Supplement to the Standard of Building Biology Testing Methods SBM-2015
and the associated Building Biology Evaluation Guidelines for Sleeping Areas

BUILDING BIOLOGY TESTING CONDITIONS

INSTRUCTIONS AND ADDITIONS

5th Draft 5/2015

In the Building Biology Testing Conditions and Instructions, we flesh out and expand in short form the main criteria for building biology assessments, analyses and testing procedures. Furthermore the instruction manuals of testing equipment, guidelines of professional associations, other standards and the scientific literature should also be consulted.

The below additions primarily apply to the Building Biology Guideline Values for Sleeping Areas; they are meant as additional guidelines, guidance values and assessment tools.

A comprehensive discussion on how to translate all the various categories of the Standard of Building Biology Testing Methods into appropriate testing procedures can be found in the following books: "Stress durch Strom und Strahlung" (Stress from Current and Radiation) by Wolfgang Maes and "Stress durch Schadstoffe und Schimmel" (Stress from Pollutants and Mold) by Dr. Manfred Mierau and Dr. Thomas Haumann. Extensive theoretical and practical training and education programs regarding the Standard of Building Biology Testing Methods, including its Guidelines Values and Testing Conditions, are offered through basic and advanced training courses in Building Biology Testing from the Institut für Baubiologie + Nachhaltigkeit IBN (Institute for Building Biology + Sustainablity IBN) as well as through additional training courses such as the practical workshops offered through the Verband Baubiologie VB (Building Biology Association VB). The Berufsverband Deutscher Baubiologen (Professional Association of German Building Biology Consultants VDB) offers additional guidelines, testing procedures and recommendations for quality assurance.

By applying several testing and analytical methods to a single subcategory, a greater measurement accuracy can be achieved. The methods described herein supplement each other; they do not replace each other but need to be combined, depending on the specifics of a given testing situation.

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 reference to ground potential

  True RMS measurement with body as part of the test setup based on TCO standard 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 potential as a reference (equipotential bonding, receptacle, metal heating and plumbing pipes, ground rod...). Probe is held close to or away from the body (follow manufacturer's specifications). 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 reference to ground potential

  True RMS measurements of the "pure" field without interference from the human body based on DIN/VDE or 26th BImSchV (German Federal Immission 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 conductive object, surface area, cable and furnishing in the field; keep a generous distance or a 2-m minimum distance to testing equipment or fiber-optic cable between probe and 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 hand electrode 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 %; hand-electrode lead wire max. 50 cm.

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

- Dominant **frequency** (Hertz, Hz) and dominant **harmonics**

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

AC electric fields are generated by an alternating electric voltage. The field lines run from a higher to a lower potential, eventually to ground (source field). 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 reference to ground potential has been used in building biology; the field probe is connected to ground with a wire. In the potential-free field strength measurement setup (DIN/VDE), 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 reference to any ground potential. The testing method with reference to ground potential (TCO) includes the presence of a person who attracts the electric fields onto his or her body; thus the human body becomes part of the field setup. The potential-free testing method (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 reference to ground potential - 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; 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 is any suspicion of measurement errors, both methods should be used in combination with body voltage testing. Comparison 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; as a result, wrong measurement results may be generated. This is no problem for the potential-free testing method. The potential-free DIN/VDE testing method 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 reference to ground potential. Use caution with the TCO testing method when in the vicinity of grounded surface areas 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 conductive materials and persons within the field and surrounding area; a distance of several meters are required. With an optimal probe alignment toward the maximum field strength, the one-dimensional TCO measurement is especially well suited for tracking down and locating field sources ("emission testing"). The three-dimensional DIN/VDE testing method is independent of direction, and therefore, very well suited for capturing the sum total of all field sources at a single point ("exposure testing"). The 1-D testing method with reference to ground potential according to TCO is often simple(r) and fast(er); the testing equipment is (more) affordable. The potential-free 3-D testing 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 the case of body voltage testing, a potential difference is measured 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, which 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, body voltage testing will show incorrect or no readings even though the person is still exposed to electric fields; sometimes, even more though than without contact to ground. Dubious sale representatives of earthing sheets frequently like to use and abuse these inexcusable measurement errors to demonstrate 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, that is the whole number multiples of the fundamental frequency, are an important aspect of the biological 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 harmonic components. Living organisms, organs and cells, they all have different "frequency windows" with increased levels of sensitivity.

Harmonics occur to a much lesser degree in resistive loads (incandescent lamp, electric range, hair dryer...) as well as in high-voltage power lines, traction current, conventional transformers... than in devices with plenty of electronics (CFL, electronic power supply unit, ballast, charger, dimmer, computer, visual display terminal, induction cooktop...). 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, the railroad operates at 16.7 Hz.

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

Measurement and data logging of low frequency magnetic **flux density** from power grid or railroad system as well as identification of dominant **frequency** and dominant **harmonics**

- **Flux density** (nanotesla, nT) of line current and traction current

  True RMS 3-D measurement of the sum total of all field line directions based on TCO standard 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 line current (50 Hz) and traction current (16.7 Hz) separately. 1-D measurement for direction finding of the field source by establishing the direction of the main field line. Coil size depends on testing objective: large induction coils according to TCO or DIN/VDE (with diameters of 10 cm and larger) show lower testing 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. railroad).

- **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, railroads, transformers, street lighting...), night storage heating and net currents is always done during nighttime, especially on workdays; if elevated exposures are suspected, for 24 hours or longer. For inhomogeneous fields in small areas, possibly use several data loggers simultaneously. While data logging the fields of external sources, pay attention to switching off or keeping sufficient distance to in-home sources. Do not move data logger at any time during the entire period of recording.

- Dominant **frequency** (Hertz, Hz) and dominant **harmonics**

  With LF spectrum analyzer, oscilloscope, frequency counter, voltmeter, field meter...: minimum frequency range 10 Hz - 100 kHz (preferably up to 400 kHz and higher).

AC magnetic fields are generated by alternating electric currents. The field lines form closed loops, without beginning or end (eddy current field). 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, respectively, 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, orthogonally arranged coils (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. If there are several magnetic field sources with a mixed field line pattern, you would have to take three separate measurements displaced by 90° with the 1-D coil whose squared results are added together then: $\sqrt{(x^2+y^2+z^2)}$. 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, electric conduits with live wiring), for which 1-D measurements are sufficient. In other cases, which occur less often, mixtures of field line patterns are present (e.g. transformers, devices, several sources...), for which measurements with a 3-D probe are more accurate. 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, 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 intense field fluctuations (e.g. high short-term peaks), the 95th percentile of the data logging records, especially those from nighttime logging, 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 therefore, can result in considerable magnetic field exposures. For net currents inside the house, possibly supplement measurement with direct readings and long-term data logging of the current-carrying sources with e.g. clamp-on ammeter, current clamp or current transformer. For net currents from external sources, possibly perform simultaneous measurements with several data loggers inside the house and near the magnetic field source.

For identifying the spatial distribution of magnetic field levels such as around high-voltage transmission lines, railroad 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 high-voltage power lines, traction current, transformers...than in devices with plenty of electronics. In Europe, the typical line frequency is 50 Hz (USA 60 Hz), many electronic devices operate at higher frequencies or mixtures of frequencies. In Germany the railroad operates at 16.7 Hz, in other countries also at 50 Hz or on direct current. Sometimes the field strength of a harmonic can be higher than its fundamental frequency, e.g. at substations.

Besides the intensity of the field, its frequency as well as the prevalence and type of harmonics are also important aspects of a biological 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 harmonic components. Living organisms, organs and cells... display specific "frequency windows" with increasing levels of sensitivity.

Regarding the frequency of extremely low frequency fields and their harmonics, also see Subcategory A1 "AC Electric Fields."

3 RADIO-FREQUENCY RADIATION (High Frequency, Electromagnetic Waves)

Measurement of radio-frequency electromagnetic **power density** with identification of dominant **frequencies** or RF **sources** as well as 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 currently 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.

  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, UMTS, TETRA, LTE, WiMAX, WLAN, DECT, broadcasting, television, microwave relay, radar, ham radio, wireless 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 currently 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. Building biology guideline values apply to individual RF sources, but not radar.

- Dominant **RF sources** and extremely low frequency **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, that is, wireless applications. 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 extremely low frequency 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) and evaluate them critically.

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 extremely low frequency electromagnetic 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, all spaces to be tested (especially sleeping areas) and directions are scanned isotropically, i.e. in all three dimensions, and checked for the various polarization planes by rotating the antenna, recording the peak values (Peak Hold). Depending on the situation, this type of testing should take at least one minute or at least as long until the meter display shows no more increase.

With the spectrum analyzer, the standard testing procedure for e.g. GSM cell phone networks is as follows: Measurement of constantly active control channel (BCCH, broadcast control channel) with Max Hold, while waving the antenna and adding up power density levels. This result is approximately equal to the minimum occupancy of the base station during nighttime when cell phones are used the least. To establish the power density level for the maximum occupancy of a base station during daytime when, for example, many cell phone calls are sent on the traffic channels (TCH, traffic channel), you can either do a rough calculation by multiplying the measurement value of the control channel by the factor 2-4 (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 relay...) are evaluated separately based on the Building Biology Guideline Values.

In the testing report, the measurement results for the time of testing are given as measured minimum value and as measured or calculated maximum value.

Not all transmitters transmit at all times and if so, not constantly at the same level. Therefore, it may be necessary to perform long-term observations or data logging, respectively. Some broadcasting transmitters or military facilities, for example, may only transmit at certain times; some public agencies and industry facilities or ham radio operators may only transmit when needed. Sometimes DECT cordless phones and Wi-Fi 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 do 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-intensive, 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 the broadband or modulation meter.

Similar to the subcategories 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 biological 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 increased levels of sensitivity. Experience to date has shown that extremely low frequency 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** as well as **discharge time**

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

  Measurement of electrostatically charged surfaces with reference to ground potential.

  With 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: Measurement at 2 to 10 cm distance to material or screen surface (possibly with spacer). One to two seconds prior to testing, cause the material to become charged through simple rubbing (e.g. with the back of one's 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.

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

  Measurement of atmospheric electricity with reference to ground potential.

  With 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 are the result of electric charges on isolating materials (plastics, synthetic materials, rubber...), unshielded screens and through direct currents (overhead streetcar power line, air purification devices...). They change the natural air electricity and other indoor air climate parameters (air ionization, dust levels...). The weather exerts a powerful influence over 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 of the interactions and issues described at "AC Electric Fields" (A1) also apply here. The surface potential is measured at suspect materials (carpeting, curtain, bedding, objects, 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 be able to compare measurement results, relative air humidity should be between 40 % and 60 % and the surfaces to be measured should 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.

  Materials and screens recommended in building biology hardly ever build up any charges, and if so, they do discharge within seconds. Critical materials become heavily charged 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, respectively.

  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 in 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 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...), long-term data logging for at least 24 hours, certainly over one night, should be performed. Put the field meter in a magnetically neutral place. Do not move 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: Without shaking, move compass slowly and straight in one direction across an area (bed...), 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 geomagnetic field hits the compass needle along the north-south axis, the needle will hardly move, but it would move in a big way if the latter field lines ran perpendicular to the compass' axis.

Technical static magnetic fields are produced as a result of ferromagnetic metals (steel in buildings, furniture, furnishings...) or direct current (street-car, photovoltaics...). Naturally occurring static magnetic fields are the result of the earth's magnetic field along whose field lines a compass needle aligns itself 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.

Magnetostatic measurements are about the magnitude and direction of magnetic fields of technical origin; reference is the undisturbed, uniform geo-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, isotropically; 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; the one-dimensionally measured value 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 for 3-D measurements only perform flux density calculations 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 spots; though, they are well suited for all other applications.

The 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. Its needle can be deflected by external magnetic fields. An electronic flux gate compass, e.g. used on sailboats, is similar to 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, the readings are taken where people actually spend time such as in bed.

Magnetic fields caused by metals can vary greatly across a given area: small areas with extremely high intensities changing every few centimeters (steep gradient) such as above innerspring mattresses in close proximity to the body, or large areas with moderate intensities across several decimeters or meters (shallow 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, and consequently, causes no field exposure. In photovoltaic systems, magnetic fields fluctuate depending on the solar exposure, i.e. no magnetic field exposure at night. Therefore: long-term data logging.

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/minutes, cps/cpm - nanosievert per hour, nSv/h)

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

  With dose rate meters (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, it is recommended to take 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 the evaluation, the higher reading is used. Additional measurements at walls, floors, corners... assist in finding the source and formulating remediation strategies. Most of the affordable detectors are usually not suitable for determining smaller differences in the background radiation level of around 100 nSv/h. Nonetheless, with instruments meeting the above requirements, 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 taken into account. Due to this challenge, it is recommended to prefer comparison measurements.

At the common background radiation level of around 100 nSv/h, the null effect, e.g. 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 really relevant because of its high disintegration rate.

For building biology assessments, we refer to the gamma disintegration rates based on natural radionuclides (Ra-226, Th-232 and K-40). In case of the 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, the 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 to electrical pulses. Comparison measurements are especially well suited for building biology evaluations. 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. It is recommended to report all measured reference values. It is especially important to determine the local dose rate or equivalent dose rate of gamma radiation.

Besides gamma radiation, beta radiation should also be considered. In building biology surveys, 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 the decay radionuclides in the air, measurements of alpha radiation via particle samples can be useful.

When measuring radioactivity in buildings, note that there are often different types of 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 are any indications of a specific exposure such as radium in a building material, as is often the case with slags, radon measurements should be carried out.

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, provide first indications of a radon issue and allow comparisons. To search for sources, most often the faster, direct-reading instruments with pumps (mass spectrometers) are used. With simple pretest procedures, an acutely 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. With an ion counter, it is possible to measure the increase of small ions in the air, which correlates quite well with radon levels and the number of decay nuclides. With a simple passive activated charcoal device, indoor air radon levels can be quickly checked; an exposure period of up to 3 days is required.

Should such a measurement of up to 3 days reveal a radon level above a certain guideline value, the measurement should be repeated or measurements should be taken over longer time periods (in occupied spaces possibly under simple remediation conditions, that is, with increased ventilation).

Overview measurements are best performed with other methods over longer periods of time. For the reliable assessment of the annual mean value, it is best to use measurements based on 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 the house via 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, a first assessment of an estimated annual mean value can be made. Prior to any comprehensive and expensive remediation efforts, it is recommended to use longer evaluation periods, e.g. simultaneous and repeated measurements.

Compliance measurements to determine if a certain guideline or action level issued by e.g. EU, WHO, UBA, BfS... has been exceeded usually use nuclear track detectors for an exposure duration of 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 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 body. According to statistical estimates, 2000 additional lung cancer deaths in Germany are attributed to

radon in indoor air. There is no threshold level below which no risk exists.

Radon problems in a house are often due to elevated concentrations in the soil, leaks between soil and house, building materials and furnishings with elevated radon concentrations and poor indoor ventilation. Radon is found especially in older homes with humid basements because radon is readily soluble 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 considerably higher due to the 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 concentration levels 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 mountain range, Thuringian Forest, Erzgebirge mountain range, southern Black Forest, Vogtland, Sauerland, Saarland and northern as well as eastern Schleswig-Holstein).

Mean radon levels between soil gas and indoor air measurements correlate quite well. While at 1-m soil depth radon levels predominantly range from ca. 10 000 to more than 600 000 Bq/m³, indoor levels are lower by a factor of ca. 1000. Even at soil gas radon levels below 10 000 Bq/m³, radon levels inside a house whose design favors radon entry may already be elevated.

The rather short-lived thoron (radon Rn-220 from the thorium series) plays hardly any role in building biology testing. However, indoor air problems can be caused by unsealed building materials with high concentrations of radionuclides. Thoron cannot be captured with measurements based on activated charcoal. Instead, the decay products (Pb212, Po-212) are measured in indoor air. Because of its intense alpha decay from its decay chain products, thoron must also be assessed rather critically. Thoron can be released into indoor air from granite (e.g. as flooring) if its radiation level is elevated. With their radioactive decay products, thoron-containing building materials, slags and thick clay plasters (> 1 m²/m³) in combination with low mean air exchange rates (< 0.5) can have a major impact on the annual dose in indoor environments.

Buildings with higher 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 the house. Certain furnishings and objects such as tiles, glazing or antiques with highly elevated levels of radioactivity can also contribute to highly elevated levels of radon in 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 the house - 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 house due to the many technical distortions.

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

  With 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 the measurement result - especially inside the house - or even make measurements impossible.

  Terrestrial radiation is everywhere. And everywhere the geomagnetic field, as well as radioactive radiation is emitted from the earth. The compass needle demonstrates the magnetic force of the earth and the Geiger counter shows its gamma radiation. There are many more physical 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 can be measured: 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 are the result of e.g. 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.

  To differentiate between magnetic fields of geological and technical origin, the positioning of the probe must be changed; magnetometer measurements should be carried out at different heights. If the unusual readings only occur close to the ground but not higher up, this indicates a technical or building-related source in contrast to a geological source.

  Technical fields decrease quickly with increasing distance to the source; 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. 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 preferably more) 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 distance from e.g. suspect buildings, road surfaces or recently fertilized lawns.

  Currently available 3-D magnetometers that only perform flux density calculations 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 the 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-born Sound)

Measurement of **noise**, **sound**, **infrasound** and **ultrasound** as well as **oscillations** and **vibrations**

Supplement to the Building Biology Guideline Values - Recommendations, guidance and assessment tools:

Sound			No Anomaly
Sound pressure level in decibel	A-weighting	dBA	< 30
	C-weighting	dBC	< 45

At night, 30 dBA should not be exceeded on an ongoing basis, short peaks of up to 40 dBA could be tolerable. This recommendation applies to sound in the hearing range, but not infrasound or ultrasound. Levels of 30 dBA can already disturb the sleep of sensitive people.

The difference between dBA and dBC measurements should not exceed 15 dB; otherwise, this may be an indication of sound exposure in the very low frequency range and additional measurements should be carried out, especially in the infrasound range.

0-10 dBA hearing threshold, breathing, rustling leaves / 10-20 peaceful sleep, whispering, wind / 20-30 library, dripping faucet, clock ticking, rain / 30-40 quiet living space, quiet conversation, "room noise level" / 40-50 lively household noise, excited conversation, radio, TV / 50-60 office, noisy conversation, door slamming, stress threshold / 60-70 daytime noise, traffic noise, shouting, noisy music / 70-80 vacuum cleaner, kitchen appliance, high traffic noise / 80-90 industrial noise, noisy railroad traffic, church bells / 90-100 jackhammer, power drill, table saw, vehicle horn / 100-110 disco, rock concert, aircraft noise, car racing, shooting / 110-120 low-flying aircrafts, aircraft runway, siren, explosion / 130 pain threshold, start of aircraft jet at 50 m / 140 rifle shot next to ear, jet engine at 10 m / 160 toy pistol next to ear, risk of ruptured eardrums / up to 250 dBA military sonar (below water).

German Technical Instructions on Noise Abatement (TA Lärm): Inside buildings at daytime 35 dBA and at nighttime 25 dBA, short-term peaks must not be more than 10 dB above threshold levels. Traffic noise: close to roads and railroad lines in residential areas on average at daytime 59 dBA and at nighttime 49 dBA, in mixed areas 64 dBA or 54 dBA, respectively. This applies to new or reconstructed roads and railroad lines only, not to existing ones. Office Workplace VDI 2058: for mostly mental activities on average at the most 55 dBA. German Federal Institute for Occupational Safety and Health (BAuA): At workplaces requiring high level of concentration (VDT work...) 35-45 dBA, optimal 30 dBA. German Federal Immission Ordinance: Noise from lawn mowing and other noisy appliances limited between 8 p.m. and 7 a.m.

- **Airborne sound** (acoustic sound waves, infrasound, ultrasound)

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

  Either with reasonably priced sound level meters 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 more expensive meters of Class 1 according to IEC 61672: frequency range 5 to 20 000 Hz (also down to the infrasound range); measurement range 20 to 140 dB in various increments; time response fast, slow and peak (C), possibly impact 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. Indicators are another option, that is, devices that can make high frequency sounds from, for example, bats or insects audible (bat detectors or bat receivers). Various technologies transform the ultrasound signal into the human hearing range; as a result, ultrasound can by assessed by audio analysis. Typically, the frequencies range from 16 to 100 kHz, sometimes up to 200 kHz. Volume, frequency and bandwidth controls available; outputs for headphones, tapes, data loggers or spectrum analyzers are integrated.

  Note: In case of intermittent or greatly fluctuating acoustic sound wave events, long-term data logging should be carried out so that frequency distributions and percentile statistics can be determined. In sleeping areas, measurements should be carried out during the night for at least 8 hours from around 11 p.m. to 7 a.m.

- **Structure-born 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 - as for 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 20 000 Hz, 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 in the form of third octave levels (Real Time Analyzer) or in high resolution as FFT (Fast Fourier Transformation, 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 (that is, in events per second). This time it is not about electromagnetic waves (that is, energy particles or waves), but it is about the movement of material particles in air, in liquids or solid objects such as building materials. These particles exert - in the true sense of the word - pressure, resulting in minimal changes in density. Any type of changes in density in air, water or another medium is sound in the widest sense: acoustic sound waves when the human ear can hear them, infrasound and ultrasound when the sound waves are below or above the human perception threshold.

  Sound waves propagate at a lower speed than electromagnetic waves: in air at 343 meters per second (m/s), that is, 1235 kilometers per hour (km/h), faster than a wide-body aircraft, 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 refer to lower and higher frequency sound events below 20 Hz and above 20 kHz, which cannot be directly heard by the ear, but which many humans can still perceive - often as an unpleasant, disturbing sensation - or may even make a person sick. Noise refers to an unwanted, disturbing or hazardous sound. Vibrations are about perceptible, mostly disturbing to tormenting mechanical oscillations, which can also go hand in hand with airborne or structure-borne sound, especially infrasound.

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

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

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. The frequency spectrum of light immediately follows the radio-frequency spectrum, which reaches up to 300 GHz (conventionally referred to as microwaves). The invisible infrared light (thermal radiation) starts at 300 GHz, which corresponds to a wavelength of 1 mm, and reaches up to 780 nm. Visible light ranges from 780 nm to 380 nm and thus from the colors red via orange, yellow and green to blue and violet. Ultraviolet light (UV) is again invisible, which ranges from 380 nm to 10 nm. When white light strikes a prism, it is separated into its different wavelengths as the colors of the rainbow.

Supplement to the Building Biology Guideline Values - Recommendations, guidance and assessment tools:

Light, Lighting		No Anomaly
AC electric field in volt per meter	V/m	Up to 2 kHz < 10 From 2 kHz < 1
AC magnetic field in nanotesla	nT	Up to 2 kHz < 50 From 2 kHz < 5
Light spectrum, spectral distribution in nanometer	nm	Similar to daylight, homogeneous, smooth transitions, no discrete spikes
Illumination level in lux		Day ~ 100 - 100.000, Evening ~ 10 - 100, Night < 1
Color temperature in kelvin	K	Day ~ 4000 - 6000, Evening ~ 1500 - 3000
Ultrasound in decibel	dB	None

Light, Lighting		No Anomaly	Slight Anomaly	Severe Anomaly	Extreme Anomaly
Light flicker in percent	%	< 2	2 - 10	10 - 50	> 50
		No light modulation for data transmission			
Color rendering index in R_a or CRI	Ra	> 90	80 - 90	60 - 80	< 60

No toxins or odors. No toxic ingredients such as mercury. Ecological manufacturing and disposal.

Measurements of AC electric and magnetic fields based on TCO (30 cm distance).

Recommendations apply in particular to the evening hours prior to going to sleep 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.

- **Electrosmog** - AC electric and magnetic fields (ELF/VLF)

  Electric field strength (volt per meter, V/m) - See also subcategory A1.

  True RMS measurement with reference to ground based on TCO standard for IT equipment, divided into ELF (up to 2 kHz) and VLF (up to 2 kHz) electric fields.

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

  Magnetic flux density (nanotesla, nT) - See also subcategory A2.

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

  With 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).

  Radio-frequency electromagnetic fields are not expected from lighting sources; if emitted, broadband RF meters and/or spectrum analyzers for frequencies above TCO frequency bands should be used.

  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: 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 < 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 < 5 / 0, CFL up to 80 / up to 80, LEDs up to 20 / up to 4. Testing on commonly available lamps with E27 base done by *BAUBIOLOGIE MAES* for Öko-Test and other consumer protection magazines.

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

  Measurement of low frequency (up to 2 kHz) and high frequency (from 2 kHz) maximum, real flicker percentage of entire light based on CIE specifications (International Commission on Illumination).

  With 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 about 400 nm to 700 nm, possibly also infrared. 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 light) and disharmonious light flicker (CFLs, some LEDs…).

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

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

Light 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: power for lighting systems supplied by direct current.

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

- **Light spectrum** and **spectral power distribution** (nanometer, nm)

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

  With light spectrometer. For selective spectral bands including infrared and UV, also use 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 across all visible light bands to infrared without large spikes in the blue band, preferably more red light. Incandescent and halogen lamps meet these criteria and some LEDs. Discrete, narrow, steep color spikes such as in compact fluorescent lamps are undesirable.

  Examples: Incandescent and halogen light is balanced with smooth transitions across all color bands, no color spikes, similar to sunlight to infrared. 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 light, others more chaotic spectrum, even though most have smooth transitions between color bands, but frequently too much blue light, the important color red or infrared is missing.

- **Color rendering index** (CRI, Ra value, R_a / R_{1-14})

  Measurement of color rendering index (Ra value or CRI, Color Rendering Index) of a light source.

  With 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, certainly above 90.

  Note: If instead of the 8 test colors all 14 test colors according to the DIN standard are checked, most test results would be much worse: for compact fluorescent lamps and LEDs by about 10 %, for incandescent and halogen lamps by very little, if at all. Color rendering measured 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 light 98-99, halogen light 95-98, LED 40-95, (compact) fluorescent light 40-85, mercury-vapor lamp 40-60, sodium-vapor lamp 20-40.

- **Color temperature**, **light temperature** (kelvin, K)

  Measurement of color or light temperature of a lamp.

  With 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 is essential for the regulation of 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 large amounts of red light.

  Examples: candle, fire 1500 K, incandescent, halogen lamp 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 ~ 8000 K, deep blue noon sky 9000 K, "blue hour" 10 000-12 000 K.

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

  Measurement of illumination level on an illuminated surface area.

  With 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 und serotonin are the major hormones regulated by this rhythm.

  The higher the exposure to light, 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 (1 meter) 1 lx, night of full moon 0.2-1 lx.

- **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 ultrasound frequencies, which most people can not hear at all or well directly, but react to anyway.

B INDOOR TOXINS, POLLUTANTS, INDOOR CLIMATE

To be able to reliably investigate and evaluate chemical and other indoor climate parameters in indoor environments, usually a combination of testing methods are needed that specifically build upon each other and are well integrated. In addition to the analysis of acute indoor air exposures caused by pollutants via air, dust, surface or material concentrations, the assessment focuses on identifying the sources of indoor toxins.

Inspection and **interview**

Take history of building and occupants, visual inspection, general and olfactory impressions (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 regarding floor, wall and ceiling structures, the usage of accessory spaces and suites, usage and ventilation habits, typical weaknesses associated with building year and type of structure: e.g. PAH- and PCB-containing tar-based adhesives underneath the parquet flooring in older buildings, formaldehyde and wood preservatives e.g. in manufactured homes from the 70s or indoor spaces whose wood paneling or other treatments are suspect.

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 photo-ionization detection (PID). Sensitive instruments can often display low total solvent concentrations and thus often allow the identification of emission source(s).

This type of investigation can be useful in addition to pretests or more involved sample taking with laboratory analyses; it can be quickly used in different rooms or suspect furniture. In cracks, gaps, cavities and on surfaces comparative measurements can be easily and directly carried out on site. Moreover, suspect materials can be checked, for example, directly on suspect surfaces (carpeting, flooring structure...) while being sealed off or in a test container.

For pesticides and other semivolatile compounds, there are no reliable quick tests available, only for pentachlorophenol (Bio-Check-PCP).

If first quick measurements show pollutant levels close to or above a guideline level (SBM, UBA, WHO, AGÖF) that should be tested more accurately, the compliance or the extent of noncompliance of the guideline value should be determined with an appropriate sample including a professional laboratory analysis (for evaluation measurements, see below).

Sampling with **laboratory analysis**

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

These more detailed and more 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. More details can be found at the corresponding subcategory below. Samples are taken and sent to an analytical laboratory, which specializes in the analysis of indoor toxins. Sample medium, sample sizes and sampling conditions as well as testing parameters must be coordinated with the laboratory. Especially for air sampling, the following testing conditions must be taken into account when collecting samples.

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 space should not be ventilated for a minimum of 6 to 8 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 as well as in surrounding spaces. Samples are best collected at normal and preferably stable indoor temperatures (18°C to 24°C during the assessment/sample collecting as well as 24 hours beforehand). Mechanical ventilation, air-conditioning or filter systems should also be turned off 6 to 8 hours beforehand. In the spaces to be tested, preferably very few or no person at all should be present prior to and during sampling.

In the case of exploratory and comparative measurements, testing conditions can be chosen deliberately, but they must be taken into consideration 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 air and other combustion gases

Measurement of concentrations in indoor air, test chamber (microgram per cubic meter, µ/m³ respectively parts per million, ppm) or in material (mg/kg)... with direct-reading instruments, pretest procedures and samples for 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 (~ 50 µg/m³). The accuracy and diagnostic power of these tests should not be overestimated; these are simple, quick and comparative pretests to set the course, e.g. for more accurate laboratory analyses or to narrow down emission sources.

Direct-reading instruments: Measurement of formaldehyde with direct-reading instruments such as formaldehyde meter or PID. Sensitivity about 0.1 ppm, preferably lower. The digital display shows the degree of formaldehyde exposure. This is about fast and comparison pretests, to set the course, e.g. for needing detailed laboratory analyses or to trace such results to the source or to narrow down sources. For critical and detailed indoor air quality testing, these instruments are often not sensitive enough, but are rather 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. In this case, 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 B2). The test results are given as volume-based concentration level in microgram per cubic meter (µg/m³). Measurements according to the SBM correspond to corrected values (calculated for 23 °C and 45 % relative air humidity analog VDI Guideline 4300).

Flow rate 0.5-1.5 liters per minute and total volume of about 30 liters for DNPH (see also VDI 3484 Sheet 3), 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 match the real living conditions in a building, and the air change rate should be set at 0.5/h or less; the results are given as a test chamber concentration in µg/m³ or the mass-based material concentration 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 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 for laboratory analysis

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

Direct-reading instruments: On-site measurements with direct-reading, sensitive photo-ionization detectors (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. As a result, a volume-based concentration level is given corresponding to the TVOC (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. As a testing result, a volume-based, precise concentration level is given for individual substances and the total amount (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 is especially sensitive and can be very helpful, e.g. in the assessment of odor problems and determination of the TVOC concentration level. For odorous aldehydes and ketones, additional DNPH cartridges can be used.

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 Silicagel
A flow rate of 0.5-1.5 liters per minute and a total volume of about 90 liters for activated charcoal and Silicagel.

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 are sent for analysis to a laboratory. The laboratory analysis provides similar levels of sensitivity for the solvents found in 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, it can also be useful in the context of this method to carry out a long-term measurement in addition to the active sampling. The testing results are given as a qualitative individual substance evaluation and an approximate concentration per volume 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 sent for a solvent analysis to an analytical laboratory. For experiments in test chambers, conditions are best adjusted as much as possible to match the real living conditions in a building, and the air change rate should be set at 0.5/h or less; the results are given as a test chamber concentration in µg/m³ or the mass-based material concentration 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, 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 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. In this case, a test strip, similar to a Band-Aid, is applied to a suspect wood surface for 24 hours. After shipping 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. The house dust to be assessed can be sampled through simple vacuuming. The spaces to be assessed should be thoroughly vacuumed 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 is 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 testing results of samples collected by directly vacuuming contaminated materials and surface area 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 a noncontaminated bag of plastic and then sent to the laboratory. The test result is given as a mass-based concentration level in e.g. milligram per kilogram (mg/kg) with detailed descriptions of the 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 bag with an intermediate layer, 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 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), which is about one to a maximum of two millimeters 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. In the case of fabric or leather samples, a postage stamp-sized piece will be sufficient. In the case of carpeting, it is a good idea to gently pick up fluff as to not destroy the material. The samples are packed in an airtight package of aluminum or sealed in a noncontaminated bag of plastic and then sent to the analytical laboratory. The test result is given as a mass-based concentration level in e.g. milligram per kilogram (mg/kg) with detailed descriptions of the individual substances.

Surface sampling with **laboratory analysis**: For assessing materials and identifying secondary contamination, wipe samples are well suited as a nondestructive method. With a clean cotton cloth and some alcohol (most commonly isopropyl alcohol), a defined (a few square centimeters), mostly smooth surface area is thoroughly wiped and then the sample is sent to the analytical laboratory. The test result is given as a concentration level based on the surface area in e.g. microgram per square meter (µg/m²) or microgram per square decimeter (µg/dm²).

Air sampling with **laboratory analysis**: With air sampling pumps, a defined - rather large - volume of indoor air is pulled through sampling media such as PU/polyurethane foam or NIOSH activated charcoal (plasticizers only) to be prepared and analyzed 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 results are given as a volume-based concentration level 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 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 2-cm diameter. A flow rate of 0.5-1.5 liters per minute and a total volume of about 500 liters for NIOSH activated charcoal.

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 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). In some cases, it is good to search for certain oxidation products such as chromium-6 (Cr-6) in material (leather).

Dust sampling with **laboratory analysis**: In building biology assessments, house dust sampling is used to detect metals. The sampling follows the instructions as described at 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 bag with an interlayer, preferably 1 to 2 grams 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 fine particulate matter, fraction: < 200 µm, preferably < 63 µm.

Material sampling with **laboratory analysis**: Sampling on a suspect material surface (wood, leather, paint, slag) or collecting a material sample and then sending it to the analytical laboratory. Samples (2 to 3 grams) are put into jars or packaged in aluminum and then send to the analytical laboratory. The test result is given as a mass-based concentration level in e.g. milligram per kilogram (mg/kg).

Surface sampling with **laboratory analysis**: For assessing materials and identifying secondary contamination (e.g. for mercury), wipe samples are well suited as a nondestructive method. With a clean cotton cloth and some alcohol (most commonly isopropyl alcohol), a defined (a few square centimeters), mostly smooth surface area is thoroughly wiped and then the sample is sent to the analytical laboratory. The test result is given as a concentration level based on the surface area in e.g. 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 B2. Sampling tubes used specifically for mercury analysis are activated charcoal tubes impregnated with iodine. The detection threshold is sufficiently low with 30 ng/m³. Concentration levels are determined through cold vapor AAS. The test result is given as a volume-based concentration level 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 to be contaminated, a corresponding water analysis should be carried out, especially for lead, copper, nickel, cadmium and arsenic. Samples are collected with PE bottles (ca. 50 ml for urine analysis from the pharmacy) and the analysis is performed through ICP-MS. The test result is given as a concentration level 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 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 indoor air (µg/m³ l), in dust (/g), in material (/g) or on surfaces (/cm² with direct-reading instruments and samples for 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 (multi-channel system for particles from 0.3 to 0.5 µm diameter) or condensation particle counter (for smaller particles down to 1 nm), possibly 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 result is given as a concentration level 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. The sampling follows the instructions as described at B3. After having burnt the filter to ashes, the dust sample is analyzed with a scanning electron microscope and energy-dispersive X-ray microanalysis (REM-EDXA) at an analytical laboratory. 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 sampling it is important not to cause any contamination of the surrounding environment (asbestos sampling based on suitable training e.g. according to TRGS 519, use protective gloves and respiratory protection). Material samples (no more than 1 g) are put into airtight containers or glass jars and then sent to the laboratory. The samples are analyzed 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, asbestos fibers and MMMF can be determined on surfaces. Special graphite adhesive stamps are pressed on a horizontal surface that has been dusted 3 to 7 days before samples are collected, and then they are analyzed with a scanning electron microscope via an 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 Sheet 2. Prior to sample collection, also ensure that accumulated dust or hidden fiber accumulations are stirred up to simulate usage. Otherwise, the specifications of VDI Guideline 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 volume 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, and a portion of the filter, after having been burnt to ash, is then analyzed with a scanning electron microscope and energy-dispersive X-ray microanalysis (REM-EDXA) at an analytical laboratory. This analysis differentiates between the number, type, thickness, and length of the 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.

You must follow the "Guideline for the Assessment and Remediation of Loosely Bound Asbestos Products in Buildings - Asbestos Guideline," including its assessment form. The analysis of dust, material and surface samples for asbestos is performed according to VDI Guideline 3866 Sheet 5.

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** as well as **air electricity**, identification of **odors** and **air exchange rate**

Measurement of temperature (°C), humidity (r.h., a.h., %), oxygen (vol.%), carbon dioxide (ppm), pressure (mbar), air movement (m/s), air ions (/cm³), air electricity (V/m)

Humidity and **temperature** of **air** and **materials** - Measurements with thermometers, hygrometers, building moisture meters, IAQ data loggers, modular systems....

Measurements of air temperature and air humidity with thermohygrometers. In situations with condensation problems where the cause(s) is not obvious, long-term data logging of the indoor climate over several days or weeks is necessary. Values are given in degrees Celsius (°C) and percent relative humidity (% r.h.). 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).

In the case of indoor air humidity, both the relative as well as the absolute humidity levels are to be established. For short-term measurements, make sure that the probes are sufficiently acclimated, especially when moving the instruments from the outside to the inside. Probes need to be kept at a sufficient distance to 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 wrong; the problem is rather an excessive amount of available CO2. Therefore, measurements of oxygen are usually not necessary. It is possible to estimate its level via CO2 levels. Exact values are only given by measurements with e.g. detector tubes or direct-reading instruments.

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

Carbon dioxide measurements can provide a good impression of the indoor climate and air exchange rate. The carbon dioxide concentration is also a good indicator of potential exposures 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 levels are given in parts per million (ppm) or volume percent (vol.%).

Air pressure - Measurements with barometers

In the context of building biology assessments, the measurement of air pressure is also important because it is a criterion for the assessment of other

environmental factors (e.g. for the measurement of air pollutants) and because knowing the air pressure level also allows to draw conclusions regarding specific health symptoms typically associated with it. Air pressure is measured with barometers.

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 feature a plotter or data logger function.

Air movement - Measurements with airflow indicator tubes or instruments

For a first impression of air movement within a given space, airflow indicator tubes are well suited. 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 counters

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 exposures. 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 is a result of static electricity and surface potentials; measurements are carried out as described under 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 prior to testing, it is important to slightly rub the material (carpeting, drapes). The neutral ground is used as the reference ground.

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, it can be distinguished as to whether the odor is unpleasant or pleasant or as to whether the odor provides a clear indication of its cause (molds or chemicals?). As needed, measurements can be carried out following the instructions under B1/B2. Search for volatile 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.

Under the leadership of AGÖF, a new guideline for the identification of odors in indoor air has been developed by trained odor inspectors; see also the AGÖF Guideline "Gerüche in Innenräumen - sensorische Bestimmung und Bewertung" (Odors in Indoor Air - Sensory Assessment and Evaluation).

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 changes per hour	/h	> 1	0,5 - 1	0,1 - 0,5	< 0,1
Fresh air supply in cubic meter per hour	m³/h	> 50	25 - 50	5 - 25	< 5

Applies to normal-sized bedroom (~ 20 m² / ~ 50 m³) used by one or up to two persons.

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 is dependent on many factors such as airtightness of the building envelope, outdoor and indoor climate or season, wind and pressure conditions at and within the building, location and dimension of windows, natural ventilation through windows and stack ventilation, as well as mechanical systems (local or central) through fans. In many cases, it is possible to estimate fairly well the actually occurring or potential air exchange rate based on the above-mentioned factors prevalent on site and the occupants' behavior (how often do they ventilate for how long).

Exact data can only be provided by actual measurements. 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 the space volume, the air exchange rate per hour (/h) is determined. Often several measurement points are established in order to be able to document a uniform concentration distribution across a given space.

The new ventilation standard DIN 1946-6 from 2009 also serves as an evaluation tool. In this document, the required minimum air exchange rates are defined for certain sizes of apartments.

In new, modern and airtight buildings, the ventilation standard must be included during planning to ensure the minimum air exchange rate.

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, the combination of different diagnostic methods that take the specifics of each situation into account and the pooling of 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 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 guidance values and empirical values found below:

Mold		No Anomaly	Slight Anomaly	Severe Anomaly	Extreme Anomaly
Mold visible - Extent in square centimeter	cm²	0	0 - 50	50 - 5000	> 5000
Mold visible under microscope - Hyphae, spore-forming organs, spores per square centimeter	/cm²	None	Few	Many	Mass

Critical fungi such as Aspergillus, Stachybotrys... and/or mold growth that reaches deep into materials should be assessed more critically.

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 rooms and the number of individual mold species, which are very different from the species in the 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 indoor air, at least 15 individual substances including sum value.

Water activity of a material	a_w	< 0,65	0,65 - 0,75	0,75 - 0,85	> 0,85
Air humidity, relative on material in percent	% r.h.	< 65	65 - 75	75 - 85	> 85

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

For detailed assessments and data, see "Schimmelpilz-Leitfaden" (Mold Guideline) and "Schimmelpilzsanierungs-Leitfaden" (Mold Remediation Guideline) by Umweltbundesamt (German Federal Environment Agency).

For your convenience, here again is the binding text you find in the Building Biology Evaluation Guidelines SBM-2015 with five relevant additions:

In indoor environments **mold growth** should not be visible to the naked eye or a microscope. Contamination with **mold spores** or **mold metabolites***1 should not exist either. The mold **count** in indoor air, on surfaces, in house dust, in cavities and in materials... should be lower compared to ambient outdoor air or uncontaminated comparison rooms. Mold **types** in indoor spaces should be **very similar** to those outside or in uncontaminated comparison rooms. Particularly **critical** molds*2, e.g. toxigenic or allergenic molds or those thriving at 37 °C body temperature*3, should **not** be detectable or only minimally detectable. Constantly high levels of material moisture or air humidity as well as cool surface temperatures should be avoided because they promote mold growth.

Any **sign**, **suspicion** or indication of a potential microbial problem should be investigated, including: visible mold growth such as discoloration and mold spots, odors typical of microorganisms, moisture-indicating molds*4, construction and moisture damage, problematic construction details, hygiene aspects, excessive exposure from outside*5, old damage, building history, on-site inspection, ill-health symptoms of occupants, results of environmental medicine investigations...

*1 Mold metabolites, e.g. mycotoxins, MVOC, glucans, allergens (proteins)
*2 Especially critical and toxin-forming molds, e.g. Stachybotrys, Aspergillus, Alternaria, certain Chaetomium, Paecilomyces, Penicillium, Trichoderma species
*3 Molds growing at body temperature of 37°C and potentially causing infections, e.g. Aspergillus, certain Absidia, Acremonium, Fusarium, Mucor, Paecilomyces, Rhizopus, Trichoderma species
*4 Moisture-indicating molds, e.g. a) Acremonium, Aspergillus fumigatus, Auroeobasidium pullulans, Chaetomium, Stachybotrys, Trichoderma or yeasts for large amounts of moisture, as well as b) Aspergillus versicolor, A. penicilloides, A. restrictus, Eurotium or Wallemia sebi for slightly increased moisture levels
*5 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...

Subcategories C1 through **C3**: **Molds, yeasts** and **bacteria**

Meaningful assessments of microbial exposures to molds, yeasts and bacteria usually require various diagnostic methods that are tailored to the specific situation and issue; together testing results and findings must 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 subcategories should therefore be met equally 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 impressions (odors). Possibly also use endoscope, magnifying glass, pen microscope, odor detector, warning device, 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...

Culture 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 analyses 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.

In the case of air samples (ideally also for surface samples), a minimum of two different culture media with different media and water conditions should be used per collection area for molds and an additional culture media for bacteria.

The culture temperature usually is at 20 °C to 25 °C (room temperature), for thermotolerant species (e.g. Aspergillius, Candida species) also at 37 °C (body temperature), for thermophilic species (Actinomycetes, Legionella…) 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 are usually sufficient.

Indoor air sampling

Sampling of fungi, mold spores and bacteria from indoor air to assess through culturing and/or microscopy. With 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 as well as to normal samples from reference spaces (this applies to samples taken to be cultured as well as to those for direct microscopy).

As a general rule, spaces 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 testing results.

It should also be considered and reported which activities took place in a given space 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 of time) or (depending on the issue in question deliberately) intensively moving about and stirring up things (i.e. so-called aggressive sampling, especially suitable for control testing after remediation). Especially when testing for bacteria, no person or pets should be in the room to be investigated prior to sample taking.

In the case of ventilation and air-conditioning systems, an air sample should be taken prior and several minutes after it is turned on.

As a sampling place 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, samples can be taken directly in front of suspect areas or air can be sucked 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 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. Air volume to be sampled needs to be appropriate for the testing situation at hand: In general, 50 to100 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 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 anticipated 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 20 to 50 often roughly corresponds to the microbial count per m³ 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 as well as nonculturable-nonviable microbes), use slit samplers specifically suited for the sampling of fungal spores, including the appropriate pump systems, sizes and coated slides. Sampled particulates and fungal fragments are assessed with direct optical microscopy. As a general rule, the sampling air volume is about 100 to 200 liters of air (the lower the microbial count to be anticipated, the lower the volume).

The fungal count is given as spores per cubic meter of air, and additional statements or descriptions (additional findings) can be made (e.g. about other

fungal components 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 slide or foil to be inspected under a microscope, with relevant staining techniques if required. These samples provide quick answers, sometimes even species identifications as well as differentiations, as to whether there are only spore deposits or actual fungal hyphae or fruiting bodies and also as to whether these are secondary or primary contaminated surfaces.

Samples on culture media are collected, for example, by using Rodac plates, contact slides or dip slide paddles. The agar surface must for several seconds be placed in firm contact with the surface to be sampled. This type of sampling is useful for the assessment of secondary contamination in the case of mold damage, for an overview of not visibly contaminated surfaces, for control testing after fine cleaning as part of mold remediation or for control testing of the general hygiene status.

For a first comparison, a sterile moist swab can also scan or be rolled over a defined surface area (e.g. 1 dm²), and it is then rolled 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, that is, 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). In the case of swab samples, only semiquantitative counts or 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 on a regular basis 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.

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

Preventive material examination of e.g. building materials (insulation materials, clay plaster...) or finishes (wall finishes...) is useful to prevent a microbial risk prior to installation. Especially wall finishes can - even though rarely - be contaminated with bacteria and must not be applied.

In the case of culture media, fungal and bacterial counts are given as colony forming units per gram (CFU/g); in the case of a 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 objective), 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 contamination of mold or the mold contamination itself. Again, pay attention to additional findings: skin scales, hair, particulates, mites, allergens, mineral fibers...

To collect 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 as well as specialist laboratory analyses.

Concentrations of volatile chemical-organic compounds given off by microorganisms are identified by sampling indoor air through activated charcoal or Tenax tubes followed by a chromatographic and spectroscopic analysis at a laboratory. Preferably consult 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 analyses should be performed in close consultation with the analytical laboratory because errors can easily occur when working in such a highly sensitive range or close to the detection level due to inappropriate testing conditions, sample media, sample handling or laboratory preparation. MVOC analyses should not be done on their own but only in combination with additional testing methods. The level of MVOC concentrations is 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....

These types of measurements must be carried out with sufficiently accurate and calibrated thermometers, hygrometers and building moisture meters. The

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

In the case of indoor air humidity, both the relative as well as the absolute humidity levels are to be established. For short-term measurements, make sure that the probes are sufficiently acclimated, especially when moving the instruments from the outside to the inside. Probes need to be kept at a sufficient distance to 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 to then 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 the house, 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 more detailed water analyses, the requirements of the drinking water regulation need to be considered (disinfection of faucets with a flame, pour plate method...).

In the case of 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 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 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 Building Biology Standard with its Building Biology Evaluation Guidelines for Sleeping Areas and Building Biology Testing Conditions, Instructions and Additions has been developed by *BAUBIOLOGIE MAES* at the request and with the support of the Institut für Baubiologie + Nachhaltigkeit IBN (Institute of Building Biology + Sustainability IBN) between 1987 and 1992. Colleagues and medical doctors have also offered their support. It was first published in 1992. Since 1999 experienced building biology professionals with the support of independent scientists from physics, chemistry, biology and architecture, as well as experts from analytical laboratories, environmental health care professionals and other experts have helped shape the Building Biology Standard, Evaluation Guidelines and Testing Conditions. This current SBM-2015 is the eighth update, which was released in May 2015.

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Feedback and suggestions regarding the Building Biology Standard, the 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.