13 Biological exposure

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13.1 Introduction

Health problems such as watery eyes, sneezing attacks, ticklish throats, malaise and unpleasant odours are often thought to be linked to the presence of organisms such as mould, bacteria, mites or their metabolites and excrements. Frequently, the microbiological pollution of the indoor air is attributed to the operation of air conditioning systems or visible or suspected damp damage in the building, and measurements are requested to determine the cause.

However, steps to improve the workplace situation can often be initiated without the need for measurements if the workplace is inspected by an expert and the causes eliminated. If measurements are still needed, a measurement plan must be drawn up for the specific issues involved.

This chapter brings together the knowledge currently held by the German statutory accident insurance institutions on investigations of indoor problems due to biological exposure. It makes example recommendations on how to assess the occurrence of biological agents in indoor workplaces. The information is mainly derived from research and measurements taken when investigating damp problems caused by structural faults and water damage, and hygiene assessments of ventilation and air conditioning systems [1] (see also Section 6.2, "Ventilation and air conditioning systems").

13.2 Occurrence of biological agents

Biological agents occur all around us. As part of human skin and mucous membrane flora, they are a natural safeguard against pathogens. Humans themselves emit microorganisms into indoor workplace environments by means, for example, of exhalation or shedding of skin. However, these recommendations do not cover this natural bio-emission, which can also contain potentially pathogenic microorganisms, nor excretion of pathogenic microorganisms by people with an illness. The hazards posed by microbiological metabolites, e.g. MVOCs and mycotoxins, and cellular components such as endotoxins, have also been omitted since the scientific data regarding them has not yet been fully substantiated.

Potential causes and sources of biological agents in indoor workplaces are listed in Table 33.

Ventilation and air conditioning systems (VACs) are frequently a key factor in workplace pollution caused by indoor biological exposure. Table 34 shows potential sources of biological agents in such systems and the hygiene problems that can ensue. Thanks to improved hygiene regulations concerning VAC maintenance [2], diseases of the respiratory tract are a seldom occurrence nowadays.

Table 33:
Examples of possible sources of biological agents in indoor workplaces

Cause/source	Effects
Outdoor air	
Farms, composting/waste-sorting facilities, sewage plants in the immediate vicinity	Contamination with microorganisms from the surrounding environment, e.g. due to natural ventilation via windows, doors or VACs' outdoor air intake
Indoor air	
Inadequately maintained plant pots, hydroculture; prolonged storage of organic waste	Colonisation with microorganisms (e.g. stagnant water in plant pots), especially mould colonisation
Condensation resulting from thermal bridges; building damage, e.g. due to water ingress or due to the building design	When dampness reaches a certain level: colonisation with microorganisms, particularly mould, on wallpaper, paper, cardboard, drywalls, insulating materials, brickwork, wood and joints
Inadequate removal of damp due to incorrect ventilation	See "condensation"
Contamination in the form of, e.g. spilt foods or hair, flakes of skin in dust	Basis for in situ growth of various microorganisms; see "condensation" Plus colonisation with household dust mites, especially in upholstered office chairs or carpets

Table 34:
Potential sources of biological agents in indoor workplaces due to incorrectly installed/operated ventilation and air conditioning systems [2]

Source	Effects
Intake of outdoor air Intake and recirculation air filters missing Grid missing in front of inlet passage	Intake of microorganisms and dusts from environmental sources, e.g. farms, waste/sewage treatment plants or composting facilities; intake of mist from cooling towers/recooling plant; access for animals, animal faeces in outdoor air pipes
Exhaust air outlet	Repeat intake of polluted extracted air; short-circuit between outdoor and exhaust air
Humidifiers Condensate collecting plate Fans	Colonisation of the circulating water with microorganisms, formation of biofilms on appropriate surfaces
Air coolers Heat regenerators	Colonisation of the condensation with microorganisms; formation of biofilms on appropriate surfaces
Air pipes	Colonisation of dust deposits and condensate with microorganisms
Air filters	High dust accumulation, contamination of indoor air with microorganisms or microbial components
Servicing and repairs	Release of dust, contamination of indoor air with microorganisms or microbial components if not carried out properly

13.3 Intake and effect of biological agents

Since the main route of exposure to biological agents in indoor workplaces is the respiratory tract, this section does not cover other routes. Most biological agents are so small that they can be inhaled. This is particularly true of the main components of microbial aerosols, such as airborne mould spores, and bacterial cells and fragments of bacterial cell walls, most of which can be assumed to be respirable too. Table 35 shows the dimensions of biological agents and various particles of biological origin that can be contained in respirable bioaerosols.

Table 35:
Dimensions of possible bioaerosol components (based on [3])

Biological particle	Aerodynamic diameter in µm
Viruses	0.02 to 0.03
Actinomycetes, airborne spores	0.5 to 1.5
Bacteria	0.2 to 10
Mould, airborne spores	2 to 8
Moss spores	5 to 30
Fungal cells, hyphae	10
Amoebae	10 to 40
Mites, faecal and body particles	10 to 40
Fern spores	20 to 60
Pollen	5 to 250
Microbiological cellular wall components (e.g. endotoxins, glucans)	Considerably smaller than the respective organisms

By way of comparison:
Particle › 100 µm inhalable, › 10 µm thoracic, › 4 µm respirable (Johannesburg Convention)

In many cases, there is a lack of conclusive evidence regarding the links between the occurrence of biological agents in indoor workplaces and incidence of illness. However, based on the knowledge currently available, the assumption is that damp and/or mould-infested rooms pose a particular risk for allergy sufferers and people with chronic respiratory/skin diseases who spend time in those rooms. Allergic reactions and mucous membrane irritations in the eyes and respiratory tracts are probably the most significant health disorders associated with mould [4].

Allergic effects

A person's tendency to develop an allergy depends on various factors, i.e.:

- the allergological relevance, i.e. level of the allergen's sensitising potential,
- the individual's predisposition,
- the allergen concentration in the respirable air,
- the duration and frequency of exposure and
- any other aggravating factors such as simultaneous occurrence of other allergenic substances.

Sensitisation itself is not an illness but it can cause allergies to develop at a later stage and affect the extent of such allergies. A high level of prolonged contact with the allergen is normally necessary for sensitisation to occur. In individuals who are already sensitised, even small amounts of allergens are enough to trigger allergic reactions.

Allergic effects of mould and actinomycetes

Airborne actinomycete and mould spores are major allergy triggers. Actinomycetes are "Gram positive"[1] bacteria that grow in much the same way as mould, which is why they are also known as "ray fungi". Where building materials have been damaged by damp, a wide range of actinomycetes can be present, some of them at high concentrations [5]. However, it is rare for detectable

[1] Gram staining is a bacteriological staining method, invented by *Hans Christian Gram* in 1884. Due to their multilayered cellular wall structure, Gram positive bacteria retain the dye and appear violet under a microscope. Gram negative bacteria, on the other hand, have a single-layer cellular wall structure, which means that they do not retain the dye and therefore appear light red under a microscope.

concentrations of actinomycete spores from these materials to find their way into the indoor air.

The allergen levels measured to date in the air in mould-infested indoor workplaces are much lower than in work areas with a high level of microbial pollution, e.g. as in agricultural or waste-sorting workplaces. Though the risk of sensitisation cannot be completely ruled out, it is relatively low.

Various studies have shown that the incidence of mould allergies in people with respiratory symptoms is between 1 and 10%, and in people with a predisposition for allergic hypersensitivity reactions (atopic individuals) as much as 30%. Around 5% of the population are thought to be sensitised to mould.

The only cause-effect relationships to have been substantiated to date with regard to mould exposure concern allergies, infections and respiratory illnesses at high-exposure workplaces. According to the WHO “Guidelines on Dampness and Mould”, there is sufficient evidence of a link between the presence of mould/dampness indoors and the occurrence of symptoms such as asthma, certain respiratory complaints and respiratory infections. Consequently, excessive levels of dampness and/or mould indoors must be considered a potential hazard [6]. However, these findings cannot be used to derive guide values for harmful indoor mould concentrations. It is only possible to provide an approximate classification of the hazards to room users though individual predisposition to react with an illness must also be taken into account (as in the case of allergy sufferers, individuals with an immunodeficiency or people with chronic respiratory illnesses) [7].

Allergic effects of mites

Mites can be found in such places as mattresses, bed linen and upholstered furniture. The optimum development conditions for most species of mite are an ambient temperature of around 25 °C combined with approximately 70% relative humidity. Studies dealing with the occurrence of mite allergens in indoor workplaces are few and far between. Following their study of 14 office rooms in which employees had sick building syndrome symptoms, *Janko* et al. suggested that upholstered office chairs be cleaned regularly [8]. The method used to detect exposure to mite allergens is to examine dust deposits. Measuring methods for detecting mites (and mite allergens) are described in the literature [9].

Currently, the main method used to sample the air to detect allergen exposure in the workplace is filtration. A research project by the IFA aims to test a newly developed sampling procedure [10].

Irritative and toxic effects

One of the irritative/irritative-toxic complaints linked to exposure to biological agents is mucous membrane irritation (MMI) [11]. It occurs at average mould concentration levels (> 10^3 spores/m^3 of air) and is also observed indoors [4; 10; 12]. Possible symptoms of MMI are non-specific irritation of the mucous membranes in the eyes (e.g. stinging or watery eyes), the nose (e.g. sneezing attacks, secretion and obstruction of the sinuses) and the throat (e.g. a dry feeling or a need to clear one’s throat).

Infections

The infection potential of biological agents that occur in indoor workplaces is low. For instance, individuals exposed to mould will only develop an infection if they are immunocompromised. Infections caused by bacteria in indoor workplaces are also extremely rare. They are often felt to be linked to contaminated ventilation and air conditioning systems, particularly in the case of legionella. The research carried out by the German statutory accident insurance institutions to date has not detected any legionellae in the humidifier water in ventilation and air conditioning systems [1].

13.4 Investigation and measuring method

Before determining whether an elaborate microbiological examination is necessary, the health complaints must be documented. Then the conditions within the work environment (building, rooms, furnishings, etc.) must be assessed (see Questionnaire G2 in Annex III and the S2 questionnaire available at www.dguv.de/ifa (webcode 650356)) to identify any links between them and the complaints. This step should be used for fact-finding, as illustrated in the special S10 questionnaire available on the internet (www.dguv.de/ifa, webcode 650356), which uses mould as an example.

In many cases, the information available and the visual evidence are sufficient for a conclusive assessment without having to carry out measurements. This is particularly true if there is clear visual evidence of damage caused by mould or damp and it is therefore obvious that action is needed.

Where inspection of the workplace does not permit a conclusive assessment of the situation, microbiological sampling may be necessary in the following instances:

- if action is required in order to protect health, e.g. in order to initiate any necessary remediation,
- when the bio-emission sources are not clear, e.g. contamination from ventilation and air conditioning systems, or
- as part of investigations into suspected cases of formally recognised occupational disease

The subsequent procedure depends on, among other things, whether there are visible changes in the room, e.g. mould infestation or watermarks. The following two case studies explain the approach.

Case study 1

Employees complain of health problems that are linked to certain rooms. There are no visible changes such as mould or watermarks but there are frequent cases of subjective odour perception.

In these cases, the first step is to investigate the odour. If it smells of chemical substances, e.g. solvents, paints, adhesives, rubber, cardboard or freshly treated wood, microbiological measurement is not necessary. The action to be taken to determine the cause is described in Chapter 12, “Chemical exposure”.

If, on the other hand, the odour smells of substances typical of the metabolic activity of microorganisms, e.g. musty, putrid, mouldy or like alcoholic fermentation, a workplace inspection should be conducted to attempt to identify the source of the odour. There may be concealed damage, e.g. behind panels, units, in false floors or suspended ceilings. Stagnant water in plant pots can also be a source of odour.

If no odour source is identified despite thorough investigation and if there are still grounds to suspect exposure to biological agents, indicative microbiological measurements can be performed. The following methods can be used for this:

- Air measurement

  Determination of the mould spore count (particle sampling, e.g. using a PS 30 particle sampler, “Holbach sampler”) compared to the total viable count of the mould (sieve plate impactor, e.g. Microbial Air Sampler, MAS) and the respective reference values in the outdoor air or in apparently unexposed rooms.

  Standardised measurement procedures for air-sampling of bacteria, actinomycetes and mould are described in various sources [13 to 18].

- Surface sampling

  Contact sampling (with “Rodac plates”), preferably in conjunction with tape-stripping samples to compare with non-suspicious surfaces.

  A further possibility is determination of material moisture levels (see [19]).

Indicative assessments do not usually determine the species of mould present. Their findings cannot be used to draw conclusions as to individual health hazards or remediation requirements. Instead, they merely indicate the presence and quantity of any mould at the site examined.

Case study 2

There is visible discolouration, e.g. mould or watermarks, which is thought to be linked to employee health complaints.

If the discolouration on the wall is obviously due to damp ingress, countermeasures need to be taken to preserve the building’s structure. In such cases, microbiological measurement or sampling is not necessary. Where there are extraordinary circumstances that warrant such action, contact sampling or examination of a material sample can be used to determine whether the discolouration is due to mould or which types of mould are involved. Information on the standardised procedure for sampling materials is given in the literature [16; 19].

13.5 Assessment

Since activities involving biological agents are not carried out on indoor workplaces, these workplaces must be assessed on the basis of the Arbeitsstättenverordnung (Ordinance on Workplaces) [21], not the Biostoffverordnung (Ordinance on Biological Substances) [20].

The “Quality assurance – Mould in indoor spaces” working group at the Landesgesundheitsamt Baden-Württemberg (LGA; Baden-Württemberg State Health Agency) in Stuttgart has produced a comprehensive position paper on this topic [19]. Entitled “Mould in indoor spaces – Detection, assessment, quality management”, it describes various sampling methods and the criteria for assessing the findings from a hygiene point of view.

The Federal Environmental Agency’s Indoor Air Hygiene Commission also published a “Mould guide”, in December 2002, which deals with the assessment of indoor mould problems [12]. It states that it is not possible to make a blanket judgement as to whether visible mould poses a health risk to room users. The company physician should be consulted to help establish whether employees can continue to work in the rooms affected until refurbishment has been completed, if the rooms are properly ventilated.

Assessment of mould in material samples

Tables 36 and 37 show suggestions for assessing mould occurrence [22]. The proposals are based on research conducted by the IFA and the Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege (BGW; German Social Accident Insurance Institution for the health and welfare services) over a period of many years, and the experience gained in the assessment of indoor problems connected to mould occurrence, based on the findings of that research. They do not take health complaints into account.

If water damage is refurbished without eliminating the cause (e.g. new wallpaper/plaster, fungicidal paint), mould will recur in the building material in the space of a few weeks.

Ideally, samples from new/unused material or from similar rooms but without health problems should be examined along with the suspicious material. The results of the comparison can then be used as a reference for the materials to be assessed.

Tape-stripping samples can be used to distinguish between active fungal infestations and airborne spores on surfaces, making it possible to indentify acute mould infestations. This cannot be done with contact samples.

Table 36:
Assessment of results of indoor material sample examinations [22]

Total mould in CFUs*)/g material	Rating
< 10^3	Normal background to low mould contamination, usually no damp problems
10^3 to 10^5	High mould contamination, damp problems/water damage, etc.
10^6 to 10^8	Very high mould contamination, damp problems/water damage, etc.

*) CFU = Colony-forming unit

Table 37:
Assessment criteria table for visibly mould-infested indoor surfaces [19]

Visibly mould-infested surfaces	Assessment
< 20 cm^2	Minor damage
< 0.5 m^2	Moderate damage
> 0.5 m^2	Major damage

The assessment should also consider the spectrum of mould species found in the various material samples as this information can be used, for example, to draw conclusions concerning the presence of damage caused by damp. Special attention must be given to mould species that are typical indicators of very high levels of damp or that have high pathogenic potential. The following genera and species of mould have been described as examples that provide a strong indication of damp-induced indoor damage [19]:

- *Acremonium* spp.
- *Aspergillus penicillioides*
- *Aspergillus restrictus*
- *Aspergillus versicolor*
- *Chaetomium* spp.
- *Phialophora* spp.
- *Scopulariopsis brevicaulis/fusca*
- *Stachybotrys chartarum*
- *Tritrachium album* and
- *Trichoderma* spp.

Other mould species often found in connection with damp-induced indoor damage are, for example, *Penicillium chrysogenum* and *Cladosporium sphaerospermum*.

Assessment of mould occurrence in air samples

In some cases, the concentrations of biological agents in indoor workplaces exceed the natural background exposure level by more than a power of ten. In other words, they are higher than the microorganism content of the outdoor air or of a similar room deemed to be a suitable reference. This should be considered an indication of potential contamination.

Indoor material samples that reveal large numbers of mould species typical of damp are a clear indication of damage due to damp. In the case of air samples, however, the mould sources must be carefully investigated as the fungal spores are distributed diffusely throughout the air and can come from a variety of sources.

The spore sampling process can also include mould spores that cannot be cultivated in the laboratory and can therefore not be detected when determining the colony count.

The spore concentration and the total colony count determined in the air can only ever reflect the situation at the time of measurement. But mould does not distribute its spores evenly throughout the indoor air. Consequently, the results of the measurements may underestimate or overestimate the actual level of mould exposure in the indoor air.

At present, there are no mandatory exposure limit values or guide concentration levels in Germany for assessing the biological parameters of air in indoor workplaces. It is recommended that the “reference outdoor air value” and the “normal indoor air pollution level” be used to characterise the level of microbial pollution in the indoor air. Section 3.6, “Ventilation”, of the annex to the Arbeitsstättenverordnung (Ordinance on Workplaces) [21] states that “*an adequate amount of healthy, breathable air must be ensured in work areas*”. This is not the case in rooms with evident mould infestations because the possibility of mould spores being released and thus of inhalation exposure to mould cannot be ruled out. Nor should it be forgotten that spores can become airborne at any time despite air sample measurements yielding negative results.

As a general guide, Table 38 (see page 102) lists the microorganism concentrations measured in the outdoor air during workplace measurements conducted by the German statutory accident insurance institutions and the IFA.

In the warm months, the higher level of airborne spores can cause the concentration in the outdoor air to increase, leading to a rise in the indoor air values if windows and/or doors are opened for the purpose of natural ventilation. Values of several thousand CFUs of mould per m^3 of outdoor air are common during these months (cf. also [16]).

If it is suspected that external sources are masking an indoor mould source (e.g. outdoor air or contamination from a different part of the building), it may be possible to confirm or disprove the suspicion by comparing the species spectrums in the respective air samples.

Table 39 (see page 102) shows suggested criteria for assessing the results of mould measurements in indoor air [22].

Further suggestions for assessment criteria tables can be found in the guides produced by the LGA in Stuttgart and the UBA [12; 19; 24; 25].

Table 38:
Concentrations of mould and bacteria in the outdoor air [23]

Month	Number of results evaluated	Minimum	Arithmetic mean	Median	Maximum
Mould in CFUs/m³					
January	54	4	195	188	1,286
February	60	28	314	132	3,457
March	59	10	551	157	17,571
April	57	4	812	809	25,715
May	51	4	2,201	1,005	28,571
June	59	26	1,715	2,429	10,512
July	79	316	4,189	2,243	26,280
August	59	328	3,208	937	26,280
September	58	1	1,330	850	10,000
October	86	143	1,244	372	10,512
November	40	57	646	471	3,500
December	3	202	436	188	634
Bacteria in CFUs/m³					
January	25	4	232	57	2,886
February	15	28	367	71	3,571
March	26	10	178	61	945
April	29	4	98	43	630
May	9	4	804	1,115	1,555
June	19	28	198	154	943
July	25	33	268	143	1,055
August	18	57	429	229	2,985
September	20	28	565	157	8,000
October	20	30	229	123	1,429
November	10	30	158	150	339

Table 39:
Assessment criteria table for results of microbiological measurements of indoor air [22]

Determining parameters in CFUs/m³ of air	Assessment criterion	Result of assessment
Total mould and/or spectrum of mould species	Indoor air has significantly higher mould spore content than outdoor air and/or significantly different spectrums of species in indoor and outdoor air *)	Indicates mould pollution in room
Occurrence of special indicator species (see above)	Presence of such species	Indicates damp problem
Occurrence of pathogenic species	Presence of such species	Unacceptable for reasons of general hygiene

*) In the case of typical outdoor air species, e.g. *Cladosporium*, indoor sources cannot be ruled out if the indoor air values are 1.5 times those in the outdoor air; where the values are twice as high as those for the outdoor air, indoor sources should be considered likely [19]

13.6 Prevention and refurbishment measures

According to a landmark ruling by Germany's Bundesgerichtshof (Federal Court of Justice), *"Mould in a building constitutes a defect even if it does not pose a specific hazard to health."* [26].

In addition to the aspects illustrated in this chapter, further general information and recommendations concerning prevention and refurbishment measures designed to prevent hazards caused by indoor mould is available from a variety of sources [12; 19; 24; 25; 27].

Extensive, complicated and/or recurrent instances of mould damage should be examined by a qualified building surveyor.

Refurbishment measures can involve several different contractors. For instance, repairing a wall that has been damaged by water brings little benefit if the cause, e.g. a leaking roof, a broken water pipe or a thermal bridge, has not been refurbished.

Those at most risk of coming into contact with mould from infested building materials are the people who carry out refurbishment. DGUV Information 201-028 (formerly BGI 858) provides comprehensive information on the health hazards posed by biological agents during building refurbishment and on the measures to protect workers from exposure [28].

13.7 References

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