nature and extent of the damage. Due to lack of scientific data, for example, in some instances exposure-response relationship cannot normally be quantified accurately.

However, as epidemiological studies have shown that adverse health effects can be associated with moisture damage and mould growth in indoor areas (see Chapter 2) **indoor mould infestation can be considered a hygiene problem and should be professionally eliminated depending on utilisation class.**

A precautionary principle applies – namely potentially harmful exposures to mould infestation should be minimised before any illness occurs.

1 WMF Mould Fungi Guidelines “Medical Clinical Diagnosis for Mould Exposure indoors” AWMF Register No. 161-001 – Final Version

5.2.1 Assessment in the case of visible mould infestation

As a rule, mould pollution in indoor air can be traced back to infested or contaminated materials.

The assessment of whether indoor mould infestation is classified as low and therefore considered an acceptable negative impact, or as significant and therefore an unacceptable negative impact is based on the extent of the damage and the utilisation class. It is assumed that a smaller infestation produces less biogenic pollutants than a larger infestation both in terms of surface and depth.

The extent of the damage is classified into the following three categories to provide an assessment aid for Utilisation class II (see Section 6.1) in the case of visible mould infestation, and to establish whether the mould infestation is an unavoidable normal condition or an avoidable problem (see Table 8). For Utilisation class III, the urgency of the remediation is lower, and the scope of the recommended measures can be reduced (see Section 6.1).

Category 1: normal condition or minor mould infestation.
Emergency measures are usually not required. The cause should be identified and remediation action should be taken. Typical examples of minor mould infestation are mould-covered silicone seals in bathrooms and on window joints or mould growth on potting soil.

Category 2: low to medium mould infestation.
The release of mould components should be stopped in a timely manner, the cause of the infestation should be determined and remedied in the medium term and the mould infestation should be removed.

Category 3: Extensive mould infestation.
The release of mould particles should be stopped immediately, and the cause of the infestation should be determined and eliminated in the short term.

The persons concerned must be informed about the situation in a suitable manner. The remediation should be carried out by a specialist firm (see Chapter 6).

Table 8

Assessment of materials with detectable, mostly visible mould infestation on their surfaces

Extent of damage	Category 1 Normal condition or minor mould infestation	Category 2 Low to medium mould infestation	Category 3 Extensive mould infestation
Growth on the surface and in the medium	Minor surface damage ‹ 20 cm^2	Superficial growth ‹ 0,5 m^2, deeper layers are only affected locally	Large surface growth › 0,5 m^2, deeper layers can also be affected
Resulting microbial biomass	No or very little microbial biomass	Medium microbial biomass	Large microbial biomass

The surface data in Table 8 should not be used as absolute values, it only provides orientation. An assessment should always examine the individual case and special circumstances. In particular, the following points should be noted:

- The assessment of visible mould growth should also consider the depth and type of infestation in addition to the extent of the damage. This depends on the infested material. The categories apply to lawn-like growth. In the case of point-shaped growth, the area actually covered is estimated.

- The specified surface categories do not necessarily have to exist as a contiguous expansion but are generally to be understood per room area. An area may be an office space, a living space or an open plan living space such as a living and dining room. In practice, there can be an infestation in several room corners whose individual surfaces are added together.

- In practice, the estimation of the area overrun with mould takes place by means of visual inspection. This must also include mould that is not yet visible to the naked eye. In case of doubt, it makes sense to confirm the infestation with adhesive film samples (see Section 5.1.2.1).

- A distinction should be made between an active infestation and dried-out old damage. In the case of an active infestation, it must be considered that such damage can continuously release high levels of viable spores and metabolites over a longer period of time. In the case of dried-out old damage, the spore concentration and metabolism production generally decrease over time. In addition, an active mould infestation often provides the nutrient base for other health-related organisms such as mites.

- In the case of a mould infestation that only becomes visible after the component has been opened, a categorisation analogous to the directly visible infestation should be carried out.

The assessment of visible mould growth should also consider the depth and type of infestation in addition to the extent of the damage. The overall assessment of the extent of damage should also consider the infestation in deeper layers and hidden infestations in addition to those that are visible. In the case of a hidden infestation, a case-by-case assessment must be carried out depending on the biomass and the probability of exposure.

5.2.2 Assessment of material samples

In the case of suspected mould damage, comparing the concentrations of mould fungi and/or bacteria in material samples obtained with concentrations in unpolluted materials can determine whether relevant growth has taken place in the material and whether the material must therefore be removed. It is also important to include investigations using microscopy (see Annex 6).

Since the detection method for **mould fungi** was first standardised in 2014, only a few standardised comparison concentrations are available. A research project funded by the German Environment Agency collected background concentrations for different materials (UBA, 2015: Determination of base concentrations of mould fungi in insulating materials and other interior materials with regard to remediation recommendations, FKZ 3710 62 223). Growth in the material can be assumed for most materials from new and old buildings alike, starting from a concentration range of 10^5 CFU/g of material. Concentrations in the range of 10^3 CFU/g to 10^4 CFU/g indicate active growth in materials straight from the factory and in materials stored dry on the building site. Since the study examined only 391 material samples and therefore only about 20 to 30 samples per category (material of a certain age), the results should only be taken as initial signpost values that must be substantiated by further investigations.

However, the orders of magnitude coincide in principle with published assessment values from the experience of individual laboratories (Trautmann, 2005, Richardson and Grün, 2005).

There are no uniform comparison values to determine the concentration of **bacteria** (total CFU) in materials. However, experience shows that the concentrations of bacteria are approximately one order of magnitude higher than the levels of mould fungi.

For the evaluation of mould infestation in floors, reference is made to the recommendation for action for moisture damage in floors (see Infobox 13 and Annex 6). This recommendation also provides guidance for evaluating the results of microscopic investigations.

INFOBOX 13

Assessment of mould infestation in floors

The Indoor Air Hygiene Commission (IRK) of the German Environment Agency (UBA) has developed a recommendation for action on how floors with moisture damage can be assessed (see Annex 6). It considered practical experience, which in many cases enabled a quick assessment without time-consuming investigations. This recommendation is aimed at experts in mould fungi, construction experts, insurance experts and other professionals who in their daily practice face the decision whether a floor with moisture damage must be removed due to hygiene considerations or if simple measures such as edge joint sealing are feasible.

When dealing with mould infestation in floors, the recommendation for action for assessing moisture and mould damage in floors should always be used in addition to the general recommendations in the guideline.

5.2.3 Assessment of air samples

Assessing the concentration and composition of mould fungi spores in indoor air serves primarily as an indication of invisible (hidden) mould.

Judging the probability of the presence of a mould source in the indoor space using air samples requires a high level of expertise. An isolated studying of only the results of indoor air measurements may lead to an erroneous assessment of the case. The specific individual situation must be assessed in each case taking into account both from all information obtained during the site inspection and in further investigations. It must be born in mind that the results of airborne bacteria counts may not contain evidence of indoor sources, despite the presence of extensive mould damage.

The seasonal and possibly local influence of outdoor air on species composition, on the concentration of cultivable mould fungi or on the total spore count must be particularly taken into account when assessing air samples. Annex 7 and Annex 8 contain tables with empirical values for concentrations of cultivable mould fungi and for the total spore count in indoor and outdoor air in summer and winter in Germany.

When assessing the results, it must be remembered that these are short-term measurements. Mould fungi concentrations in indoor air can have high temporal and spatial fluctuations since fungi spores are not evenly distributed in the room and their concentration can change from day to day.

Assessment of the concentration and composition of mould fungi spores in indoor air serves predominantly as an **indication** of invisible (hidden) **mould infestation.**

A quantitative exposure and risk assessment is not possible and the derivation of health-related guidelines or limiting values is also not expected in the near future.

For specific health issues in individual cases, it may be useful to use additional methods for the detection of certain types of mould fungi (e.g. by cultivation at 36 °C for pathogenic and facultatively pathogenic species).

Determining the genus or species composition of an air sample is necessary in order to detect differences in the spectrum vis-à-vis outdoor air and the occurrence of fungal genera or species indicating moisture or structural damage (moisture indicators, see Chapter 1). Certain problems in individual cases may also require the detection of mould fungi that have a special health significance (e.g. *Aspergillus fumigatus, Stachybotrys chartarum)* (see Section 5.2).

Furthermore, it must be taken into account that spores from different species of mould fungi can have very different airborne dissemination capabilities. Therefore, in order to assess the sources of mould in an indoor space, it is important to distinguish the individual species of mould fungi according to their nature of spore dissemination.

Experience shows that mould fungi species with dry spores with a good airborne dissemination capability can lead to increased spore concentrations in the air, even in the case of minor material damage. The spores of these species are usually relatively small and are formed in large numbers. They are not embedded in a slime matrix which means that individual spores or small spore aggregates can be easily spread by slight air movements. The leading species for this type of dissemination are species of genera *Penicillium* and *Aspergillus*. However, significantly lower air pollution can be detected when materials are colonised by mould fungi whose spores are relatively large or are collected in slime substances after their formation and therefore have a poor airborne dissemination capability. The leading species for this type of dissemination are many species of the genera *Acremonium* or *Fusarium* and *Stachybotrys*.

The following assessment aids have the aim of determining the probability of the presence of a hidden or invisible mould infestation. The measured values do not provide for a quantitative exposure and risk assessment with regard to health effects.

The three ranges given below can be used as assessment and orientation aids for determining mould fungi in indoor air (see Tables 9 and 10):

- the **background load** range for important mould fungi genera or species,
- a **transition range** within which there are elevated concentrations of certain mould fungi genera or species that may indicate indoor sources,
- a range of concentrations that exceed this transition range and are **highly likely** to indicate an **indoor source.**

It is important to note that not all situations can be evaluated with the proposed scheme. A schematic approach based exclusively on Tables 9 and 10 is problematic. This means that assessing an air sample in late autumn, for example, may be difficult if the spore content of outdoor air is greatly reduced over a short period (October–November with cold and humid weather). During this period, sedimented spores originating from the outdoor air can strongly influence the result of an air sample taken in the indoor space (if they are disturbed before or during a sampling) and feign an increased load in the indoor air in relation to the outdoor air. Conversely, unusually contaminated outdoor air samples can also make it difficult to interpret the results. The application of the tables therefore requires a high level of expertise.

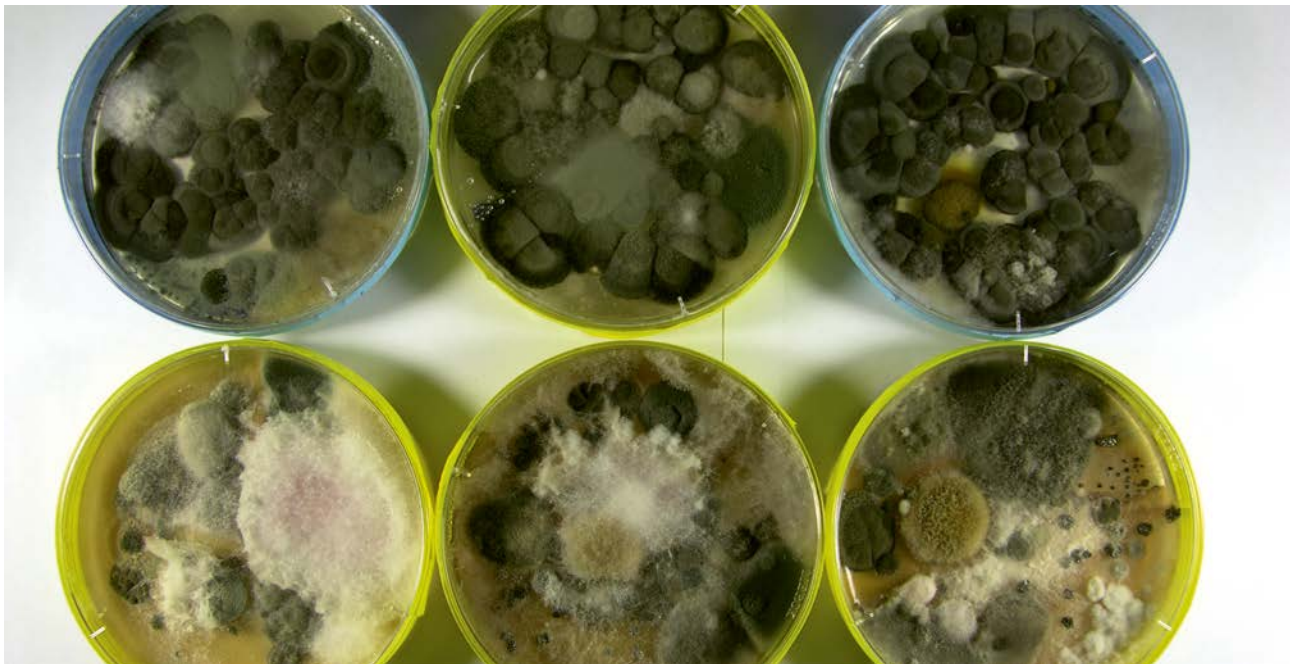


Table 9

Assessment aid for air samples – culturable mould fungi (CFU/m³)

Parameter	Background load indoor source unlikely	Indoor source possible	Indoor source likely
Cladosporium and other fungi genera that can reach elevated concentrations in outdoor air (e.g. sterile mycelia, yeasts, *Alternaria, Botrytis)*	If there are no more spores of a genus in indoor air than in outdoor air. $I_{otype} \leq O_{otype}$	If the concentration of a genus in indoor air is more than 1 times and up to 2 times that of outdoor air. $O_{otype} < I_{otype} \leq O_{otype} \times 2$	If the concentration of one genus in indoor air is more than 2 times that of outdoor air. $I_{otype} > O_{otype} \times 2$
CFU sum of all atypical outdoor air types	If the difference in concentration between indoor and outdoor air does not exceed 150 CFU/m³. $I_{\Sigma aotype} \leq O_{\Sigma aotype} + 150$	If the difference in concentration between indoor and outdoor air is between 150 CFU/m³ and 500 CFU/m³. $O_{\Sigma aotype} + 150 < I_{\Sigma aotype} \leq O_{\Sigma aotype} + 500$	If the difference in concentration between indoor and outdoor air exceeds 500 CFU/m³. $I_{\Sigma aotype} > O_{\Sigma aotype} + 500$
***One* genus** (CFU sum of all related species) of atypical outdoor air types.	If the difference in concentration between indoor and outdoor air does not exceed 100 CFU/m³. $I_{Ogatype} \leq O_{Ogatype} + 100$	If the difference in concentration between indoor and outdoor air is between 100 CFU/m³ and 300 CFU/m³. $O_{Ogatype} + 100 < I_{Ogatype} \leq O_{Ogatype} + 300$	If the difference in concentration between indoor and outdoor air exceeds 300 CFU/m³. $I_{Ogatype} > O_{Ogatype} + 300$
***One* species** of atypical outdoor air types with good airborne dissemination e.g. *Aspergillus* spp.	If the difference in concentration between indoor and outdoor air does not exceed 50 CFU/m³*. $I_{Oaotype} \leq O_{Oaotype} + 50$	If the difference in concentration between indoor and outdoor air is between 50 CFU/m³ and 100 CFU/m³* $O_{Oaotype} + 50 < I_{Oaotype} \leq O_{Oaotype} + 100$	If the difference in concentration between indoor and outdoor air exceeds 100 CFU/m³. $I_{Oaotype} > O_{Oaotype} + 100$
***One* species** of atypical outdoor air types with poor airborne dissemination e.g. *Phialophora* spp., *Stachybotrys chartarum*	If the difference in concentration between indoor and outdoor air does not exceed 30 CFU/m³*. $I_{Oaoptype} \leq O_{Oaoptype} + 30$	If the difference in concentration between indoor and outdoor air is between 30 CFU/m³ and 50 CFU/m³*. $O_{Oaoptype} + 30 < I_{Oaoptype} \leq O_{Oaoptype} + 50$	If the difference in concentration between indoor and outdoor air exceeds 50 CFU/m³. $I_{Oaoptype} > O_{Oaoptype} + 50$

The five lines of the table are not meant to be independent criteria but should be considered together in a comprehensive assessment.
The data refers to air samples that were taken under normal use or similar conditions in normal living rooms without raising dust in accordance with DIN ISO 16000-16 and DIN ISO 16000-18 (see also Annex 7).

* Concentrations of less than 100 CFU/m³ or less than 50 CFU/m³ cannot be detected with satisfactory accuracy in a sample volume of 100 l or 200 l since quantitative evaluation with sufficient statistical certainty is only feasible above 10 colonies per slide. Nevertheless, the detection of individual colonies of these mould fungi may give an initial indication of a potential indoor source.

CFU Colony forming units

I Indoor air concentration in CFU/m³

O Outdoor air concentration in CFU/m³

otype typical outdoor air species or genera (extramural fungi such as *Cladosporium*, sterile mycelia, possibly yeasts, possibly *Alternaria*, possibly *Botrytis*)

aotype atypical outdoor air species or genera (intramural fungi such as fungi with high indication of moisture damage e.g. *Acremonium* spp., *Aspergillus versicolor, A. penicillioides, A. restrictus, Chaetomium* spp., *Phialophora* spp., *Scopulariopsis brevicaulis, S. fusca, Stachybotrys chartarum, Tritirachium (Engyodontium) album, Trichoderma* spp.)

Σaotype Sum of atypical outdoor air species (other than *otype*)

Oaotype ***One*** species that is atypical in outdoor air with good airborne dissemination

Oaoptype ***One*** species that is atypical in outdoor air with poor airborne dissemination

Ogatype ***One*** genus that is atypical in outdoor air

Table 10

Assessment aid for air samples – total spore collection (spores or mycelial fragments/m³)

Spore type	Background exposure indoor source unlikely	Indoor source possible	Indoor source likely
spore types that can reach elevated concentrations in outdoor air e.g. Ascospores type *Alternaria/Ulocladium* type, Basidiospores type *Cladosporium* type	Counting basidio- and ascospores from typical outdoor air species is not relevant for detecting mould sources. However, an outdoor air influence can generally be detected from the concentration of these spores and a plausibility test can be carried out on the specified sample origin (outdoor air, indoors, storage, cellar). When assessing spores of the *Cladosporium* and *Alternaria/Ulocladium* genera in the case of indoor infestation, it is not possible to define general concentrations that indicate mould growth because outdoor air concentrations fluctuate widely, the depot effect of settled dust and poor spore release. When mould infestation with *Cladosporium* spp. is suspected, whether the same types of *Cladosporium* occur outdoors and indoors should in particular be checked.		
Penicillium/Aspergillus type	If the concentration difference between indoor air and outdoor air does not exceed 300 spores/m³ $I_{\Sigma P+A} \leq O_{\Sigma P+A} + 300$	If the concentration difference between indoor air and outdoor air is between 300 spores/m³ and 800 spores/m³ $O_{\Sigma P+A} + 300 < I_{\Sigma P+A} \leq O_{\Sigma P+A} + 800$	If the concentration difference between indoor air and outdoor air exceeds 800 spores/m³ $I_{\Sigma P+A} > O_{\Sigma P+A} + 800$
Other typical spores from moisture damage *Scopulariopsis* type *Acremonium.murorum* type *Paecilomyces* type *Microascus* type *Ascotricha* type (*Alternaria* type, *Ulocladium* type)	If the concentration difference between indoor air and outdoor air does not exceed 100 spores/m³ $I_{\Sigma mtype} \leq O_{\Sigma mtype} + 100$	If the concentration difference between indoor air and outdoor air is between 100 spores/m³ and 300 spores/m³ $O_{\Sigma mtype} + 100 < I_{\Sigma mtype} \leq O_{\Sigma mtype} + 300$	If the concentration difference between indoor air and outdoor air exceeds 300 spores/m³ $I_{\Sigma mtype} > O_{\Sigma mtype} + 300$
Typical spores from moisture damage with poor airborne spread *Chaetomium* type *Stachybotrys* type *Chromelosporium* type *Pyronema* type	If there are less spores in the indoor air than in the outdoor air $I_{mptype} \leq O_{mptype}$	If the concentration difference between indoor air and outdoor air does not exceed 20 spores/m³* $O_{mptype} < I_{mptype} \leq O_{mptype} + 20$	If the concentration difference between indoor air and outdoor air exceeds 20 spores/m³* $I_{mptype} > O_{mptype} + 20$
Mycelial fragments	If the concentration difference between indoor air and outdoor air does not exceed 150 mycelial fragments/m³ $I_{mycel} \leq O_{mycel} + 150$	If the concentration difference between indoor air and outdoor air is between 150 mycelial fragments/m³ and 300 mycelial fragments/m³ $O_{mycel} + 150 < I_{mycel} \leq O_{mycel} + 300$	If the concentration difference between indoor air and outdoor air exceeds 300 mycelial fragments/m³ $I_{mycel} > O_{mycel} + 300$

The five lines of the table are not meant to be independent criteria but should be considered together in a comprehensive assessment.
The data refers to air samples that were taken under normal use or similar conditions in normal living rooms without raising dust in accordance with DIN ISO 16000-20 (see also Annex 8).

* Concentrations of less than 10 spores/m³ or less than 5 spores/m³ cannot be detected with satisfactory statistical accuracy in a sample volume of 100 l or 200 l even when evaluating the total track, since quantitative evaluation is only feasible above 10 spores per slide. Nevertheless, the detection of individual spores of these moulds may give an indication of a potential indoor source.

O Outdoor air concentration in spore count/m³,

I Indoor air concentration in spore count/m³

ΣP+A Total spore count of *Penicillium* and *Aspergillus* types

Σmtype Total count of other typical spores from moisture damage

mptype Spore types from moisture damage with poor airborne dissemination

5.3 Expert reports

There are no uniform regulations prescribing the form or structure of expert reports. However, an expert report must be understandable and comprehensible to the reader. Useful expert reports therefore have an established structure:

- Cover page/Introduction
- Reason for the investigation
- Tasks/Mission and objectives of the report/Aim of measurements
- Site investigation and local findings
- Procedure/Measurement plan/Measurement strategy/Measurement methods
- Sampling protocols
- Test results
- Conclusions/Evaluation basis
- Summary/Recommendations for further action
- Annexes and documentation (e.g. Measurement protocols/Laboratory findings/Photo documentation/Evaluation basis)

Health diagnoses for individuals concerned are the responsibility of a medical doctor and cannot be given by a scientific expert.

Conclusions about the influences on general health of proven mould fungi such as being potentially toxic or infectious are not useful and should not be included in expert reports, they only would lead to uncertainty of those affected and provide no practical information for specific cases.

However, general conclusions about the urgency or extent of remediation in consideration of the potentially harmful effects of mould infestation, as described in the Guideline, are possible.

The expert report should describe and evaluate as comprehensibly and precisely as possible all building-related and other circumstances which may have caused the problem to enable a court to decide, if necessary, what is the primary cause of the damage.

6

Measures in the event of damage

The causes that lead to mould infestation must always be clarified and eliminated before a mould remediation (see Chapters 3 and 4). In the event of damage, intensity and extent of mould infestation (see Section 5.2.1) and the utilisation class (see Section 6.1) must be considered when assessing the urgency of the measures to be taken.

It is also important to consider if the mould can be eliminated by the occupants themselves (see Section 6.2) or if a specialist firm must be involved (see Section 6.3). The use of biocides is usually not required; important aspects of their application are summarised in Section 6.4. Section 6.5 briefly describes building reconstruction measures after remediation and Section 6.6 deals with activities after completion of all work.

When choosing different remedial measures (e.g. dismantling or sealing), it should be considered that microorganisms may not be the sole accompanying factor of mould infestation and small and highly mobile biogenic particles or substances may also occur (see Section 2.2).

6.1 Utilisation classes

For the first time, the guideline introduces utilisation classes (room classes) with distinct requirements and recommendations in terms of remedial measures. The background is that mould infestation in indoor areas and areas of buildings where one resides permanently or temporarily, represents a higher health risk to room occupants than mould in neighbouring rooms some distance away from commonly used rooms which people use infrequently or only use them as a storage room or a garage. In addition to the type and duration of use, the fact that the rooms are within or outside the flat (or the office) is the key aspect for allocating rooms to utilisation classes.

A room for the purposes of this recommendation is generally a self-contained part of a building formed by the floor, ceiling and walls. The recommendations extend to all building structures and areas adjacent to a room, including any cavities that are either permanently or temporarily in contact with the room air or from which the diffusion of substances hazardous to health into the room cannot be ruled out. In addition to the type and duration of use, the fact that the rooms are within or outside the flat (or the office) is the key aspect for allocating rooms to utilisation classes.

The subsequent sections describe the distinct requirements for remediation of mould infestation taking into account the utilisation class.

All the recommendations in Chapter 6 generally apply to Utilisation class II (see Section 6.1.2). Special attention is drawn to possible different requirements for Utilisation class III (see Section 6.1.3).

6.1.1 Utilisation class I

Rooms with special hygienic requirements, especially for patients with immunosuppression, form Utilisation class I (see Table 11). The Guideline does not deal with necessary measures for such cases as they are covered by separate recommendations such as Hospital hygiene.

6.1.2 Utilisation class II

Rooms with adjoining rooms used regularly or over longer periods form Utilisation class II (see Table 11). All requirements described in the Guideline apply here in principle. Adjoining rooms within a flat or office may be pantries, cloakrooms or storage rooms of all kinds. Attic rooms, directly accessible from the living level e.g. via a staircase are also adjoining rooms within the residential space. The same high standards apply in such rooms as in the rest of the flat because it cannot be ruled out that mould components can get from these adjoining rooms into the other rooms of the flat.

6.1.3 Utilisation class III

Cellar rooms in multi-family houses or office buildings where access to the cellar is separate from the courtyard or the staircase but not from the flat (or office), and garages or other adjoining rooms outside the rooms of Utilisation class II create Utilisation class III (see Table 11). The Guideline's requirements do not fully apply here. This may concern both the urgency of a remedial measure and the nature and extent of the measure itself. Attic floors not developed and accessible via a roof hatch or a lockable door from the staircase outside the flat, also belong to Utilisation class III. Staircases in multi-family houses are also covered by Utilisation class III.

Table 11

Utilisation classes in buildings

Utilisation class	Requirements for indoor hygiene	Example	Comments
I	Special, very high requirements due to an individuals' disposition	Rooms for patients with immunosuppression	Not covered by this guideline; the requirements need separate agreements
II	Normal requirements	Indoors for longer term residential use: living or office space, schools, day-care centres, etc. adjoining rooms	The same requirements apply to all rooms used (i.e.all rooms of a flat including adjoining rooms within the flat)
III	Reduced requirements	Spaces not used permanently **outside** of homes, offices, schools, etc., e.g. cellars and storage rooms (without direct access to the flat), non-developed attics and garages or staircases	Reduced requirement level for remediation and repair, less urgent remediation

6.2 Remediating a minor mould infestation

Mould infestation of a minor to medium extent (< 0.5 m², superficial infestation only, see Section 5.2.1, Table 8) with a known cause can often be eliminated by those affected unless they are allergic to fungi or suffer immune system disorders. If the infestation is large or has a minor to medium extent and its cause is not known, a specialist firm should be involved (see also Figure 23 and Section 6.3). It is imperative to immediately start mould remediation so that infestation cannot expand.

Remediation measures may be waived entirely in the case of minor mould infestation (Category 2, Chapter 5) in Utilisation class III, depending on the type of use and local conditions.

It is important for all remediation measures to disturb as little dust as possible to minimise the spread of mould spores with dust and air movement. Moist cleaning (wiping) is therefore always preferable to dry suction. When hoovering, only devices with additional filters (high efficiency particulate air or HEPA filters) should be used. Sweeping should be avoided altogether as it unnecessarily disturbs and spreads dust.

6.2.1 Measures occupants can take

The following issues should be considered:

- **Smooth surfaces:** It is sufficient to wash off smooth surfaces (tiles, ceramics, glass, metal and tile joints) using water and household cleaner to remove infestation, contaminated dust or dirt. The water should be changed frequently to prevent uncontrolled spreading or smearing. Silicon joints in the bathroom noticeably infested with mould should be replaced because they cannot normally be cleaned. Tenants should in any case consult the landlord. It is advisable to use special sanitary silicone (low-emission types if possible, instructions for use of the product to be consulted) for new jointing and to thoroughly cleanse the sublayer beforehand.

- **Porous surfaces:** Plastered or painted walls can be wiped with an alcoholic cleaner containing 70 % to 80 % alcohol or a common household detergent (not vinegar) using a microfibre cloth. Before that, one can hoover using a commercially available vacuum cleaner equipped with an additional filter (HEPA filter) and an airtight housing. Vacuum cleaner bags can be disposed of in the household waste. When cleaning with alcohol, good ventilation must be ensured!

Alcohol should only be used in small quantities due to fire and explosion risk. Smoking or using naked flames is not permitted under any circumstances.

- For **furniture** wet cleaning may be applied to contaminated wardrobe backs, for example. If mould has already heavily penetrated the material (e.g. severely mouldy or moisture-swollen chipboards), affected parts of the furniture must be disposed of. The infested part of the piece can be covered with a foil prior to disposal in order to prevent the spores from spreading. Solid wood furniture is usually not affected, and cleaning is almost always possible because mould on solid wood is usually superficial.

- For **upholstery and upholstered furniture,** a distinction must also be made between infested material on which moulds have grown and pieces of furniture that have only been secondarily contaminated with mould spores from the air. Infested upholstered furniture is often difficult to clean as the mould may have penetrated upholstery deeply, especially if it has acted over a long period. Cleaning is then often not possible using only reasonable effort and in case of doubt the furniture should be disposed of. Upholstered furniture that is not infested but has only been standing in an area where infested materials occur and is therefore contaminated with spores and other microbial components, can be cleaned by intensive suction (special vacuum cleaner with HEPA filter and airtight housing). Vacuum cleaner bags can be disposed of in household waste.

- Infested **wallpaper** should be moistened and removed. Contaminated **textiles,** e.g. curtains or blankets, even garments, should be carefully removed and washed in the washing machine (possibly several times) or dry cleaned. However, stains and odour caused by mould under certain circumstances cannot be removed and the textiles must be disposed of in these cases.

6.2.2 Measures by specialist firms

In the case of minor to medium mould infestation (Category 2, see Section 5.2.1, Table 8), specialist firms should be consulted if the mould has penetrated the building materials deeply and the plaster must be removed, or the cause of infestation is unclear.

INFOBOX 14

Personal protective and precautionary measures when removing small mould infestations

- Do not touch the mould with your bare hands – wear protective plastic gloves (available in drugstores or DIY warehouses),
- Avoid breathing in mould components as much as possible – wear simple respiratory protection (available in DIY warehouses) and dispose of them after use!
- Wear safety goggles when executing overhead work or if there is a risk of splashing!
- Wash clothes thoroughly after carrying out the measures!
- Infested items and materials that are no longer usable must be packed in tear-resistant plastic bags (e.g. plastic rubble sacks) as air and dust-tight as possible and disposed of with household waste! In order to avoid the unnecessary spread of spores in the room air, avoid 'forcibly expelling' the air when closing the bags.

INFOBOX 15

What specialist firms are qualified to carry out a remediation?

There is currently no national 'authorisation or certification body' for mould remediation firms.

A firm specialising in remediation must be able to professionally organise, prepare and execute remediation of a mould infestation. There is currently no training on the job that comprehensively conveys the knowledge and skills required for mould remediation. Also, there is no official verification or approval process for firms specialising in remediation (from VdS 3151 "Guidelines for mould fungi remediation after tap water damage").

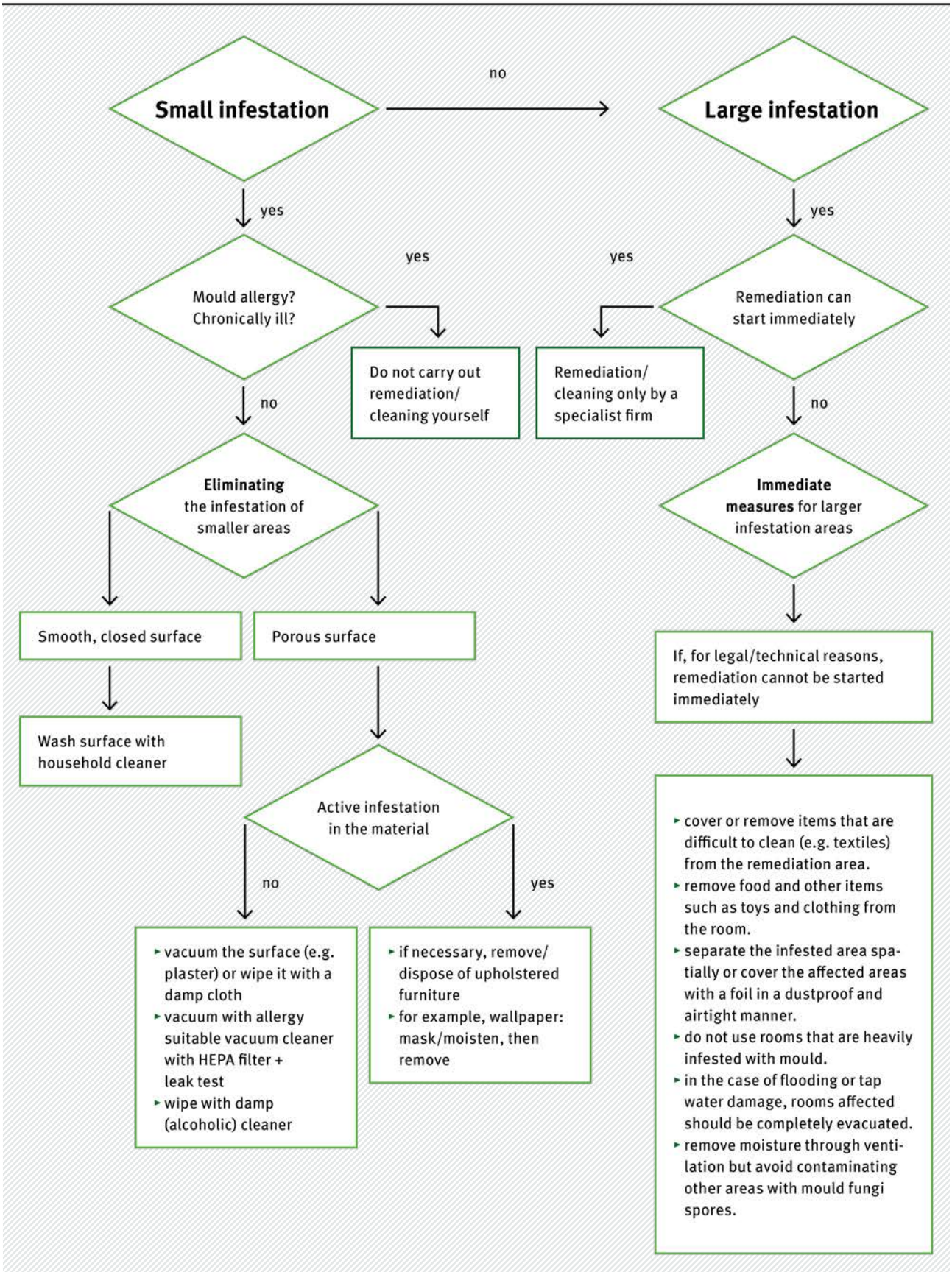
Information on quality criteria for specialist firms can be found on the German Environment Agency's website (https://www.umweltbundesamt.de/en/topics/health/environmental-impact-on-people/mould).

Mould remediation is not a targeted activity within the meaning of the Biological Agents Ordinance, which focuses on the sensitising and toxic effects of biological agents. The specialist knowledge requirements as outlined by the Biological Agents Ordinance are concretised in the Technical Rules for Biological Agents (TRBA) 200. Among others, the Biological Agents Ordinance requires specialist knowledge in order to carry out a risk assessment. Furthermore, in the case of high protection levels, the employees' specialist knowledge and the appointment of an expert are also required (see Section 6.2.2).

Various associations and institutions offer regular further education, training courses and seminars that teach the necessary specialist knowledge (e.g. microbiology, building physics and basics of hygiene, planning, coordination and verification of the remediation success, etc.).

Figure 23

Procedure (flowchart) for the elimination of small and large mould infestation, explanations in the text



Source: German Environment Agency 2016

6.3 Remediating a large mould infestation

The professional remediation of a large mould infestation (Category 3, see Section 5.2.1, Table 8) is best left to specialist firms that have the necessary specialist knowledge and the technical capabilities. However, the occupant may have to take immediate measures in advance to cover delays until the start of the remediation. Such measures can include the partitioning of infested areas or rooms, intensified ventilation of the flat as well as cleaning or separation of infested furniture and items (see Section 6.3.2).

The remediation must observe the pertinent health and safety regulations (see Section 6.3.1). The process of remediating a large mould infestation involves the following steps:

- Immediate measures, if necessary (see Section 6.3.2)
- Identifying the extent of the damage caused by the mould infestation, preferably by independent experts (see Section 6.3.3)
- Identifying the cause/s of elevated humidity and of the mould infestation (see Section 6.3.4)
- Removing the cause/s of the infestation (see Section 6.3.4)
- Carrying out the mould remediation
  - Removing materials infested with mould (see Section 6.3.5)
  - If necessary, drying damp building materials (see Section 6.3.6)
  - Cleaning items after the removal of contaminated building materials in order to remove contaminated dusts (also called deep cleaning, see Section 6.3.7)
- Quality control by independent experts (see Section 6.3.8)
- Reconstruction (see Section 6.5)
- Verification and, if necessary, cleaning the items to be brought into the room, and cleaning the item after completion of all measures (see Section 6.6)

The order can vary and is not compulsory. Before the start of remediation, it is necessary to check whether contact with the contaminated material or an activity with increased exposure to mould can be expected. In the context of the risk assessment, the necessary protective measures must be specified.

In the case of mould infestation in Utilisation class III, the bullet points ‘extent of the damage’ (see Section 6.3.3) and ‘explanation of the cause’ (see Section 6.3.4) are treated the same as in Utilisation class II. The other points (immediate measures, elimination of causes, execution of mould remediation and control) can be treated in stages according to the use of the room (see corresponding Sections).

6.3.1 Occupational health and safety

The removal of mould-contaminated materials involves dusty work processes (e.g. chiselling off plaster) releases high levels of dust and microorganisms. This can lead to health problems, especially in the case of prolonged or frequent exposure to employees. The aim is to minimise the release of dust and spores during remediation by selecting suitable working methods.

Identifying and assessing hazards caused by biological agents:
The Biological Agents Ordinance (BioStoffV) applies to the activities of mould remediation. It regulates measures for the protection of employees and also describes measures for the protection of other persons who can be endangered by the remediation activities.

Remediation and cleaning works that remove mould infestation are not targeted activities within the meaning of the Biological Agents Ordinance. Generally speaking, mould remediation does not pose an increased risk of infection for employees; health risks particularly stem from the sensitising and toxic effects of biological agents. Sensitising biological agents include mould fungi and certain bacteria (including thermophilic actinomycetes). Toxic effects may stem from metabolic products or cell wall components (see Section 2.2).

The employer must carry out a risk assessment before the start of the remediation and determine the necessary protective measures. This must follow a special order. The exposure of employees must first be reduced through technical and organisational measures such as the use of machines with effective suction or mechanical ventilation measures. If these measures are not sufficient to remove a hazard, the use of personal protective equipment is required. Any deviation from this order of precautionary measures must be justified in the context of the risk assessment.

The reliable protection of employees is only possible if all influencing factors that can lead to a hazard are identified and assessed. Information about the expected biological agents and the activities to be carried out forms the essential basis of the risk assessment.

To carry out the risk assessment, the employer must specifically identify the following:

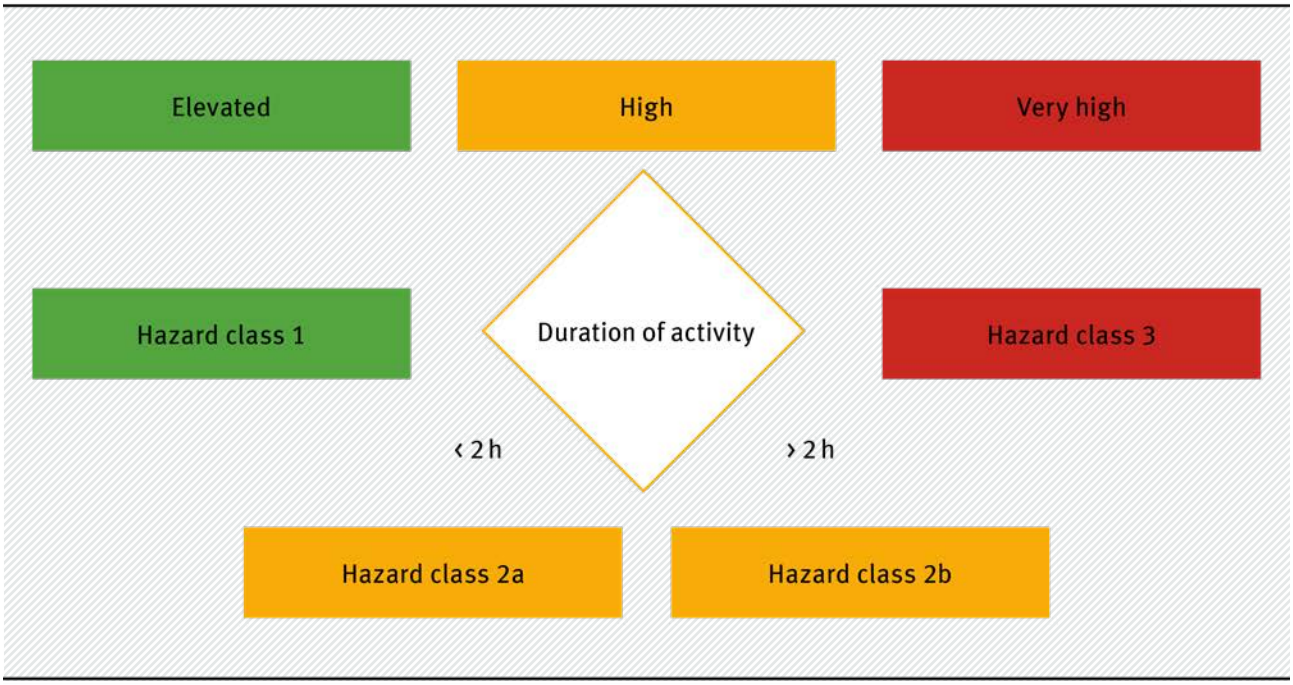
- Biological agents (mould fungi, bacteria and potentially pathogens from wastewater), their potential to cause an infection as well as possible sensitising and toxic effects, absorption pathways of the substances in the body, the cause, size and depth of the mould infestation
- Activities to be carried out considering the work procedure and the work equipment used
- Expected release of spores and dust during remediation
- Expected duration of the activities
- Possibility of using work procedures that lead to a lower risk for workers (substitution test).

The DGUV Information leaflet “Health Hazards due to Biological Agents in Building Renovation” (DGUV Information 201-028), which is available online, provides a guideline for the execution of the risk assessment and practical assistance in the selection of suitable protective measures.

The leaflet offers information on the expected spore concentration in the workplace for typical activities of mould remediation. Depending on the exposure and the duration of the activities, the activities are assigned to a hazard class (see Figure 24). It is usually not necessary to measure the concentration of mould fungi and bacteria nor to determine their species for a risk assessment based on the DGUV information.

Figure 24

Assigning activities to a hazard class depending on the expected exposure and duration of the activity



Source: DGUV Information 201-028, BG Bau 2016

Selecting adequate protective measures:
The required protective measures are based on the determined hazard class (see Figure 24).

The basic measures outlined in the Technical Rules for Biological Agents (TRBA) 500 must always be implemented when carrying out the activities. In addition to personal hygiene measures, these include technical, organisational and personal measures to reduce exposure. Basic protective measures include:

- Application of low-dust work methods
- Moistening the infested surfaces before removal
- Use of machines and devices with integrated suction
- Building ventilation measures
- Use of dust class H industrial vacuum cleaners

Further hazards:
Risk assessment must consider not only the biological impact but also the hazardous substances used in a biocide treatment and the presence of building pollutants such as old mineral wool insulation materials.

Table 12

Depending on the determined hazard class, the following protective measures are required (according to DGUV Information 201-028, BG Bau 2016)

Measures	Hazard class 1	Hazard class 2	Hazard class 3
Partitioning the work area	–	Dust-proof partition, transition area/personnel airlock[1] if necessary	Black and white separation using personnel airlock
Ventilation	–	Mechanical ventilation, if necessary	Mechanical ventilation
Respiratory protection	–	Half mask with P2 filter	Fan-assisted hoods or masks with P3 filter
Eye protection	In the case of splashing or overhead work		Always required
Protective suit	–	Dustproof protective suit	Dustproof protective suit
Hand protection	Waterproof gloves, for example, made from nitrile		

6.3.2 Immediate measures

In the case of a larger mould infestation, it may be necessary to take immediate measures if the remediation cannot be started in a timely manner. These measures are intended to minimise or eliminate exposure for the room occupants. The immediate measures depend on the type of room utilisation and on the duration of their occupation. In rooms assigned to Utilisation class III, the need for immediate measures is significantly lower depending on the use than in rooms assigned to Utilisation class II. Whether and what immediate measures are useful and necessary must be decided on a case-by-case basis. The personal susceptibility (predisposition) to microbial environmental impacts must also be considered if the occupants carry out measures themselves.

Immediate measures include:

- Informing the affected persons
- Restricting the duration of occupation
- Suspending utilisation and partitioning the contaminated rooms, sealing joints on doors with adhesive tape (marking rooms with ‘No entry’)
- Avoiding passive dispersal of microbial particles and dust and therefore dispose infested items on site or pack away
- Partitioning the infestation by (temporary) airtight covering with plastic sheeting; avoiding condensation under the partition
- Binding the infestation (painting with paint/lacquer as a transitional measure)

1 A compartment made from plastic sheeting and parallel sets of doors to reduce the transport of spores

- Cleaning dirty, non-microbially infested items taken from the rooms
- Using air purifiers or carrying out ventilation measures, whilst avoiding the passive dispersal of microbial components to other non-infested areas and endangering third parties

6.3.3 Identifying the extent of damage

A specialist remediation in both Utilisation class II and in Utilisation class III relies on investigating the item (specialist site inspection, see Section 5.1.1) and the exact knowledge of the cause of infestation and the total extent of damage (both in spatial extent and in terms of intensity). The sustainable success of the remediation is reduced if moisture or water damage within buildings is not fully identified and immediately and professionally eliminated. There continues to be the risk of consequential damage with negative effects to the building materials and room occupants.

Due to the complexity of building structures and materials, it must be checked whether other building areas have been penetrated by moisture and if mould growth has already begun. Moisture-sensitive components (e.g. wood liners, gypsum plasterboard, etc.) and cavities and layers that are not directly visible (e.g. screed insulation layers, shafts, etc.) must be particularly inspected. The determination of the spatial extent and intensity of the moisture in the building structure must also consider the 'water paths' – not only in the liquid state but also in the form of water vapour. Extensive moisture in concealed or prefabricated components can be present without being apparent or detectable by measurements on the surface. A permanently prevailing relative humidity above about 70 % is already sufficient for xerophilic mould fungi growth under otherwise optimal conditions (see Chapters 1 and 3).

6.3.4 Eliminating the cause of the damage

The causes of elevated moisture must be recognised and eliminated. Construction defects or structural damage must be eliminated. Moisture damage from accidents (flooding, leaks) must be dried as quickly as possible to prevent mould infestation. Tap water damage should be localised and repaired properly.

Any mould remediation must always start with the clarification and elimination of the causes of the occurrence of mould infestation.

If the infestation is visible and identified, mould should preferably be eliminated before mechanical drying to prevent the drying equipment from spreading bioaerosols. The Recommendation for action for moisture damage in floors (Annex 6) describes the procedure to deal with water intrusion in floors.

When searching for causes in damp components, a distinction must be made between surface moisture and water in the components.

Surface moisture:
Surface moisture occurs when the humidity is too high and/or the surfaces are too cold. If the search for causes detects too high surface moisture on the walls due to inadequate heat insulation or thermal bridges, the thermal insulation should be checked to see if it can be improved to increase surface temperature and prevent mould growth.

"Summer condensation", which mainly occurs in basement and cellar rooms or buildings not used permanently is a special case of high surface moisture. Special ventilation measures where the ventilation is regulated by moisture sensors detecting absolute humidity can prevent mould infestation in this case. In addition, dehumidifiers may be required. This in particular applies to Utilisation class II rooms. It is reasonable for Utilisation class III rooms to schedule the ventilation for early morning or late night in order to avoid elevated condensation moisture on the walls in the summer.

Component moisture:
Figure 25 illustrates some idealised moisture profiles in the external wall area depending on the cause of moisture penetration in the wall.

Suitable building diagnostics using moisture profiles and testing the building structure can determine the predominant moisture supply in the component considered (see WTA Leaflet 4-11, 2016). However, practical test results are much less unambiguous than those in Figure 25. Mixed cases may occur where several moisture profiles are superimposed. The cause of moisture supply must be identified by experts so that the infestation can be remedied with regard to the cause.

When no mould infestation has occurred in old buildings with no proper damp course on the outside, additional sealing measures need not necessarily be taken. Building experts can decide about such cases relying on their on-site analysis.

The following measures can help avoid elevated component moisture:

- Installation of a subsequent horizontal barrier against rising moisture by drill hole injection or mechanical methods. Under certain circumstances, the masonry must be renewed to create a horizontal barrier. WTA Leaflets 4-7-15/D and 4-10-15/D describe the methods of building a subsequent horizontal barrier (see Annex 4). WTA Leaflet 4-6-14/D provides information about the subsequent sealing of components in contact with the earth.

- Internal sealing: applying a multi-layered internal sealing system using rigid and flexible sealing slurry on the inside of the wall according to WTA Leaflet 4-6-14/D. When doing so, it must be borne in mind that moisture present in the wall can continue to rise unless this is prevented by a horizontal seal.

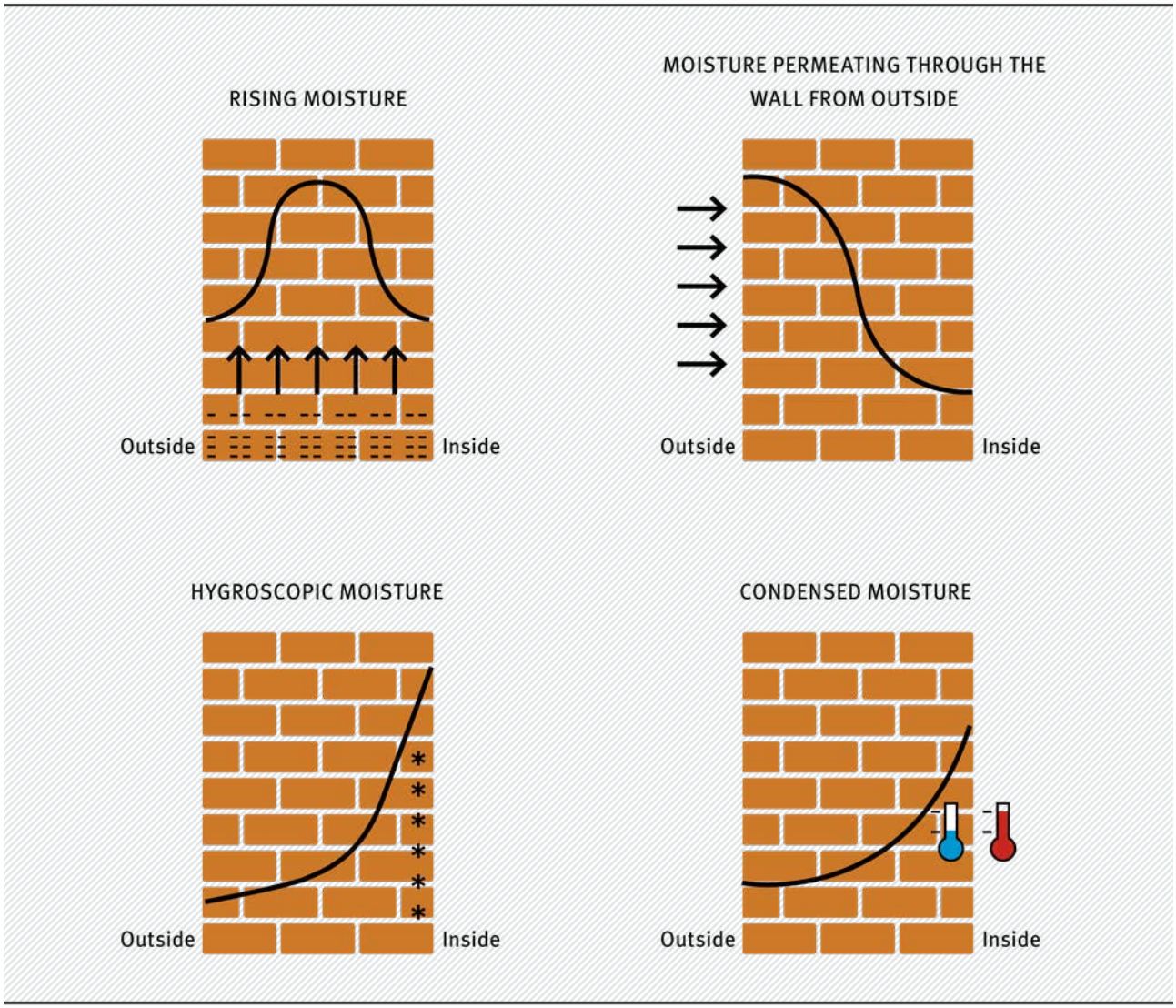
- Filling construction joints and cracks in concrete components: crack injection is carried out using resins (e.g. permanently elastic synthetic resins based on polyurethane) in order to positively fill cracks or leaking joints by high pressure.

For further technical specifications regarding drying and testing buildings, see also WTA Leaflet 4-12-16D (Annex 4).

For Utilisation class III rooms depending on the type of utilisation, it must be decided whether and what measures are necessary. No action is normally needed for moisture-insensitive objects stored in rooms that are infrequently entered. If the rooms are frequently accessed or they are to be used for the storage of moisture-sensitive materials, structural or ventilation measures may be required to improve the situation.

Figure 25

Moisture profiles in the wall



Source: Fraunhofer Institute for Building Physics, IBP

6.3.5 Removal of infested materials

Both the urgency of the remediation and the measures to be taken in the remediation itself largely depend on the type and frequency of the use of the room. The utilisation class must always be taken into account whether contaminated materials and components should be removed or support by other measures such as separation or sealing is needed.

The occupational safety and surrounding protection measures described above (see Section 6.3.1) must be carried out before the damaged structure is demolished or removed. The remediation area must be sealed off from the non-affected parts of the building and, if necessary, kept under a vacuum by mechanical ventilation.

Important aspects in the removal and processing of materials are:

- Removal of mould-infested materials can release large amounts of dust, mould fungus spores and other biogenic particles and substances. In order to minimise dust formation, these materials may be moistened before or during the demolition work or treated with a spore binder without biocide additive. Treatment with biocides does not normally make sense because the materials are removed anyway (applies to all utilisation classes).

- If lightweight walls, stud walls and partition walls (usually made of plasterboard) are infested with mould, they must be dismantled. As a rule, it is also necessary to remove any insulation materials installed (e.g. synthetic mineral fibre insulation) as they are also likely to be infested and it cannot be excluded that spores may enter the indoor air. Material up to about 30–40 cm beyond the affected zone or the moisture horizon should be removed. Removal is not always required in Utilisation class III, depending on the use of the room and material damage. It must only be confirmed that the insulation wool is properly dry (again) in this class after the remediation.

- When removing screeds with underlying footfall sound and heat insulation layers and when removing lightweight walls (gypsum plasterboards, synthetic mineral fibre insulation, etc.), low-dust and spore-binding methods must be used (e.g. moistening). An extraction system connected to the work area (e.g. exhaust hose of a filtered vacuum system) can absorb released dust and microbial particles (applies to all utilisation classes).

- If the plaster structure on the walls has already been damaged (salting-out, wearing down, saponification, softening) due to long-lasting exposure to trapped moisture, a partial removal of the plaster or mechanical removal with simultaneous HEPA filtered suction are the only remaining options.

- Exposed masonry and possibly concrete surfaces should first be carefully hoovered and properly scorched to the extent that is possible for fire safety reasons to remove adhering organic and microbial particles (applies to all utilisation classes).

- Superficial mould infestations on massive components e.g. wall plaster can best be eliminated by milling or grinding equipment with integrated dust extraction and downstream filtration (HEPA filter). If infestation has penetrated deeply into wall and ceiling plasters, the plasters must be removed. In Utilisation class III rooms it must be decided whether and to what extent the plaster must be removed depending on the use of the room.

- Abrasive methods (such as planing) can be used to remove mould on solid wood (e.g. rafters). Recommendations are also given in the DHBV Leaflet 02-15/S[2]. In Utilisation class III, superficial vacuuming/wiping is sufficient depending on the use of the room.

- When leaving the protected working area, all removed contaminated material should be transported in containers or airtight bags by the shortest possible route out of the building into containers (applies to all utilisation classes) as airtight as possible.

Microbially clearly infested materials that can be dismantled easily and thus economically such as plasterboard, wood-based panels or insulation materials should not be left in the building. In Utilisation class III rooms, depending on the type of use of the room and the damage to the material, it can be decided whether it is possible and sufficient to allow the materials to be left behind or to superficially remove the infestation by cleaning.

The UBA Recommendation for action for moisture damage in floors describes the procedure for mould infestation in insulation layers of floor structures in Utilisation class II rooms (see Annex 6). In the case of mould infestation in floor structures in Utilisation class III rooms, depending on the type of use of the room, it may be decided if the infested materials can be left there even if the infestation is obvious, or other alternatives such as suitable sealing measures should be applied.

2 DHBV Leaflet 02-15/S: Deutscher Holz- und Bautenschutzverband (German Timber and Building Protection Association): Schimmelpilzbefall an Holz- und Holzwerkstoffen in Dachstühlen (Mould infestation on wood and wood materials in roof trusses)

6.3.6 Drying methods

In all cases where moisture damage in buildings is so extensive that airing and heating alone are not sufficient to dry it out, mechanical drying methods must be employed. In Utilisation class III rooms that are only occasionally used and where moisture-resistant objects are stored, it may suffice to ventilate more often. Mechanical drying of buildings requires special expertise which must be proved to be acceptable.

Depending on the temperature and material, mould growth must always be anticipated if water damage lasts for several days or weeks. If microbiologically contaminated wastewater has entered the rooms it may have introduced pathogens. During drying, indoor hygiene must therefore be considered and no dust, fibres and mould constituents may be released and distributed.

Drying should be started as soon as possible after water damage has occurred so that no mould can grow and the damage is reduced.

Whether drying can be carried out and whether further use during drying is possible primarily depends on the following points:

- Type, extent and age of the damage;
- Type of moistened material and building construction;
- Extent of microbial contamination;
- Type of use (see Chapter 6.1);
- Health status of occupants (if present during drying)
- Type of drying.

Before installing the drying equipment, it must first be checked which areas the moisture has penetrated and whether a microbial infestation has already developed. Drying paper and cardboard does not make sense and often not for wood-based materials (OSB, hardboard or chipboard) either. If insulation materials have been infested, further investigations must clarify whether removal is necessary.

Various drying devices, procedures and methods (including condensation dryers, absorption dryers, hot plates, infrared radiation, see WTA 6-15-13/D) are available for various types of damage.

If components are infested by mould, care must be taken to ensure that no microbial constituents are released and distributed during drying. Methods must be used to prevent mould fungus spores, fibres from insulation materials and other particles (suction or suction/pressure method) from being released. If necessary, the rooms should be sealed off from unaffected rooms during drying.

Infested material must always be removed before the drying activities.

In addition to selecting the technology, successful drying requires the respective local conditions, the complexity of the materials affected and the use of the rooms to be taken into account. If the rooms are used during drying, only suction or suction/pressure methods are to be employed.

For Utilisation class III rooms, the extent of drying necessary must be decided depending on the type of rooms and the use of the room.

Mechanical drying is considered to have been successfully completed when the previously damp component has dried to such an extent that microbial infestation or damage to the component can no longer occur and the entire component again exhibits normal equilibrium moisture content.

The result of the drying process must be verified by measurements (see also WTA Leaflets 4-11-16/D and 4-12-16/D). The drying process is monitored in practice by measuring the temperature and humidity of the in- and outflowing air. If the drying air cannot absorb any more moisture, further drying does not normally make sense. However, there may always be areas where the air flow of the drying unit failed to access. Whether the drying target has actually been achieved can be checked by measuring the equilibrium moisture content by a probe in the component to be dried – ideally in newly drilled holes.

The reconstruction (building reconstruction, see Section 6.5) can be started if the conditions are suitable both in terms of building and hygiene.

INFOBOX 16

Drying floor structures and cavities

If floor structures without footfall sound and heat insulation layers, so-called composite screeds, are heavily soaked, moisture can only be removed by diffusion processes. Airtight surface coverings can delay or even prevent these water vapour transport processes. Diffusion-proof seals, paints or glued coverings (e.g. made of PVC) must therefore be stripped off or removed beforehand (see also Annex 6).

Special drying methods are needed for floor structures with underlying cavities and insulation layers and for inaccessible manholes. Three methods can be used for mechanical drying of floor structures with footfall sound and heat insulation layers (see also WTA Leaflet 6-15-13/D).

In the **suction process,** moist air is sucked out of the insulation material and/or cavity which creates a vacuum in the structure. Indoor air dried by a mechanical drying device flows through the edge joints or openings into the cavity to be dried. This dry air absorbs moisture from the damp materials as it flows through. The microbial components present in the extracted air are transported directly to the outdoors and/or filtered by a downstream filter.

In the **suction/pressure process** moist air is sucked through openings into the cavity to be dried, as in the suction process. In parallel, dried air is pumped under pressure into the footfall sound or heat insulation or the cavity. The suction flow rate must exceed the pressure flow rate in this process.

In the **pressure process,** air dried by a mechanical drying device is pumped through inlet openings (e.g. edge joints or holes in the screed) below the screed into the footfall sound or heat insulation or cavity. The dry air absorbs moisture from the building materials, enters the room through outlet openings and then must be removed from there. In the case of mould infestation, an uncontrolled release of microbial components into the indoor air takes place. Therefore, this method should only be used for mould infestation if the rooms are not used (e.g. in a shell construction). This not only applies to suspected microbial infestation but also because dust, fibres, etc. are also distributed to the environment.

6.3.7 Cleaning after removal of contaminated building materials

Remediation activities usually release dust contaminated with microbes which in turn contaminates indoor air and room surfaces. Therefore, the remediated area must be thoroughly and carefully cleaned before the protective measures (partition walls and airlocks) are removed to avoid exposure to subsequent work or occupants. This also applies to mould remediation in Utilisation class III rooms.

Cleaning after removal of contaminated building materials is also called deep cleaning – in the sense of a thorough cleaning including niches and corners. The aim of this deep cleaning is for all dust, mould constituents and other microbial particles to be removed. Partition walls, access areas (e.g. airlocks) and possibly neighbouring areas should also be included.

Care should be taken when performing deep cleaning to make sure that subsequent cleaning steps do not recontaminate areas already cleaned with disturbed material. Biocides are not required to be used in deep cleaning since mould constituents are removed mechanically by hoovering or wiping.

Areas in the affected rooms must be carefully cleaned after removal of contaminated building materials. The use of biocides to kill microorganisms before the removal of contaminated building materials or cleaning and spraying biocides to treat the indoor air is not necessary (see Section 6.4).

Important aspects for successful dust removal and cleaning in the affected rooms are:

- Hard-to-access or difficult-to-clean objects and furnishings (e.g. radiator cladding, acoustic ceilings, textile wall coverings) must be dust-tight sealed before removal of contaminated building materials begins.
- Dust class H industrial vacuum cleaners should be used for cleaning. Dust class M vacuum cleaners should only be used if the exhaust air is vented to the outdoors.
- Wet cleaning using a surfactant cleaning agent is best suited for smooth surfaces (e.g. windows, doors, partition foils).
- Dust class H air cleaners with filters can efficiently support deep cleaning in reducing the concentration of airborne mould constituents and dust.

- Deep cleaning must be carried out before dismantling partition walls and airlocks and these protective devices must also be cleaned. Partitions abutting non-contaminated areas should only be removed after successful cleansing to avoid the spread of contamination.

- The use of biocides (e.g. for room nebulising) does not make sense and cannot replace a comprehensive cleaning.

- All objects that may be contaminated in the room may also be cleaned using a suitable method to free them from dust.

6.3.8 Checking remediation and cleaning results

After completion of remediation, the success of the measures should be checked and recorded before dismantling dust protection walls, airlocks and other kind of partitioning.

Successful **removal of the cause** must be monitored and confirmed by inspection and may be supported by special measurements. Depending on the cause, relevant experts should be consulted who are able to expertly inspect the work performed such as seals in the building, newly installed thermal insulation and pipe repairs, roofs or façades.

Measurements can be performed and recorded to monitor the results of **mechanical drying** (see specifications in WTA Leaflet 4-12-16/D).

The **removal of contaminated building materials** should be checked by visual inspection. Checking the extent of damage cannot be determined after remediation; this must be done before or during the removal of contaminated building materials at the latest. It must be checked whether the executing refurbishment company has dismantled the material according to the contract, e.g. whether the wall plaster has been removed to a specified depth? Have all remains of an infested plasterboard been removed in a room? Has the wallpaper been removed from the external wall? etc. If it becomes clear after removal of contaminated building materials that the damage exceeds the amount agreed to in the contract, the contract shall be extended accordingly (so-called follow-up contract).

The task of checking and recording a successful **cleaning after the removal of contaminated building materials,** at least by visual inspection (possibly using wipe samples to detect settled dust), is rather demanding. The procedure described in WTA Leaflet 4-12-16/D provides a good tool for checking and recording the cleaning success, in particular in the case of major damage. The procedure is based on total spore measurement as per DIN ISO 16000 Part 20 after mobilising existing settled dust.

Surface samples using blotting plates or adhesive film samples capture only a very small part of the cleaned areas. For a representative conclusion many points would have to be sampled which is usually not possible from an economic point of view.

It is advisable to agree on specific remediation steps and goals in writing before commissioning a company.

6.4 Biocides

Disinfection is by definition a measure in which pathogens are destroyed to the extent that they can no longer trigger infection. Disinfection measures are therefore used to prevent a risk of infection e.g. in strongly immunosuppressed patients in hospitals. In such cases, relevant specialists must use products, instructions or technologies which have shown to satisfactorily reduce the pathogens that occur there (e.g. *Aspergillus fumigatus, Nocardia* spp.). This guideline does not address such special requirements in Class I rooms.

If biocides are used in mould remediation in Class II or III rooms, this is not disinfection, even if these biocides are listed as disinfectants. The issue is not avoiding infection, but other aspects such as the delay of further mould growth are of more import.

6.4.1 Efficacy of biocides in the case of mould infestation

The efficacy of biocides is usually tested on specified but impractical systems in the laboratory. There are only a small number of systematic studies about the effect of biocides on mould infestation on building materials under realistic conditions. The results of these studies show that no effects at all, or no lasting effects can be achieved by biocide treatment under practical conditions in most cases. Even if the concentration of cultivable moulds was reduced by the biocide treatment, high mould fungus concentrations reappeared on/in the material a few weeks later.

Certain biocidal substances may slow down or reduce microbial growth depending on the mould or bacterial species, the medium or building material and factors such as moisture content and temperature. However, a significant reduction of existing microbial biomass is generally not expected since biocide treatment does not remove mould infestation.

High concentration (> 10 %) hydrogen peroxide (H_2O_2) is an exception. This biocide treatment can kill moulds and bacteria. However, its use in dealing with mould growth is limited due to its strong oxidising effect on and in the materials because it can discolour sensitive surfaces.

The use of vinegar solutions should be discouraged on breathable building materials since a potential chemical reaction with building materials raises the pH and produces an additional nutrient substrate on infested areas. Both can promote mould growth instead of inhibiting it.

6.4.2 Use of biocides in the case of mould infestation

Since the aim of mould remediation in Utilisation class II and III rooms is not the prevention of infection, biocide treatment is basically not necessary.

Biocide treatment, in particular, does **not** make sense:

- if a timely drying of the moisture damage is feasible;
- in the case of visible infestation on surfaces (e.g. wallpaper, plaster), which can be removed immediately using simple methods;
- in the case of a clear infestation of the building material since biocide treatment at best reduces the concentration of colony forming units but not the microbial biomass and possibly not their activity;
- as a method where biocides are nebulised in the indoor air (except inaccessible cavities) before, after or instead of a remediation or cleaning;
- before refurbishment or demolition in the case of mould infestation (often incorrectly referred to as 'disinfection');
- if material resistance against biocides is not (necessarily) available;
- as an addition to wall coatings after drying (mould-inhibiting wall paints). This does not apply to Utilisation class III rooms.

Flooding of floor structures with biocides (often incorrectly called disinfection in practice) is not a sustainable remediation measure. This also applies to Utilisation class III rooms. There is no evidence that this can provide a permanent inactivation of mould and bacteria.

There are only a few exceptions where biocide treatment can be useful for mould remediation. If the building material should not be removed e.g. for historic monument protection reasons or if rapid drying is not possible, biocide treatment using immediately degrading preparations is acceptable in individual cases where there is a suspected infestation to delay or slow down the growth on hard-to-access surfaces. An example is when active ingredients (hydrogen peroxide) are nebulised in cavities of structures that are inaccessible for structural reasons.

It must be ensured that any biocide treatment reaches all areas of the infested component (a professional inspection is required in advance) and the success of the action must be checked.

Efficacy of the products to be used must be proven. Products used in mould remediation require an approval for legal use according to the biocide regulation in Main group 1, Product type (PT) 2. Biocide products obtain an approval number (e.g. DE-1234567-1234) in the approval procedure which is indicated on the label of approved products including the approval holder. Currently, no biocide is approved for use in cases of mould infestation on indoor building materials. A list of biocide products approved in Germany can be found at: http://www.baua.de/de/Chemikaliengesetz-Biozidverfahren/Biozide/Produkt/Zugelassene-Biozidprodukte.html.

Products containing certain old active substance may be made available, subject to certain conditions and used on the market under transitional regulations before approval is granted under the active substance approval or product approval procedure, but they must be registered with the Federal Agency for Chemicals. These products are given a registration number (N-xxxxx), which must be indicated on the label. The registration must be distinguished from the approval and is only a simple notification of a biocide product. The products covered can be found at: https://www.biozid-meldeverordnung.de/offen/

INFOBOX 17

Use of biocides in cases of mould infestation in Utilisation class II and III rooms

In the case of remediation of microbial damage, biocide treatment is in principle not necessary because it is unsuitable for the proper removal of the biomass and the remediation of the cause of damage.

The nebulisation of active ingredients in the indoor air – except of inaccessible cavities – is discouraged in any case.

In individual cases, biocide treatment using immediately-degrading preparations such as hydrogen peroxide may be acceptable in the case of suspected infestation to retard or slow down growth on hard-to-access surfaces.

Mould-inhibiting wall paints can be used after a drying process in Utilisation class III rooms.

6.5 Structural reconstruction after removal of contaminated building materials

The surfaces or components damaged by the infestation or by remedial measures must subsequently be restored. This can be done after mould remediation has been completed and use of the space is permitted under "normal" conditions for craftsmen of relevant trades without special protective measures. The reconstruction of the object should take into account the specific environmental circumstances so that a renewed mould growth is excluded. The relevant building materials and structure and the correct building technology are of great significance in avoiding renewed mould growth.

The choice of building materials plays an important role since this can counteract renewed mould growth, e.g. by isolating areas with short-term damp peaks with the additional use of moisture-buffering materials (see Chapter 4).

Since mould fungi preferably grow in a certain pH range (see Chapter 1), silicate paints, whitewash and lime plasters or other mineral paints with a high pH (> 11) can prevent renewed mould growth or significantly inhibit its growth. Especially in Utilisation class III rooms, this can be an effective alternative to an expensive structural refurbishment. The pH value is shifted so far into the alkaline range that a renewed microbial growth on the surface is reduced or prevented. However, this effect does not last long: e.g. whitewash must be renewed regularly in the case of strong moisture attack (e.g. in cellars) because the pH can gradually change due to neutralisation reactions and mould can grow on a developing dust layer.

Another disadvantage of pure whitewash is that these paints are often not resistant to wiping and abrasion. Silicate paints are better because, like lime paints, they can prevent renewed mould growth due to their high pH value. Whether the substrate is suitable for the respective application must be clarified in each case.

Vapour-permeable materials that achieve a positive insulating effect have proven themselves as interior wall insulations (see also Section 3.2.2). For use, it must be ensured that the materials are of mineral character and have the highest possible alkalinity (e.g. calcium silicate plates). When this is the case, they are less likely to be infested by mould.

It is important for all new developments that the effectiveness and durability of the specified suitability of materials, methods and procedures is proven both scientifically and in practical use. The scope of application should be clearly described. Specific instructions for use, safety data sheets and operating instructions must be available.

Newly plastered components must be completely dry before new wallpaper can be applied or be repainted. Similarly, when introducing new screeds, etc., residual moisture must be removed from the screed and the building.

6.6 Measures after completion of all work

Furnishings and other objects such as textiles or books that have been removed during remediation should be cleaned prior to returning them to the cleaned, remediated area after removal of the contaminated building materials (see Section 6.3.7) to prevent subsequent contamination by microbially contaminated dust.

When all work has been completed and all furnishings have been returned, an air measurement can be performed after a few days waiting period for cultivable moulds according to DIN ISO 16000-16 to -18 or DIN EN ISO 16000-19 or for total spore count according to DIN ISO 16000-20 using qualified test devices (see Section 5.1.3.1). If necessary, neighbouring parts of the building can also be included in the test. In this way it can be checked whether mould fungus concentration has been increased by (re)introducing dust during the last remediation phases. If this is the case, the rooms must be cleaned again.

Using the air spore measurements to check the cleaning effectiveness is not aimed at producing completely “mould-free” rooms or parts of buildings. Simply an indoor air concentration not significantly higher than the usual background concentration should be achieved after completion of the remediation.

A

Annexes

A1

ANNEX 1

Examples of recent changes in the nomenclature of indoor mould fungi

Valid name (as of 2017)	Basionym/name until 2012
***Talaromyces* spp.** e.g.: *Talaromyces rugulosus* *Talaromyces variabilis* *Talaromyces funiculosus*	***Biverticillate Penicillium* spp.** e.g.: *Penicillium rugulosum* *Penicillium variabile* *Penicillium funiculosum*
***Aspergillus* spp.** e.g.: *Aspergillus glaucus* *Aspergillus rubrobrunneus* *Aspergillus chevalieri*	***Eurotium* spp.** e.g.: *Eurotium herbariorum* *Eurotium rubrum* *Eurotium chevalieri*
***Aspergillus* spp.** e.g.: *Aspergillus nidulans*	***Emericella* spp.** e.g.: *Emericella nidulans*

Internet link with further information on this topic: http://www.mycobank.org/

A2

ANNEX 2

Molecularbiology techniques for the identification of mould fungi

The application of molecular biology techniques to identify mould fungi has provided new insights into the phylogeny of various species of mould fungi. For example, it showed that many morphologically and physiologically near identical organisms that have so far been grouped together as one species are generally closely related but genetically too different to belong to one species. At the moment, phylogenetically similar species are grouped into species complexes (see table).

For example, molecular biology has so far identified 15 species that correspond to the morphological characteristics of *'Aspergillus versicolor'* – an indicator organism for moisture damage. It identifies strains of this complex isolated in indoor spaces predominantly as *Aspergillus creber* or *Aspergillus jensenii*.

In the case of multi-complexes, identifying mould fungi at the species level with certainty is only possible through molecular biology (e.g. *Aspergillus versicolor* complex). Morphologically speaking, not all species of mould fungi within a complex can be reliably differentiated at the species level.

Thanks to the findings from molecular biology investigations, the taxonomy of mould fungi is currently in transition. From today's point of view, however, the molecular biology identification at the species level provides little gain in understanding the problems that this guideline addresses. Findings or expert reports should therefore summarise the different species of a complex in the form of *'Aspergillus versicolor* complex' including the identification criteria or literature used.

Examples of species complexes based on molecular analyses

Complex or group	Species	Molecular markers for differentiation
Aspergillus versicolor complex	***A. versicolor***, *A. amoenus, A. austroafricanus, A. creber, A. cvjetkovicii, A. fructus, A. jensenii, A. protuberus, A. puulaauensis, A. subversicolor, A. tabacinus, A. tennesseensis, A. venatus, A. hongkongiensis*	CaM
Aspergillus niger complex	Black Aspergilli, including ***A. niger***, *A. acidus, A. aculeatus, A. brasiliensis* and *A. tubingensis*.	CaM
Aspergillus fumigatus complex	***A. fumigatus***, *A. lentulus, A. novofumigatus, A. fumigatiaffines*	CaM (note: cultivation at 37 °C; differentiation *A. lentulus*)
Fusarium solani complex	Minimum 50 Fusarium species including ***F. solani***, *F. keratoplasticum, F. petroliphilum, F. lichenicola*	EF-1α, RPβ1 and/or RPβ2
Penicillium olsonii and *P. brevicompactum* complex		ITS and/or β-tubuline, alternative marker BenA

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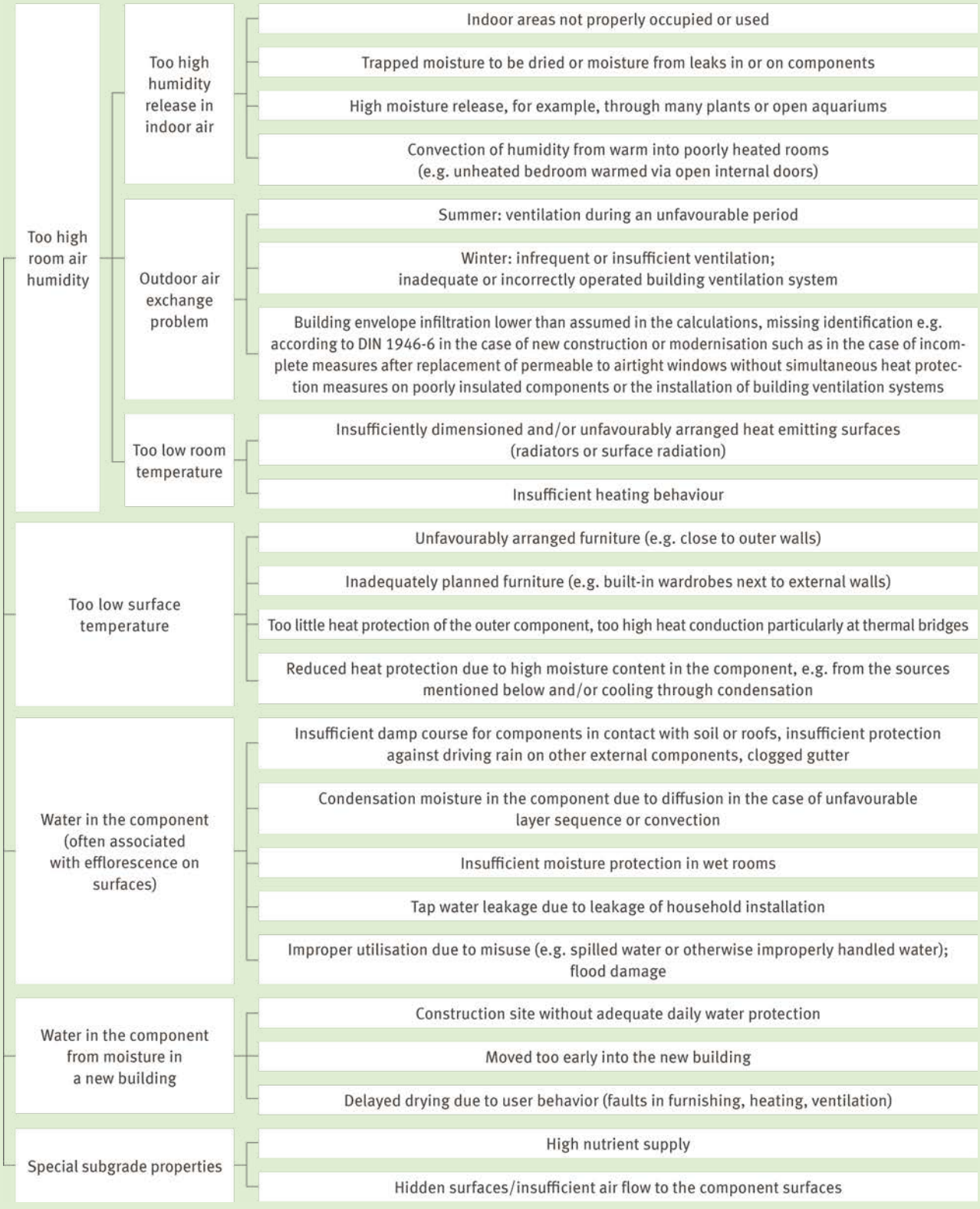
ANNEX 3

Overview of the identification of the causes of damage in mould infestation

Cause tree for mould infestation on building components (according to Oswald 2003, revised Zöller, Aachener Institut für Bauschadensforschung, AIBau 2014)
The left box lists the situations present; the right the possible causes.



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ANNEX 4

Standards, technical data sheets and guidelines on moisture and mould (excerpts)

Source	Methodical approach	Objective
DIN 4108-2 (2013)	Thermal protection and energy economy in buildings – Part 2: Minimum requirements to thermal insulation	Prevention of condensation moisture and mould growth
DIN 4108-3 (2014)	Thermal protection and energy economy in buildings – Part 3: Protection against moisture subject to climate conditions – Requirements, calculation methods and directions for planning and construction	Assessment of condensation moisture in building materials
DIN 4108-7 (2011)	Thermal insulation and energy economy in buildings – Part 7: Air tightness of buildings. Requirements, recommendations and examples for planning and performance	Thermal insulation and air tightness
DIN 4108-8 (2010)	Thermal insulation and energy economy in buildings – Part 8: Avoidance of mould growth in residential buildings	Prevention of mould growth
DIN 1946-6 (2009)	Ventilation and air conditioning – Part 6: Ventilation for residential buildings – General requirements, requirements for measuring, performance and labelling, delivery/acceptance (certification) and maintenance	Ventilation, air conditioning
DIN EN 15215 (2007)	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics	Indoor climate
DIN EN 13779 (2012)	Ventilation for non-residential buildings – General performance requirements for ventilation and room-conditioning systems	Ventilation, air conditioning
DIN 13788 (2013)	Surface temperatures, critical surface moisture	Prevention of critical surface moisture and condensation moisture in the interior of building materials
DIN 68800-1 (2011)	Limiting wood moisture	Prevention of microbial growth
Anhang 14 DIN 68800	Indication of temperature and humidity	Prevention of mould growth
DIN ISO 16000-16 (2009)	Indoor air – Part 16: Detection and enumeration of moulds – Sampling by filtration	Detection of mould fungi
DIN ISO 16000-17 (2010)	Indoor air – Part 17: Detection and enumeration of moulds – Culture-based method	Detection of mould fungi
DIN ISO 16000-18 (2009)	Indoor air – Part 18: Detection and enumeration of moulds – Sampling by impaction	Detection of mould fungi

DIN EN ISO 16000-19 (2012)	Indoor air – Part 19: Sampling strategy for moulds	Detection of mould fungi
DIN ISO 16000-20 (2014)	Indoor air – Part 20: Detection and enumeration of moulds – Determination of total spore count	Detection of mould fungi
VDI 4254-1 (2016)	Bioaerosols and biological agents – Measurement of metabolites of microorganisms – Measurement of MVOC in ambient air	MVOC measurements
VDI 6022-1 (2017) Entwurf	Ventilation and indoor air quality – Hygiene requirements for ventilation and air-conditioning systems and units (VDI ventilation code of practice)	Building ventilation technology
WTA 1-2-05/D	True dry rot	Exclusion of dry rot
WTA 2-13-15/D	External Thermal Insulation Composite Systems (ETICS) – Maintenance, Renovation, Enhancement	Professional execution of thermal insulation on façade
WTA 4-6-14/D	Sealing of structural elements in contact with soil at a later stage	Prevention of moisture damage to the building
WTA 4-7-15/D	Mechanical horizontal barriers for existing buildings	Prevention of moisture damage to the building
WTA 4-10-15/D	Injection techniques with certified injection materials against capillary moisture transport	Prevention of moisture damage to the building
WTA 4-11-16/D	Measuring the water content or the moisture of mineral building materials	Moisture measurement
WTA 4-12-16/D	Mould fungi damage: Goals and control of treatments of internal mould fungus damage	Mould remediation: monitoring and control of the remediation success
WTA 6-1-01/D	A guide to hygrothermal computer simulation	Hygrothermal behaviour of components
WTA 6-3-05/D	Calculative prognosis of mould growth risk	Prognosis procedure for indoor mould growth
WTA 6-4-16/D	Internal thermal insulation according to WTA I: Planning guide	Internal thermal insulation measures
WTA 6-5-14/D	Interior insulation according to WTA II: Evaluation of internal insulation systems with numerical design methods	Internal thermal insulation measures
WTA 6-8-16/D	Assessment of humidity in timber constructions – Simplified verifications and simulation	Assessment of moisture in wood
WTA 6-9 bis 11-15/D	Airtightness of buildings	Planning bases, execution, control
WTA 6-15-13/D	Drying techniques for water saturated building elements – Part 1: General principles	Drying of building elements
WTA 8-5-08/D	Restoration of historical half-timbered buildings according to WTA V: Internal thermal insulation systems	Internal thermal insulation measures

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ANNEX 5

Mineral agar for the cultivation of actinomycetesaccording to Gauze

Mineral-Agar (Gauze, 1983)	
Soluble starch	20.0 g
KNO_3	1.0 g
K_2HPO_4	0.5 g
$MgSO_4 * 7\ H_2O$	0.5 g
NaCl	0.5 g
$FeSO_4 * 7\ H_2O$	0.01 g
Agar	20.0 g
Distilled water	1000 ml

The individual components are suspended in 1000 ml of distilled water. 0.1 g of natamycin (dissolved in 10 ml of 96 % pure ethanol) is added to this suspension. If necessary, adjust the pH with 1N HCl or 1N NaOH so that it corresponds to minimum 7.2 ± 0.1 for (15 ± 1) minutes after autoclaving at (121 ± 3) °C.

The ready-to-use Petri dishes can be kept dehydration-resistant at (5 ± 3 °C) for a maximum of 4 weeks.

A6

ANNEX 6

Recommendation for action for assessing moisture and mould damage in floors

A. Preliminary note

This recommendation is aimed at experts who, during the assessment and remediation of moisture damage in floors, decide whether a floor must be removed for health reasons or not. It also contains key information for consumer advice centres and on-site competent authorities to aid them in their consulting services and provides useful guidance to building occupants and owners to help them better understand the advice of experts. The recommendation for action does not replace the respective expert opinion and the associated responsibility in each individual case.

The recommendation applies to indoor spaces of Utilisation class II of the guideline on mould (see Section 6.1).

Non-frequently used outbuildings of flats, offices, schools such as storage rooms without direct access to the flat, as well as garages, basements or staircases (Utilisation class III rooms of the guideline on mould) are generally less exposed and therefore fall under fewer requirements for remediation and repair. In the case of mould infestation in the floors of Utilisation class III rooms, it may need to be decided whether to retain the infested materials despite an obvious infestation, or to apply other alternatives such as suitable waterproofing measures.

As for the entire guideline on mould, the recommendation does not apply to commercial wet rooms such as large kitchens or swimming pools. The floor materials of these rooms are often structurally conditioned above the seal level and permanently wet unconnected to water damage.

Rooms occupied by particularly sensitive groups of people such as in hospitals (Utilisation class I, see Section 6.1) are also excluded. Such areas may have more requirements for remediation and environment protection.

The assessment of moisture damage in floors relies not only on microbiological and health aspects but also on structural aspects. For example, some insulating materials lose their specific properties when wetted and dried (e.g. thermal insulation, sound insulation) and must therefore be replaced in the case of moisture damage, irrespective of microbial growth (see Section A.2). The load-bearing capacity of individual floor structures can also suffer as a result of extensive moisture penetration.

Floor structures are often affected by moisture damage. At the same time, the removal of contaminated building materials in the floor structure often implies extensive structural alteration which is expensive and presents firms and room occupants with major logistical problems, especially if the remaining rooms of the flat continue to be occupied. The decision to remove contaminated building materials has far-reaching consequences and should therefore consider both the protection of the room occupants and indoor health aspects so avoid exaggerated assessments and unnecessary removal measures.

The purpose of this recommendation is to ensure the execution of a consistent indoor health assessment for moisture damage and mould growth in floor structures regarding conservation, removal of contaminated building materials or alternative measures.

Alternative measures that can be applied in practice rather than the removal of contaminated building materials in the case of mould growth include the

flooding of the floor structure with biocides and the so-called edge joint remediation. The total surface (waterproof) sealing of the floor can also be considered in individual cases.

Flooding with biocides (in practice often mistakenly called disinfection) is not a sustainable remediation measure. There is no evidence that it achieves a permanent inactivation of mould fungi and bacteria (see Section 6.4).

So-called edge joint remediation is another frequently chosen alternative for the removal of screeds, if the edge is the only microbially infested area (which is very often the case in damage caused by residual moisture in new buildings) or if the infestation in the floor structure turns out to be minimal. The method involves the removal of the edge strip and sealing the joint. Damage is very rarely partitioned using diffusion brakes (plastic sheets) or diffusion barriers (aluminium foil).

When considering the installation of a permanent seal, the expert must check and consider the following aspects:

- Can it be ensured that the seal, including the edge seal, is watertight overall and remains permanently sealed?
- Is it guaranteed that the partitioned area under the seal remains dry and no further mould growth takes place?
- Can a water vapour impermeable seal lead to constructional disadvantages?
- How can it be ensured that the microbially contaminated component is not unsealed carelessly during later manual work, but that the craftsmen are informed well in advance so that they can carry out the required risk assessment and the relevant operating instructions in accordance with the Biological Agents Ordinance?

In addition, the building owner and/or authorised occupant should be informed about the consequences and risks associated with a seal.

B. Introduction to the assessment scheme

The assessment scheme consists of two levels. Assessment level 1 considers experience gained in practice, which in many cases makes it possible to carry out a rapid assessment without extensive investigations. It has been shown that certain cases do not require decision-making based on microbiological analyses to determine whether to remove a damp material or not. These cases are summarised in assessment level 1 using four scenarios (see Section B.1).

A microbiological material analysis must be carried out in all other cases, the results of which, together with other aspects, are used for an assessment at the second evaluation level (assessment level 2) (see Section B.2).

The evaluation of the microbiological results requires professional sampling (see Section C) and standardised processing of the samples (see Section D).

The two assessment levels 1 and 2 form one unit. Assessment level 2 must not be used without prior verification according to assessment level 1. By answering the questions in assessment level 1, the moisture damage is first assigned to clear, easily identifiable scenarios. This enables a quick decision whether further measures such as mechanical drying or laboratory analysis are useful or necessary. A subsequent assessment level 2 evaluation based on microbiological test results and other aspects is carried out only if none of the scenarios apply.

The assessment requires a great deal of expertise and should only be carried out by qualified experts, otherwise gross misjudgements in one direction or another can occur. The aim is to use this scheme to achieve a uniform assessment of typical cases of damage. However, there are individual cases in practice that do not fall under this scheme. The experience of appropriately trained professionals in mould remediation is therefore an absolute prerequisite at all stages.

The procedures described in the recommendation do not account for legal aspects such as obligations under employment and insurance contracts.

The individual assessment steps are briefly summarised in a flow chart.

B.1 Assessment level1

Assessment level 1 for evaluating moisture damage in floors includes both microbiological and technical exclusion criteria. Due to the unambiguous nature of the damage, these criteria do not require a detailed expert opinion or a microbiological analysis. Assessment level 1 describes four unambiguous scenarios (see Sections B.1.1–B.1.4) from practical experience, which quickly help decide whether or not it is necessary to remove the contaminated materials from the floor after moisture damage. It is essential to know the construction of the floor structure for this assessment.

Microbiological investigation and a further expert assessment must be carried out according to assessment level 2 (see Section B.2) for all cases of damage in which the type and duration of the moisture penetration does not correspond to the cited scenarios (e.g. if drying finished after one month or in the case of readily degradable materials) or there are uncertainties with regard to previous damage, duration of damage or effectiveness of drying. If the exact occurrence of the damage is unknown, the worst-case scenario should be used and, if necessary, further evaluated according to assessment level 2.

B.1.1 Scenario: Removal of contaminated building materials not required due to rapid drying and non-colonisable materials

The removal of moisture-laden building materials in floor structures is usually not necessary if significant microbial growth on the material is not expected. This is to be assumed in the case of a current single, short-term event without previous damage with non-faeces contaminated water and if the affected building materials are difficult to colonise by microorganisms because of their mineral or dense structure and if adequate drying can be ensured within about one month after the occurrence of damage. In these cases, a microbiological investigation is not required, but may be useful for legal reasons.

B.1.2 Scenario: Removal of contaminated building materials recommended due to microbial growth

Removing the contaminated building materials from the floor structure is recommended if drying will extend or has extended more than three months after the damage event, or the moisture damage has repeatedly occurred over longer time periods (multiple moisture events) and each case contains building materials that can easily be colonised by microorganisms that can lead to extensive growth. In this scenario, microbial infestation of the floor structure is very likely. Microbiological investigations are nevertheless generally not required. In individual case of need, however, a microbiological investigation can be carried out for legal reasons or to enable a final decision and should proceed according to assessment level 2.

B.1.3 Scenario: Removal of contaminated building materials is recommended for technical reasons

The removal of contaminated building materials from a floor structure is recommended if drying is not possible for technical reasons or is economically not justifiable. This applies in particular to materials that lose their specific functional properties due to the impact of moisture and/or during drying. This is the case for materials such as cellulose fibres or (aged) artificial mineral fibres in the insulating layer of float screeds (assessing material integrity via visual inspection) and for materials such as sand, loam or perlite that are difficult and thus expensive to dry in thin layers and usually impossible to dry in thick layers. Wood beam ceilings with inserts of clay/straw also belong to this scenario.

Thus, in the case of these materials, technical reasons that speak against drying and further use outweigh microbial infestation in being the decisive aspect for the decision to remove contaminated building materials.

Therefore, a microbiological investigation is not necessary for this scenario.

The mechanical drying of wet composite screed is usually also not economical which is why the removal of contaminated building materials is recommended.

If the composite screed is not wet but moistened below the materials' moisture saturation point (measurement with the probe gives relative moisture values below 100 %), mechanical drying can be carried out under certain conditions by removing the floor coverings and cleansing the exposed screed with mechanically dried room air. This should ensure that drying is achieved in a short time (max. 4 weeks). In addition, there should be no release of odour during and after drying and the connection area between the walls and floor must be checked for damp and potential mould infestation.

If the screed is thoroughly moistened and has tiles laid in a mortar bed, removing the tiles without removing the screed is not really sensible since the screed will be damaged and will need to be repaired.

Screeds on separation layers are assessed according to level 2 (with microbiological investigation).

B.1.4 Scenario: Removal of contaminated building materials recommended due to odour formation

Removing contaminated building materials from a floor structure is recommended if a conspicuous odour sets in and if lasting odour is expected even after remediation. The odour can be caused by decomposition processes in damp materials or by the introduction of contaminated water (wastewater or flood water contaminated with faeces).

The expert must check whether the odour can reasonably be attributed to the moisture damage. It is not necessary to investigate microbial contamination (including faecal bacteria in the case of moisture damage with faeces-contaminated water), since the recommendation to remove contaminated building materials relies on odour formation and the entry of nutrients and biomass, not the supposed risk of infection.

Odour may also occur after a treatment with biocides if the affected materials have not been removed. Odour binders are not a sustainable solution.

Measures to prevent infection are necessary when handling faeces-contaminated water or building materials (protective clothing, disinfection if necessary).

Further recommendations on wastewater damage can be found in the VDB information leaflet[1].

B.2 Assessment level 2

If none of the four scenarios of assessment level 1 (see Section B.1) apply, a microbiological investigation (Criterion I) is recommended. In addition, other aspects (Criteria II–VI, see Section B.2.1) should be included in order to decide about necessary measures (see Section B.2.2).

B.2.1 Explanation of the criteria

First, the results of the microbiological investigations (Criterion I) are used. Additional criteria to consider include the permeability of the floor (Criterion II), the moisture in the floor structure (III), the type of materials in the floor structure (IV), nutrient input (V) and the age of the damage (VI). The criteria are explained in more detail below.

Criterion I

Results of microbiological investigations

The material samples for the microbiological investigation must be taken in accordance with the sampling instructions (see Chapter C) and reprocessed in the laboratory in accordance with a uniform method (see Chapter D) to allow the comparability of the results.

The data required for assessing the occurrence of cultivable mould fungi in materials, which enables the unambiguous detection of an infestation based on the identified concentration ranges (see Section D.2), is currently only available for polystyrene and mineral fibre insulation materials. Recent

1 Information leaflet on the assessment and remediation of faecal damage in building construction. Ed. VDB 2010

investigations show that these concentration ranges can also be applied to other materials such as polyurethane foam or plaster[2].

In addition to the concentration, the occurrence of mould fungi species or genera that are typical for moisture damage (moisture indicators, see Section 1.2.2, Table 2) is an important indication of a material infestation.

In addition to cultivation, microscopy is also necessary to distinguish an infestation from an impurity (see also Section 1.1). If microscopy detects only a moderate number of spores without mycelium or sporophors, it is probably not an infestation but an impurity on the material from an adjacent mould infestation or from the air. If a fairly large or large amount of mycelium with sporophors is detected, growth has taken place in the material and there is a mould infestation (see also Chapter D, Tables 6.2 and 6.3).

If the floor structure is very heavily soaked, bacteria have a growth advantage over mould fungi. Additional measurements of bacteria/actinomycetes or ATP in the material can provide further information. However, these methods are not yet accepted rules (see Section 5.1.2). There are no generally valid concentrations of bacteria according to the following assessment (see Chapter D). Experience shows that their concentration is about 10-fold above the concentration of mould fungi.

Indication that a positive infestation
with microorganisms is present in a material sample (polystyrene, mineral fibre) if:

- a mould fungi concentration above 10^5 CFU/g has been identified and/or
- there is a microscopically recognisable growth with bacteria or mould fungi with a fairly large or large amount of mycelium and/or many or very many sporophors and associated spores.

Evidence of a minor infestation
with microorganisms is present in a material sample (polystyrene, mineral fibre) if:

- a mould fungi concentration between 10^4 CFU/g and 10^5 CFU/g has been identified and/or
- there is a microscopically recognisable low growth of bacteria or mould fungi with moderate mycelium, sporophors and a moderate number of spores.

Evidence of a minor infestation
with microorganisms is also present in a material sample (polystyrene, mineral fibre) if:

- a mould fungi concentration above 10^5 CFU/g has been identified and/or
- there is a microscopically recognisable minor growth of bacteria or mould fungi with moderate mycelium, sporophors and a moderate number of spores.

No evidence of an infestation
with microorganisms is present in a material sample (polystyrene, mineral fibre) if:

- a mould fungi concentration below 10^4 CFU/g has been identified and
- there are microscopically recognisable isolated bacteria or spores and only isolated or no sporophors or mould fungi mycelium.

If microscopy clearly detects a growth, verification of culturable mould fungi is not necessary.

If microscopy detects a minor growth, cultivation may provide additional information because in some materials, minor growth is not readily apparent microscopically. This also applies to dried out old damage where the mycelium and the sporophors in the material can often only be detected by more detailed use of the microscope because the mycelia have been reduced. If cultivation detects a high

2 Background values of mould fungi and bacteria on building materials, 3rd German Mould Fungus Seminar in Neuss, 03. + 04.02.2017

concentration of mould fungi, a repeated, particularly careful microscopy should be carried out in order to rule out a clear infestation.

Experience shows that if microscopy fails to provide any evidence of the infestation, verification of cultivable mould fungi is necessary in order to rule out false negative results.

The concentration of cultivable mould fungi can be reduced by stress factors such as biocide application or mechanical drying. This should be taken into account when assessing microbiological investigations.

The assessment criteria cannot be used for building materials that naturally contain higher concentrations of microorganisms (e.g. loam).

Criterion II

Permeability of floor coverings and wall connections and the resulting risk of exposure

If mould growth occurs in the footfall sound and heat insulation of the floor structure, exposure of the room occupants via the room air is influenced by the airtightness of the floor structure and the wall connections. In addition, other open connections with the floor structure (cracks, sockets, heat distributors) also have an impact on the exposure of the room occupants.

The **permeability** of wooden floors (e.g. floorboards, nailed parquet floors) is classified as **high** if the joint pattern enables biogenic particles from the floor structure such as mould spores to enter the room air. In the case of a breathable support material e.g. carpets on such floors, odours and other biogenic substances are usually release into the room air. Depending on their quality of weave, they may also release particles.

A **medium permeability** is assumed for impermeable floor coverings with airtight joints such as elastic top floors (e.g. PVC, linoleum), tiles or glued parquet without properly attached sealed edge connections. The gaps may therefore provide a passageway from the floor structure to the room air.

Low permeability is assumed for impermeable floor coverings such as tiles and elastic top floors with airtight joints and airtight edge connections. It is assumed that particles such as mould spores, as well as odours find it difficult to reach the indoor air.

Criterion III

Moisture in the floor structure

Quantitative measurements that enable an estimation of whether there is elevated moisture in the floor structure that would promote microbial growth can only be obtained through hygrothermal probe measurement. These measurements are often referred to as ‘equilibrium moisture measurements’ which, however, does not refer to the material equilibrium moisture with regard to the mass (see also Section C.4).

In addition, a gravimetric moisture measuring method (called Darr weighing method) can be used to check whether the material moisture content of the screed is within the range of the material equilibrium moisture content. However, gravimetric moisture analyses of the insulation materials are not technically feasible because even in the case of high relative humidity only small amounts of water are present in the material and therefore very large amounts of material would have to be measured.

While elevated moisture is a necessary prerequisite for microbial growth to take place, it may be the case that assessment of the floor structure takes place when there is no longer elevated moisture (e.g. after drying). In this case, no further microbial growth can take place. Nevertheless, high concentrations of mould fungi or bacteria may be present from a previous growth phase. The assessment must therefore take into account any signs of previous moisture (water spots, rust spots, salts).

Wetness or highly elevated moisture
Wetness, meaning liquid water, is visually recognisable (if necessary, one can squeeze out water droplets from materials such as the footfall sound insulation) and one can also feel the dampness due to gaseous water.

Highly elevated moisture
Hygrothermal probe measurements at temperatures of 19 °C to 21 °C show moisture values of 80 % or higher (corresponds to water activity $a_W \geq 0.8$). Microbial growth is possible.

Elevated moisture
Hygrothermal probe measurements at temperatures of 19 °C to 21 °C show moisture values between 70 % and 80 % (corresponds to water activity $a_W = 0.7 – 0.8$). Microbial growth is less likely.

No elevated moisture
Hygrothermal probe measurements at temperatures of 19 °C to 21 °C show moisture values below 70 % (corresponds to water activity $a_W < 0.7$). Microbial growth usually does not occur.

However, relative moisture increases when the temperature is lowered meaning that cooling the materials can result in high moisture values. If, for example, the component temperature decreases to values below 18 °C and the material therefore has a higher relative moisture content, microbial infestation is also possible at moisture values of 70 % at 20 °C.

Criterion IV
Material of the floor structure
The assessment requires knowledge about the construction of the floor structure, even if this – in the case of an unknown structure – requires destructive methods.

In general, the introduced water can be found between the upper edge of the raw concrete floor or underfloor membrane and the footfall sound and heat insulation. The footfall sound and thermal insulation is thus the material that is most likely to be colonised when moisture is introduced. Depending on the nutrient content of these materials, microbial infestation takes place quickly or more slowly.

In the case of some materials (e.g. in wood panels), microbial growth is often relatively noticeable due to odours. In the presence of a typical odour, samples for microbiological analysis are not required to determine the remediation requirement. In the case of other materials (e.g. in polystyrene), there is no odour at all despite strong microbial growth or there is an atypical odour for microorganisms.

The following materials are examples to illustrate gradation and do not exclude other materials. There may also be more or less susceptible mixtures and product variants within a building material. For example, non-pressed, untreated softwood fibre boards colonise very easily while pressed and bituminised softwood fibre boards are much less easily colonisable.

Easily colonisable materials
These include building materials such as coconut insulation panels or sisal structures. These materials absorb a lot of moisture and also contain nutrients. Due to these properties there is a risk of rapid mould growth in the case of moisture damage.

Screed constructions with or without insulation in some older floor structures contain separating layers of cardboard, paper or impregnated oil paper between the raw concrete floor or underfloor membrane and screed. These ‘cellulosic’ separating layers are very susceptible to microbial growth in the case of moisture damage but contain only relatively little microbial biomass in the case of mould infestation due to the thinness of the layer. Cable ducts that are filled with organic insulation material, as well as bituminous waterproof insulation on the underfloor membrane below the screed or the footfall sound insulation are also among the easily colonisable materials.

Drywall elements such as gypsum plasterboard, gypsum fibre board, softwood fibre boards, soft fibre mats, which are adjacent to the floor, can also absorb moisture well and mould growth can take place within a very short time.

Less easily colonisable materials
These include insulation materials such as artificial mineral fibres, polyurethane, XPS (extruded polystyrene hard foam), EPS (expanded polystyrene hard foam). These materials absorb moisture comparatively less easily. Practice shows that these materials are much less overgrown with mould fungi than the materials from the group 'easily colonised materials'. A significant mould growth in footfall sound and thermal insulation materials can only be expected after a few months.

Wood-based materials such as chipboards or OSB are less prone to colonisation than plasterboards or similar dry construction elements. Depending on the type of wood-based material, the amount of water and the exposure time, infestation with microorganisms can nevertheless take place relatively quickly.

Poorly colonisable materials
These materials are characterised by a high inorganic content. Practice has shown that building materials such as mastic asphalt, cement screed, anhydrite or calcium sulphate screed are poorly colonisable, or that the microorganisms require a very long time to cause infestation.

Criterion V
Nutrient input
In order to determine the urgency of remediation, it is necessary to establish the causes of the damage. This principally considers the quality of the water involved. Major wastewater damage in the building structure has already been dealt with in assessment level 1 (4th scenario) and is therefore not considered in the following.

High nutrient input through rain or grey water
This type of input shows a high microbial contamination and can additionally favour microbial growth through nutrient input.

Low nutrient input through drinking water or groundwater damage
Such damage is usually associated with higher amounts of water. Causes of this water damage can include leaking water pipes or sealing defects. However, the water has little or no microbiological contamination, and is certainly not heavily contaminated, even if **caused by building physics.** In the case of condensation in the building material, the entry of moisture is usually more temporary and generally lower than in the case of the pathways mentioned above.

Criterion VI
Age of the damage
The longer the damage is not detected or dried and the more frequent moisture damage occurs (multiple event), the higher the risk of microbial growth. The three months chosen as a distinguishing feature in the two categories are not to be understood as an absolute limit but represent only an order of magnitude for estimating the age of the damage. In many cases, the age of the damage is not known exactly, meaning that a further classification is not seen as necessary.

Older than 3 months or multiple event
The likelihood that mould fungi growth has formed independently of the building material (this factor is already considered in criterion IV) is rated higher than for shorter or one-off events.

One-off damage event, maximum 3 months old
Regardless of the building material (this factor is already considered in criterion IV), the likelihood of mould growth is lower for rapidly detected and dried damage.

B.2.2 Assessment based on the criteria

Assessment level 2 first uses the results of the microbiological investigation (I) (see Section D.3).

If an unequivocal infestation is identified on a floor, removing the contaminated building materials is recommended regardless of the permeability of the floor.

Although it is unlikely that the room occupants will be exposed in the case of a less permeable floor (see B.2.1, Criterion II), there may be exposure when opening the floor or altering the floor covering. If the contaminated building materials are not removed, other measures (e.g. information) must be taken to ensure that no exposure occurs at a later date (e.g. by a craftsman in the case of repair or extensions).

In the case of little or no microbial infestation, further criteria (II–VI) must be taken into account in order to be able to decide on conservation, removal of the contaminated building materials or alternative measures (e.g. full-surface sealing, edge joint remediation).

This assessment estimates how many of the criteria imply that, given the circumstances, increased microbial growth and exposure of the room occupants can be expected in the future.

A 'traffic light system' can show which criteria characteristics carry no risk of subsequent mould growth and the potential exposure of the room users (category: green), increased (category: yellow) or greatly increased (category: red) (see Table 6.1).

If at least three of the Criteria II–VI are in the green category, removing the contaminated building materials is usually not required. In the case of elevated moisture an immediate drying must be done regardless.

In the presence of elevated or highly elevated moisture (Criterion III), mould growth may occur depending on the presence of other unfavourable criteria. The more criteria are in the red category, the more the removal of contaminated building materials from the floor is recommended.

Criteria that are classified in the yellow category speak in favour of removing the contaminated building materials, especially if there are other unfavourable factors. Thus, an already elevated moisture in the component can increase even more as the temperature drops (see VI) and materials that are less easily colonisable can lead to microbial growth if the moisture persist for longer (see III and IV).

Table 6.1:

Assessment based on the criteria

Criteria	Assessment (category) Green	Yellow	Red
II Permeability of floor coverings	Low	Medium	High
III Moisture in the floor structure	Low	Medium	High
IV Material in the floor structure	Difficult to colonise	Less easy to colonise	Easy to colonise
V Nutrient input	Low	Medium	High
VI Age of the damage	One-off event and ‹ 3 months		Multiple event or › 3 months

C. SAMPLING

C.1 Basics

The investigation of microbial damage using material samples cannot be based on a rigid scheme. Both the nature of the task as well as the damage itself can be extremely varied. In the following recommendations, instructions are provided for professional sampling for microbiological analysis and minimum quality standards are formulated. The recommendations do not provide general operating instructions but must be adapted to the circumstances. For many issues, such as the search for causes, further investigation is required. Due to the complexity of investigating microbial damage, it is essential to involve experienced and suitably qualified and proven professionals. At the very least, the criteria listed in Section B.2.1 must be recorded and documented.

For professionally based statements about the condition of the floor structure, several samples must normally be taken. Should only one sample be taken, there is a risk that results will not be representative but will only reflect the condition of a very small area which may not be of any great relevance. In this case, the remedial advice thus derived would not be adequate.

When taking samples, care must be given to ensure that extraction takes place with clean, disinfected tools and that no dusty or soiled material is removed. In sampling following an analysis by cultivating microorganisms, contamination with spores adhering loosely to the surfaces may simulate mould fungi growth.

In addition, it should be noted that mould fungi from mould damage on the walls can be transported into the floor structure via open edge joints or house dust, where they can simulate mould growth in the floor structure in upper layers at the edge. Samples for assessing the floor structure in the area must therefore be taken at a considerable distance from the wall surfaces.

Measures for environmental protection and occupational safety are required during sampling (see also Section 6.3.1).

C.2 Strategy for the investigation of microbial damage

As a rule, material samples are taken and analysed to answer two questions:

- Is there a relevant microbial infestation in the material?
- How extensive is the damage?

In order to estimate the extent of any damage there is a basic requirement for professional sampling with careful consideration of sampling points, sampled material and number of samples. As well as this, both the extent of the damage within the area as well as the depth must be taken into account. Further, the type of damage and cause of this (see Section C.3) and the age of damage (see Section B.2.1 Criterion VI) and the material concerned (see Section B.2.1 Criterion IV) must also be taken into account. In the case of current moisture damage, the extent of the damage is determined by means of moisture measurements (see Section C.4). If the damage has been dry for some time, the extent can only be estimated based on the cause, the age of the damage and structural criteria.

If different results for the concentration of mould fungi are obtained for samples taken from the presumed centre of the damage, checks must be made as to whether the damage range has been correctly assessed or whether there are causes for uneven growth in the area of damage e.g. different moisture contents in the material. Any such uncertainty must be taken into account for the final assessment. If necessary, further samples should be analysed.

Further notes on sampling strategy can be found in the standard DIN EN ISO 16000-19.

C.3 Causes of damage

In relation to the extent of the damage, causes can be divided into three groups: trapped moisture, accidents (spills, flooding, fire extinguishing water, etc.) and hygrothermal damage.

Moisture damage caused by trapped moisture is usually over an extended area. Too little drying time during the construction phase or insufficient

ventilation can lead to a high level of trapped moisture. Diffusion of this moisture from the building can, for example, be hindered by watertight surface coverings or lack of ventilation. The risk of extensive microbial growth increases with the duration of the moisture in the component. The extent of the growth cannot be predicted with certainty and depends above all on the residual moisture, the materials used, the initial contamination of the materials with microorganisms and the length of time. Experience has shown that no relevant microbial growth due to trapped moisture should be expected in the first few months after the construction of a building, in accordance with the recognised rules of technology. However, larger amounts of dust or dirt on or under insulating layers can lead relatively quickly to a selective or large-area microbial growth.

In the event of accidents, with an understanding of the cause it is often possible to estimate the course and distribution of the water. Damage can be very extensive depending on the amount of water leaked and its ability to spread (both as liquid and as water vapour) but it can also be limited to a local area.

Hygrothermal damage due to increased moisture in the room or room surfaces that are too cold is usually localised damage without microbial growth in deeper layers. In deeper layers or within the construction, hygrothermal damage occurs due to damp in that area of the building e.g. due to inadequate internal insulation or leaking vapour barrier.

C.4 Moisture measurements

Moisture measurements are taken to determine the extent of damage. Also, the moisture in the material is determined to ascertain whether microorganisms can grow.

For the first orienting measurement and an overview of the distribution of the moisture in the object, the use of conductivity-based or capacitive measuring devices is helpful and the measurements can be carried out non-destructively and without any particular time requirement. With these methods it can be estimated where an increase in moisture is present. Meaningful qualitative comparison values between dry and wet areas can be obtained. However, due to the considerable material influences on the measured value, no useful quantitative value for the material moisture can be obtained. Hence with this measurement method, except for very moist materials, a reliable assessment of whether microbial growth can take place is not possible.

With regard to microbiological issues, one considers humidity in the gas phase directly at the external and internal material/air interfaces. This “interfacial moisture content”, which in practice is often incorrectly called “equilibrium moisture content”, is given in % and corresponds to the hundredfold a_w value.

This “equilibrium value” of the gas phase must not be confused with the equilibrium value of the material moisture content (content of liquid and gaseous water in the material in relation to its mass or volume, Darr weighing method), since the equilibrium moisture content is strongly material-dependent and is not necessarily correlated with the moisture in the material interface. The determination of the material equilibrium moisture content by gravimetric measurement (Darr weighing method) or the calcium carbide method is therefore unsuitable in practice with regard to microbiological issues since the assessment of the building material-specific characteristics of the moisture (sorption isotherm/specific water content) must be taken into account.

Depending on the substrate materials and the species, mould fungi can grow at room temperature (about 20 °C) from permanent moisture of 70 % – 80 % relative material moisture. In order to determine by measurements whether this critical value has been reached or exceeded in the floors or walls, probe measurements must be carried out using measuring electrodes to detect the moisture in the structure or in the insulating layer (hygrometric measuring methods). For these measurements, holes must be drilled in the floor corresponding to the diameter of the probe used for moisture measurement, i.e. the measurement tests are not non-destructive.

By means of a suitable seal, there must be no air exchange between the hole and the surroundings. To meaningfully detect the damage with these measurements, several measurements at different locations are required. Measurements taken in holes drilled for

drying purposes are not useful, as it may take weeks before realistic moisture levels can be detected. With newly drilled holes, care must be taken to ensure that the heat introduced by the drilling has completely dissipated when the measurement is taken.

When interpreting measured values, it must be taken into account that the relative moisture depends on actual temperature. For this reason, at temperatures well above 20 °C, the relative moisture valid for 20 °C must be determined using absolute moisture levels derived from the measured values and used as a benchmark. It should also be noted that the measured values are very inaccurate at temperatures below 10 °C and that the measurements may need to be repeated at higher temperatures.

To detect obviously damp areas in the insulating layer, it is also possible to carry out simple semi-quantitative resistance measurements by means of long piercing electrodes at the edge joints.

In order to measure the moisture directly on surfaces (e.g. walls), measuring devices with external sensors are appropriate.

Moisture measurements and their assessment require a great deal of expertise and should only be carried out by suitably trained specialists with knowledge of building physics, otherwise misinterpretations may easily occur.

C.5 Number of samples

If sampling is considered necessary, it is important to take enough samples to obtain as representative a result as possible. In most cases a compromise has to be found between economic aspects and representativeness.

For normal living rooms (up to approx. 20 m²) at least 2 samples are taken from the damaged area, as far apart as possible.

If technically speaking a partial remediation makes sense, then samples should be taken from the edge (with sufficient distance from the edge strips), the middle and half-way between the edge and middle, in order to limit the remediation area.

If larger rooms (> 20 m²) or numerous rooms are affected, a representative number of samples must be taken.

The specialist must then undertake thorough planning for the sampling based on the conditions on site and the nature of the damage. The number of samples must be determined on the basis of cause of damage, building construction, the issues posed and the room layout in individual cases. With a recognised cause and the same building construction in affected areas, even for large amounts of damage it is sufficient to sample a few representative rooms. If the cause or construction is unknown, more samples must be taken accordingly.

Reference samples can be very important for identifying the cause, but also for clarifying whether two causes have overlapped and whether there was already some kind of predisposition. For this it is necessary to take reference samples from an area that is definitely not affected by the actual damage. The number of reference samples will depend on the amount of damage, with 2 to 3 reference samples usually being sufficient; for very small amounts of damage one sample may suffice.

C.6 Sampling implementation

The sampling as well as the transport and storage of the samples are carried out in accordance with DIN ISO 16000-21 Section 7.2 (material sampling depth), taking into account the sampling strategy in accordance with DIN EN ISO 16000-19.

The following sections give additional guidance summarised from practice.

Samples should be taken from the part of the floor structure where increased moisture is detected or known to be present. Care should be taken to sample those sites where the highest relative moisture content is suspected, for example underneath the insulating layers in the floor.

In addition, care should be taken to remove the material within the structure that can be microbially colonised i.e. the insulating materials and not the screeds or the concrete.

In order to minimise the intrusion on the floor structure during sampling, it may be advisable to combine the sampling with the installation for drying.

The size of the sample will depend on the desired analysis and the material.

For cultivation, and in particular for microscopy, a contiguous material sample with a diameter of at least 5 cm is required.

If samples are taken by means of an electrical device, e.g. power drill with core drill, then particular attention must be paid to environmental protection due to the possible release of dust (use devices with suction). Also when drilling, beware that the sample material does not get heated too much. At contact surfaces directly between the drill and the material, high temperatures can occur which kill the microorganisms. For drilling cores, therefore, a core of at least 3 cm should be taken – if possible of 5 cm in diameter; alternatively, a slower drilling speed will prevent overheating of the material.

When sampling polystyrene from footfall sound and heat insulation, care must be taken that the polystyrene is not contaminated by the screed located above the insulation. This means, for example, that a core drill with suction is used to drill through the screed layer up to the separating foil and the screed part is then removed. The resulting hole must be vacuum cleaned to remove dust. The separating foil is then cut through with a parcel knife and removed. Subsequently, a drill core (diameter 3–5 cm) is removed from the footfall sound and heat insulation using a suitable disinfected tool.

The top of the material core is clearly marked and the entire core is sent to the laboratory as a sample.

As a rule, when the moisture has soaked through, the bottom of the drill core is most heavily colonised by microorganisms. In the laboratory, therefore, usually the lowest 1 cm of the core is used for cultivation analyses. For microscopy, samples are then taken directly from the bottom surface of the drill core.

However, an infestation of the upper side of the drill core (upper side of the foil) may also occur, which must then be included in the examination.

When evaluating the analysis results of material samples, it is important to specify where the material sample was taken, the thickness of the core and which part of the core was examined.

For mineral wool, an attempt should be made to obtain a contiguous piece of material of at least 5 cm^3. Again, the top should be marked with a sticker. For thin layers of mineral wool, the entire piece of material is analysed; for thicker layers, only the bottom centimetre is analysed as the moisture primarily occurs there.

If an infestation is suspected elsewhere, the samples should be taken from these sites and the result should show the exact location of the sub-samples used for the study.

D. MICROBIOLOGICAL ANALYSIS

Mould fungi and bacteria are investigated with material samples both by cultivation (see Section D.1) and by microscopy (see Section D.2).

Only microscopic examination can distinguish between contamination and infestation (see also Section 1.1).

In interlaboratory tests to determine the concentration of cultivable mould fungi in materials, it has been shown that replicable results can only be achieved if the prescribed method specification is strictly adhered to (see Section D.1).

Further investigations, such as total cell count determination or ATP measurements, can provide additional information but are not standardised and have not yet been sufficiently validated in practice.

Until now, sufficient data was only available for cultivable mould fungi in polystyrene samples and to a limited extent also for mineral fibres in order to determine concentration ranges for the assessment categories (see Section D.3).

A problem with the assessment is the lack of generally accepted background concentrations as a basis for assessing microbial growth in building materials. To evaluate the concentration of mould fungi and bacteria in material samples, there are a number of publications based on statistical analyses of individual laboratories. Systematically collected background data for assessing microbial growth in building materials are still lacking however.

In a research project, the German Environment Agency conducted exploratory investigations on background values in building materials. The project also examined 20 material samples from floor structures. For polystyrene samples from the shell/new building, the median for the concentration of cultivable mould fungi was 150 CFU/g material, the 75th percentile at approx. 1 x 10^3 CFU/g material and the 95th percentile at approx. 4 x 10^4 CFU/g material. This shows that in new buildings, despite trapped moisture, there is generally no relevant mould growth.

Since no samples from floors in old buildings were examined, no statement can be made on polystyrene samples from floors in old buildings.

For bacteria on CASO agar, higher background concentrations were detected in polystyrene samples from the shell/new building. The median was about 1.7 x 10^4 CFU/g material, the 75th percentile at 6 x 10^4 CFU/g material and the 95th percentile at 2 x 10^5 CFU/g material.

Due to the small number of samples examined, these background concentrations can only serve as a first orientation.

D.1 Determination of cultivable mould fungi and bacteria

The processing of material samples is carried out following the suspension method according to DIN ISO 16000-21.

The cultivation of mould fungi is carried out according to DIN ISO 16000-17 in parallel to malt extract agar and DG18 agar. To achieve reproducible results for the given assessment categories, these method specifications must be followed exactly.

It is only useful to investigate materials for bacteria in exceptional cases (see Sections 5.1.2 and 5.1.2.4). There is still no standardised procedure for the detection of bacteria in material samples. Cultivation of the bacteria should be carried out on CASO or TSA agar with natamycin. For actinomycetes, according to Gauze, natamycin tends to capture higher concentrations and diversity, so this agar should additionally be used for the cultivation of actinomycetes (see Annex 5). Bacteria are not routinely differentiated. As in the case of mould fungi, it is advisable to have multiple checks during the incubation period, as many bacteria grow very quickly, while others – especially actinomycetes – grow very slowly.

The samples are processed in accordance with DIN ISO 16000-21 Section 7.5 (suspension of material and wipe samples).

The samples examined in the laboratory are from the area closest to the moisture damage, i.e. where microbial growth is most likely to occur (see also Section C.6).

Please note the following points:

- The amount of buffer depends on the type and quantity of material used. While non-floating samples such as plaster and mineral fibre samples are completely covered with buffer, the buffer addition for polystyrene samples is chosen so that a good washing result is guaranteed through shaking. As a guide, add 50–100 ml of buffer to one gram of polystyrene in a 250 ml (baffled) flask.

- Often only small amounts of sample are available. The amount of buffer should be adjusted (e.g. 20 ml) for material samples < 1 g, as would be expected from drilling cores from polystyrene floor structures.

- Depending on the material, the pH of the initial suspension should be checked. This is especially important with plaster samples. If the pH is in the acidic or alkaline range, the sample must be neutralised.

D.2 Microscopic examination of material samples

In the following chapters pointers are given for a meaningful microscopic assessment of the material samples, as only general statements are made in DIN ISO 16000-21.

The statements relate to adhesive film samples (foil contact samples) and thin layer materials.

Analysis methods for detecting the total cell count (mould fungi and bacteria) from material suspensions by means of fluorescence staining are not taken into consideration as up until now they have only been used by individual laboratories and have not yet been standardised.

D.2.1 Processing of samples for microscopic analysis

For the material samples, adhesive foil samples, thin layers or plucking samples can be applied. The application of adhesive film samples involves little effort and a great many material samples can be assessed sufficiently well with this method. In some cases, the use of thin layers may be necessary. Particularly in the case of very moist samples, the transfer of microorganisms from the material to the film contact can be impeded. Furthermore, infestation in the gap structure of materials can often be detected better in thin layers than with film contacts.

The samples are embedded in lactic acid cotton blue (see DIN ISO 16000-21 Section 6.6) in order first of all to colour microorganisms blue and thus increase the contrast in the microscopic picture. The dye should be applied for at least 10 minutes before any microscopic analysis is performed. In calcareous materials (e.g. plaster), gas bubbles develop due to a reaction of the lactic acid with carbonates, therefore, the cover slip should only be placed on such samples after completion of this reaction.

To make thin layers, use a razor blade to slice the material as thinly as possible. The thickness of the slice must be selected so that the sample remains transparent. Depending on the issue, the slices can be made in different material thicknesses. The slices of material are transferred to a slide with lactic acid cotton blue and covered with a cover slip.

For assessing materials using adhesive film samples, transparent adhesive strips are pressed onto the material sample and then placed on a microscope slide previously prepared with lactic acid blue. As a rule, it is sufficient to place the contact foil with the sticky side directly into the staining solution so that the microscopic assessment can be carried out without an additional cover slip.

D.2.2 Microscopicanalysis

The detection of microorganisms in the microscopic image requires sufficient resolution or overall magnification. While extensive fungal mycelia and aggregates of microorganisms are already recognisable with a 20x lens resolution, the detection of individual fungal spores or bacteria is only possible at significantly higher resolution. Single bacteria are often less than one micron in size and can therefore only be detected safely with the maximum light microscopic resolution (1000 x – 1250 x magnification). The larger the microscopic resolution, the smaller is

the microscopic field of view. For the complete assessment of one square centimetre of material surface a 100 x lens would require an assessment of approximately 3,000 microscopic fields of view, whereas with a 20 x lens, only 130 microscopic fields of view would need to be assessed.

Due to the high microscopic resolution a complete assessment of material samples is not possible and not necessary. Typical adhesive film samples are approx. 6 cm x 1.5 cm in size. Clarification as to whether an infestation is present and whether it may be present uniformly or concentrated in individual areas, can be achieved by multiple screening of the specimen with the 20 x objective (approximately 100 fields of view). During this initial assessment, it should become clear whether there are fungal mycelia and aggregates of microorganisms and whether these may be restricted to specific areas. This is followed by a microscopic analysis with maximum resolution (100 x objective), either distributed over the entire sample or in sample areas that have already been identified as conspicuous. Apart from more heavily contaminated samples, where it is already possible to determine a corresponding load by evaluating fewer fields of view, it is necessary to analyse samples with a lower load more intensively. For a reliable analysis, approx. 200–300 fields of view should be analysed – if possible with counting grids.

D.2.3. Qualitative assessment of microscopic analysis

At the forefront of qualitative analysis is the question of whether the samples are grown over by microorganisms or are only contaminated. In the case of an infestation, generally associated fungal mycelia, actinomycetes filaments or typically arranged bacterial aggregates can be detected.

Frequently, in addition to characteristic spores, other structures can also be identified which allow for a rough systematic classification of the fungus species. Often it may even be possible to determine or narrow down the genus of the fungus species developed on the material. This qualitative analysis of material samples along with the results of the cultivation may, for example, help in assessing whether concurrent indoor air pollutants can be linked to the investigated materials.

Contaminated materials may possibly have increased spore concentrations but contain little or no mycelium or bacterial aggregates. Typical contamination from outdoor air influence can usually be identified by the heterogeneous spore composition and the high proportion of spores of Basidiomycetes, Cladosporium species and Ascomycetes, while spores of the genera *Aspergillus* and *Penicillium* occur in lower concentrations. In contrast, spore contamination by moisture damage is characterised by a high proportion of spores that originate from moisture damage indicators. Very often, fewer spore types of the genera *Aspergillus, Penicillium, Scopulariopsis* have a particularly high proportion in these samples.

Persistent dustiness can increasingly contaminate materials with spores and short fragments of mycelium. Very dusty materials can contain many diverse fungal spores typical for outdoor air, as well as containing a small to moderate amount of short melanin mycelium fragments.

On brand new mineral materials or plastics, microscopic examinations do not usually detect any mycelia or spores due to the high detection limits of the method.

On organic materials made of wood or cellulose fibres as well as cork and similar materials, a small to moderate amount of mycelia and spores will often be detected. These are often already mechanically disturbed and result from a contamination that has already grown on the raw materials before the material production.

D.2.4. Quantitative assessment of the microscopic analysis

In addition to the qualitative analysis, a rough estimate is made of the concentration of microorganisms on or in the material. This concentration estimate can only provide an approximate result because using a foil contact test, only a part of mycelia and spores present on the material surface are transferred to the contact foil. Furthermore, microorganisms are rarely homogeneous but often have a cluster-like pattern on the material, thus an uneconomically high cost would be needed for a statistically reliable assessment (low standard deviation).

The various mould fungi components (spores, sporophors, mycelia) will be evaluated and assessed as follows:

- The assessment is "No infestation" or "Background load" if sporadic spores, sporophors and mycelial fragments are present in the material or contact samples.

  Non-infested materials usually do not contain mycelia. However, single mycelial fragments may also occur on non-infested materials due to sedimentation.

- The sample is rated "Minor infestation" if there is a moderate number of spores, contiguous mycelia and sporophors in the material or contact sample.

  A moderate number of mycelial observations already indicate an onset of microbial development. Moderate numbers of spores, however, can also be observed in cases of excessive dust pollution or contamination by adjacent moisture damage.

- In the case of a (very) large number of spores, contiguous mycelia and sporophors in the material or contact sample, the sample is rated as "Clear infestation". Many or very many spores also indicate an infestation if mycelium can only be found sporadically because especially fine mycelia disintegrate in older mould damage and are difficult to detect.

Corresponding categories with concentrations higher by an order of magnitude can be used for bacteria (see Table 6.2).

Table 6.2

Microscopic assessment of polystyrene material samples* for small mould spores with good flight capacity (e.g. *Penicillium, Aspergillus*), mycelia and bacteria**

Assessment	Fungus mycelium/cm²	Fungus spores/cm²	Bacteria/cm²
Sporadic	≤ 50	≤ 150	≤ 1,500
Moderate	› 50–300	› 150–3,000	› 1,500–30,000
Large number	› 300–6,000	› 3,000–60,000	› 30,000–600,000
Very large number	› 6,000	› 60,000	› 600,000

* The table refers to an evaluation of 100 fields of view (corresponds to approx. 100 mm²) with the 20 x objective (200x) for recording how heterogeneously the sample is contaminated and a detailed evaluation with the 100 x objective of 200–300 fields of view (corresponds to approx. 7–10 mm²).

** Only one fifth of the spore concentrations given in the table should be applied in the category "Moderate" and higher when the fungi have large spores or those with poor dispersion capability (e.g. *Stachybotrys, Alternaria* or *Epicoccum*).

D.3 Assessment of the results

The concentrations of mould fungi obtained are assigned to the assessment categories together with the results of the microscopic examination taking into account moisture indicators (see also Section B.2.1, Criterion I for further information about the assessment and Table 6.3.).

The frequent occurrence of mould species or genera which are often detected in the case of moisture damage (so-called moisture indicators, see Section 1.2.2, Table 2) indicates that the case is an infestation and not an impurity when mould concentrations are in the 10^4 CFU/g – 10^5 CFU/g range. Contaminated materials can yield high concentrations of mould fungi during cultivation, simulating infestation.

The indicated concentration ranges of cultivable moulds relate primarily to polystyrene materials and to mineral wool. Recent studies show, that these concentration ranges may also be applied to other materials such as polyurethane foam or plaster[3].

Concentrations of 10^4 CFU/g in moulds with low sporulation (e.g. *Stachybotrys*, *Chaetomium*) can already be considered as clear evidence of an infestation if passive dispersal of spores e.g. from screed edge joints to the sampling point is excluded.

Quantitative assessments in material analyses are subject to a high level of uncertainty (see also Chapter D). Interlaboratory tests provided a standard deviation of 30 % – 50 % for the total concentration of cultivable moulds. The figures are therefore to be understood as orders of magnitude and not as limiting values. Thus a sample with a mould fungus concentration of 7.8×10^4 CFU/g is of the same order of magnitude as a sample with 1.2×10^5 CFU/g.

3 Background values of mould fungi and bacteria on building materials, 3rd German Mould Fungus Seminar in Neuss, 03. + 04.02.2017

Table 6.3

Assessment of the concentration of cultivable mould fungi (CFU/g material) and microscopic results for polystyrene and mineral wool for the three assessment categories in the evaluation level 2 and for impurities

No infestation Background load	**Impurity ***	**Minor infestation**	**Minor infestation**	**Clear infestation**
Cultivation ‹ 10^4 CFU/g	**Cultivation** 10^4–10^5 CFU/g	**Cultivation** 10^4–10^5 CFU/g	**Cultivation** › 10^5 CFU/g ‹ 10^6 CFU/g**	**Cultivation** › 10^5 CFU/g
and	and/or***	and/or***	and/or***	and/or***
Microscopy sporadic or no spores, mycelium, sporophors	**Microscopy** moderately large number of spores without mycelium and sporophors	**Microscopy** moderately large number of spores, mycelium, sporophors	**Microscopy** moderately large number of spores, mycelium, sporophors	**Microscopy** (very) large number of spores, mycelium, sporophors

* Contaminations of › 10^5 CFU/g without growth are usually not achieved in floor structures due to poor accessibility to the materials.

** Concentrations of › 10^6 CFU/g indicate a clear infestation regardless of the microscopy.

*** and/or means: cultivation and microscopy or only microscopy

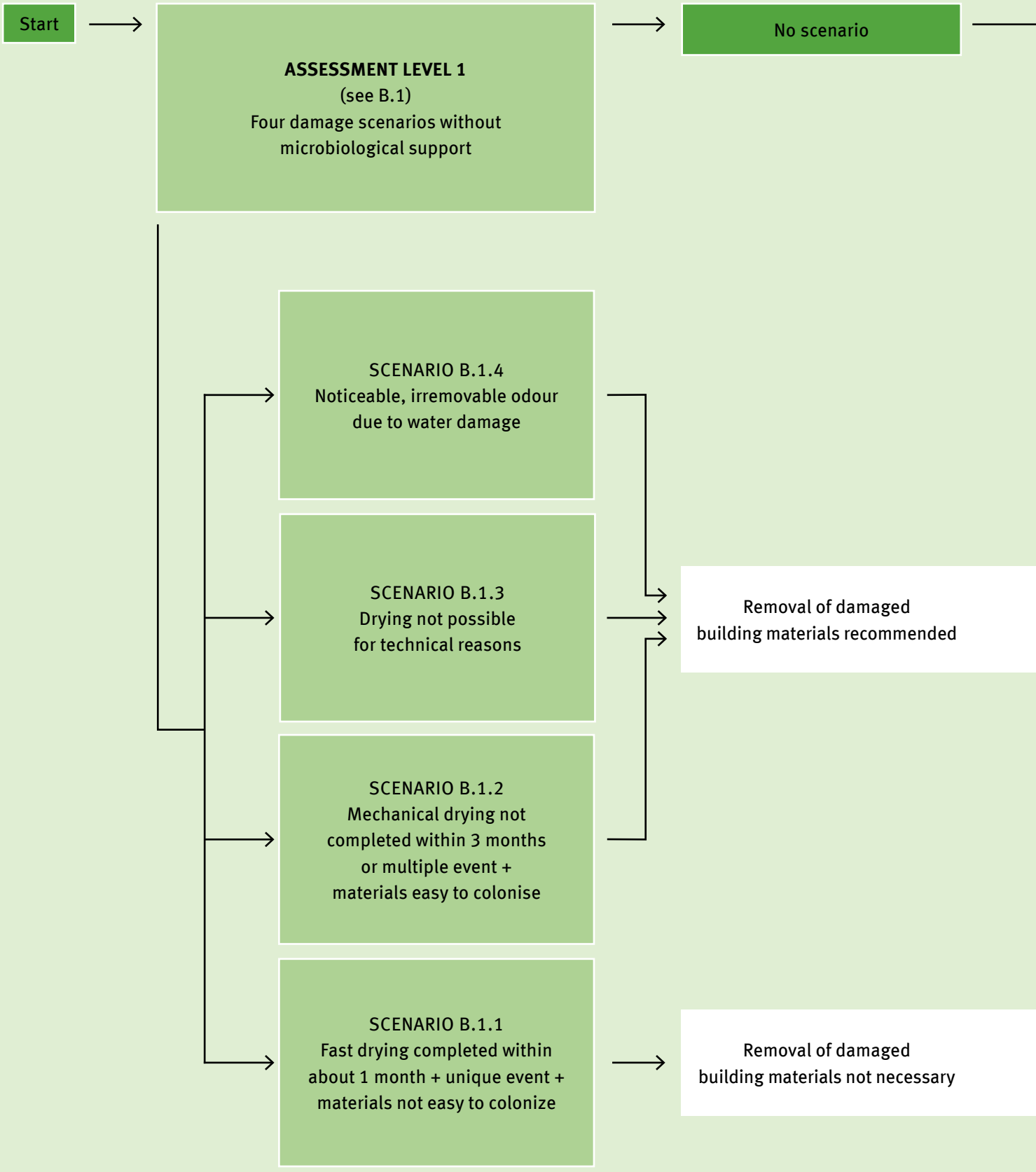
The microscopic results provide important indications of a potential infestation of the material with mould fungi. Microscopic examination allows the detection of dried-up or killed infestations, in which the microorganisms are no longer able to grow. Microbial damage can be clearly detected based on mould fungus mycelium and sporophors or dense bacterial layers grown on the material, while the detection of spores alone can also be due to contamination of the material. The cause – usually adjacent damage – should be clarified and eliminated even if the issue is a heavy contamination of the material without any growth. Cleaning or removal of the affected material e.g. in edge joints in the case of damage to the walls may be necessary.

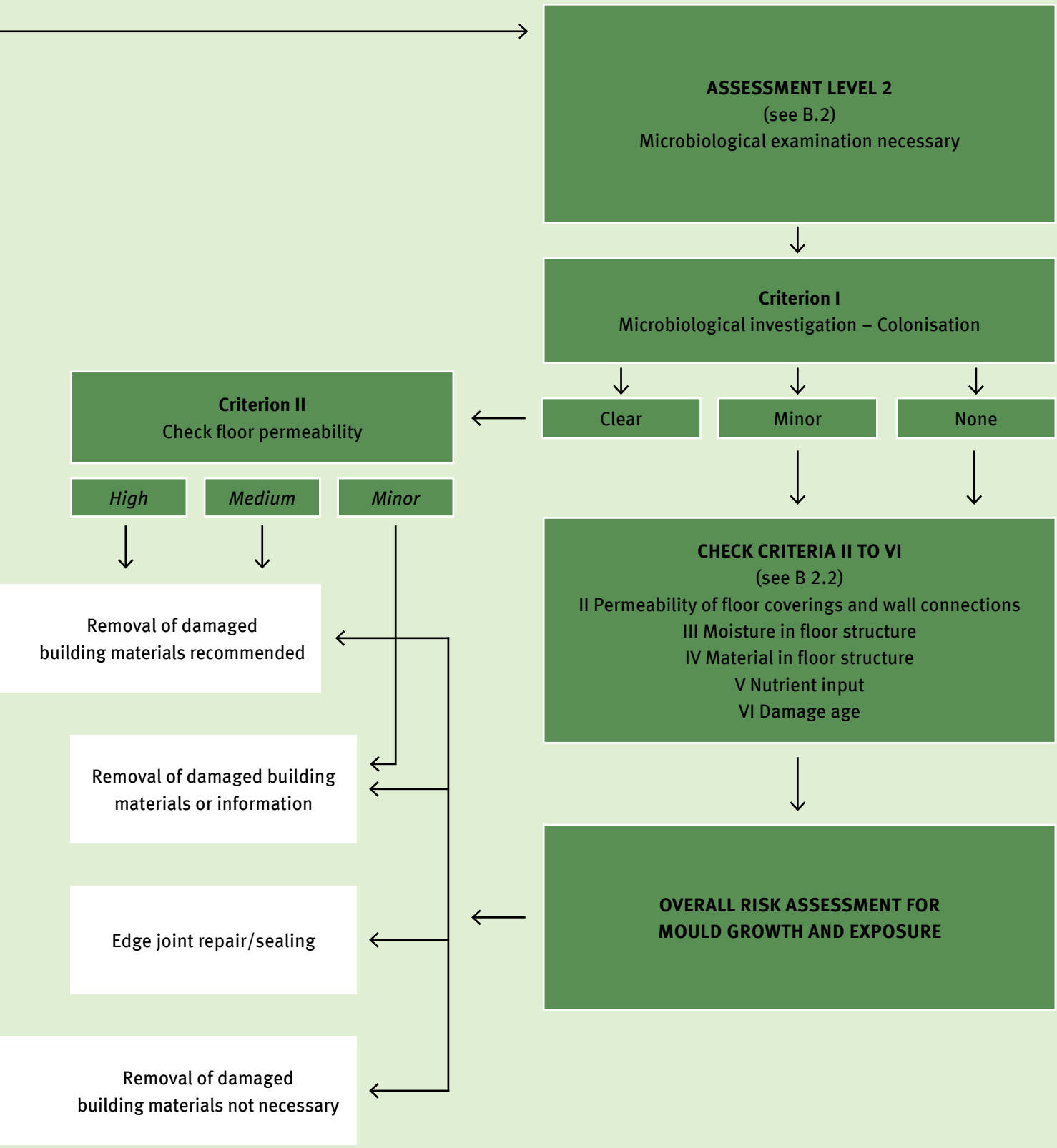
No general concentration ranges can yet be specified for the assessment categories of culturable bacteria. Empirical values from individual laboratories show that the concentrations in the three assessment categories are approximately one order of magnitude higher than the concentrations of mould fungi, i.e. that an infestation is to be assumed from a concentration of 10^6 CFU bacteria/g material.

Outlook

The aim of the presented schemes is a uniform assessment of moisture and mould damage in floors based on common criteria. Due to the complexity of the factors to be considered, there are certainly cases that cannot be assessed by this schematic approach. Therefore, the assessment must be done by knowledgeable people. Open questions must be clarified by further research and practical experience, and the assessment schemes must be updated if new findings are available.

Summary of the assessment of Utilisation class II rooms




ASSESSMENT LEVEL 2
(see B.2)
Microbiological examination necessary
Criterion I
Microbiological investigation – Colonisation
Clear
Minor
None
Criterion II
Check floor permeability
High
Medium
Minor
CHECK CRITERIA II TO VI
(see B 2.2)
II Permeability of floor coverings and wall connections
III Moisture in floor structure
IV Material in floor structure
V Nutrient input
VI Damage age
Removal of damaged building materials recommended
Removal of damaged building materials or information
Edge joint repair/sealing
Removal of damaged building materials not necessary
OVERALL RISK ASSESSMENT FOR MOULD GROWTH AND EXPOSURE

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ANNEX 7

Guide concentrations of cultivable mould fungi

Guide concentrations [CFU/m³] of cultivable mould fungi in indoor and outdoor air in summer and winter in Germany (from UFOPLAN 20161218/07 final report (2004) Collection of background concentrations for the assessment of indoor moulds).

Guide concentrations of selected mould fungus species in outdoor air

	Winter			Summer			Summer + winter		
	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
Alternaria spp.	0	0	10	0	20	80	0	5	60
Cladosporium spp.	5	50	337	0	980	4124	0	100	3288
Aspergillus flavus	0	0	0	0	0	20	0	0	20
Aspergillus fumigatus	0	0	65	0	10	45	0	0	51
Emericella nidulans	0	0	0	0	0	20	0	0	10
Aspergillus niger	0	0	0	0	10	40	0	0	21
Aspergillus ochraceus	0	0	0	0	0	20	0	0	0
Aspergillus penicillioides	0	0	0	0	0	0	0	0	0
Aspergillus restrictus	0	0	0	0	0	0	0	0	0
Aspergillus sydowii	0	0	0	0	0	0	0	0	0
Aspergillus versicolor	0	0	0	0	0	20	0	0	20
Aspergillus ustus	0	0	0	0	0	0	0	0	0
Other Aspergillus spp.	0	8	20	0	0	20	0	0	20
Total Aspergillus spp.	0	10	81	0	35	106	0	15	100

Eurotium amstelodamii	0	0	2	0	0	0	0	0	0
Eurotium herbariorum	0	0	0	0	0	0	0	0	0
Eurotium spp.	0	10	30	0	0	21	0	10	30
Total Eurotium spp.	0	10	41	0	10	31	0	10	40
Penicillium brevicompactum	0	0	80	0	0	41	0	0	51
Penicillium chrysogenum	0	0	2	0	0	20	0	0	20
Penicillium expansum	0	0	0	0	0	20	0	0	20
Penicillium glabrum	0	0	0	0	0	0	0	0	0
Penicillium olsonii	0	0	0	0	0	42	0	0	40
Penicillium spp.	0	15	50	0	20	82	0	20	80
Total Penicillium spp.	5	20	217	0	50	160	0	30	160
Mucor spp.	0	0	5	0	0	20	0	0	20
Rhizopus spp.	0	0	5	0	0	20	0	0	20
Other Zygomycetes	0	0	5	0	0	0	0	0	5
Total Zygomycetes	0	0	10	0	5	25	0	0	20
Yeasts	0	5	115	0	23	2000	0	10	1106
Acremonium spp.	0	0	0	0	0	0	0	0	0
Aureobasidium spp.	0	0	0	0	0	0	0	0	0
Botrytis	0	5	20	0	0	20	0	0	20
Chaetomium spp.	0	0	0	0	0	0	0	0	0
Fusarium spp.	0	5	40	25	80	200	0	25	160
Paecilomyces spp.	0	0	0	0	0	10	0	0	5
Phialophora spp.	0	0	0	0	0	0	0	0	0
Scopulariopsis spp.	0	0	0	0	0	0	0	0	0
Stachybotrys chartarum	0	0	0	0	0	0	0	0	0
Sterile mycelia	0	5	80	0	0	20	0	0	41
Tritirachium (Engyodontium) album	0	0	0	0	0	0	0	0	0
Trichoderma spp.	0	0	0	0	0	20	0	0	20
Wallemia sebi	0	5	45	0	0	11	0	0	40

Guide concentrations of selected mould fungus species in indoor air

	Winter			Summer			Summer + winter		
	5th per-centile	Median	95th per-centile	5th per-centile	Median	95th per-centile	5th per-centile	Median	95th per-centile
Alternaria spp.	0	5	40	0	5	40	0	5	40
Cladosporium spp.	0	30	927	0	440	1800	0	70	1588
Aspergillus flavus	0	0	5	0	0	20	0	0	20
Aspergillus fumigatus	0	0	40	0	5	60	0	0	41
Emericella nidulans	0	0	0	0	0	20	0	0	10
Aspergillus niger	0	0	20	0	0	40	0	0	22
Aspergillus ochraceus	0	0	0	0	0	20	0	0	0
Aspergillus penicillioides	0	0	0	0	0	0	0	0	0
Aspergillus restrictus	0	0	0	0	0	0	0	0	0
Aspergillus sydowii	0	0	0	0	0	0	0	0	0
Aspergillus versicolor	0	0	43	0	0	40	0	0	42
Aspergillus ustus	0	0	0	0	0	0	0	0	0
Other Aspergillus spp.	0	5	25	0	0	20	0	5	25
Total Aspergillus spp.	0	18	131	5	25	250	0	25	201
Eurotium amstelodamii	0	0	0	0	0	20	0	0	1
Eurotium herbariorum	0	0	0	0	0	0	0	0	0
Eurotium spp.	0	5	20	0	5	40	0	5	20
Total Eurotium spp.	0	5	20	0	5	40	0	5	40
Penicillium brevicompactum	0	0	40	0	0	40	0	0	40
Penicillium chrysogenum	0	0	63	0	0	20	0	0	40
Penicillium expansum	0	0	20	0	0	20	0	0	20
Penicillium glabrum	0	0	3	0	0	0	0	0	1
Penicillium olsonii	0	0	40	0	0	80	0	0	60
Penicillium spp.	0	20	210	0	20	80	0	20	100
Total Penicillium spp.	5	50	354	5	60	225	5	55	281

Mucor spp.	0	0	6	0	0	20	0	0	20
Rhizopus spp.	0	0	10	0	0	20	0	0	20
Other Zygomycetes	0	0	0	0	0	0	0	0	0
Total Zygomycetes	0	0	20	0	0	30	0	0	20
Yeasts	0	10	1150	0	40	2000	0	20	2000
Acremonium spp.	0	0	0	0	0	0	0	0	0
Aureobasidium spp.	0	0	0	0	0	0	0	0	0
Botrytis	0	0	5	0	0	10	0	0	5
Chaetomium spp.	0	0	5	0	0	0	0	0	0
Fusarium spp.	0	5	71	0	40	160	0	10	131
Paecilomyces spp.,	0	0	5	0	0	5	0	0	5
Phialophora spp.	0	0	0	0	0	0	0	0	0
Scopulariopsis spp.	0	0	0	0	0	0	0	0	0
Stachybotrys chartarum	0	0	0	0	0	0	0	0	0
Sterile mycelia	0	0	11	0	0	20	0	0	20
Tritirachium (Engyodontium) album	0	0	0	0	0	0	0	0	0
Trichoderma spp.	0	0	5	0	0	0	0	0	5
Wallemia sebi	0	0	15	0	0	40	0	0	21

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ANNEX 8

Guide concentrations for the total spore count

Guide concentrations for the total spore count [spores/mycelium/m³] in indoor and outdoor air in Germany in summer and winter (from the Collection of background concentrations for the assessment of indoor moulds UFOPLAN 20161218/07 (2004) final report)

Guide concentrations for selected types of spores in indoor and outdoor air in winter and summer

	Median				95th percentile			
	ID-W	OA-W	ID-S	OA-S	ID-W	OA-W	ID-S	OA-S
Basidiospores	889	711	3822	8732	3017	11354	17384	26168
Ascospores	0	11	178	289	85	151	586	2333
Cladosporium	65	22	2000	3311	195	160	5560	11590
Alternaria/ Ulocladium type	0	0	5	5	5	5	39	69
Aspergillus/ Penicillium type, coarse	22	0	42	44	139	64	224	255
Aspergillus/ Penicillium type, smooth	67	22	111	44	560	157	422	322
Aspergillus restrictus type, group	0	0	0	0	67	42	67	42
Total Aspergillus/ Penicillium type	111	22	178	111	743	235	589	658
Other spores	22	0	44	44	178	67	244	276
Hypha fragments	0	0	67	89	67	42	451	539
Stachybotrys chartarum	0	0	0	0	0	0	0	0
Chaetomium	0	0	0	0	1	0	5	5
Helminthosporium type	0	0	10	24	5	0	87	136
Epicoccum	0	0	5	5	0	0	45	58
Torula	0	0	0	0	0	0	5	10

ID = indoors, OA = outdoor air, W = winter, S = summer

G

Glossary

A

Absolute humidity
Mass of water in one cubic metre of air (g/m³)

Actinobacteria
The German term for the Actinobacteria class, which was proposed in 1997 to take account of the great morphological diversity of the bacterial group known up to this time as *"Actinomycetes"*

Heterotrophic, predominantly aerobic bacteria that vary widely in their morphological, physiological and cytochemical properties

Actinomycetes
A microbiological parameter for the practice that includes the mycelium-forming actinobacteria that are easily recognised on nutrient agar plates

Air conditioning
Building ventilation system, which not only allows a temperature control of the air through heat recovery, but also has additional components for cooling/heating and/or for humidifying and dehumidifying the air

Allergen
A foreign organic or inorganic substance that triggers an immune response in the body

Atopy
Tendency to react with allergic reactions of immediate type (type I allergy) to contact with otherwise harmless substances from the environment

a_w value (water activity)
Water activity as a measure of the availability of "free" water in the material. Takes values between 0 (absolute dryness) and 1 (condensing humidity). Water activity must not be confused with the water content (g water/g substrate)

Air exchange rate (unit 1/h)
The air flow rate supplied as fresh air (in m³/h) divided by the air volume of the room (in m³). It indicates what air volume, related on the room volume, is exchanged per hour and replaced by outdoor air
Note: For example, an air exchange rate of 2/h means that twice the room's air volume is exchanged by the ventilation in an hour.

B

Bioaerosols
Airborne particles of biological origin

Biocide
A substance or mixture intended to destroy, deter, render harmless, prevent its action or otherwise combat harmful organisms in any way other than by mere physical or mechanical action

Bacteria
Unicellular, prokaryotic microorganisms that multiply asexually by cell division and whose DNA is not present in a cell nucleus, but in free form in the cytoplasm

C

Colony
Visible accumulations of cells that result from the proliferation of bacteria, yeasts and moulds on solid nutrient media

Colony Forming Unit (CFU)
Unit expressing the number of culturable microorganisms [EN 13098: 2000 [6]]
Note 1: A colony forming unit may be formed by a single microorganism, an aggregate of several microorganisms or one or more microorganisms attached to a particle.
Note 2: The number of colonies depends on the incubation or cultivation conditions.

Contamination
Pollution of surfaces beyond general background load or materials by microorganisms or biogenic particles and substances that are not caused by growth but by direct contact with infested materials or by air pathway

Cross ventilation
Ventilation through widely open opposite windows or windows and doors ("draft")

Cultivation
Cultivation of growth-capable microorganisms on/in nutrient media

Cultivable mould fungi
Share of the total number of ⇢ mould fungi that can be grown under the cultivation conditions applied
Note: Cultivability depends e.g. on the type of nutrient medium used and the incubation temperature.

D

DG18 agar
Dichloran glycerol 18 % agar to breed xerophilic moulds

Disinfection
A measure that reduces the number of infecting agents – e.g. on a surface or an object – to such an extent that they cannot cause an infection

E

Endotoxin
Part of the cell wall of Gram-negative bacteria

Equilibrium moisture
Equilibrium moisture, which occurs in the building material under the prevailing climatic conditions of the surroundings

Exposure
Being exposed to a pathogen, disease-causing particles or substances

F

Final cleaning
Cleaning the remedied rooms after the completion of the reconstruction and possibly the furnishings

Filtration (in detecting microorganisms)
The separation of microorganisms or mould fungi from a specified air volume using filters [DIN ISO 16000-16]

G

Germ
Non-scientific umbrella term for microorganisms and viruses; often used as a synonym for pathogens

H

Heat transfer coefficient (U value)
The insulation quality of a component of the outer shell, e.g. the outer wall. A high U value means good heat transfer and therefore poor insulation

Hyphae
Cellular threads formed by moulds, the totality of which is called ⇢ mycelium

Hyphomycetes
Fungus growing in the form of filamentous cell strands, the so-called ⇢ hyphae [DIN ISO 16000-17]
Note 1: The totality of hyphae is called mycelium.
Note 2: The term "hyphomycetes" delimits the hyphae-forming fungi against the yeasts

I

Impaction (in detecting microorganisms)
Separation of particulate matter (spores, cells, etc.) depending on mass factors on a solid surface (nutrient medium or adhesive coating)

Indicator organism of mould infestation
An organism whose detection provides sufficient evidence of damage due to its frequent occurrence under certain environmental conditions

Infestation, microbial
See mould infestation

Isopleths
Connecting lines between places having the same numerical values in graphical representation

M

Microorganism
Cellular or noncellular microbiological entity capable of proliferating or transferring genetic material or a unit that has lost this property [DIN EN 13098]

Moisture indicators
Mould fungi that require a relatively high moisture content to grow and therefore often occur due to indoor moisture damage

Morphology
Form, shape and structure of living beings and their components

Mould
Microorganisms (moulds, yeasts, bacteria) that are growing or have grown on or in a material

Mould fungi
Filamentous fungi from various taxonomic groups (Ascomycetes, Zygomycetes) and their anamorphic stages (formerly called Deuteromycetes or fungi imperfecti) that form a ⇢ mycelium and ⇢ spores

Mould infestation
Damage caused by current or past growth of microorganisms (moulds, yeasts, bacteria) on components, on surfaces or in materials

Mould mycoses
Infections caused by mould

MVOCs
Microbial volatile organic compounds (produced by microorganisms) such as some aldehydes, alcohols, esters and ketones

Mycotoxins
Products of secondary metabolism of ⇢ mould fungi that are toxic to humans and animals

Mycelium
Entirety of the ⇢ hyphae of a fungus

N

Nutrient medium
Formulation of substances in liquid, semi-solid or solid form containing natural and/or synthetic components to assist in the propagation (with or without inhibition of certain microorganisms), identification or preservation of the viability of microorganisms

O

Old buildings
Buildings that were built until the 60s and 70s of the last century and buildings built later but still having insufficient insulation standard – from today's perspective

P

Pathogenicity
Ability to trigger a disease

Pathogen Associated Molecular Pattern (PAMP)
Structural motifs or molecules that are characteristic of a broad spectrum of microorganisms and allow the innate immune system to recognise the penetration of bacteria, viruses, fungi or parasites

Phylogenesis
The phylogenetic development of the totality of all living beings and certain kinship groups at all levels of biological classification

Predisposition
The susceptibility of a person to a particular disease

R

Reference
Reference system or reference value for a certain measured value

Relative humidity
Percentage of the maximum possible water vapour content in the air
Note: the amount of water vapour that the air can absorb depends on the temperature. Warm air can absorb more water than cold air.

Residual trapped moisture
⇢ Trapped moisture

Resistance
Insensitivity of an organism to harmful external influences

S

Spores
Asexual distribution organs (sporangiospores and conidia) formed for reproduction and distribution, and sexual distribution organs (zygospores, ascospores) from ⇢ mould fungi (moulds, yeasts, bacteria) on components, on surfaces or in materials

In practice, all these distribution stages are summarised under the umbrella term ‘spores’

Shock ventilation
Short, intensive ventilation through one or more wide-opened windows

T

Taxonomy
Branch of systematics that deals with the classification of living beings in systematic categories

Thermography
An imaging process that can display surface temperatures of objects. The differences in the temperature of component surfaces are shown as colour samples

Total bacteria (in air)
All bacteria growing on CASO agar in an air sample

Trapped moisture
Moisture introduced into a building by the construction process, especially by the inevitably wet processing of building materials such as concrete, plaster, mortar, screed and paint, and by improper storage or transport of building materials

W

Water activity
See ⇢ a_W value

Y

Yeasts
Unicellular fungi multiplying by budding (also called Endomycetes)

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