Supplement to the Standard of Building Biology Testing Methods SBM-2024
and the Building Biology Evaluation Guidelines for Sleeping Areas

BUILDING BIOLOGY TESTING CONDITIONS

INSTRUCTIONS AND ADDITIONS

6th Draft 6/2024

In the Building Biology Testing Conditions and Instructions, we provide detailed information and explanations about the key requirements for conducting building biology assessments, analyses and testing procedures. In addition, the instruction manuals of testing equipment, guidelines of professional associations, other standards and the scientific literature should also be consulted.

A comprehensive discussion on how to translate all the various points of the Standard of Building Biology Testing Methods into appropriate testing procedures can be found in Wolfgang Maes' book *Stress durch Strom und Strahlung [Stress Caused by Electricity and Radiation]*. Extensive educational programs and in-person-training on how to use the Building Biology Standard, Guideline Values and Testing Conditions, are offered through basic and advanced courses in Building Biology Testing from the Institute of Building Biology + Sustainability IBN. Training courses, such as hands-on workshops, are also available through the Building Biology Association (Verband Baubiologie, VB). For quality assurance, the German Association of Building Biology Professionals (Berufsverband Deutscher Baubiologen, VDB) offers supplementary guidelines, testing procedures and recommendations for the various Standard points.

By applying several testing and analytical methods within a single Standard point, a greater measurement accuracy can be achieved. The methods described herein supplement each other; they do not replace each other and are to be used or combined as appropriate, depending on the situation or assignment.

A FIELDS, WAVES, RADIATION

1 AC ELECTRIC FIELDS (Low Frequency, ELF/VLF)

Measurement of low frequency electric **field strength** and human **body voltage** as well as identification of dominant **frequency** and dominant **harmonics**

- **Field Strength** (volt per meter, V/m)

  a) With ground reference

  True RMS measurement with the human body as part of the test setup based on the TCO Certified Criteria for IT equipment. With field detector or field probe (TCO or disk probe, small probe), field meter, LF analyzer...: frequency range 10 Hz - 100 kHz (preferably 400 kHz and higher), measurement range up to 5000 V/m or higher, sensitivity 0.1 V/m, measurement accuracy ± 10%.

  Note: Solid ground reference (equipotential bonding, receptacle, metal heating and plumbing pipes, ground rod...). Hold the probe close to or away from the body, following the manufacturer's instruction. Small probes often show lower measurement results than disk-like TCO probes with a diameter of up to 30 cm; the TCO probe is the benchmark. Direct, unimpeded alignment between probe and field sources, which often come from several directions (maximum "direction finding"). Minimum distance of 30 cm to field source.

  b) Without ground reference

  True RMS measurement of the "pure" field without interference from the human body based on DIN/VDE or 26th BImSchV (German Federal Pollution Control Ordinance).

  With field detector or field probe (3-D cube probe, 1-D disk probe), field meter, LF analyzer...: frequency range 10 Hz - 100 kHz (preferably up to 400 kHz and higher), sensitivity 0.1 V/m, measurement accuracy ± 10%.

  Note: No human body or other electrically conductive objects and surfaces, cables and furnishings in the field; keep a generous distance or a 2-m minimum distance to testing equipment or fiber-optic cable, which runs between probe and measurement display.

- **Body Voltage** (millivolt, mV)

  Measurement of body potential at electrically isolated person lying in bed with reference to ground potential.

  With body voltage meter, voltmeter, multimeter, field meter, LF analyzer... and a hand or finger electrode.

  Settings for ACV: internal impedance of meter 10 MΩ and capacitance < 100 pF across all used measurement ranges, frequency range around 50 Hz (preferably 400 kHz and higher), sensitivity 1 mV, measurement accuracy ± 10%; length of hand electrode wire max. 50 cm.

  Note: Solid ground reference (equipotential bonding, receptacle, metal heating and plumbing pipes, ground rod...). Avoid placing the test person close to a grounded surface (shielding near the bed...) or grounded connection (earthing sheet beneath the body...).

- Dominant **Frequency** (Hertz, Hz)

  With an LF spectrum analyzer, oscilloscope, voltmeter, field meter...

- Dominant **Harmonic** (volt per meter, V/m, or microwatt per square meter, $\mu W/m^2$)

  With an LF spectrum analyzer, (USB) oscilloscope, voltmeter, field meter...: frequency range about 2 kHz to 1 MHz.

An alternating electric voltage generates AC electric fields. The field lines run from a higher to a lower potential, eventually to ground (source field). Electrically conductive objects, the testing equipment, the person performing the test and the test subject influence the field.

Measurements of the electric field strength are about voltage differences or so-called potential differences. A probe detects the field and compares it to a reference potential. For over 30 years, the time-tested field strength measurement (TCO) with ground reference has been used in building biology. Here, the field probe is connected to the ground with a wire. In the field strength measurement setup (DIN/VDE) without ground reference, which only has been introduced to the Building Biology Standard in 2008, one (1-D disk probe) or three (3-D cube probe) paired electrode plates are arranged in a field probe in such a way that the potential difference can be measured between a pair of electrode plates with a defined distance and without ground reference. The testing method with ground reference (TCO) includes a person who attracts the electric fields onto their body; thus, the human body becomes part of the field interaction. The testing method without ground reference (DIN/VDE) seeks to measure the "undisturbed" field without the presence of a person who may disturb the field.

Both testing methods - with and without ground reference - have their advantages and disadvantages in building biology testing situations. Together, they provide a higher level of measurement accuracy. Both testing methods supplement each other, and they do not replace each other. In certain situations, one method may have a drawback and the other method will be more suitable and vice versa. If there are any suspected measurement errors, it is recommended to use both methods in combination with body voltage testing. Comparative measurements are only possible when using the same testing method.

Examples of advantages and disadvantages: A suboptimal grounding connection is the weak spot of the TCO testing method, which may lead to wrong measurement results. This is no problem for the testing method without ground reference. The DIN/VDE testing method without ground reference has its challenges when potential gradients of a given field are not distinct or missing altogether because sources from the various directions are of a similar or the same intensity; as a result, measurement results will be too low or nonexistent, despite obvious emission sources. This is no problem for the testing method with ground reference. Use caution with the TCO testing method when near grounded surfaces and objects. This applies especially to control measurements after installing shielding across large surface areas. Use caution with the DIN/VDE testing method regarding all electrically conductive materials and persons within the field and surrounding area; a distance of several meters is required. When the probe is optimally aligned towards the maximum field strength, the 1-D TCO measurement is particularly well suited for tracking down and locating field sources ("emission testing"). The 3-D DIN/VDE testing method is independent of direction and thus very well suited for capturing the sum total of all field sources at a single point ("exposure testing"). The 1-D testing method with ground reference according to TCO is often simple(r) and fast(er). The testing equipment is (more) affordable. The 3-D testing without ground reference according to DIN/VDE can be more complicated and elaborate. The testing equipment is more expensive and in most cases a computer is necessary for the analysis and display.

In body voltage testing, we measure a potential difference between the human body, which becomes energized by all the fields surrounding it, and ground. The simple, sensitive and time-tested method of body voltage testing ("capacitive coupling" according to Ing. Erich W. Fischer), which has been used in building biology for over 30 years, can only be applied successfully when the person to be tested is truly (!) isolated from ground. This is usually the case when a person lies in bed. If the test subject is close to or even connected to ground, as is the case with shielded wall areas near the bed or grounded earthing sheets in the bed or in direct contact with the body, measurement results will be too low or even zero. In such testing situations where a person is near the ground or connected to the ground, even though they are still exposed to electric fields, body voltage testing will show incorrect or no readings. Sometimes the electric field exposure may even be higher. Dubious salespeople of earthing sheets frequently like to use and abuse these inexcusable measurement errors to show the alleged effect of their products - though the "effect" as such does not exist.

Besides the field strength, the frequency of a field and the presence and number of harmonics (the multiple integer of the fundamental frequency) are an important aspect of the building biology evaluation. Some living organisms may respond more strongly to lower field intensities at certain frequencies than to higher field intensities at other frequencies, frequency mixtures or components of harmonics. Living organisms, organs and cells, they all have different "frequency windows" with increasing levels of sensitivity.

Harmonics occur to a much lesser degree in resistive loads (incandescent lamp, electric range, hair dryer...) and in high-voltage power and railway lines and conventional transformers... than in devices with plenty of electronics (CFL, electronic power supply unit, ballast, charger, dimmer, computer, visual display terminal, induction cooktop...), which is also referred to as "dirty electricity" or "dirty power." In Europe, the typical line frequency is 50 Hz (USA 60 Hz) and many electronic devices operate at higher frequencies (CFLs 20-60 kHz) or mixtures of frequencies (computer, screen...); in Germany, railway networks operate at 16.7 Hz.

2 AC MAGNETIC FIELDS (Low Frequency, ELF/VLF)

Measurement and long-term data logging of low frequency magnetic **flux density** from power grid or railway networks including identification of dominant **frequency** and dominant **harmonics**

- **Flux Density** (nanotesla, nT) of currents from power grids and railway networks

  True RMS 3-D measurement of the sum total of all field line directions based on TCO Certified Criteria for IT equipment or DIN/VDE.

  With field meter or field probe (induction coil, 3-D isotropic/orthogonal or 1-D), field meter, LF analyzer...: frequency range 10 Hz - 100 kHz (preferably 400 kHz and higher), measurement range up to 100,000 nT or higher, sensitivity 1 nT, measurement accuracy ± 10%, probe area < 100 cm².

  Note: Measure current from the power grid (50 Hz) and railway networks (16.7 Hz) separately. 1-D measurements are for direction finding of the field source by establishing the direction of the main field line. The coil size depends on the testing objective: large induction coils according to TCO or DIN/VDE (with diameters of 10 cm and larger) show lower test results in the near field of small field sources (small transformers, power supply units, CFLs...). During testing, do not make any sudden movements with the field meters or coils because this may result in an interaction with the Earth's magnetic field, and consequently, may translate into measurement errors, especially at lower frequencies (e.g. railway network).

- **Long-term Data Logging**

  True RMS 3-D measurement of the sum total of all directions of field lines.

  With data logger, recording instrument, computer, field meter, LF analyzer, multimeter (Min-Max-Avg)...: minimum frequency range 16.7 Hz and 50/60 Hz (better up to 2 kHz and higher), measurement intervals < 10 s, sensitivity 10 nT, measurement accuracy ± 10%.

  Note: Long-term data logging of external sources of electricity (underground transmission lines, overhead transmission lines, railway network power lines, transformers, street lighting...), night storage heating systems and net currents is always performed during nighttime, especially on workdays; if an elevated exposure is suspected, for 24 hours or longer. Use several data loggers simultaneously for inhomogeneous fields in small areas. While data logging the fields of external sources, pay attention to switching off or keeping a sufficient distance from in-home sources. Do not move data loggers at any time during the entire

period of recording.

- Dominant **Frequency** (Hertz, Hz)

  With an LF spectrum analyzer, oscilloscope, voltmeter, field meter...

- Dominant **Harmonic** (nanotesla, nT, or microwatt per square meter, μW/m^2)

  With an LF spectrum analyzer, oscilloscope, field meter... or with RF spectrum analyzer: frequency range about 2 kHz to 1 MHz

  Alternating electric currents generate AC magnetic fields. The field lines form closed loops, without beginning or end (eddy current field). Electrically conductive objects, the testing equipment, the person performing the test and the test subject hardly influence the field.

  The magnetic field strength or flux density is measured by inducing a voltage in stationary coils, which only occurs in alternating fields. Measurements are made with 3-D or 1-D coils. 3-D coils combine three coils arranged at right angles (x-, y-, and z-axis) in a single probe, simultaneously measuring and displaying all field lines. 1-D captures one axis, which can show the maximum field strength only if there is a clear field line pattern. However, it is very useful for identifying the location of linear field sources. If there are several magnetic field sources with a mixed field line pattern, then you have to take three separate measurements displaced by 90° with the 1-D coil and add the squared results: $\sqrt{(x^2+y^2+z^2)}$. These measurements should be taken all at the same time, especially if the field strength fluctuates, which in most cases is virtually impossible. In many cases, a clear field line pattern prevails (overhead transmission lines, underground transmission lines and electric conduits with live wiring), for which 1-D measurements can be sufficient. In other cases, which occur less often, mixtures of field line patterns are present (e.g. transformers, devices, several sources...), for which 3-D measurements are more accurate or indispensable. In building biology, the sum total of all field line directions is assessed.

  Short-term spot measurements provide a first overview and help identify the various magnetic field sources indoors (electronic devices, breaker panels, net currents across the wiring system...) and outdoors (underground cable, overhead transmission lines, substations, railway traction current, net currents across the power grid...). Long-term data logging over several hours or days captures a magnetic field profile that shows the common occurrence of time-dependent fluctuations. In the case of great field fluctuations (e.g. high short-term peaks), the 95th percentile of long-term measurements, especially those from nighttime measurements, shall be used for the assessment.

  Net current is the term given to electric currents that do not flow along the usual, designated pathways (e.g. the return conductor of the wiring) but along grounding conductors, PE conductors, protective screens, metallic gas and water piping..., which are mostly unbalanced, and can therefore result in considerable magnetic field exposure; they correspond to single-conductor currents whose flux density increases or decreases by a factor of 1/distance. For net currents inside a building, possibly supplement measurements with direct readings and long-term data logging of the current-carrying sources, for example, with a clamp-on ammeter, current clamp or current transformer. Consider performing simultaneous measurements with several data loggers inside the building and near the magnetic field source for net currents from external sources.

  For identifying the spatial distribution of magnetic field levels such as around high-voltage transmission lines, railway power lines, substations or underground transmission lines (especially loop networks or ring configurations, which often produce magnetic fields across large areas) - especially when magnetic field fluctuations over time and/or several magnetic field sources are present - two or more field meters at different distances from the magnetic field source should be used, whereby one of them could serve as a stationary reference meter.

  Harmonics occur to a much lesser degree in devices with resistive loads and also in high-voltage transmission lines, railway power lines, transformers... than in devices with plenty of electronics (which are also referred to as "dirty electricity" or "dirty power"). In Europe, the typical line frequency is 50 Hz (USA 60 Hz), many electronic devices produce higher frequencies or mixtures of frequencies. In Germany, railway networks operate at 16.7 Hz; in other countries, also at 50 Hz or with direct current. Sometimes the field strength of a harmonic can be higher than its fundamental frequency, e.g. at substations.

  Besides the field intensity, its frequency and the prevalence and type of harmonics are also important aspects of a building biology evaluation. Some living organisms may respond more strongly to lower field intensities at certain frequencies than to higher field intensities at other frequencies, frequency mixtures or components of harmonics. Living organisms, organs and cells... display specific "frequency windows" with increasing levels of sensitivity.

  For the frequency range of ELF fields and their harmonics, also see Standard Point A1 "AC Electric Fields."

3 RADIO FREQUENCY RADIATION (High Frequency, Electromagnetic Waves)

Measurement of radio frequency **power density** with identification of dominant **frequencies** or RF **sources** and their **signal characteristics** (ELF pulses, periodicity, broadband width, modulation…)

- **Power Density** (microwatt per square meter, μW/m²)

  a) Exploratory broadband measurement of sum total of all RF sources across **entire frequency range**

  With broadband RF meter, RF probe, RF analyzer, RF radiation monitor, RF meter...: the broadest frequency range possible from 100 kHz to above 6 GHz (at least 10 MHz - 3 GHz for identifying the most common RF sources), measurement range up to at least 20,000 μW/m² or (preferably) higher, sensitivity 0.1 μW/m², measurement accuracy ± 5 dB across the entire measurement range, option for data logging.

  Note: Measurement of peak levels in all directions, polarization planes, reflections... in the far field with isotropic 3-D antenna or 1-D antenna while waving the antenna in all directions.

  b) Detailed selective measurement to determine **individual frequencies** of RF sources (kHz, MHz, GHz) (GSM/2G, UMTS/3G, LTE/G4, 5G, TETRA, WiMAX, WLAN, DECT, Bluetooth, broadcasting, television, microwave radio relay, radar, amateur radio, mobile devices...)

  With spectrum analyzer and calibrated antennas (logarithmic-periodic antenna, dipole, monopole, biconical, loop, horn...) or broadband RF meters or analyzers with frequency-selective filters: the broadest frequency range possible from 100 kHz (preferably lower) to above 6 GHz (at least 10 MHz - 3 GHz for identifying the most common RF sources), measurement range up to at least 10,000,000 μW/m², sensitivity 0.01 μW/m², measurement accuracy ± 3 dB across the entire measurement range and setup.

  Note: Measurement of peak levels as above, consider full load, base load and the number of possible traffic channels. Building biology guideline values apply to individual RF sources, but not radar.

- Dominant **RF sources** and **ELF signal** components (pulse, periodicity, broadband width, modulation...)

  As a visual display with spectrum analyzer or as an acoustic sound with broadband meter, signal or modulation meter... based on transposed sounds of demodulated signals; the broadest frequency range possible like above.

  Note: In the case of several RF sources, acoustic superposition may occur that makes a diagnosis rather difficult or even impossible.

  Electromagnetic waves (also referred to as radio frequency radiation) are about transmitting information without wires (also referred to as wireless radiation).

The frequency spectrum provided for technical applications starts at 9 kHz, fills the entire MHz range and ends in the GHz range at 300 GHz. Radio frequency waves are transversal waves, propagating at the speed of light.

Radio frequency waves consist of a radio frequency carrier signal that is imprinted with an ELF information signal, modulated with contents, for example, in the form of video, voice, music or data. Major types of modulation include amplitude modulation (AM, often short, medium, long wave and pulsed signals like radar), frequency modulation (FM, often FM broadcasting) or phase modulation (PM, often more recent digital and pulsed technologies like GSM, UMTS, TETRA, DECT, WLAN) with numerous mixed technologies and subtypes.

Cell phone networks, cell phone handsets, DECT, WLAN and other modern digital technologies emit pulsed radiation, enabling them to transfer large amounts of information almost simultaneously. In building biology, we pay particular attention to pulsed signals, especially periodic ones (spectrum analyzer in zero-span setting and/or acoustic diagnosis also with broadband or modulation RF meters) that are assessed more seriously.

In the near field (below one wavelength), the electric and magnetic field components must be measured separately as electric (E, V/m) and magnetic field strength (H, A/m), just like ELF electric and magnetic fields. In the far field (above one wavelength), it is sufficient to measure one field component to infer the power density (S), e.g.: $S = E^2 : Z_0$ or $S = H^2 \times Z_0$ (Z_0 = wave impedance 377 Ω).

If several RF sources are present, the total power density level is derived by computing the arithmetic sum.

In building biology, we often wave the antenna in all directions for RF measurements. While holding the measurement antenna at an outstretched arm as far away from the body as possible, we scan all spaces to be tested (especially sleeping areas) and directions in all three dimensions. Additionally, we rotate the antenna and record peak values (Peak Hold) to check for the various polarization planes. Depending on the situation, this type of scanning should take at least one minute or at least as long until the meter display shows no more increase.

With a spectrum analyzer, the standard testing procedure for GSM cell phone networks, for example, is as follows: Measurement of constantly active control channel (BCCH, broadcast control channel) with Max Hold setting, while waving the antenna and adding up power density levels. This result resembles the minimum traffic load at a base station during nighttime when cell phones are used the least. To establish the power density level for the maximum traffic load at a base station during daytime when, for example, many phone calls are transmitted across the traffic channels (TCH, traffic channel), you can either do a rough calculation by multiplying the measurement value of the control channel by a factor of 2 to 4 (unless detailed information by the cell phone service provider is available) or perform long-term data logging with a broadband RF meter.

All the various wireless services (GSM, UMTS, LTE, TETRA, DECT, WLAN, broadcasting, microwave radio relay...) are evaluated separately based on the Building Biology Guideline Values.

The testing report provides the measurement results for the time of testing as both the measured minimum value and the measured or calculated maximum value.

Not all RF transmitters transmit at all times and, if so, not constantly at the same power level. Therefore, it may be necessary to perform long-term observations or data logging. Some broadcasting transmitters or military facilities, for example, may only transmit at certain times; some public agencies and industry facilities or amateur radio operators may only transmit as needed. Sometimes DECT cordless phones and WLAN networks may radiate nonstop; at other times, they may only radiate when in use. Even broadband signals (UMTS, digital television...) with their pronounced crest factors need to be watched with patience; their emissions fluctuate.

Also, and especially in view of the above: The testing methods supplement each other and together provide the necessary measurement accuracy. In most cases, broadband measurements are often simple(r), fast(er) and the equipment (more) affordable. Spectrum analysis is (more) complicated, (more) time-consuming, and spectrum analyzers are more expensive but also more accurate, sophisticated and precise. A broadband meter cannot replace a spectrum analyzer or the acoustic diagnosis, just as a spectrum analyzer cannot replace a broadband or modulation meter.

Like for Standard Points A1 "AC Electric Fields" and A2 "AC Magnetic Fields," the following also applies here: Besides the intensity of the RF radiation level, the frequency, modulation and pulse characteristics are also important aspects of the building biology evaluation. Some living organisms may respond more strongly to lower field intensities at certain frequencies and pulse characteristics than to higher field intensities at other frequencies. Living organisms, organs and cells..., they all have different "frequency windows" with increasing levels of sensitivity. Experience to date has shown that ELF pulses are the more critical, the lower the frequency of the pulse is. Harmonics are less pronounced in radio frequency electromagnetic fields than in extremely low frequency electromagnetic fields.

4 STATIC ELECTRIC FIELDS (Electrostatics)

Measurement of electric **surface potential** including **discharge time** and **air electricity**

- **Surface Potential** (volt, V)

  Measurement of electrostatically charged surfaces with ground reference.

  With a field mill, electrostatic field meter, electrostatic probe, static sensor...: measurement range up to ± 20000 V or higher, sensitivity 10 V or lower, measurement accuracy ± 10%.

  Note: Take measurements at a distance of 2-10 cm from the material or screen surface (possibly with a spacer). One to two seconds prior to testing, cause the material to become charged through simple rubbing (e.g. with the back of your hand or some nonconductive material). Record the polarity of the charge: plus or minus. Record relative air humidity, ideally between 40% and 60%, indoor air climate parameters (air humidity, air temperature, surface moisture, possibly air ionization...). Ground testing equipment and person performing the measurement.

- **Discharge Time** (seconds, s)

  Record the time it takes the charged material or screen surface to discharge and reach normal levels (also note the surface potential prior to rubbing the material).

- **Air Electricity** (volt per meter, V/m)

  Measurement of air electricity with ground reference.

  With a field mill, electric field meter...: measurement range ± 200 V/m to ± 20,000 V/m or higher, sensitivity 10 V/m, measurement accuracy ± 10%.

  Note: Measurement of indoor air electricity in the interaction with humans (especially after causing susceptible materials and computer screens to become charged) and as reference measurement for outdoor air electricity.

  Static electric fields result from unipolar electric charges on isolating materials (plastics, synthetic materials, rubber...), unshielded screens and through direct currents (overhead line equipment of streetcars, air purification devices...). They change the natural air electricity and other indoor air climate parameters (air ionization, dust levels...). Weather conditions exert a profound influence on the naturally occurring static electricity in the open air.

  The measurement of static electricity, its field intensities and zero-frequency charge, is also about potential differences, and some interactions and issues

described at Standard Point A1 "AC Electric Fields" also apply here. We measure the surface potential at suspect materials such as carpeting, curtains, bedding, objects and screens and the resulting change in the air electricity of the ambient indoor air. Conversion: surface potential (V) = field strength (V/m) x distance (m).

To compare measurement results, maintain relative air humidity between 40% and 60% and ensure that the surfaces to be measured have been exposed to this indoor climate for several hours. Air humidity levels above 60% tend to decrease surface potential readings; above 70% any testing becomes difficult, above 80% hardly possible and above 90% impossible. Air humidity levels below 40% cause measurement results to become more pronounced, below 30% to increase several times and below 20% to increase even more. Sometimes it is necessary to check at different times of the year (humid summer, dry winter). CRT monitors (older monitors and TVs) need to be turned on for several minutes prior to testing to allow for a complete charge buildup. The level of static electricity changes with the brightness of the image.

The materials and screens recommended in building biology rarely build up any static electricity, and if they do, they usually discharge within seconds. Critical materials build up static electricity within seconds after rubbing them or turning on a screen and discharge only very slowly, taking minutes, hours or days. Negative charges, which indicate plastics and synthetic materials, need to be assessed more seriously than positive charges that sometimes can also occur in nature (amber, wool...).

5 STATIC MAGNETIC FIELDS (Magnetostatics)

Measurement of **Earth's magnetic field distortion** as a **spatial deviation of magnetic flux density** (metal) or as a **temporal fluctuation of magnetic flux density** (direct current) as well as **compass deviation**

- **Earth's Magnetic Field Distortion** as a spatial deviation of magnetic flux density - **Metal** (microtesla, µT)

  Measurement of the sum total of all magnetic field line directions due to metal or permanent magnets.

  With magnetometer, magnetic field indicator, magnetostatic sensor...: measurement range at least ± 100 µT (better higher), sensitivity at least 100 nT (better lower), measurement accuracy ± 10%.

  Note: Scan area to be tested, possibly in a grid-like pattern (sleeping area, room...). Direction of sensor must not be changed along any of the grid lines. During testing, the orientation of the 1-D sensor must not be tipped, turned or tilted in any way - not even a little. Local distortions at selected points with pronounced gradients need to be assessed more seriously than those across larger areas with less pronounced gradients.

- **Earth's Magnetic Field Distortion** as a temporal fluctuation - **Current** (microtesla, µT)

  3-D measurement of the sum total of all magnetic field line directions due to direct currents.

  With a magnetometer, magnetic field indicator, magnetostatic sensor...: measurement range at least ± 100 µT (better higher), sensitivity at least 100 nT (better lower), measurement accuracy ± 10%.

  Note: If fluctuating magnetic field levels are suspected (streetcar, photovoltaics...), perform long-term data logging for at least 24 hours, definitely over one night. Put the field meter in an otherwise magnetically neutral place. Do not move the 1-D sensor during testing.

- **Compass Deviation** (degree, °)

  Observation of a compass needle deviation within the sphere of influence of static magnetic fields generated by metal or a current.

  With mechanical, liquid-filled precision compass, magnetic field rail, electronic flux gate compass...

  Note: Move compass smoothly and steadily in one direction across an area (bed...) without shaking. Scan the area in a grid-like pattern and record deviations. Also, watch for the compass needle to dip down or point up. If a technical magnetic field with the same polarity as the Earth's magnetic field hits the compass needle along the north-south axis, the needle will barely move, but it will move in a big way if the latter field lines run perpendicular to the compass' axis.

Ferromagnetic metals (such as steel in buildings, furniture, furnishings...) or direct currents (streetcar, photovoltaics...) produce technical static magnetic fields. Naturally occurring static magnetic fields result from the Earth's magnetic field. A compass needle aligns itself along the field lines of the Earth's magnetic field to point north. The term magnetic field distortion refers to influences and superpositions of the natural background field. Each magnetic field - whether of technical or natural origin - has a north and a south pole (a plus and a minus pole). The field lines run from the north pole to the south pole.

Measurements of static magnetic fields are about the magnitude and direction of magnetic fields of technical origin; reference is the undisturbed, uniform Earth's magnetic field. Like measurements of AC magnetic fields, a 3-D magnetometer also measures the magnetic flux density at a given measurement point by capturing all field lines in three dimensions; the measured value is independent of the spatial positioning of the probe. Measurements with 1-D magnetometers or magnetic field indicators only capture one axis of the field lines; a 1-D measurement is dependent of direction. If taking three separate 1-D measurements displaced by 90° and adding their squared results, you derive at the sum $\sqrt{(x^2+y^2+z^2)}$ that is automatically calculated and displayed on 3-D devices.

1-D magnetometers display the measured flux density with a plus or minus sign, indicating the polarity of the field, which is needed for calculating the flux density deviation within a localized area. Currently available magnetometers that perform 3-D flux density calculations only in relative mode and do not consider the direction of the vectors are only of limited use for capturing the flux density deviation between two measurement points; though they are well suited for all other applications.

A compass works with two dimensions and mainly aligns itself with the horizontal field lines. It is not a measuring instrument but an indicator; it does not show field intensities, but only directions. External magnetic fields can deflect the compass needle. An electronic flux gate compass, which is used on sailboats, is like a common compass, but instead of a needle, it has a digital display.

It is not really possible to convert magnetometer readings into compass deviations; if at all, this would be just a rough estimate. Again, the different testing methods supplement each other. The compass reading is easy to understand and convincing, but it does not replace magnetometer measurements.

As always, we take the readings where people actually spend time, such as in bed.

Magnetic fields caused by metals can vary significantly across a given area: small areas with extremely high intensities can change every few centimeters (high gradient) such as above innerspring mattresses in close proximity to the body, or large areas with moderate intensities can change across several decimeters or meters (small gradient) such as above steel trusses or reinforcing steel. And because of this, it is best to follow a grid-like pattern across a defined area.

Magnetic fields caused by direct currents can be subject to major fluctuations over time. Magnetic field levels from streetcar, subway and trolleybus currents constantly fluctuate, depending on the current flow in the overhead lines and tracks. At night, the streetcar does not run, causing no field exposure. In photovoltaic systems, magnetic fields fluctuate depending on the solar exposure, so there is no magnetic field exposure at night. Therefore, long-term data logging is imperative.

6 **RADIOACTIVITY** (Alpha, Beta and Gamma Radiation, Radon)

Measurement of radiation as **count rate**, **equivalent dose rate** and **deviation** as well as measurement and long-term data logging of **radon concentration**

- **Radioactive Radiation** (count rate per second/minute, cps/cpm - nanosievert per hour, nSv/h)

  Radioactivity measurements of suspect building materials, materials, devices, furnishings... and/or comparative measurements of disintegrations of alpha, beta and gamma radiation

  With a dose rate meter (Geiger-Mueller tube, large volume detector, proportional counter, scintillation counter...).

  The measuring instrument should capture the minimum range of 50 keV to 1.3 MeV gamma energy that is relevant to environmental testing. To achieve the required statistical accuracy in the low-dose range, at least 1000 disintegrations are necessary per measurement point. Sensitivity at least 100 nSv/h (preferably lower), measurement accuracy ±25%, recommended basic sensitivity 40 counts per minute at 100 nSv/h, null effect (inherent noise of detection equipment) < 50% at 100 nSv/h.

  Note: In sleeping areas, we recommend taking a minimum of two measurements, e.g. at the head and the foot end. Clear differences between head and foot measurements indicate an elevated radiation level inherent to the building structure (e.g. wall at head end). For evaluation, the higher reading is used. Additional measurements at walls, floors, corners... will help locate the source and plan appropriate remediation strategies. Most of the affordable detectors are usually not suitable for determining smaller differences in background radiation levels of around 100 nSv/h. With instruments meeting the above requirements, however, it is possible to carry out quite reliable assessments in the low-dose range; primarily the disintegration rate (counting statistics) and null effect (inherent noise in detector equipment) need to be considered. Because of this challenge, it is advisable to prioritize comparative measurements.

  At a common background radiation level of around 100 nSv/h, the null effect (which refers to the inherent noise in the detector) has a clear effect, sometimes up to 50% of the measurement value: the less sensitive the detector, the higher the effect. For scintillation counters (2-inch or 3-inch sodium iodide crystal), the null effect is not significant because of its high disintegration rate.

  For building biology assessments, we refer to gamma disintegration rates based on natural radionuclides (Ra-226, Th-232 and K-40). In the context of this natural background radiation (building site, building materials), the new ambient dose equivalent H*(10) (building site, building materials) corresponds to the photon dose equivalent.

  Small amounts of radioactivity are present everywhere. In the earth, in our bodies and in the air, natural radioactive elements (radionuclides) from the thorium (Th-232) and uranium series (Ra-226) as well as potassium (K-40) predominate. Radioactivity is measured by counting the number of radioactive decays or disintegrations over a specified unit of time. Radiation detectors convert the incident radiation into electrical pulses. Comparative measurements are especially well suited for building biology assessments. The ratio between the natural background radiation level and the radiation level in the building on a building material, in bed, etc. is given as a deviation in percent. Reporting all measured reference values is recommended. Determining the local dose rate or equivalent dose rate of gamma radiation is particularly crucial.

  Besides gamma radiation, beta radiation should also be considered. In building biology assessments, alpha radiation does not play any major role because of its rare occurrence and short reach. In the context of internal exposure pathways via radon and its decay radionuclides in the air, measurements of alpha radiation via particle samples can be useful.

  When measuring radioactivity in buildings, note that often there are different solid building materials in exterior and interior walls, which can have a major impact on gamma radiation levels.

  Gamma spectroscopy allows to differentiate between individual radionuclides. Samples of suspect materials (e.g. building materials) can be checked for their specific activity in a laboratory.

  If there is any indication of a specific exposure to, for example, radium in a building material (as is often the case with slags), it is necessary to carry out radon measurements.

  Regarding potential increases in the annual dose rate, suspect building materials often play less of a role than radon.

- **Radon** (becquerel per cubic meter, Bq/m³)

  Radon measurements in air in suspect buildings, rooms, materials and properties (pretests, short-term measurements, long-term measurements, exhalation rate measurements, soil gas measurements)

  With direct-reading radon monitors, radon daughter nuclide spectrometers, passive dosimeters, nuclear track detectors (electronic instruments based on the semiconductor principle, alpha track detectors, activated charcoal...)

  Note: Measurements or pretests, which are taken in unventilated spaces or under user conditions with poor ventilation for a period of a few hours up to three days, can detect a radon issue and allow for comparisons. To search for sources, most often the faster, direct-reading instruments with pumps (mass spectrometers) are used. By using simple pretest procedures, an elevated radon level can also be quickly recognized by measuring the decay products and/or air ionization: After positively charged radioactive decay products from the indoor air have been concentrated on negatively charged surface areas (electrostatic methods) or filter media (particle sampling), they can be detected with sensitive Geiger counters. Using an ion counter, you can measure the increase of small ions in the air, which closely corresponds with radon levels and the quantity of decaying nuclides. You can quickly check indoor air radon levels with a simple passive activated charcoal device; an exposure period of up to 3 days is required.

  If a 1- to 3-day measurement reveals a radon level above a certain guideline value, the measurement should be repeated or a long-term measurement should be performed (in occupied spaces, possibly under simple remediation conditions with increased ventilation).

  Overview measurements are best performed with other methods over longer periods of time. For the reliable assessment of the average annual concentration level, it is best to use long-term measurements with electronic dosimeters or nuclear track detectors for weeks or even longer. It is useful to take simultaneous measurements, e.g. in the living space and basement, because most often radon enters a building through the soil and basement.

  The Building Biology Guideline Values apply to measurements for exposure durations of at least 7 to 14 days during the shoulder seasons (moderate annual climate, e.g. spring/fall) under normal usage conditions. With extensive experience, and while taking all relevant parameters into account, it is possible to make a first assessment of an estimated average annual concentration level. Before undertaking any comprehensive and expensive remediation efforts, we recommend using longer evaluation periods that include simultaneous and repeated measurements.

Usually, **compliance measurements** use nuclear track detectors to determine if a certain guideline or action level issued by entities like the EU, WHO, UBA, BfS... has been exceeded. The exposure duration for these measurements is normally several months up to a year. In building biology testing situations, such long testing periods only make sense if it is reasonable to assume that such a measurement will fall below any existing pretest or overview measurements or serve as a control measurement after remediation efforts have been made or if there is any other plausible reason to do so.

In addition to radon measurements in the indoor air, material measurements (radon exhalation rate), soil gas measurements (with soil gas probe "Czech probe", recommended depth: 80 cm -100 cm) can also be used.

The radioactive gas radon is invisible, completely odorless and tasteless. Radon decays directly in the breathing air and produces decay products (Po-218, Po-214, Pb-214, Bi-214 and others). These decay products attach to respirable fine particulates in the air and become deposited in the lungs. This is how the largest portion of radon is absorbed by the human body. Statistical estimates attribute 2000 additional lung cancer deaths in Germany to radon in the indoor air. There is no threshold level below which no risk exists.

Radon problems in a building are often due to elevated concentrations in the soil, leaks between soil and the building, building materials and furnishings with elevated radon concentrations and poor indoor ventilation. Elevated radon concentrations are commonly found in older homes with humid basements because radon readily dissolves in water.

Radon levels vary significantly in a building over time; besides indoor ventilation, outdoor weather conditions as well as temperature and pressure fluctuations all have a major impact. During the heating season, radon levels are substantially higher due to thermal updraft, poorer indoor ventilation and elevated soil gas concentration levels. During summer, indoor air radon levels can be lower by a factor of 5 compared to winter. Depending on the season, radon soil gas concentrations can also vary greatly. Here, the difference between summer and winter levels, however, is much lower, by a factor of ca. 1.5 to 3.

In Germany, higher radon levels are most prevalent in Bavaria, Saxony, Saxony-Anhalt and Thuringia (Bavarian Forest, Upper Palatinate, Fichtelgebirge Mountains, Thuringian Forest, Erzgebirge Mountains, southern Black Forest, Vogtland, Sauerland, Saarland and northern and eastern Schleswig-Holstein).

Average radon levels between soil gas and indoor air measurements correlate well. While radon levels mainly range from ca. 10,000 to more than 600,000 Bq/m³ at a soil depth of 1 m, indoor levels are much lower, by a factor of ca. 1000. Even if soil gas radon levels are below 10,000 Bq/m³, a building with a design that favors radon entry may already have elevated radon levels inside.

The rather short-lived thoron (radon Rn-220 from the thorium series) has little significance in building biology testing. However, high concentrations of radionuclides in unsealed building materials can cause indoor air problems. Measurements based on activated charcoal cannot capture thoron. Instead, the decay products (Pb212, Po-212) are measured in the indoor air. Because of its intense alpha decay from its decay chain products, thoron must also be assessed more seriously. Granite (e.g. from flooring) with elevated radiation levels, for example, can release thoron into the indoor air. With their radioactive decay products, thoron-containing building materials, slags and thick clay plasters (> 1 m²/m³) in combination with low average air exchange rates (< 0.5) can have a major impact on the annual dose in indoor environments.

Buildings with elevated levels of radioactivity in their building structure can cause building material-dependent radon problems due to their radium content (Ra-226); however, a highly elevated radon exhalation rate due to building materials is rather low. The reverse, however, does not hold true because buildings with low gamma radiation levels can have unexpectedly high levels of radon owing to the fact that radon often finds its way from the soil through convective pathways into a building. Certain furnishings and objects, such as tiles, glazing or antiques, with highly elevated levels of radioactivity can also contribute to highly elevated radon levels in the indoor air.

7 GEOLOGICAL DISTURBANCES (Earth's Magnetic Field, Terrestrial Radiation)

Measurement of Earth's **magnetic field** and Earth's radioactive **radiation** and its dominant **disturbances**

- Dominant deviation of **Earth's Magnetic Field** (nanotesla, nT)

  With 3-D magnetometer: measurement range up to ± 100,000 nT, sensitivity 10 nT (preferably lower), measurement accuracy ± 10%.

  Note: Measurements should follow a grid-like pattern, e.g. a measurement point every 50 cm. Magnetic building components or materials (even if just slightly magnetic) can distort the measurement result - especially inside a building - or even make measurements impossible. Thus, most of the time, it is not possible to carry out a geological magnetometer measurement in a conventionally built and furnished building due to the many technical distortions.

- Dominant disturbances of radioactive **Terrestrial Radiation** (counts per second, cps or percent, %)

  With a scintillation counter: measurement sensitivity at least 20 cps (preferably 200 cps or higher), measurement accuracy ±10%. Sodium-iodide and lithium-iodide crystals have proven themselves as sensors, minimum size 2 inches (preferably 3 inches), preferably with thallium as a dopant, possibly shielded against nonterrestrial ambient background radiation with radionuclide-free lead, possibly with neutron moderator.

  Note: These types of measurements also should follow a grid-like pattern, e.g. in sensitive areas (sleeping area) a measurement point every 50 cm; the count or disintegration rate required per point must be at least 1000, preferably 5000. Radioactive building materials, furnishings or materials (even if with just slightly elevated levels) can distort measurement results - especially inside a building - or even make measurements impossible.

Terrestrial radiation is everywhere. And the Earth emits magnetic fields and radioactive radiation everywhere. The compass needle shows the magnetic force of the Earth and the Geiger counter shows its gamma radiation. There are many more forces emanating from planet Earth.

So-called geological disturbances are zones of altered activities within the Earth. In comparison to average fluctuations, this is where anomalies become noticeable and measurable: Limited to a certain area, the flux density of the Earth's magnetic field increases or decreases, and terrestrial radiation levels change. Other physical factors are also more striking, penetrating or less so in these specific areas in comparison to undisturbed environments. Geological disturbances result from, for example, underground watercourses - so-called water veins and spring areas - or other terrestrial anomalies such as faults, crevices, chasms or fractures.

Based on current experience, magnetometer and scintillation counter readings - more often than not - tend to decrease above underground watercourses and to increase in the presence of geological faults, crevices and fractures.

Changing the positioning of the probe is necessary to differentiate between magnetic fields of geological and technical origin. Magnetometer measurements should be carried out at different heights. If the unusual readings only occur close to the ground but not higher up, this points to a technical or building-related source in contrast to a geological source.

Technical fields diminish rapidly as the distance to the source increases; geological disturbances remain constant over large height differences. A wire fence or a car parked within 10 m or more can already result in magnetic field deviations like geological disturbances. Therefore: For better accuracy, carry out measurements at least at two levels, e.g. just above the ground and then at a height of 2 m along the same section. Only if the same measurement

results are produced at both levels (or at even more measurement distances) over the zones of suspected geological disturbances can one be sure(r).

Follow a similar procedure with scintillation counter measurements. Indoors: change measurement distances from ground, walls and suspect furnishings. Outdoors: keep your distance to suspect buildings, road surfaces, recently fertilized lawns and the like.

Currently available 3-D magnetometers that perform flux density calculations only in relative mode and do not consider the direction of the vectors are well suited for the measurement of geological disturbances.

Radiation measurements in geologically disturbed areas seem to involve not only gamma radiation but also neutron radiation, which is also detected by the sodium-iodide or lithium-iodide crystal of a scintillation counter.

For comparison reasons, locating an area with undisturbed, uniform magnetic field and gamma radiation background levels is an important prerequisite.

8 **SOUND** (Airborne and Structure-borne Sound)

Measurement of **noise**, **audible sound**, **infrasound** and **ultrasound**,**oscillations** and **vibrations**

- **Airborne Sound** (audible sound, infrasound, ultrasound)

  Measurement of unweighted and/or weighted sound pressure levels for the evaluation of sound or noise exposure levels, their equivalent continuous sound level (time-average sound level) and time sequences.

  Either with a reasonably priced sound level meter of Class 2 according to IEC 61672 with the following specifications: frequency range 31 to 8000 Hz, measurement range 30 to 130 dB in various increments, time response fast and slow, weighting scales A and C, data storage capacity at least 30,000 samples, stand-alone operation recommended, option to transfer data to PC.

  Or with a more expensive meter of Class 1 according to IEC 61672: frequency range 5 Hz to 20 kHz (also down to the infrasound range); measurement range 20 to 140 dB in various increments; time response fast, slow and peak (C), possibly impulse sound; weighting scales A, C and linear; data storage capacity 1 to 2 GB; PC connectivity.

  At the moment, there is no ultrasound meter available at a reasonable cost. Another option are ultrasound detectors that can make high frequency sounds from, for example, bats or insects audible (bat detectors or bat receivers). Various technologies convert the ultrasound signal into an audible sound in the human hearing range; as a result, audio analysis can be used to assess ultrasound. Typically, ultrasound frequencies range from 16 to 100 kHz, sometimes up to 200 kHz. Volume, frequency and bandwidth controls are available; outputs for headphones, tapes, data loggers or spectrum analyzers are integrated.

  Note: When there are intermittent or greatly fluctuating audible sound events, it is important to conduct long-term data logging to determine frequency distributions and percentile statistics. In sleeping areas, conduct measurements during the night for at least 8 hours from around 11 p.m. to 7 a.m.

- **Structure-borne Sound, vibrations** (mechanical oscillations)

  Measurement of vibrations or oscillations of building components such as walls, floors, ceilings, radiators, piping, doors, window panes (watch out: natural resonant frequencies)...

  With relevant vibration meters and sensors (vibration and acceleration detector, accelerometer, laser vibrometer...). From the data collected (typically sound pressure level values), the acceleration values are calculated in m/s². Depending on the type of floor covering, a nonabsorbent contact with the floor screed may have to be established, e.g. via signal sensor mount with spikes and leveling option. Frequency range 5 Hz (preferably lower) to 10 kHz (and higher), high- and low-pass filter desirable, sensitivity below 0.1 m/s².

  Note: In the case of intermittent vibration events - like intermittent airborne sound - carry out long-term data logging. Human perception of vibrations correlates with vibration acceleration.

- **Frequency Analysis**

  Selective analysis of airborne and structure-borne sound events via frequency analysis in the minimum hearing range from 20 to 20 kHz, preferably even to lower ranges, below 20 Hz to 5 Hz and less (infrasound, vibration) or also to higher ranges above 20 kHz (ultrasound), either as third octave band analysis (real-time analyzer) or in high resolution as FFT (fast Fourier transform, a narrow-band frequency analysis). As an FFT time window, at least there should be a Hanning window available.

  Like electromagnetic fields, sound is also about waves and frequencies, which are denoted in Hertz (events per second). Sound is not about electromagnetic waves (energy particles or waves), but it is about the movement of material particles in the air, in liquids or solid objects like building materials. These particles exert - in the true sense of the word - pressure, resulting in minimal changes in density. In the broadest sense, sound is any type of changes in the density of air, water or another medium: audible sound waves are audible to the human ear, infrasound and ultrasound refers to sound waves below or above the human perception threshold.

  Sound waves propagate at a lower speed than electromagnetic waves: in the air at 343 meters per second (m/s) or 1235 kilometers per hour (km/h), faster than a wide-body aircraft or jumbo jet, but only a millionth of the speed of light or radio waves.

  Ideally, a healthy young person can hear frequencies from 20 Hz to 20 kHz, especially the middle frequencies between 1 and 5 kHz. Infrasound and ultrasound are lower and higher frequency sound events, below 20 Hz and above 20 kHz, that the human ear cannot directly hear, but many humans can still perceive - often as an unpleasant, disturbing sensation - or they may even make a person sick. Noise refers to an unwanted, disturbing or hazardous sound. Vibrations are perceptible, ranging from disturbing to tormenting mechanical oscillations, which can also go hand in hand with airborne or structure-borne sound, especially infrasound.

  Sound measurements and frequency analysis are usually carried out in the center of a given space, as far away from walls, floors and ceilings as possible. This is because sound levels tend to increase and vary more widely next to such boundary surfaces. For building biology assessments, it is especially important to establish exposure levels in spaces where occupants spend long periods of time regularly (sleeping area, workplace).

9 **LIGHT** (Artificial Lighting, Visible Light, UV and Infrared Radiation)

Measurement of **electromagnetic fields**, **light spectrum**, **spectral power distribution**, **light flicker**, **illumination level**, **color rendering index**, **color temperature**, **ultrasound**

Like electromagnetic fields and sound, light is also about waves and frequencies. Light travels at the unimaginably fast speed of 300,000 kilometers per second. In the electromagnetic frequency spectrum, light frequencies are located just above the radio frequency region, which extends up to 300 GHz and is commonly known as microwaves. Invisible infrared light (thermal radiation) starts at 300 GHz, which corresponds to a wavelength of 1 mm, and extends up to 780 nm. Visible light ranges from 780 nm to 380 nm, spanning from the color red to orange, yellow and green to blue and violet. Ultraviolet light (UV)

is again invisible, ranging from 380 nm to 10 nm. When a prism is struck by white light, it separates the light into its different wavelengths, creating the colors of the rainbow.

Supplement to the Building Biology Guideline Values - Recommendations, Guidance and Assessment tools:

Light, Lighting		No Anomaly
Illumination level in lux	lx	Day ca. 100 - 100,000 lx, evening ca. 10 - 100 lx, night < 1
Color temperature in kelvin	K	Day ca. 4000 - 6000 K, evening ca. 1500 - 3000 K
Ultrasound in decibel	dB	None
AC electric field in volt per meter	V/m	Up to 2 kHz < 10 V/m From 2 kHz < 1 V/m
AC magnetic field in nanotesla	nT	Up to 2 kHz < 50 V/m From 2 kHz < 5 V/m

No light modulation for data transmission (precautionary approach because of insufficient data). No toxins or odors. No toxic ingredients such as mercury. Ecological manufacturing and disposal.

Measurements of AC electric and AC magnetic fields according to TCO Certified Criteria (30 cm distance to source).

Recommendations apply in particular to the evening hours prior to going to sleep so as not to interfere with subsequent sleep.

The current building biology recommendations regarding light are primarily based on technically available options and less so on experience - as the other binding Building Biology Guideline Values do - due to a lack of long-term experience. First case histories and several scientific findings reveal biological effects and associated risks.

- **Light Spectrum** and **Spectral Power Distribution** (nanometer, nm)

  Measurement of the entire light spectrum, first visible light with wavelengths from about 380 nm to 780 nm, possibly infrared radiation above 780 nm and ultraviolet radiation below 380 nm, including an assessment of the spectral distribution.

  With a light spectrometer. For selective spectral bands, including infrared and UV radiation, also use a light meter. Or with a light spectrometer for a first overall visual impression.

  Light spectrum of artificial lighting sources should be as similar to daylight as possible: constant, continuous, balanced, uninterrupted and with smooth transitions from UV radiation across all visible light bands to infrared radiation without large spikes in the blue band, preferably more red light. Incandescent and halogen lamps meet these criteria, also some LEDs. Discrete, narrow, steep color spikes such as in compact fluorescent lamps are undesirable.

  Examples: Incandescent and halogen incandescent lamps are balanced with smooth transitions across all color bands, no color spikes, similar to sunlight and include infrared radiation. Compact fluorescent lamps only have a few discrete narrow and steep color spikes pulled out from the entire light spectrum, alien to nature; LEDs can be either way: some more or less similar to incandescent lamps, others have a more chaotic spectrum, even though most have smooth transitions between color bands, but frequently too much blue light; the important red light or infrared radiation is always missing.

- **Light Flicker** (Hertz, Hz - percent, %)

  Measurement of actual maximum flicker percentage of low frequency bands (up to 2 kHz) and high frequency bands (from 2 kHz) of the entire light spectrum based on CIE specifications 1957 regarding ripple content (International Commission on Illumination) or the commonly measured modulation depth (percent flicker).

  With a flicker frequency or flicker photometer, light meter... and fast silicone photodiodes (at min. up to 400 kHz, better 100 MHz and higher). Display of flicker percentage from 0% to 100% or with oscilloscope and/or spectrum analyzer. Spectral bands of visible light to be measured from about 380 nm to 700 nm, possibly also infrared radiation. Possibly audio signal for flicker in hearing range, AC output for further analysis.

  Note the dominant lower and higher frequencies. Assess the number and type of harmonics (spectrum analysis) and the type, smoothness or distortion of sine waves (oscilloscope). Few harmonics and comparably clean, undistorted sine waves are better than numerous harmonics and noticeable, distorted signal waveforms. Distinguish between harmonious light fluctuations (grid-powered incandescent and halogen incandescent light 100 Hz) and disharmonious light flicker (CFLs, some LEDs...).

  In principle, always use daylight as a guide. Artificial lighting sources should strive to be as free of low frequency and high frequency light flicker (light fluctuations, light flicker, light modulation, light signals) and harmonics ("dirty light") as possible and technically achievable.

  Artificial lighting sources should not pulse periodically as found in LEDs or screens with electronic brightness controls based on pulse width modulation.

  Light that can reach the eyes should not be modulated with low or high frequency signals and, in this way, misused as a data transmission pathway (e.g. Visible Light Communication, VLC).

  Optimal solution: power for lighting systems supplied by direct current.

  Examples of light flicker in percent of total light: grid-powered incandescent and halogen incandescent lamps (without electronic ballast) 5-20% (harmonious light fluctuations, sine waves hardly distorted, few harmonics); compact fluorescent lamps 20-70% (very disharmonious, heavily distorted sine waves, high in harmonics, "dirty light"); LEDs 2-100% (often - not always - more or less disharmonious, distorted sine waves, high in harmonics). Testing on commonly available lamps with E27 base performed by BAUBIOLOGIE MAES for Öko-Test and other consumer protection magazines.

- **Illumination Level** (lux, lx)

  Measurement of illumination level on an illuminated surface area.

  With a lux meter, light meter... measurement range at least 1-100 000 lx, resolution 1 lx, measurement accuracy ± 5%.

  The level of light also has a considerable impact on the day-night rhythm. Melatonin and serotonin are the major hormones regulated by this rhythm.

  The higher the light exposure, the lower the melatonin levels, but the higher the melatonin levels, the darker it is. Melatonin starts being released below about 500 lx.

  Examples: sunny summer day 100,000 lx, overcast summer day 30,000 lx, sunny winter day 20,000 lx, overcast winter day 10,000 lx, dim winter day 5000 lx, bright workplace 1000 lx, space, office lighting 100-500 lx, street lighting 10-50 lx, candle (at 1 meter distance) 1 lx, night with full moon 0.2-1 lx.

- **Color Rendering Index** (CRI, Ra value)

  Measurement of color rendering index (CRI or Ra value) of a light source.

With a spectrometer. Measurement of at least 8 test colors according to DIN 6169 (standard measurement, common labels on packaging or technical specifications of lamps); better yet, all 14 test colors according to DIN 6169.

The color rendering index should be as high and thus as similar to daylight as possible, definitely above 90.

Note: Checking all 14 test colors according to the DIN standard instead of just the 8 test colors would lead to much worse test results: compact fluorescent lamps and LEDs would be worse by about 10%, while there would be very little, if any, difference for incandescent and halogen incandescent lamps. Measuring the color rendering index according to R_{1-14} reveals more information, especially regarding the red hues, which are almost completely missing in the R_a measurements.

Examples: sunlight has an R_a value of 100, daylight 95-100, candle light 98, incandescent lamps 98-99, halogen incandescent lamps 95-98, LEDs 40-95, (compact) fluorescent lamps 40-85, mercury-vapor lamps 40-60, sodium-vapor lamps 20-40.

- **Color Temperature**, **Light Temperature** (kelvin, K)

  Measurement of color or light temperature of a lamp.

  With a spectrometer, color temperature meter, light meter, Colormaster...

  The color temperature of artificial lighting sources should be as similar to daylight as possible: during daytime "cooler" temperatures, in the evenings "warmer" temperatures.

  The higher the color temperature, the higher the blue light portion of the light spectrum; the lower the color temperature, the greater the portion of red. Blue and red light are essential for regulating the day-night rhythm / sleep rhythm. Melatonin is the main hormone that is regulated by it.

  The higher the level of blue light, the less "sleep hormone" is released; the higher the level of red light, the more melatonin is released. Daylight at midday gives off the greatest amount of blue light; the evening sun emits large amounts of red light.

  Examples: candle, fire 1500 K, incandescent, halogen incandescent lamps 2600-3200 K, warm white < 3300 K, neutral white 3300-5000 K, cold white > 5000 K, sun 3000-5800 K, overcast sky 6500-7500 K, LED headlights ca. 8000 K, deep blue noon sky 9000 K, "blue hour" 10,000-12,000 K.

- **Electrosmog** - AC Electric and Magnetic Fields (ELF/VLF)

  Electric Field Strength (volt per meter, V/m) - See also Standard Point A1.

  True RMS measurement with ground reference according to TCO Certified Criteria for IT equipment, divided into ELF (up to 2 kHz) and VLF (above 2 kHz) electric fields.

  With a field detector or field probe (TCO or disk probe, small probe), field meter, LF analyzer...

  Magnetic Flux Density (nanotesla, nT) - See also Standard Point A2.

  True RMS measurement of the sum total of all field line directions based on TCO Certified Criteria for IT equipment, divided into ELF (up to 2 kHz) and VLF (above 2 kHz) magnetic fields.

  With a field meter or field probe (induction coil, 3-D isotropic/orthogonal or 1-D), field meter, LF analyzer...

  Dominant **Frequencies** (Hertz, Hz) and Dominant **Harmonics**

  With low frequency spectrum analyzer, oscilloscope, frequency counter, voltmeter, field meter...: frequency range 10 Hz - 100 kHz (better 400 kHz and higher).

  Lighting sources are not expected to emit radio frequency electromagnetic fields; if emitted, broadband RF meters and/or spectrum analyzers should be used for frequencies above TCO frequency bands (> 400 kHz).

  In principle, electrosmog from lighting sources should be as free or low-emitting of ELF and VLF electric and magnetic fields as well as harmonics ("dirty power") as possible and technically achievable.

  Optimal solution: power for lighting systems supplied by direct current.

  Examples of AC electric fields up to 2 kHz / from 2 kHz (30 cm) in V/m: incandescent lamps < 10 / 0, CFL up to 68 / up to 71, LEDs up to 125 / up to 7.
  Examples of AC magnetic fields up to 2 kHz / from 2 kHz (30 cm) in nT: incandescent lamps < 5 / 0, CFL up to 80 / up to 80, LEDs up to 20 / up to 4.
  Testing on commonly available lamps with E27 base performed by BAUBIOLOGIE MAES for Öko-Test and other consumer protection magazines.

- **Ultrasound** (decibel, dB)

  Measurement of lamps that emit ultrasound.

  With sound level meter, light meter, possibly using a bat detector...

  Some compact fluorescent lamps and electronic devices emit high, hardly directly audible sound frequencies, which are in the ultrasound range.

B INDOOR TOXINS, POLLUTANTS, INDOOR CLIMATE

To reliably investigate and evaluate chemical and other indoor climate parameters in indoor environments, a combination of testing methods are usually needed that specifically build upon each other and are well integrated. Besides the analysis of acute indoor air pollution through air, dust, surface or material concentration levels, building biology assessments focus on identifying indoor sources of pollutants.

Inspection and **Interview**

Take history of building and occupants, visual inspection, general and olfactory perceptions (odors); possibly consult material safety data sheets, technical specifications, building files, photo documentation...

Inspect the indoor spaces to be investigated, including questioning the occupants about the history of the building, the building materials used, furnishings, furniture, floorings, adhesives, finishes, varnishes or other building and renovation materials, current or previous odor anomalies, other anomalies or health symptoms. The comprehensive visual inspection should possibly also include information about floor, wall and ceiling assemblies, the use of accessory spaces and suites, usage and ventilation habits, typical weaknesses associated with building year and construction type: e.g. PAH- and PCB-containing tar-based adhesives underneath parquet flooring in older buildings, formaldehyde and wood preservatives e.g. in manufactured homes from the 70s or indoor spaces where wood paneling or other treatments are suspected.

Direct-reading Measurements, Pretests and Exploratory Measurements

Exploratory and comparative measurements with direct-reading detection tubes, badges and testing equipment.

For a first and quick assessment of the current indoor air quality, simple pretests can be used (e.g. Bio-Check-F for formaldehyde or direct-reading detection tubes, which are pretty sensitive and rarely susceptible to disturbances while assessing a given exposure situation). There are also direct-reading instruments for formaldehyde, especially modern instruments are sufficiently sensitive and can selectively be used for a first assessment and especially for finding a source.

Instruments for solvents and other volatile or semivolatile organic compounds are based on photoionization detection (PID). Sensitive instruments can often display low total solvent concentrations and thus often allow for the identification of emission source(s).

This type of investigation can be useful in addition to pretests or more involved sample taking with laboratory analysis; it can be quickly used in different rooms or for suspect building elements or furniture. It is simple to perform comparative measurements directly on site in cracks, gaps, cavities and on surfaces. Suspect materials can be checked, for example, directly on suspect surfaces (carpeting, flooring structure...) while being sealed off or in a test container.

Reliable quick tests for pesticides and other semivolatile compounds are not available.

If first quick measurements show pollutant levels close to or above a guideline threshold level (SBM, UBA, WHO, AGÖF), more accurate tests should be performed. The compliance or the extent of noncompliance of a threshold level should be determined with an appropriate sampling method with a professional laboratory analysis (see below for evaluation measurements).

Sampling with **Laboratory Analysis**

Evaluation measurements (e.g. SBM Guideline Values for sleeping areas) with on-site sampling and laboratory analysis

These more detailed and sophisticated assessments do not provide direct results on site but require a subsequent laboratory analysis, which makes them more expensive. Air, dust, surface and material samples can be taken. You can find more details at the various standard points below. Samples are taken and sent to an analytical laboratory, which specializes in the analysis of indoor toxins. Sampling medium, sizes and conditions and also testing parameters must be coordinated with the laboratory. Especially for collecting air sampling, the following testing conditions must be considered.

Testing Conditions for **Indoor Air Assessments** and **Sample Collection**

When performing indoor air measurements and collecting samples for laboratory analysis to evaluate exposure levels (comparison to guidelines, threshold levels, guidance values or Building Biology Guideline Values), the indoor space is usually not ventilated for hours. Twenty-four hours prior to the assessment, no chemicals, cleaning agents, cosmetics, sprays, perfumes or other disturbing and odorous applications should be used in the space to be assessed and surrounding spaces. Samples are best collected at normal and preferably stable indoor temperatures (18 °C to 24 °C during the assessment / sample collection and 24 hours beforehand). Mechanical ventilation, air-conditioning or filter systems should also be turned off 8 hours beforehand. In the spaces to be tested, it is best to have very few persons or no person at all present prior to and during sampling.

For exploratory and comparative measurements, testing conditions can be deliberately chosen, but they must be considered during interpretation (finding sources, worst-case scenario and necessity of additional testing) and must be reported accordingly.

1 **FORMALDEHYDE** and other Toxic Gases

Measurement of **toxic gases** such as formaldehyde, ozone and chlorine, urban and industrial gases, natural gas, carbon monoxide and nitrogen dioxide in the air and other combustion gases

Measurement of concentrations in the indoor air, test chamber (microgram per cubic meter, µ/m³ or parts per million, ppm) or in material (mg/kg)... with direct-reading instruments, pretest procedures and samples with laboratory analysis

Pretests: Measurement of formaldehyde with Bio-Check-F or direct-reading detector tubes. The digital display or the degree of color change roughly indicates the extent of the formaldehyde exposure. These types of tests often provide sound first impressions with a sensitivity level of about 0.04 ppm (ca. 50 µg/m³). It is important not to overestimate the accuracy and diagnostic power of these tests: these are simple, quick and comparative pretests for deciding on the next course of action: e.g. for a more accurate laboratory analysis or to narrow down emission sources.

Direct-reading Instruments: Measurement of formaldehyde with direct-reading instruments such as formaldehyde meters or PIDs. Sensitivity about 0.1 ppm, preferably lower. The digital display shows the level of formaldehyde. This is about a fast and comparative pretest for deciding which next course of action to take: e.g. is a detailed laboratory analysis needed or can the results help trace or narrow down the source(s). For a critical and accurate indoor air analysis, these instruments are often not sensitive enough, but are quite suitable for exploratory measurements.

Air Sampling with **Laboratory Analysis**: Collection of samples for the analysis of formaldehyde and other aldehydes or gaseous toxins via pump and detector tubes. Air is pulled through silica gel tubes, DNPH cartridges... in which formaldehyde is collected. The laboratory analysis achieves a sensitivity level of about 10 µg/m³ (silica gel) or even 1 µg/m³ (DNPH) and can also be used for higher aldehydes (see Standard Point B2). The test provides volume concentration levels in micrograms per cubic meter (µg/m³). Measurements according to the SBM correspond to corrected values (calculated for 23 °C and 45% relative air humidity according to VDI Guideline 4300).
Sampling flow rate 0.5-1.5 liters per minute: total volume of about 30 liters for DNPH (see also VDI 3484 Sheet 3) and about 90 liters for silica gel.

Material Sampling with **Laboratory Analysis**: A suspect material such as a piece of particleboard, wood or fabric is collected on site and sent for a formaldehyde analysis to an analytical laboratory. For experiments in test chambers, conditions are best adjusted as much as possible to represent the actual conditions in a building, and the air exchange rate should be set at 0.5/h or less. The test provides test chamber concentrations in microgram per cubic meter µg/m³ or mass concentration levels by material in milligram per kilogram (mg/kg).

2 **SOLVENTS** and other Volatile Organic Compounds

Measurement of **volatile organic compounds** (µg/m³, ppm) as aldehydes, aliphatics, alcohols, aromatics, esters, ethers, glycols, ketones, cresols, phenols, siloxanes, terpenes and other organic compounds (VOC)

Measurement of concentration levels in the indoor air or test chamber (microgram per cubic meter, µg/m³ or parts per million, ppm) or in material (milligram per kilogram, mg/kg)... with pretests, direct-reading instruments and samples with laboratory analysis

Pretests: Use of sufficiently sensitive, direct-reading detector tubes for individual substances or substance mixtures with a suitable sampling pump (manual pump, automatic pump). Depending on the testing situation and the chosen detector tube, a defined volume of air is sampled (pump volume according to manufacturer's instructions). If a pollutant tested for is present, the color of the detector tube will change.

Direct-reading Instruments: On-site measurements with a direct-reading, sensitive photoionization detector (PID). A direct conversion into the base

unit µg/m³ is usually not possible because often there are substance mixtures present, whereby the detector responds with different levels of sensitivity to individual substances and is unable to identify them. The test provides volume concentration levels that correspond to TVOC levels (sum total of VOC) in parts per million (ppm) or parts per billion (ppb). The sensitivity level should be around 100 ppb or 0.1 ppm for the most common isobutylene detector tube, preferably lower. If possible, use also sufficiently sensitive direct-reading detector tubes for individual substances or substance mixtures with an appropriate pump.

Air Sampling with **Laboratory Analysis**: Sampling for the quantitative and qualitative assessment of solvents and other volatile and semivolatile toxins with pump and substrate tubes. Air is pulled through Tenax tubes in which the broadest possible spectrum of polar and nonpolar VOCs is collected (see also DIN EN ISO 16000-6). For the analysis of individual substances or a general assessment, activated charcoal, Anasorb or silica gel tubes can also be used, depending on the substance and substance class. The test provides a precise volume concentration level for individual substances and the total amount of VOCs (TVOC) in microgram per cubic meter (µg/m³). The laboratory analysis of samples collected on site should achieve a sensitivity level of about 1 µg/m³ for each individual substance. Tenax tubes are especially sensitive and can be very helpful, e.g. in the assessment of odor problems and the determination of TVOC concentration levels. For odorous aldehydes and ketones, use additional DNPH cartridges.

Method A - Tenax
A flow rate of 0.1 liter per minute and a total volume of about 1 to 4 liters for Tenax.

Method B - Activated charcoal combined with silica gel
A flow rate of 0.5-1.5 liters per minute and a total volume of about 90 liters for activated charcoal and silica gel.

Method C - Anasorb activated charcoal
A flow rate of 0.5-1.5 liters per minute and a total volume of about 90 to 150 liters for Anasorb.

Additional information on aldehydes and ketones (DNPH)
A flow rate of 0.5-1.5 liters per minute and a total volume of about 50 liters for DNPH.

For special measurement tasks, passive mini activated charcoal tubes (e.g. ORSA) can also be used, which are hung in the suspect space at the client's premise for one to two weeks or the suspect material is put in a defined space (testing chamber...) for several days. And afterward they forward them to a laboratory for analysis. The laboratory analysis provides similar levels of sensitivity for the solvents found in the indoor air but with a somewhat limited versatility (nonpolar VOCs are not detected as easily) in comparison to the above-mentioned active samples. Depending on the issue, this method can also be used to carry out a long-term measurement in addition to active sampling. The test provides individual substances for a qualitative evaluation and an approximate volume concentration level in microgram per cubic meter (µg/m³).

Material Sampling with **Laboratory Analysis**: A suspect material such as a piece of varnished or sealed material, wood or fabric is collected on site and forwarded to an analytical laboratory for a solvent analysis. For experiments in test chambers, conditions are best adjusted as much as possible to represent the actual conditions in a building, and the air change rate should be set at 0.5/h or less. The test provides test chamber concentrations in µg/m³ or mass concentration levels by material in milligram per kilogram (mg/kg).

3 **PESTICIDES** and other Semivolatile Organic Compounds

Measurement of **semivolatile organic compounds** as biocides, insecticides, fungicides, wood preservatives, carpet chemicals, fire retardants, plasticizers, pyrethroids, PCBs, PAHs, PFAS, dioxins

Measurement of concentrations in dust (milligram per kilogram, mg/kg), materials (milligram per kilogram, mg/kg), on surfaces (microgram per square meter, µg/m²), in test chambers or in the indoor air (nanogram per cubic meter, ng/m³) with pretests, direct-reading instruments and samples for laboratory analysis

Pretests: For the wood preservative pentachlorophenol, the Bio-Check-PCP provides a first on-site test. Here, a test strip, similar to a Band-Aid, is applied to a suspect wood surface for 24 hours. After forwarding the sample to the laboratory, the analysis will provide information about the concentration level. Advantage: nondestructive sampling. Disadvantage: PCP detection only, no other pesticides.

Dust Sampling with **Laboratory Analysis**: Semivolatile toxins accumulate preferably in house dust in which it is relatively easy to detect them with an often reasonable level of sensitivity, and they provide clear evidence of existing indoor sources. Simple vacuuming allows you to sample the house dust to be assessed. You should thoroughly vacuum the rooms to be assessed 7 days prior to collecting samples. Then, 7 days later and without any additional cleaning, the sample is collected. Usually, the vacuum cleaner from the house is used for collecting the sample; alternatively, a special vacuum cleaner can be used either with a new bag or a special collection container that filters the dust. When collecting samples with a vacuum bag, the vacuum cleaner should run idle for a couple of minutes beforehand. Depending on the situation, not only the floor should be vacuumed but also fabric surfaces, cushions, pillows, mattresses, stuffed toy animals, curtains, drapes, wall hangings, books... and other dust traps.

Do not vacuum directly on surfaces suspected of or known to contain pesticides because we wish to capture the secondary contamination, which is caused by primary sources, such as a pesticide-containing wood ceiling. The Building Biology Guideline Values apply to samples of secondary contamination. The test results of samples collected by directly vacuuming contaminated materials and surface areas would be higher, but they can be of interest when trying to locate sources.

The sample (vacuum bag...) is packed in an airtight package of aluminum or sealed in an uncontaminated plastic bag and then sent to the analytical laboratory for analysis. The test provides mass concentration levels in e.g. milligram per kilogram (mg/kg) with detailed descriptions of individual substances (pesticides, pyrethroids, plasticizers, flame retardants, PCB, PAH...). Ensure that the laboratory identifies a broad spectrum of as many toxins as possible.

Method A - Vacuum bag
On-site sampling with vacuum cleaner, preferably a paper vacuum bag with an insert, preferably 1 to 2 grams of fine particulate matter, fraction < 200 µm, preferably < 63 µm.

Method B - Dust collection container
On-site sampling with ALK dust collection container and special filter, preferably 1-2 grams of fine particulate matter, fraction: < 200 µm, preferably < 63 µm.

Material Sampling with **Laboratory Analysis**: Sample of a suspect material surface (wood) or a material sample (leather, carpet...) with subsequent laboratory analysis. A piece of wood surface is required (a total of ca. 10 to 20 cm², ca. 2 to 3 g) that is about 1 to max. 2 mm thick. It is recommended to collect several samples from different areas of a suspect wood surface, e.g. at one end, at the other end and in the middle of a beam. For fabric or leather samples, a postage stamp-sized piece will be sufficient. For carpeting samples, it is a good idea to pick up fluff gently so as not to destroy the material. The samples are packed in an airtight package of aluminum or sealed in an uncontaminated plastic bag and then sent to the analytical laboratory. The test provides mass concentration levels in e.g. milligram per kilogram (mg/kg) with detailed descriptions of individual substances.

Surface Sampling with **Laboratory Analysis**: Wipe samples provide a nondestructive method for assessing materials and identifying secondary contamination. Thoroughly wipe a defined (a few square centimeters), mostly smooth surface area using a clean cotton cloth and some alcohol (most commonly isopropyl alcohol). Then, send the sample to the analytical laboratory. The test provides concentration levels based on the surface area in

microgram per square meter (µg/m²) or microgram per square decimeter (µg/dm²).

Air Sampling with **Laboratory Analysis**: Air sampling pumps extract a defined - rather large - volume of indoor air through sampling media, such as PU/polyurethane foam or activated charcoal (plasticizers only), NIOSH, for preparation and analysis in an analytical laboratory. For some pesticides, indoor air measurements are rather insensitive, and depending on the situation, results may appear relatively normal because the concentrations of semivolatile substances in the air are low. However, should a higher and significant concentration level be found in the air, there is often a problem and an indoor source. When test results are within normal limits, any conclusions regarding this space to be safe should be treated with caution. Air sampling should not replace specific material and dust sampling, but rather supplement it. The test provides volume concentration levels in nanogram per cubic meter (µg/m³).

A flow rate of 30 liters per minute and a total volume of about 1000 to 2000 liters, PU foam plug with a 5-cm diameter. A flow rate of 5 liters per minute and a total volume of about 1000 to 2000 liters, PU foam plug with a 2-cm diameter. A flow rate of 0.5-1.5 liters per minute and a total volume of about 500 liters for activated charcoal, NIOSH.

4 **HEAVY METALS** and other Similar Toxins

Measurement of inorganic substances as light and heavy metals (aluminum, antimony, arsenic, barium, lead, cadmium, chromium, cobalt, copper, nickel, mercury, zinc…), metal compounds and salts

Measurement of concentration levels in dust (milligram per kilogram, mg/kg), in materials (milligram per kilogram, mg/kg), on surfaces (microgram per square meter, µg/m², in the indoor air (nanogram per cubic meter, ng/m³) and in drinking water (microgram per liter, µg/l), sampling with laboratory analysis

Identification of at least 12 common light and heavy metals (preferably more), including, among others, the metals aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), tin (Sn), thallium (Tl) and zinc (Zn). Sometimes, it is beneficial to test for specific oxidation products like chromium-6 (Cr-6) in materials like leather.

Dust Sampling with **Laboratory Analysis**: In building biology assessments, house dust samples are used to detect metals. The sampling follows the instructions as described at Standard Point B3. Ensure that the dust analysis also includes as many individual components as possible. After acidification with nitric acid or aqua regia, samples can be identified through ICP-MS. The detection threshold is around 0.1-5 mg/kg.

Method A - Vacuum Bag
On-site sampling with vacuum cleaner, preferably a paper vacuum bag with an insert, preferably 1 to 2 grams of fine particulate matter, fraction < 200 µm, preferably < 63 µm.

Method B - Dust Collection Container
On-site sampling with ALK dust collection container and special filter, preferably 1 to 2 grams of fine particulate matter, fraction: < 200 µm, preferably < 63 µm.

Material Sampling with **Laboratory Analysis**: Samples are collected from suspect surfaces (wood, leather, paint, slag) or material/product samples are chosen for subsequent laboratory analysis. Samples (2 to 3 grams) are put into jars or packaged in aluminum and then sent to the analytical laboratory. The test provides mass concentration levels in e.g. milligram per kilogram (mg/kg).

Surface Sampling with **Laboratory Analysis**: Wipe samples are well suited as a nondestructive method for assessing materials and identifying secondary contamination, such as mercury. Thoroughly wipe a defined (a few square centimeters), mostly smooth surface area using a clean cotton cloth and some alcohol (most commonly isopropyl alcohol). Then, send the sample to the analytical laboratory. The test provides concentration levels based on the surface area in microgram per square meter (µg/m²) or microgram per square decimeter (µg/dm²).

Air Sampling with **Laboratory Analysis**: An air analysis only makes sense for mercury. The sampling follows the instructions as described at Standard Point B2. Activated charcoal tubes impregnated with iodine are used specifically for mercury analysis. The detection threshold is sufficiently low with 30 ng/m³. Concentration levels are determined through cold vapor AAS. The test provides volume concentration levels in e.g. microgram per cubic meter (µg/m²) or nanogram per cubic meter (ng/m³).

A flow rate of 0.5 to 1.5 liters per minute and a total volume of about 250 liters for activated charcoal tubes impregnated with iodine.

Drinking Water Sampling with **Laboratory Analysis**: If drinking water is suspected of being contaminated, it is important to perform a water analysis, particularly for lead, copper, nickel, cadmium and arsenic. Samples are collected with PE bottles (provided by the analytical laboratory or ca. 50 mL bottle for urinalysis from a pharmacy) and the analysis is performed using ICP-MS. The test provides concentration levels in e.g. microgram per liter (µg/L).

For a more detailed water analysis, the drinking water regulations need to be considered during sampling and for the laboratory analysis.

5 **PARTICLE** and **FIBERS** (Fine Particulate Matter, Nanoparticles, Asbestos, Mineral Fibers...)

Measurement of **dust**, **number** and **size of particle**, **asbestos** and other **fibers**

Measurement of concentration levels in the indoor air (µg/m³ l), in dust (/g), in material (/g) or on surfaces (/cm² with direct-reading instruments and samples with laboratory analysis

Microscopy Pretests: With particulate sampling device (e.g. Allergenco, MBASS30-PS30) and adhesive tape on a slide, assessment with light microscope.

Direct-reading Measurements with Particle Counters: Measurements with laser particle counters (multichannel system for particles from 0.3 to 0.5 µm diameter) or condensation particle counter (for smaller particles down to 1 nm), preferably classified by size.

Direct-reading Measurements or Collection of Fine Particulate Matter: Measurements to determine the mass of dusts with suitable pumps and filtration units as well as pre-separators; the test provides concentration levels in e.g. microgram per cubic meter (µg/m³).

Dust Sampling with **Laboratory Analysis**: Asbestos and man-made mineral fibers (MMMF) can be detected in house dust with an exploratory measurement. The sampling follows the instructions as described at Standard Point B3. After burning the filter to ashes, the analytical laboratory analyzes the dust sample using a scanning electron microscope and energy dispersive X-ray microanalysis (REM-EDXA). This type of analysis differentiates between the number and type of fibers.

Material Sampling with **Laboratory Analysis**: Collecting samples of asbestos and MMMF or a material sample with subsequent laboratory analysis. During sample collection, it is important not to cause any contamination of the surrounding environment (asbestos sampling according to VDI 6202 Sheet 3 and after suitable training, e.g. TRGS 519 certification). Airtight containers or glass jars are used to store material samples (no more than 1 g), which are then sent to the laboratory. The laboratory analyzes the samples (usually at least 2 g) with a scanning electron microscope and energy

dispersive X-ray microanalysis (REM-EDXA). The analysis differentiates between mass proportions in % for asbestos or MMMF and the carcinogenicity index for MMMF.

Surface Sampling with **Laboratory Analysis**: With the adhesive stamp sampling method according to VDI 3877 Sheet 1, asbestos fibers and MMMF can be determined on surfaces. The sampling method according to VDI 3877 Sheet 1 involves pressing special adhesive tapes or graphite adhesive stamps onto a horizontal surface that has been dusted 3 to 7 days prior to collecting samples. Afterward, the samples are analyzed using a scanning electron microscope with energy dispersive X-ray microanalysis (REM-EDXA). This type of analysis differentiates between the number and type of fibers.

Air Sampling with **Laboratory Analysis**: Air sampling of asbestos fibers and MMMFs are performed according to VDI Guideline 3492. Prior to sample collection, also make sure to stir up accumulated dust or hidden fiber accumulations to simulate usage. Otherwise, the specifications of VDI 4300 apply as for the other air sampling methods. With special pumps, indoor air is sampled for more than eight hours. As a general rule, 3800 liters of air must be sampled. If dust or smoke levels are high, a lower air volume should be sampled; otherwise, the air sampler will become overloaded. The asbestos fibers and MMMFs accumulate in the air sampler on a gold-coated capillary pore membrane filter. After burning the filter to ashes, the analytical laboratory analyzes a portion of it using a scanning electron microscope and energy dispersive X-ray microanalysis (REM-EDXA). This analysis differentiates between the number, type, thickness and length of fibers.

Sampling with a suitable asbestos pump (pulsation-free, e.g. rotary vane pump).

A flow rate of 8 liters per minute and a total air volume of about 3800 liters through the air sampler with a gold-coated capillary pore membrane filter.

In Germany, you must follow the "Guideline for the Assessment and Remediation of Loosely Bound Asbestos Products in Buildings - Asbestos Guideline," including its assessment form and the "Guideline for Asbestos Detection in Preparation for Working in and on Older Buildings" by the German Environment Agency (UBA), among others. The analysis of dust, material and surface samples for asbestos is performed according to VDI Guideline 3866.

6 INDOOR CLIMATE (Temperature, Humidity, Carbon Dioxide, Air Ions, Air Changes, Odors...)

Measurement of **air** and **surface temperature**, **air humidity** and **material moisture**, **oxygen**, **carbon dioxide**, **air pressure**, **air movement** and **air ions**, identification of **odors** and **air exchange rate**

Measurement of temperature (°C), humidity (% RH, AH), oxygen (vol%), carbon dioxide (ppm), pressure (mbar), air movement (m/s), air ions (/cm³)

Humidity and **Temperature** of **Air** and **Materials** - Measurements with thermometers, hygrometers, building moisture meters, IAQ data loggers, modular systems....

Air temperature and air humidity can be measured with thermohygrometers. In situations with condensation problems where the cause(s) is not obvious, long-term data logging of the indoor climate for several days or weeks is necessary. Values are given in degrees Celsius (°C) and percent relative humidity (% RH). Calculations performed by the instruments or those based on tables and computer programs will also provide the dew point (in °C) and the absolute humidity in gram per cubic meter (g/m³).

To assess indoor air humidity, both relative and absolute humidity levels need to be established. For short-term measurements, ensure that the probes have time to adjust to ambient conditions, especially when moving instruments from the outside to the inside. Probes need to be kept at a sufficient distance from the body or mouth to avoid interference.

Surface temperatures in degrees Celsius (°C) can be measured with contact thermometers or - without contact and more conveniently - with infrared laser thermometers. Especially when using the latter, it is recommended to perform comparative measurements on the same material; for surfaces with widely varying reflection characteristics, relevant emission angles need to be considered and adjusted for.

Measurements of air humidity and surface temperatures for the assessment of condensation problems must be carried out during the season or weather condition appropriate for the question under consideration: For the investigation of condensation problems at cold exterior walls in above-ground spaces, cold outdoor temperatures should prevail - the colder, the better; investigations of condensation problems in basements or basement suites are usually only useful in summer or fall.

When taking measurements of air humidity and surface temperatures, the occupants' behavior should also be considered and reported.

At first, nondestructive building moisture measurements can be carried out with a radio frequency sensor; suspect areas can then be measured with surface and/or penetration electrodes via the electrical conductivity on the surface or at various depths. Depending on the situation, microwave testing can also be used. Conductivity measurements often provide values as wood moisture equivalent (% WME) or device-specific digits. Based on tables, it is possible to establish the moisture content of a given material. For its exact determination, calcium carbide (CM method) or drying/weighing (Darr method) can be used. Possible errors of the latter type of measurements include salt deposits on building materials or metals or other electrically conductive layers, building materials and surface treatments. It can be helpful to measure air humidity inside materials at newly drilled holes into which the humidity probe is inserted and sealed to the indoor air.

Oxygen - Measurements with detector tubes or instruments

This gas, so very essential to life, is almost always available in sufficient amounts indoors. The claim "there is no oxygen" is incorrect; the problem is rather an excessive amount of available carbon dioxide. Therefore, measurements of oxygen are usually unnecessary. It is possible to estimate its level via carbon dioxide levels. For exact oxygen levels, measuring instruments are used, such as detector tubes or direct-reading instruments.

Carbon Dioxide - Measurements with direct-reading detector tubes or carbon dioxide monitors

Carbon dioxide measurements can provide good insights into the indoor climate and air exchange rate. The carbon dioxide concentration is also a good indicator of potential exposure to toxins and odors. On-site measurements can be done with detector tubes, but preferably with direct-reading instruments such as carbon dioxide monitors (possibly with internal data logging or data logging output for long-term measurements). The test provides carbon dioxide levels in parts per million (ppm) or volume percent (vol%).

Air Pressure - Measurements with barometers

For building biology assessments, measuring air pressure is also important because it is a criterion for the assessment of other environmental factors (e.g. for air pollutant measurements) and because knowing the air pressure level also allows to draw conclusions regarding specific health symptoms typically associated with it. Barometers are used to measure air pressure. In building biology, digital instruments are used, often combination instruments that also include sensors for air temperature and air humidity. Values are given in millibar (mbar) or hectopascal (hPa). Air pressure fluctuations can only be monitored with instruments that have a plotter or data logger function.

Air Movement - Measurements with airflow indicator tubes or instruments

Flow indicator tubes are well suited for providing a first impression of air movement within a given space. They emit a fog-like smoke that moves in the air like a cloud following the thermal updraft and air movement. These methods are often used to observe the effectiveness of heating, ventilation and air-conditioning systems (caution! do not inhale sulfuric acid).

Additional measurements are carried out with airflow instruments, e.g. thermal anemometers or hot ball anemometers. Sometimes flames (candle, lighter) already indicate air movements. Values of airflow instruments are given in meter per second (m/s). Instruments should be sensitive enough to still register weak air movements below 0.1 m/s (meter per second).

Air Ions - Measurements with ion counter

Measurements of small ions in the air provide an overall impression of the indoor climate. Levels far above normal and constantly increasing levels within a given time period are a valuable indicator of radon exposure. Low levels suggest electrostatically charged surfaces, fine particulate matter or other anomalies. Small air ions are measured with ion counters. Modern instruments can simultaneously measure positively and negatively charged ions; they also have data logging functions for long-term assessments. Measurement results are given in ions per cubic centimeter (ions/cm³).

Air Electricity - Measurements with electric field meters or field mills

Indoor air electricity results from static electricity and surface potentials; measurements are carried out as described at Standard Point A4 with field probes (electric field meters), most of which operate according to the induction-based field mill principle. Air electricity is the result of the static electric field strength within a given space. At 1 m to an electrostatically charged object with a surface potential of 1000 V, the resulting field strength is 1000 V/m. Conversion: surface potential (V) = field strength (V/m) x distance (m). Just before testing, it is important to rub the material (carpeting, drapes) slightly. The neutral earth is used as a ground reference.

Odors - Sensory assessment or measurements with air sampling

Odors are primarily detected by sensory or olfactory pathways. Intensity and quality play an important part in this regard. Also, one can distinguish if odors smell pleasant or unpleasant, if odors are acceptable or unacceptable or if there are clear indications of odor sources (mold or chemicals? what type of building materials, other materials, furnishings... what does it smell like?). As needed, measurements can be carried out following the instructions at Standard Points B1, B2 and B3. Search for pollutants and compounds with strong odors in the air or in materials. Sometimes simple tests with suspect materials in air-tight test containers made of glass can provide odor-related information about the source.

Air Change - Measurements with tracer gas

Supplement to the Building Biology Guideline Values - Recommendations, Guidance and Assessment tools:

Air change		No Anomaly	Slight Anomaly	Severe Anomaly	Extreme Anomaly
Air exchange rate per hour	air changes/h	> 1	0.5 - 1	0.1 - 0.5	< 0.1
Fresh air supply in cubic meter per hour and person	m³/h	> 50	25 - 50	5 - 25	< 5

Air change values apply to a normal-sized bedroom (ca. 20 m²) used by one person as an average value during sleep; smaller rooms or a higher number of persons must be assessed more seriously.

General recommendations of air exchange rates for other spaces: open-floor office 40-50 m³/h, single office 40 m³/h, classroom, lecture hall, restaurant 30-40 m³/h, conference room 30 m³/h, theater, concert hall, movie theater 20 m³/h. The minimum air exchange rate to meet hygiene requirements is about 0.3/h.

The air change within a building depends on many factors such as airtightness of the building enclosure, outdoor and indoor climate or season, heating conditions, wind and pressure conditions at and within the building, location and dimension of windows, natural ventilation through windows and stack ventilation and mechanical systems (local or central) through fans. We can often estimate current and potential air exchange rates fairly well based on the above-mentioned factors present on site and the occupants' behavior, such as how often they ventilate and for how long.

Only actual measurements can provide exact data. The air exchange rate can be measured with the concentration decay method according to VDI Guideline 4300 Sheet 7 or DIN EN ISO 16000 Sheet 7. Based on this method, a tracer gas (e.g. carbon dioxide) is pumped into the indoor space and then the concentration decay is monitored over time. From the decay curve and space volume, the air exchange rate per hour (/h) is determined. Often several measurement points are established to document a uniform concentration distribution across a given space.

The ventilation standard DIN 1946-6 from 2019 also serves as an evaluation tool. This DIN standard defines the required minimum air exchange rates for certain sizes of apartments.

To ensure minimum air exchange rates, the ventilation standard must be included in the planning of new, modern, and airtight buildings.

In most cases, reasonable manual window ventilation is not sufficient anymore to meet minimum ventilation and even moisture protection requirements; therefore, a ventilation strategy with technical support is required.

C FUNGI, BACTERIA, ALLERGENS

1 MOLDS and their Spores and Metabolites

Measurement and identification of culturable and nonculturable **molds**, their spores and fragments as well as their metabolites (MVOC, toxins...)

2 YEASTS and their Metabolites

Measurement and identification of **yeasts** and their metabolites

3 BACTERIA and their Metabolites

Measurement and identification of **bacteria** and their metabolites

Supplement to the Building Biology Guideline Values - Recommendations, Guidance and Assessment Tools:

Especially in the case of mold, combining different diagnostic methods that consider the specifics of each situation and gathering diverse results and observations maximizes the analytical certainty and makes it possible to identify sources and reach meaningful assessments, but not single findings.

In addition to the main recommendations and values of the Building Biology Evaluation Guidelines for Sleeping Areas, indoor sources, suspect conditions, elevated exposure levels or health risks can in many cases be identified and assessed, among others, using the information and empirical values found below:

Mold		No Anomaly	Slight Anomaly	Severe Anomaly	Extreme Anomaly
Molds, relative per cubic meter of indoor air *	/m³	< Outdoor	< 100 more	< 500 more	> 500 more
Individual species, relative per cubic meter of indoor air *	/m³	< Outdoor	< 50 more	< 300 more	> 300 more

Total mold count in indoor air in comparison to reference samples of outdoor air and/or uncontaminated reference rooms and the number of individual mold species, which are very different from the species in outdoor air and/or uncontaminated reference rooms.

Mold, absolute per cubic meter of indoor air *	/m³	< 200	200 - 500	500 - 1000	> 1000

Indoor air at moderate mold counts in outdoor air below 500/m³, depending on climate and hygiene conditions.

Mold per square decimeter of surface area *	/dm²	< 20	20 - 100	100 - 200	> 200

Mold and spores deposited on common, regularly cleaned surface areas that are not covered with thick dust layers.

Mold per gram of house dust *	/g	< 500	500 - 2000	2000 - 10000	> 10000

Number of mold spores in 7-day-old house dust. Direct culturing of dust on culture media. Comparative samples of other and especially those rooms that are not contaminated.

MVOC Sum total in nanogram per cubic meter of air	ng/m³	< 200	200 - 1000	1000 - 10000	> 10000
Specific individual substances	ng/m³	< 50	50 - 200	200 - 2000	> 2000

Microbial volatile organic compounds in the indoor air, at least 15 individual substances including sum value.

* Mold cultured on culture media is counted in colony forming units (CFU) at a culture temperature of 20 °C to 25 °C.

For detailed assessments and data, see UBA Mold Guideline, WTA-Merkblatt 4-12 05.2021/D, VDB-Zert, LGA guideline

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For your convenience, the relevant paragraphs from the Building Biology Evaluation Guidelines SBM-2024 with four relevant additions are provided below:

The mold **count** in the indoor air, on surfaces, in house dust, cavities and materials... should be **lower** compared to ambient outdoor air or uncontaminated reference rooms. Mold **types** in indoor environments should be **very similar** to those outside or in uncontaminated reference rooms. **Particularly serious** types of molds*1, such as toxigenic or allergenic molds or those thriving at 37 °C body temperature*2, should be **undetectable** or only minimally detectable. There must be no contamination with mold **metabolites** (mycotoxins, MVOCs, glucans...).

To counteract mold growth, constantly high levels of material moisture or air humidity and cool surface temperatures and severe thermal bridges should be avoided; the **water activity** of materials should not stay above **0.65** for longer periods of time.

Any additional **sign**, **suspicion,** or indication of a potential microbial problem should be investigated or included in the assessment: e.g. discoloration and mold stains, odors typical of microorganisms, moisture-indicating mold species*3, construction, moisture damage and fecal contamination, problematic construction details, hygiene aspects, increased exposure from outside*4, previous damage, building history, on-site inspection, health issues of occupants, occupants' medical lab test results...

*1 More serious and toxigenic molds, such as Stachybotry, Aspergillus, Alternaria, certain species of Chaetomium, Paecilomyces, Penicillium, Trichoderma

*2 Molds growing at 37 °C body temperature and potentially causing infections, e.g. Aspergillus, certain species of Absidia, Acremonium, Fusarium, Mucor, Paecilomyces, Rhizopus, Trichoderma

*3 Moisture-indicating molds, such as a) Acremonium, Aspergillus fumigatus, Auroeobasidium pullulans, Chaetomium, Stachybotrys, Trichoderma or yeasts for large amounts of moisture, and b) Aspergillus versicolor, A. penicilloides, A. restrictus, Eurotium or Wallemia sebi for slightly increased moisture levels

*4 Above-average mold exposure from outside sources, e.g. landfill sites, recycling facilities, composting and shredding facilities, dust-generating construction, demolition, agricultural and garden activities...

Standard Points C1 through **C3**: **Molds, Yeasts** and **Bacteria**

Meaningful assessments of microbial exposure to molds, yeasts and bacteria usually require various diagnostic methods that are tailored to the specific situation and issue; both test results and findings must together provide a plausible overall picture.

Note: As a result of moisture or hygiene problems, frequently (or sometimes even exclusively) there are also bacteria involved besides mold. The occupants' health problems can be associated with molds and bacteria. All three microbiological standard points should receive equal attention in building biology investigations. Pay attention to specific surrogate microbes for moisture and the presence of highly toxic microbes.

Inspection and **Interview**

History of building and occupants, visual inspection, general and olfactory perceptions (odors). Possibly also use endoscope, magnifying glass, pen microscope, forensic lights, photo documentation...

Gather or verify information that points to microbial issues by inspecting the indoor spaces to be investigated and by interviewing the occupants regarding the history of the building; current or previous building, moisture or water damage; problem structures, odor problems, occupant behavior or health symptoms.

If indicated, a thorough visual inspection also includes hidden places and surfaces such as behind furniture, also in cavities of interior walls, roof structures, wall paneling, floor structures, fireplaces, ducts...

Culturing methods

Culturing of microorganisms that are subsequently counted and identified. On culture media (agars, petri dishes, Rodac plates, contact slides...).

Culture media for molds and yeasts suitable for indoor air analysis include primarily YM building biology agar and DG18 agar, depending on the application, also e.g. rose bengal, Sabouraud or malt extract agar; for bacteria CASO (TSA) or plate count agar.

For air samples (ideally also for surface samples) from a given collection area, use a minimum of two different culture media with different media and water conditions for molds and one additional culture media for bacteria.

The culture temperature is usually 20 °C to 25 °C (room temperature), for thermotolerant species (e.g. Aspergillus, Candida species) also 37 °C (body temperature), for thermophilic species (Actinomycete, Legionella species...) at even higher temperatures.

The microbial count is given as colony forming units (CFU).

Be very careful to keep culture media and relevant sampling devices as sterile and clean as possible during handling. Therefore, place culture media and devices on new aluminum foils, only work with clean hands or use hand protection, and regularly (at least prior to each new testing contract) disinfect devices with alcohol or heat.

Microscopy Analysis

Samples (air, surfaces, materials, dust...) are put directly under an optical microscope for analysis. With optical microscopes, slides, microscopy solutions...

In this process, usually common microbiological staining techniques are used for molds (e.g. cotton blue or lactophenol blue). Magnification of up to 600 is usually sufficient.

Indoor Air Sampling

Sampling of fungi, mold spores and bacteria from indoor air to assess through culturing and/or microscopy. With an air sampling device, air sampler, impactor, particulate or slit air sampler and coated slides, gelatin filter...

Always compare air samples from indoor spaces to those from outdoor air and to normal samples from reference rooms (this applies to samples taken to be cultured and those for direct microscopy).

As a general rule, rooms should not be ventilated for at least 6 to 8 hours prior to air sampling. For each testing situation, inquire and report in detail about the conditions and consider those in the interpretation of the test results.

It should also be considered and reported which activities took place in a given room prior to sampling: e.g. typical occupant behavior (perhaps could be imitated prior to sampling by walking through the room, opening furniture, moving curtains...); or quiet conditions (no persons in the room for a longer period) or (depending on the issue in question) intentionally stirring up things by moving about intensively (so-called aggressive sampling, especially suitable for control testing after remediation). Especially when testing for bacteria, no person(s) should be in the room to be investigated prior to sample taking.

For ventilation and air-conditioning systems, one should take an air sample prior to and several minutes after turning on such a system.

As a sampling location in a given space, it is best to choose a representative area, usually in the center at a height of about 1 to 1.5 m. Alternatively, one can also walk with an air sampler at the outstretched arm through the space to collect a random sample of the entire space. In specific situations, it is possible to take samples directly in front of suspect areas or to suck air from cavities or drilled holes (when taking samples from cavities, be careful not to stir up dust and avoid depositing it on the culture media).

Microbial Air Sampling

Sampling with an air sampler, impactor, gelatin filter...

Prefer active air sampling based on impaction with suitable cut-off values for fungi and bacteria of 1 µm or less. The air volume to be sampled needs to be appropriate for the testing situation at hand: In general, 50 to 100 liters per standard petri dish; during summer (with its trend of a higher microbial count) preferably 50 L; during winter preferably 100 L; in situations where contamination is suspected or inside cavities, choose a lower volume; in extremely clean rooms or those not suspected to be contaminated, choose a higher volume. Culture media should be at room temperature during air sampling.

When using passive air sampling such as sedimentation (OPD or open petri dish), it is recommended to put out several petri dishes at various points of a given room for reasons of accuracy (e.g. flooring at the center of room, desk, book shelves...). The culture medium in the petri dish should be open and in contact with the indoor air for 30 to 60 minutes (the lower the expected microbial count, the longer).

Fungal and bacterial counts are given as colony forming units per cubic meter of air (CFU/m³) for active air samples and as colony forming units per culture medium (CFU/agar) for passive air samples. As a rule of thumb: 1 hour sedimentation multiplied by a factor of 20 to 50 often roughly corresponds to the microbial count per m³ of air established with impactors.

Particulate Air Sampling

Sampling with particulate or slit air samplers and coated slides.

To capture the total spore count with particulate samplers (i.e. both culturable-viable and nonculturable-nonviable microbes), use slit samplers specifically suited for the sampling of fungal spores, including the appropriate pump systems, sizes and coated slides. The assessment of sampled particulates and fungal fragments is done using direct optical microscopy. As a general rule, the sample comprises about 100 to 200 liters of air (the lower the expected microbial count, the higher the volume of sampled air).

The fungal count is given as spores per cubic meter of air including additional statements, findings or descriptions (e.g. about other fungal parts, such as hyphae or mycelia, also about skin scales, hair, mites, dust, particulates, mineral fibers...).

Surface Sampling

For culture media or direct microscopy analysis. With dip slides, petri dishes, sterile swabs, adhesive tapes.

For direct microscopy analysis, so-called lift tape samples are taken: Apply transparent adhesive tape (e.g. clear Scotch tape) to suspect or contaminated surface areas, lift and apply to a slide or foil to be inspected under a microscope, with relevant staining techniques as required. These samples provide quick answers, sometimes even species can be identified and differentiated. It can also reveal whether they are only spore deposits or actual fungal hyphae or fruiting bodies and whether the surface the sample was taken from presents with secondary or primary contamination.

Samples on culture media are collected, for example, by using Rodac plates, contact slides or dip slide paddles. One must place the agar surface in firm contact with the surface to be sampled for several seconds. This type of sampling is useful for identifying secondary contamination in the event of mold damage, for the assessment of surfaces not visibly contaminated, for control testing after special cleaning as part of mold remediation efforts or for control testing of general hygiene safety monitoring.

For a first comparison, it is also possible to scan or roll a sterile moist swab over a defined surface area (e.g. 1 dm²) and then roll it over a culture medium (e.g. petri dish) several times to transfer the captured mold spores.

Wipe samples with sterile swabs are especially suitable for taking samples from cracks and joints or drill holes in walls, floors or cavities. Slightly moisten swabs prior to sampling and then roll them over culture media. These swab samples are also well suited for reserve samples, which can be placed in contact with the culture media as required, even weeks or months later.

Besides contact slides, sterile swabs are used specifically for yeast sampling, e.g. in refrigerators, dishwashers, washers, flushing cisterns, drains, shower heads, mouth showers, inhalers, baby bottles, grain mills, food and food storage...

The fungal and bacterial counts of contact slides or wipe samples are given as colony forming units per square decimeter or square centimeter of surface area (CFU/dm² or CFU/cm²). For swab samples, only semiquantitative counts/impressions or qualitative species identification should be performed, e.g. comparative counts per culture medium (CFU/agar).

For horizontal surface areas (e.g. floors, tables, furniture...), always report for how long these had not been cleaned prior to sample taking: When comparing to the building biology guideline values, surfaces should have been cleaned regularly in the past, but preferably not within the few days prior to sampling. The guideline values certainly do not apply to dust-laden surfaces or those that have not been cleaned for the longest time.

For samples from surface areas with visible mold growth, count values are not very meaningful, but the identification of species is rather useful and important.

Material Sampling

For culture media or direct microscopy analysis. With culture media, dilution solutions, adhesive tapes, swabs.

Materials contaminated or suspected to be contaminated with fungi (wallpapers, plasters, insulation materials, wood, carpeting, documents, furnishings...) are carefully removed on site, without stirring up fungi or their spores (while using clean tools, sterile tools for samples to be cultured, and preferably wearing gloves to prevent contamination of samples and to avoid risks for the person removing the samples). Then the samples are wrapped into aluminum foil or sealed into plastic bags and sent for preparation (comminution, setup of dilution series) and culture-based or microscopy analysis.

Material testing of building materials (insulation materials, clay plaster...) or surface treatments (wall finishes...) is useful to prevent a microbial risk prior to installation. Especially wall finishes can, although rarely, become contaminated with bacteria and must not be applied.

For culture media, fungal and bacterial counts are given as colony forming units per gram (CFU/g); for microscopy analysis, the semiquantitative value or description of counts of spores, hyphae, fruiting bodies... is given.

Dust Sampling

For culture media or direct microscopy analysis. With culture media, dilution solutions, adhesive tapes.

Dust is collected by vacuuming defined surface areas (floors, carpeting, upholstery, furniture..., to be chosen and reported, depending on the assignment), e.g. via vacuum cleaner with an appropriate sampling tool (ALK sampler) and cellulose filters or directly from the dust bag of the vacuum cleaner (fine particulate fraction, possibly after screening). Type and size of the vacuumed surface area must be documented.

Dust levels can indicate a secondary or primary mold contamination. Again, pay attention to additional findings: skin scales, hair, particulates, mites, allergens, mineral fibers...

For collecting surface dust with adhesive tapes, see above at "Surface Sampling."

Fungal and bacterial counts are given per gram of dust (/g) or per square meter of vacuumed surface area (/m²).

MVOC Analysis (Microbial Volatile Organic Compounds)

To identify fungi-specific (and bacteria-specific) outgassing. With sampling pumps and collection media and specialist laboratory analysis.

Microorganisms emit volatile organic compounds that can be identified by sampling indoor air through activated charcoal or Tenax tubes and then forwarding the samples to the laboratory for a chromatographic and spectroscopic analysis. Look specifically for fungi-specific substances such as dimethyl sulfide, dimethyl disulfide, dimethyl sulfoxide, geosmin, 2-methylfuran, 3-methylfuran, 1-octen-3-ol, 2-pentanol, 1-decanol, 2-heptanone, 2-methyl-isoborneol, 3-octanol, 3-octanone.

MVOC analysis should be performed in close consultation with the analytical laboratory because errors can easily occur when working in such a highly sensitive range or so close to the detection level because of inappropriate testing conditions, sample media, sample handling or laboratory preparation. MVOC analysis should not be performed by itself but only in combination with additional testing methods. MVOC concentration levels are given in nanogram per cubic meter (ng/m³).

Mycotoxin Analysis

For the identification of fungi-specific toxins. Based on the analysis of material and dust samples by a specialist laboratory.

Mycotoxins can be detected as semivolatile compounds in either materials or dust. Standardized testing methods are only available for very few mycotoxins (e.g. ochratoxin A, trichothecene), even though several hundred of these toxic fungal metabolites are known. Moreover, there are only very few reference values.

Toxin levels are given in microgram or nanogram per gram dust or material (µg/g or ng/g).

Humidity and Temperature Measurements

For identifying causes of microbial damage related to indoor air climate and building science or for risk assessments. With suitable thermometers, hygrometers, building moisture meters, IAQ data loggers, modular systems....

To carry out these types of measurements, accurate and calibrated thermometers, hygrometers, and building moisture meters are required. Air humidity and surface temperature assessments should, if required, be based on long-term measurements with IAQ data loggers. Carry out relevant measurements during the appropriate season or weather conditions in line with the assessment objective: For the investigation of condensation problems at cold exterior walls in above-ground spaces, cold outdoor temperatures should prevail (the colder, the better); for investigations of condensation problems in basements or basement suites, measurements are usually only useful in summer or fall.

When measuring air humidity and surface temperatures, the occupants' behavior should also be considered and reported.

To assess indoor air humidity, both relative and absolute humidity levels need to be established. For short-term measurements, ensure that the probes have time to adjust to ambient conditions, especially when moving instruments from the outside to the inside. Probes need to be kept at a sufficient distance from the body or mouth to avoid interference.

Surface temperatures can be measured with contact thermometers or - without contact and more conveniently - with infrared laser thermometers. Especially when using the latter, it is recommended to perform comparative measurements on the same material; for surfaces with widely varying reflection characteristics, relevant emission angles need to be considered and adjusted for.

At first, nondestructive building moisture measurements can be carried out with a radio frequency sensor; suspect areas can then be measured with surface and/or penetration electrodes via the electrical conductivity on the surface or at various depths. Conductivity measurements often provide values as wood moisture equivalent or device-specific digits. Possible errors of the latter type of measurements include salt deposits on building materials or metals or other electrically conductive layers, building materials and surface treatments. It can be helpful to measure air humidity inside materials at newly drilled holes into which the humidity probe is inserted and sealed to the indoor air.

Testing of Drinking and Tap Water or Food

For culturing and counting on culture media. With petri dishes, dip slides, contact slides, microbial indicators, paddles...

Regarding water samples (drinking water, municipal water, water filters, water stirrers, water carbonators, water treatment devices, water storage..., fountains and decorative fountains...), bacteria are the prime suspects, sometimes molds and yeasts, as well. For a first comparison, it is sufficient to insert dip slides or paddles into the liquid and then to culture the sample (preferably at two temperatures: room temperature 20 °C to 25 °C and body temperature 37 °C), to count them and, if useful or desirable, to identify the species at a specialist microbiology laboratory.

If a microbial contamination such as a biofilm is suspected in the plumbing system of a building, it is useful to collect several samples at various points of use and at different times to narrow down the problem area(s) and to compare these levels to those in the municipal water as a reference.

For a more detailed water analysis, the requirements of the drinking water regulation need to be considered (disinfect faucets with a flame, pour plate method...).

With food, it is mostly about yeasts (vegetables, fruit, dairy products, sausages, cheese, cold cuts, pickled food..., especially raw and from open bars, also juicers, blenders, sprouting devices, yogurt makers, kitchen waste, compost...), sometimes also about molds (teas, nuts, grains, grain mills...). For exploratory purposes, food can be placed in direct contact with suitable culture media (petri dish, Rodac plates, paddles) or wiped with swabs to be cultured and assessed.

The microbial count is given as per milliliter of water (/mL), per area of a solid sample (e.g. /cm²) or as count per culture media (/agar).

4 **DUST MITES** and other Allergens

Measurement and identification of **mite count** and **feces**, **pollen**, **animal hair**, **allergens** (/m³, /g, %)

Measurement of concentration levels in dust (microgram per gram, µ/g), on surfaces (per square meter, /m²) or in the indoor air (nanogram per cubic meter, ng/m³) with pretests, microscope and sampling with laboratory analysis

Pretests: For mite allergens, there are on-site tests available (Allergen Control, Acarex-Test e.g. from a pharmacy) with which it is possible to roughly estimate the concentration level of a mite-specific metabolite (guanine) or mite allergens on surfaces or in house dust due to a change in color on a test strip. Well suited for first impressions with a measurement sensitivity of about 100 mites or 2 µg of allergens per gram of dust.

Microscopy analysis: During the analysis of house dust, mites can be counted under the microscope (100 mites per gram of dust is regarded as a guidance threshold level regarding hygiene). Pollen are collected with a Burkard trap and counted under an optical microscope; particulate or slit air samplers with coated slides can also be used (see also at C).

Dust sampling with laboratory analysis: House dust can be collected as described at B3 and analyzed quite accurately for the concentration levels of various allergens (mites, cats…) by determining antibody titers with the help of ELISA (enzyme-linked immunosorbent assay). Testing results are provided as a mass-based concentration level in e.g. microgram per gram (µg/g).

Air sampling with laboratory analysis: With the sampling pump of an allergen collection system several hundred to several thousand liters of air are pulled through a filter or microtiter strip, and this sample is then analyzed via ELISA at an analytical laboratory.testing results are provided as a volume-based concentration level in nanogram per cubic meter (ng/m³).

The multipart Building Biology Standard including the Guideline Values for Sleeping Areas was developed by Baubiologie Maes at the request and with the support of the Institute of Building Biology + Sustainability IBN between 1987 and 1992. Colleagues and medical doctors contributed to this work. The Standard was first published in May 1992. Since 1999 the Standard, Guideline Values, Testing Conditions and Guiding Principles have been further developed by the ten-member SBM Standard Committee of experienced building biology professionals with the support of independent scientists from physics, chemistry, biology and architecture including experts from analytical laboratories, environmental medicine specialists and others.

The development, design, update, finalization and improvement... of the Building Biology Standard, Guidelines Values and Testing Conditions was carried out until 2019 under the leadership of Wolfgang Maes. First and foremost, the partners of Baubiologie Maes Dr. Dipl.-Biol. Manfred Mierau and Dr. Dipl.-Chem. Thomas Haumann were involved in providing technical support and advice and then also the members of the current SBM Standard Committee: Christian Blank, Dipl.-Ing. Joachim Gertenbach, Dr. Dipl.-Chem. Thomas Haumann, Bernd Kinze, Dipl.-Ing. Friedbert Lohner, Dr. Dipl.-Biol. Manfred Mierau, Karlheinz Müller, Johannes Schmidt, Peter Sierck and Stephan Streil. Over the years, other colleagues were also involved in providing technical support and advice, namely Dipl.-Ing. Peter Danell, Dipl.-Ing. Norbert Honisch, Dipl.-Med. Frank Mehlis, Dipl.-Ing. Helmut Merkel, Dipl.-Ing. Jürgen Muck, Uwe Münzenberg, Dipl.-Chem. Jörg Thumulla, Rupert Schneider, Arch. Winfried Schneider and Dr. Dipl.-Ing. Martin Virnich.

The first draft of the Building Biology Testing Conditions, Instructions and Additions was presented at the Building Biology Testing Workshop at Fulda-Loheland in April 2010; the second draft at the Building Biology Testing Workshop in December 2011 and the third edition was presented at the basic seminar on Building Biology Testing Methods in October 2012, also at Fulda-Loheland; in the fourth edition, only some details were revised. The fifth edition was presented at the International IBN Congress at Rosenheim in May 2015.

The current SBM-2024 is the 9th edition, which was released in August 2024.

Feedback and suggestions regarding the Standard of Building Biology Testing Methods, Evaluation Guidelines and Testing Conditions by colleagues in the field are always welcome.

Building Biology Standard, Evaluation Guidelines and Testing Conditions were translated from German into English by Katharina Gustavs, Canada.