Indoor Relative Humidity in Residential Buildings – A Necessary Boundary Condition to Assess the Moisture Performance of Building Envelope Systems

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1. Introduction

Indoor humidity in residential buildings is a recurrent topic of building physics. Even in buildings with high-quality insulation excessive indoor humidity conditions may occur because the occupants produce too much moisture which is not compensated by adequate ventilation. Such behaviour may lead to moisture problems like condensation or mould growth on external walls. This is, however, the exception, which must be avoided for reasons of hygiene. Therefore the hygrothermal design of the building envelope should be oriented to the normal case providing an adequate safety margin, if necessary. This contribution summarizes the findings concerning indoor relative humidity, and specifications, which are partly derived from standards or guidelines for the hygrothermal design of building components.

2. Series of Investigations in Living Spaces

In the context of a study to assess the influence of the building envelope on the indoor climate [1] the transient temperature and relative humidity conditions were continuously measured (in 10-minute cycles) in several houses of different types of construction in the area around Rosenheim (Southern Germany) in the period from 2002 to 2005. To clarify the variety of investigated flats and the scope of prevalent hygrothermal conditions, the living room of a single-family house (building 1: masonry of 36.5 cm, year of construction: 1981) with a tiled stove (typical type of local heating in the rural areas of Upper Bavaria) and the eat-in kitchen of a dormitory (building 3: concrete structural skeleton construction with insulation, year of construction: 1980) with central heating were selected.

Fig. 1 shows the 10-minute-cycle values of temperature and relative humidity measured in building 1 and the running monthly mean value (thick red or dark blue line) over a period of $2^1/_2$ years. Due to the periodic firing of the tiled stove in combination with the relatively low thermal insulation of the building extreme daily temperature fluctuations occur of up to 10 K during the heating period. The large temperature differences, however, do not have the expected consequences on indoor relative humidity. It remains comparatively stable with day-time maximum amplitudes of approx. 10 % of r. h. A temperature difference around 10 K without any additional influences should result in a difference in indoor relative humidity of 50% r. h. This is not the case and the reason is the humidity-buffering effect of the enclosure surfaces and furniture. They absorb water vapour, if indoor relative humidity increases and release it, if indoor relative humidity decreases. The result is the damping of fluctuations in air humidity in dependence of the water vapour sorptivity and permeability (humidity-buffering capacity) of the materials in contact with indoor air. Besides bookshelves and a carpet the living room also has an untreated wooden floor with high humidity-buffering capacity [2]. The mean indoor air temperature (thick lines in Fig. 1) in the winter amounts to almost 20°C. The mean relative humidity is between 30% and 40% in winter and between 50% and 60% in summer.

The measurement results for the eat-in kitchen of the dormitory (building 3) are shown in Fig. 2. Temperature fluctuations in winter are much lower in comparison to building 1 due to the central heating. Therefore, thermal variations cannot cause the high fluctuations of indoor air humidity. Since the humidity-buffering capacity of the enclosure surfaces (PVC flooring, plasterboards) is rather low, changes in moisture generation for example by cooking are clearly noticeable. It is, however, obvious that ventilation is sufficient, as the mean relative humidity measured in the eat-in kitchen of building 3 over a period of 30 days tends to be low in comparison to the living room of building 1. Although the two living spaces show considerable differences in utilisation, heating system and building envelope, mean humidity during the entire period of investigation was very similar.

If we summarize the findings for all 10 investigated houses in the surroundings of Rosenheim [1] and the results of similar investigations in 10 other residential buildings in the surroundings of Holzkirchen in 1996 [3], we can make the following statement for this region near the Alps: During the winter months, the mean value of indoor relative humidity is usually clearly lower than 40 %. During the summer months, the highest values for mean indoor air humidity amount to approx. 60 %. This result can obviously be transferred to other regions in Germany, as is proved by publications of investigations in more than 400 flats in Hamburg and Erfurt (reproduced in Fig. 3) in [4].

3. Influencing Factors of Indoor Air Humidity

Neglecting the air exchange with adjacent rooms according to [5] the humidity balance of a living space can be defined as follows:

$$V \cdot \frac{dc_i}{d\tau} = \sum_j A_j \, \dot{g}_{w\,j} + n \cdot V\left(c_a - c_i\right) + \dot{W}_{IFQ} + \dot{W}_{RLT} \qquad (1)$$

with:

V [m^3]	room volume
A_j [m^2]	enclosure surfaces
c_i [kg/m^3]	water vapour concentration (absolute humidity) of indoor air
c_a [kg/m^3]	water vapour concentration (absolute humidity) of outdoor air
$\dot{g}_{w\,j}$ [kg/(m²h)]	humidity exchange between building envelope and indoor air
n [1/h]	air exchange (exchange of indoor air by outdoor air)

$\dot{W}_{IFQ}$ [kg/h] indoor humidity generation by internal moisture sources

$\dot{W}_{RLT}$ [kg/h] moisture supply or removal by ventilation and air conditioning systems

The steady-state humidity exchange by enclosure surfaces, i.e. diffusion of water vapour through walls, ceilings and floors, is negligible in comparison to natural air exchange. The situation is quite different with regard to the transient humidity exchange by sorption in the vicinity of surfaces. This effect, which is also described as humidity-buffering effect, is only significant during short-term (day-time) humidity variations by damping them. The intensity of this damping effect is primarily dependent on the water vapour sorption and diffusion properties of the indoor surface materials. Building component layers at a distance of more than 10 mm below the surfaces can be neglected, as they are not reached by daily fluctuations of indoor relative humidity [6, 7], i.e. they are only influenced by the mean indoor relative humidity. Therefore, only the daily or monthly mean values of indoor relative humidity are relevant to assess the moisture control performance of building envelope systems.

Thus, humidity exchange with enclosure surfaces is disregarded here for any further considerations. Since ventilation and air conditioning systems, which humidify or dry indoor air, are rather the exception in German living spaces, also the last term in equation (1) remains unconsidered for the time being. The result for quasi steady-state conditions (i.e. indoor humidity generation and air exchange are based on daily or better monthly mean values) is the following simple relation

$$c_i = c_a + \dot{W}_{IFQ}/(n \cdot V) = c_a + \Delta c \qquad (2)$$

where the ratio of moisture generation and air exchange Δc is also described as moisture load. If air exchange rate and mean moisture generation are known, indoor relative humidity can be determined by means of in-situ climate conditions.

3.1 Humidity Generation and Air Exchange in Flats

As concerns the size of moisture generation in flats, the results of various investigations were summarized within the framework of the IEA Project Annex 14 [8], whereby the result for the daily amount of moisture generation in dependence of the household size is listed in Table 1. The same specifications can be found in the ASHRAE standard for the hygrothermal design of buildings [9], where in case of more than 5 persons 1 kg/d is added for any additional person. Moreover, in case of more than 2 persons it is assumed that any person has a sleeping room of their own.

Since moisture generation must be related to the volume of the living space to calculate indoor relative humidity according to equation (2), several persons in a room do not mean a simultaneous deterioration of humidity conditions. Based on the average per capita living space of 62 m² in the U.S., the result for households of 2 or 3 persons (ceiling height 2.5 m) is a mean moisture generation rate of approx. 1.0 g/m³h. For German conditions with a per capita living space between 38 m² and 46 m² the result would be 1.4 to 1.8 g/m³h. According to recent investigations in [10], however, a daily moisture generation of 12 kg in a household of 3 persons is a very high level. There, the measured values for a model flat of 3 persons range between 5.6 and 7.8 kg dependent on whether or not laundry is dried in the flat. Based on these values, the result for German conditions is a mean moisture generation rate in living spaces of approx. 1.0 g/m³h.

The result for an average moisture load in living spaces is 2.0 g/m³ based on the minimum air exchange for the heating period according to DIN 4108 [11] of 0.5 h^{-1} and according to equation (2). Now, the water vapour concentration of the outdoor air remains to be determined, to obtain the mean indoor relative humidity during the heating period. This can be done on the basis of locally representative meteorological data on temperature and relative humidity. These data are available for example as hourly mean values in the German test reference years [12]. Temperature and humidity values comply with the long-term monthly mean values in the respective regions. They are listed in Fig. 4 for all climatic regions in the old German federal states (analogue data for the new German federal states were not yet available at the time of evaluation). The bars show the regional fluctuation range and the circles monthly values averaged by all datasets. The mean annual value for temperature and humidity can be approximated by a sine function. Thus, the mean temperature for Germany amounts to 9°C with a seasonal fluctuation range of the same size (± 9 K) and a relative humidity of 80% ± 8%.

The guideline of the International Association for Science and Technology of Building Maintenance and Monument Preservation (WTA) 6-2 [13] contains the same boundary conditions for the outdoor climate. By means of equation (2) an indoor relative humidity of 6.3 g/m³ can be calculated for example for January (outdoors: 4.3 g/m³) at a moisture load of 2.0 g/m³. At a temperature of 20°C this is equivalent to a relative humidity of approx. 35%. This value is almost equal to the mean value for indoor relative humidity measured in January in 1996 in approx. 400 investigated flats in Hamburg and Erfurt (see Fig. 3). Consequently, assumptions turn out to be realistic. But they correspond only to mean conditions and do not show the possible range.

If for example a flat is not adequately ventilated, infiltration air exchange occurs due to leakage in the building envelope instead of the hygienic minimum air exchange. In modern buildings it amounts to less than 0.2 h^{-1}. As a result, the moisture load could increase up to 6 g/m³. As Fig. 5 shows the consequence would be an indoor relative humidity of almost 60% in winter and in summer mould growth could occur to a large extent under these conditions (indoor relative humidity > 90% r. h.). Therefore, the operation of a residential building cannot be performed without additional ventilation by means of opening the windows or installing mechanical ventilation and air conditioning systems.

Whereas ventilation and air conditioning systems can be adjusted to secure a minimum air exchange rate, it is not so easy to control ventilation by opening the windows. Investigations on window opening times in low-energy and passive houses in [14, 15] showed that occupants clearly tend to open the windows more frequently at higher temperatures than at temperatures around the freezing point. One of the most comprehensive studies on window ventilation in 67 flats in [16] classifies the users according to their behaviour concerning window ventilation in three categories (low ventilation, normal ventilation, frequent ventilation). Fig. 6 represents findings, which clearly show an increase in window opening times at higher outdoor temperatures. This applies to all user categories. Even at temperatures below 0°C windows are opened although only for short periods. This means, the real air exchange in flats is usually clearly higher under conditions in winter than the pure infiltration air exchange.

It can be assumed that humidity produced by human activities, e.g. cooking or taking a shower, is not influenced by weather conditions. Therefore adequate ventilation to control indoor humidity is as important in winter as in summer. But the lower vapour concentration difference between the indoor and the outdoor air in summer must be taken into consideration, which can only be compensated by a higher air exchange. According to several analyses of ventilation behaviour and indoor air conditions in Germany this is obviously achieved by means of longer and more frequent window opening periods at higher outdoor temperatures.

3.2 Moisture Load in Homes, Dependent on Outdoor Temperature

The assumption of a constant air change independent of the season is inadequate to solve equation (2). A functional relation of air exchange and outdoor air temperature must be found instead. The air exchange rate cannot be quantified by means of window opening periods alone, as the location and dimensions of the windows and the investigated space as well as the pressure conditions at the building due to incident wind flow or buoyancy forces are significant influencing parameters. Therefore, a more practical solution would be to determine indoor the moisture load in a direct way and not in the indirect way by means of air exchange. Investigations of this kind, where the differences between water vapour pressures or water vapour concentrations were determined between indoor and outdoor air and related to the outdoor temperature were performed and analyzed within the framework of the IEA Project Annex 24 [17] for flats in Belgium, Great Britain and Italy.

Exemplary investigations of the German conditions were performed in ten homes in the surroundings of the meteorological station of the Holzkirchen outdoor testing site of the Fraunhofer Institute for Building Physics (IBP) [18]. Over a period of one year, thermohygrographs were installed in the respective homes, which were calibrated once a month (while exchanging the recording strip) by means of an aspiration psychrometer. Water vapour concentrations in living spaces were determined from the recorded temperatures and humidities and compared with the measured values of the meteorological station. The daily mean values for the moisture load (difference between the indoor and the outdoor water vapour concentration) are represented in Fig. 7 top as an example for one home in dependence of outdoor air temperature. Since the tendency of linear relation between moisture load and outdoor temperature is obvious, the regression line of the individual values is drawn in the same diagram. Fig. 7 bottom gives a summary of analogue regression lines of all investigated homes.

The mean moisture load at an outdoor temperature of 0°C (mean value for the winter months according to Fig. 4) is between 2.0 g/m³ and 4.0 g/m³ for eight out of ten homes. On the basis of a mean humidity generation rate of 1.0 g/m³h (see above), the values for the mean air exchange rate determined in the investigated living spaces lie between 0.25 h^{-1} and 0.5 h^{-1} under winter conditions. As already discussed windows are more frequently opened at rising temperatures and therefore the air exchange rate also increases. This obviously results in an aproximately linear decrease of the moisture load, which falls to almost zero at a temperature of 20°C in summer.

The normal moisture load range are derived from investigations in [18] and represented in green colour in Fig. 8, the validity of which could be confirmed by later investigations [1]. It represents normal conditions in living spaces including the so-called moist areas like kitchen and bathroom. The highest measured value (regression line on top) represents the dark-drawn limit of the normal moisture load range. The lower limit of this range simultaneously represents the upper limit of the range, where a lower moisture load prevails (drawn in light-brown colour in Fig. 8). This range represents living spaces and offices with lower moisture generation or adequate ventilation. The range for high moisture load (drawn in blue in Fig. 8) represents living spaces with unusually high moisture generation or insufficient ventilation. Among these homes are those with high occupancy or additional moisture sources (e.g. humidifiers). Additional moisture sources can also occur shortly after building erection (construction moisture in building materials) or after pipe leaks. An additional moisture source can also be driving rain moisture, which is drying towards the interior in case of inadequate protection of the external walls against rainfall. Since results from living spaces with high moisture load were not available, the upper limit of this range was randomized by adding 50% to the upper limit of the normal moisture load.

By referring the relations between the upper limits of the moisture load ranges and outdoor air temperature, represented in Fig. 8, to the climate conditions in Fig. 4, representative for Germany, the indoor relative humidity (monthly mean value) can be determined in dependence of the moisture load. Under the condition of normal indoor temperatures (20°C in winter and 22°C in summer with sinusoidal interpolation) these results are represented in Fig. 9. The circles represent the mean values for Germany (West) and the bars the maximum range of results for the various climatic regions. Due to the low influence of regional climatic differences the mean indoor relative humidity conditions (straight line) approximated by sine curve in Fig. 9 can be assessed as representative throughout Germany. Thus, minimum values of 30%, 40% and 50% for relative humidity occur in winter, whereas the maximum value in summer is approx. 60 % in all cases due to the moisture load approximating zero at high outdoor air temperatures.

If we compare the indoor relative humidity of Fig. 9 with the results of the comprehensive study of Fig. 3, we find that a low moisture load is prevailing in most homes. As a rule, we are on the safe side to assume normal moisture load (Fig. 9, centre) for envelope moisture control assessments. This fact is due to the classification of moisture load in Fig. 8, which has been set equal to the upper limits of the real life measurements.

4. Specifications of Indoor Relative Humidity in Standards and Guidelines

For moisture control assessments a general differentiation is made between avoiding condensation or mould growth on internal surfaces of external building components and the moisture protection of the construction. For reasons of hygiene, top priority is given to avoid condensation on surfaces and mould growth. A detailed consideration of the hygrothermal behaviour makes only sense, if the construction complies with this condition (minimum thermal insulation). These two aspects will be discussed in the following.

4.1 Avoiding Surface Condensation and Mould Growth

The current version of DIN 4108-2 [11] defines the minimum requirements for thermal insulation of external building components no longer as requirements to avoid condensation but to avoid mould growth on internal surfaces of external building components. This means the relative humidity on these surfaces must not exceed 80%. In contrast to the previous version [19] milder outdoor air conditions (-5 °C instead of -15 °C) are assumed so that the requirements seem to remain almost unchanged at first glance. But these requirements are now valid also for geometric (e.g. room corners) and other thermal bridges (e.g. balcony slabs), which were not considered in previous regulations.

The result is that external walls of existing buildings comply with the old hygienic minimum requirements ($R = 0.55$ m²K/W) but no longer with the new ones ($R = 1.2$ m²K/W). The definition of the new minimum requirements for thermal insulation was based on the indoor air conditions of 50% r. h. and 20°C. By assuming that the new requirements are correct, problems arise for older buildings, which do not comply with these more stringent requirements. As a consequence, mould growth should be frequently observed. However, since the assumed boundary conditions are for most interior spaces way on the safe side problems will occur rather rarely in practice.

This means, the assumption of an indoor relative humidity of 50 % during the heating period is very conservative. In other words, mould growth can also be avoided in constructions with inadequate thermal insulation, if indoor relative humidity is limited by appropriate user behaviour (see [20]). Fig. 10 shows the limits, critical to avoid mould growth, for indoor relative humidity in dependence of outdoor air temperature in buildings with poor and good thermal insulation. In this case, poor thermal insulation refers to buildings, where external building components barely comply with the old minimum requirements for thermal insulation ($R_{min} = 0.55$ m²K/W). It is assumed that in the area of geometric thermal bridges the temperature factor (f_{Rsi}: temperature difference between internal surface and external air divided by the temperature difference between indoor air and outdoor air) is approx. 0.6. In contrast, buildings are rated to have good thermal insulation, if the external building components have a maximum U-value of 0.5 W/m²K ($R = 1.8$ m²K/W) showing a temperature factor in the area of thermal bridges of approximately 0.8. The representation in Fig. 10 clearly shows that the maximum admissible indoor relative humidity to avoid mould growth is extremely dependent on the outdoor temperature. Whereas an indoor relative humidity of 50 % in winter causes no problems in buildings with good thermal insulation, the indoor humidity should be considerably lower (< 40 % r. h.) in homes with poor thermal insulation during the cold season.

With regard to previous considerations this means that normal but not high moisture load is admissible in existing buildings with poor thermal insulation. Generally, this situation can only be improved by applying an additional external thermal insulation.

4.2 Hygrothermal Assessment of the Building Envelope

4.2.1 Boundary Conditions for Dew-point Calculations

In former times, the hygrothermal assessment of building components was mostly limited to vapour diffusion assessments under steady-state conditions in winter, the so-called dew-point method. Other moisture sources such as rain water or construction moisture could not be considered by means of this method and consequently were neglected. The same is true of some relevant material properties, e.g. heat and moisture storage or capillary transport. This causes considerable uncertainties and therefore, by selecting extreme climatic conditions, this calculation method tries to achieve results, which can be used in practice and are on the safe side as far as possible.

This also explains the boundary conditions for living spaces according to DIN 4108-3 [21] consisting of a 60-day condensation and a 90-day evaporation period. Outdoor conditions are assumed to be -10°C / 80% r. h. and indoor conditions 20°C / 50% r. h. during the condensation period. Indoor as well as outdoor conditions are assumed to be 12°C / 70% r. h. during the evaporation period. These boundary conditions are not based on investigations but are exclusively used in the context of dew-point calculations with good success as it turned out in the course of practical application.

For the European dew-point method according to DIN EN ISO 13788 [23] average temperature and humidity conditions (monthly mean values) for the outdoor climate are used for the respective climatic region. To be on the safe side in this case, too, the calculations results must be based on corresponding extreme indoor climate conditions. Fig. 11 shows the moisture load categories proposed in [23]. Classification is analogue to the moisture load areas in Fig. 8, the only difference is that the moisture load below 0°C does no longer increase. Since indoor air humidity is determined from outdoor air conditions and moisture load on the basis of monthly mean values, the difference in moisture load lines below 0 °C has almost no influence on the indoor conditions under German climate.

There is, however, a great difference in classification. Class 3 in [23] for residential buildings with low occupancy corresponds to the high moisture load range in Fig. 8, whereas class 2 for offices and business premises corresponds to the normal moisture load range. This means there is a shift of at least one class. The situation is becoming rather extreme when applying class 4 (residential building with high occupancy). In this case, indoor air humidity amounts to almost 70 % r. h. in winter (outdoor air temperature 0 °C) according to equation (2). Under these conditions the problem of mould growth and condensation at windows occurs even in modern buildings. This kind of extreme indoor boundary conditions is not suitable for hygrothermal building simulation, intended to reproduce real life situations.

4.2.2 Boundary Conditions for Hygrothermal Building Component Simulation

The above-mentioned disadvantages of the dew-point method have been known for a long time. Due to the complexity of hygrothermal simulation models and an initial lack of available hygrothermal material data, the replacement of the dew-point method, however, has been a slow process. In the meantime, hygrothermal simulation of building components is widely used in practice and standards and guidelines have been worked out for their application [13, 24]. Even DIN 4108-3 [21] refers to hygrothermal simulation methods for the hygrothermal assessment of green-roof systems or the calculation of drying out moisture in building materials. Since simulations of this kind are intended to analyze the transient heat and moisture behaviour of the building envelope as realistic as possible, there must be an input of reliable boundary conditions. Thus, for the most part, onsite recorded hourly data or representative meteorological data of the respective location are applied for the outdoor climate.

The WTA guideline 6-2 [13] recommends for the indoor climate the seasonal progressions plotted in Fig. 9. The European Standard EN 15026 [24] contains a more differentiated selection method for indoor climate data. The first choice are data, measured for a similar building in a similar climate or, if a ventilation and air-conditioning system is used the assumed set value. Results from thermal and hygrothermal building simulations, e.g. [5], are considered to be second choice. Since measurement or simulation results for indoor climate are rarely available in practice, the third choice is probably the one that is usually employed. It concerns the assessment according to equation (2) with reference to the purely empirical relation (see also [25]) in Fig. 12. In contrast to Fig. 8 and 11, indoor air humidity instead of moisture load is plotted over the outdoor air temperature in this diagram.

The main reason to introduce these new empirical functions is the possibility of direct reading of indoor air humidity. Implausible results due to the selection of a too high moisture load class can be excluded to a large extent. The indoor air humidity is also clearly defined for outdoor air temperatures of more than 20°C. This is especially important for Southern European climate zones. Below -10°C and over 20°C indoor air the humidity remains constant at a terminal value. For warm regions this implies that the air must be air-conditioned to a certain degree in order to maintain comfortable and healthy indoor climate conditions. It also implies that the air is frequently humidified in very cold regions to avoid static electrical charges, extensive dust and the drying out of mucosa. The disadvantage of the new functions to determine indoor air humidity is certainly the fact that the outdoor air humidity is disregarded, the monthly mean values of which, however, often show relatively minor seasonal fluctuations (± 8% r. h.) in Germany.

The application of empirical relations (Fig. 12) for normal and high occupancy (number of occupants to be expected) in EN 15026 [24] on average climate conditions in Germany (on the basis of monthly mean values of the individual climatic regions, see Fig. 4) results in the seasonal progressions of indoor air humidity as shown in Fig. 13.

Daily mean values of outdoor temperature as a basis to determine indoor air humidity are listed in [24], but the effect of averaging on the simulation results is negligible for Central European conditions according to our own investigations. This only applies, however, to the comparison of daily and monthly mean values as a basis for the functions in Fig. 12 as well as for climatic regions, where the daily mean values of the outdoor air temperature rarely fall below -10°C or rise higher than 20°C. In regions with lower or higher temperatures mean values may vary due to the horizontal progression of the empirical functions in these ranges.

To allow the comparison of the different approaches to determine indoor air humidity, progressions according to the WTA guideline 6-2 [13] are represented in Fig. 13, which were already shown in Fig. 9. Differences are comparatively small for normal moisture load or occupancy. Differences of almost 10 % r. h. occur for indoor air humidity according to EN 15026 and the guideline 6-2 [13] in summer in case of high moisture load or occupancy, whereas patterns in winter are almost identical. The higher values for summer according to EN 15026 appear to be in line with the experience in Southern European countries.

The simplified method to determine indoor air humidity in EN 15026 [24] was integrated with some restrictions in the ASHRAE Standard 160 [9]. Since there are stronger variations in the climate conditions within the individual regions in North America in comparison to Europe (from extremely cold Alaska to subtropical conditions in Florida or tropical conditions in Hawaii), a more precise method is favoured there to determine indoor air humidity including the application of HVAC. This is why the simplified method in [9] indicates only the function for high occupancy as represented in Fig. 12. If a building component fails under these boundary conditions, it is recommended to apply the more precise method to determine indoor air humidity.

5. Summary and Conclusions

The average indoor air humidity in residential buildings clearly shows a seasonal character under the climate conditions in Central Europe. At outdoor air temperatures around the freezing point it normally amounts to approx. 30% r. h.; during the swing seasons it varies between 40% and 50% and can reach 60% r. h. in mid-summer. Effects of the daily fluctuations of humidity due to user activities are limited to the near-surface areas (approx. 10 mm) of the building envelope. Layers of the building envelope components below this level are only influenced by average humidity levels.

Since a result “on the safe side” is intended for the hygrothermal assessment of building components, extreme boundary conditions are employed instead of average indoor climate conditions. While this seems to be justifiable to a certain degree when the steady-state dew-point method is applied to compensate for the intrinsic uncertainties of this method, we must be careful with regard to the hygrothermal building component simulation. Since boundary conditions have various effects on simulation results (e.g. on humidity and temperature-related material parameters), climate conditions should be as realistic as possible in this case.

Supported by new standards and guidelines, hygrothermal building component simulation is increasingly replacing the dew-point method as a hygrothermal assessment tool for building constructions. Adequate boundary conditions are selected accordingly. Indoor air humidity is especially important in this context. Boundary conditions according to the International Association for Science and Technology of Building Maintenance and Monument Preservation (WTA) for a normal moisture load in residential buildings should be applied as a rule. With a relative humidity of 40% in winter and 60% in summer, these conditions for normal living spaces including moist spaces (kitchen, bathroom) are on the safe side in an adequate manner. The boundary conditions for normal occupancy according to the European Standard EN 15026 may serve as an alternative, as they provide similar results.

In contrast to EN 15026 the WTA guideline 6-2 contains the boundary condition for a low moisture load. This is of almost no importance for the hygrothermal design of new buildings, but significant for the design of retrofitting and renovation measures. As concerns for example the rehabilitation of older buildings or buildings listed for preservation, a compromise must frequently be found between the technically desirable and compatible solution for the building itself. Thus, the assumption of a low moisture load on the basis of adequate instruction of the users can be justified.

It seems to be reasonable to assume a high moisture load for buildings, where especially unfavourable indoor air humidity conditions must be supposed. Unfortunately, there are hardly any measured data available for such cases so that it is difficult to decide, whether the respective specifications of the WTA guideline 6-2 or En 15026 are better suited. To make this decision, further investigations are necessary. This is also true for the humidity in buildings with high and changing occupancy, e.g. schools, restaurants or rooms with discontinuous operation, e.g. churches or conference halls. In these cases, hygrothermal building simulation tools could be helpful in future besides measurements.

6. References

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[24] En 15026: Hygrothermal performance of building components and building elements – Assessment of moisture transfer by numerical simulation. April 2007.

[25] Künzel, H.M., Holm, A. & Kaufmann, A.: Raumluftbedingungen für die Feuchteschutzbeurteilung von Wohngebäuden. IBP-Mitteilung 30 (2003), Nr. 427.

Table 1: Data on mean moisture generation in homes according to [8]

size of household	number of persons	moisture production
without children	2	8 kg/d
with one child	3	12 kg/d
with two children	4	14 kg/d
with three and more children	≥ 5	15 kg/d

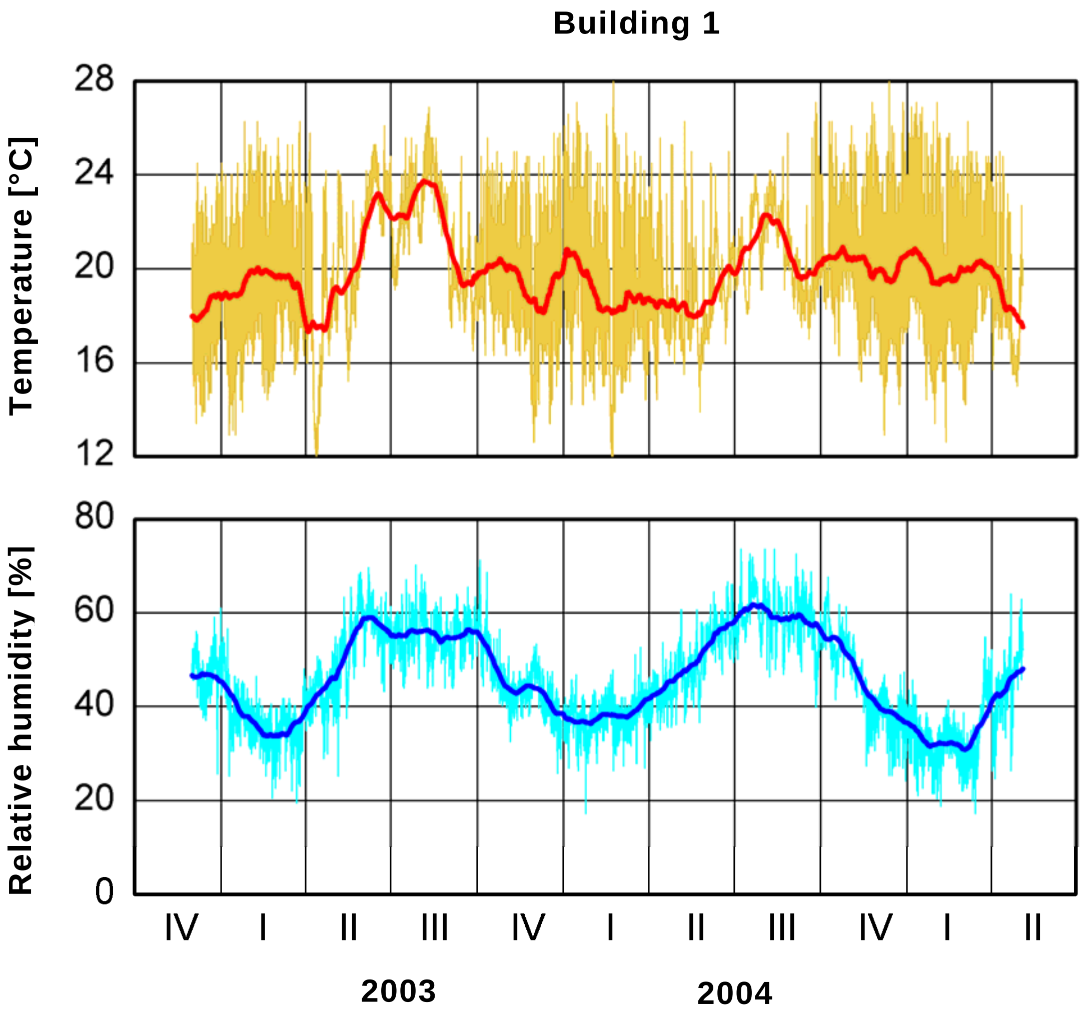

Fig. 1: Measured temperatures and relative humidity in the living room of building 1 (masonry 36.5 cm thick, year of construction 1981, tiled stove), represented in 10-minute values (light, thin lines) and as running monthly mean value (thick, dark lines).

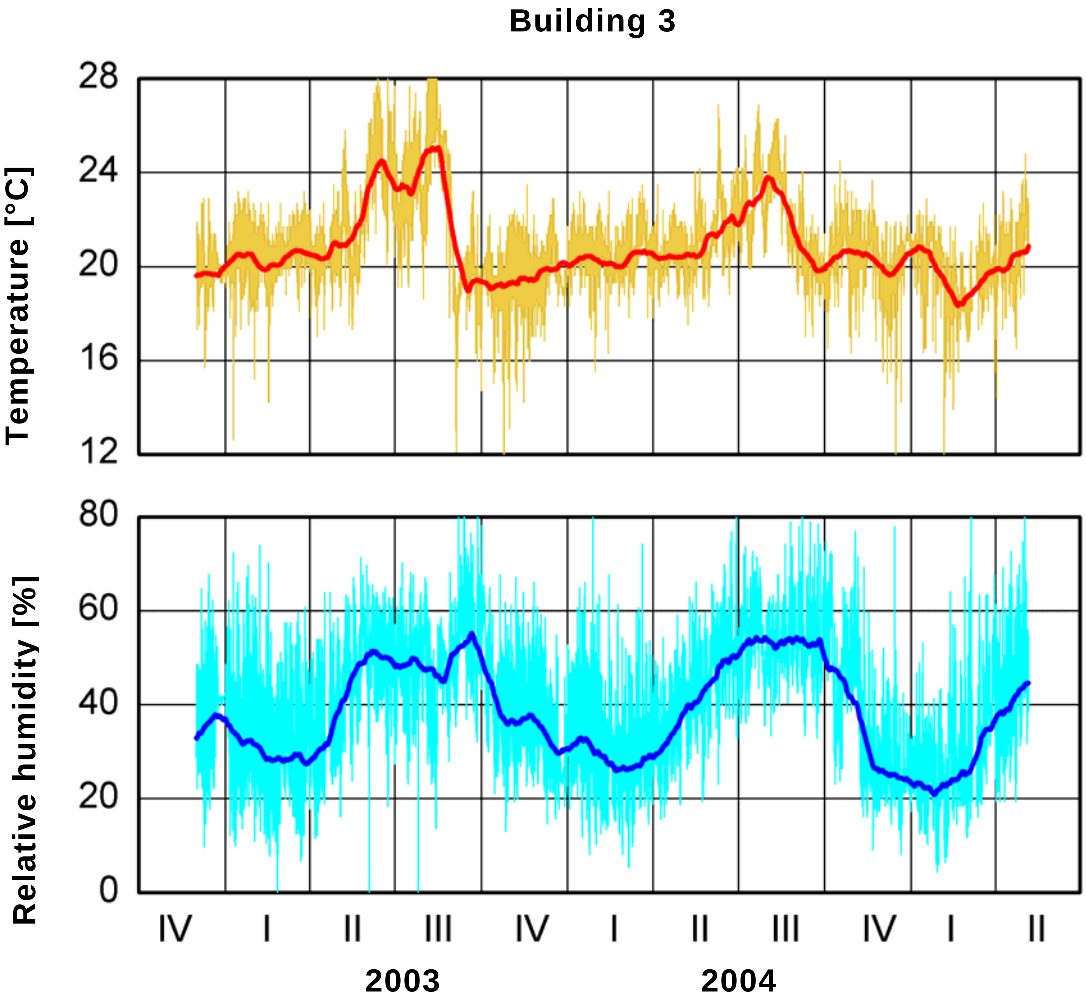

Fig. 2: Measured temperatures and relative humidity in the eat-in kitchen of building 3 (concrete skeleton construction with insulation, year of construction 1980, central heating), represented in 10-minute values (light, thin lines) and as running monthly mean value (thick, dark lines).

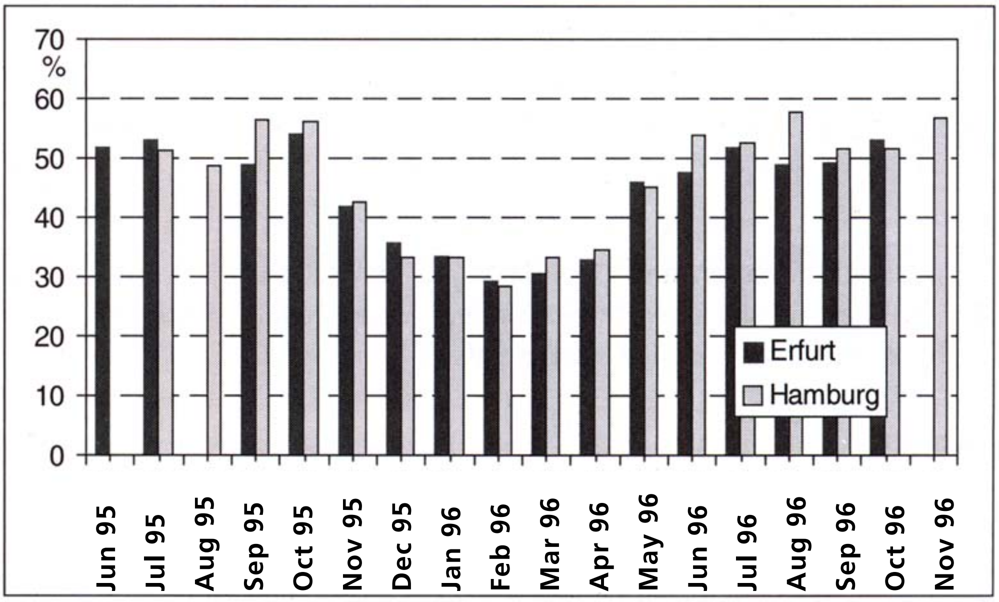

Fig. 3: Average results of relative humidity conditions in living spaces recorded within the context of a case-control study of approx. 200 homes in Hamburg and Erfurt from [4].

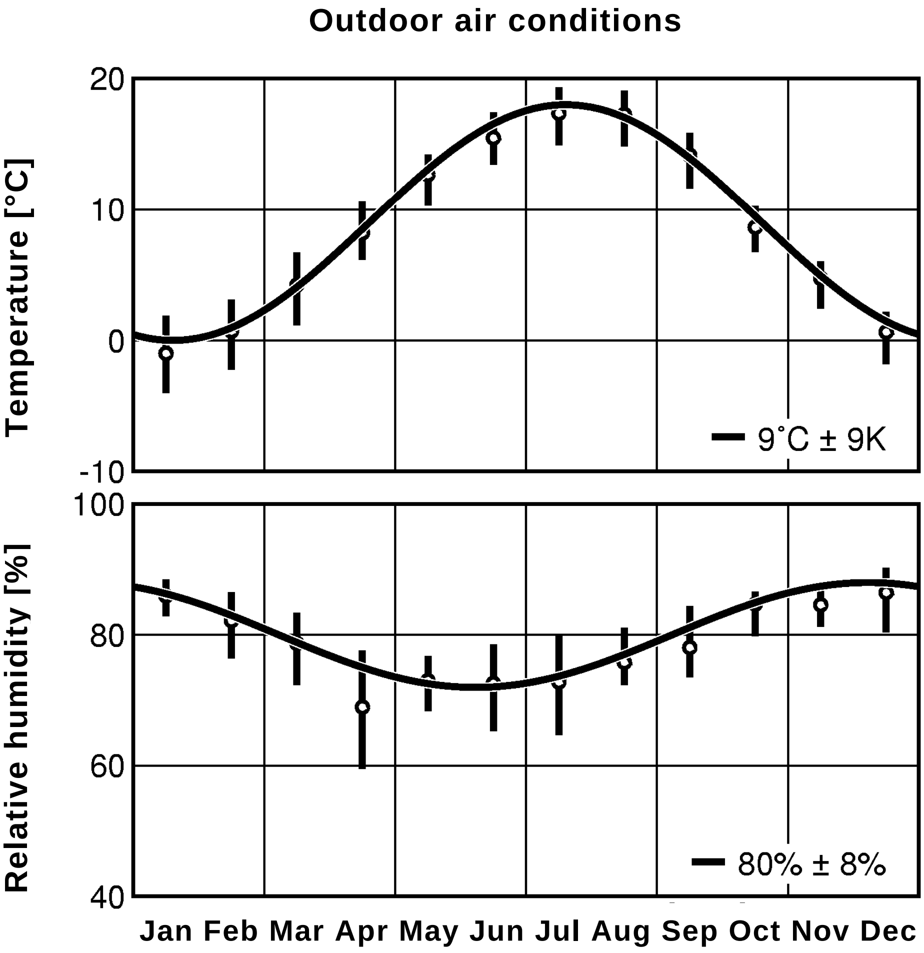

Fig. 4 Ranges of monthly mean values of temperature and relative humidity for various climate regions in Germany and their average values (circles) determined on the basis of test-reference years [12]. The variation of the monthly means can be approximated by the sine functions (continuous line) represented above.

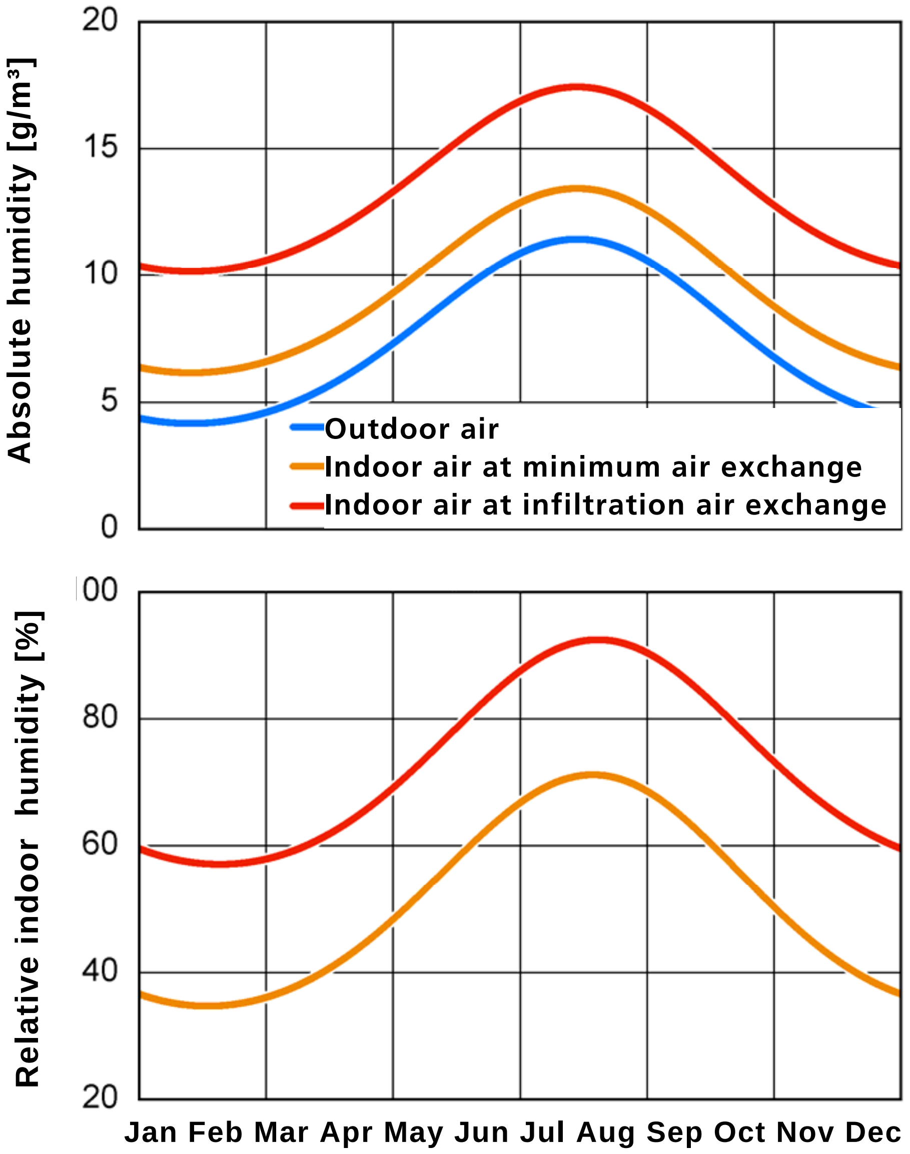

Fig. 5 Absolute (above) and relative (below) humidity values determined from outdoor air conditions represented in Fig. 4 for a residential building (moisture production = 1.0 g/m³h), where the mean value for outdoor air supply either complies with the minimum air exchange of 0.5 h^{-1} (Δc = 2 g/m³) according to [11] for the whole year or is set to the infiltration air exchange ($n < 0.2$ h^{-1}, Δc = 6 g/m³). The indoor air temperature varies between 20 °C in winter and 22 °C in summer according to [13].

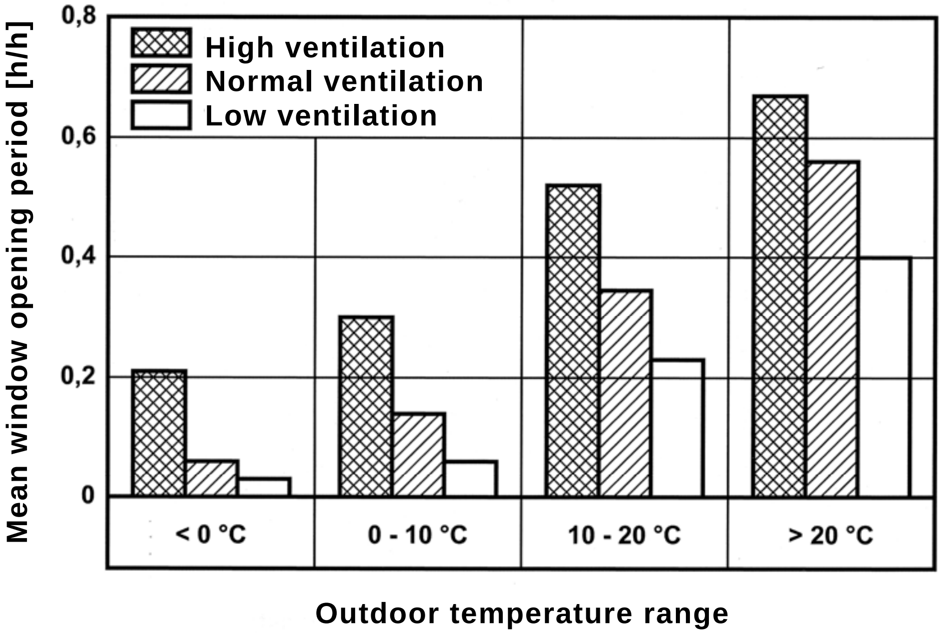

Fig. 6 Mean values for window opening periods as measure for homes without ventilation and air-conditioning system in dependence of the outdoor air temperature range for three user categories from [16]

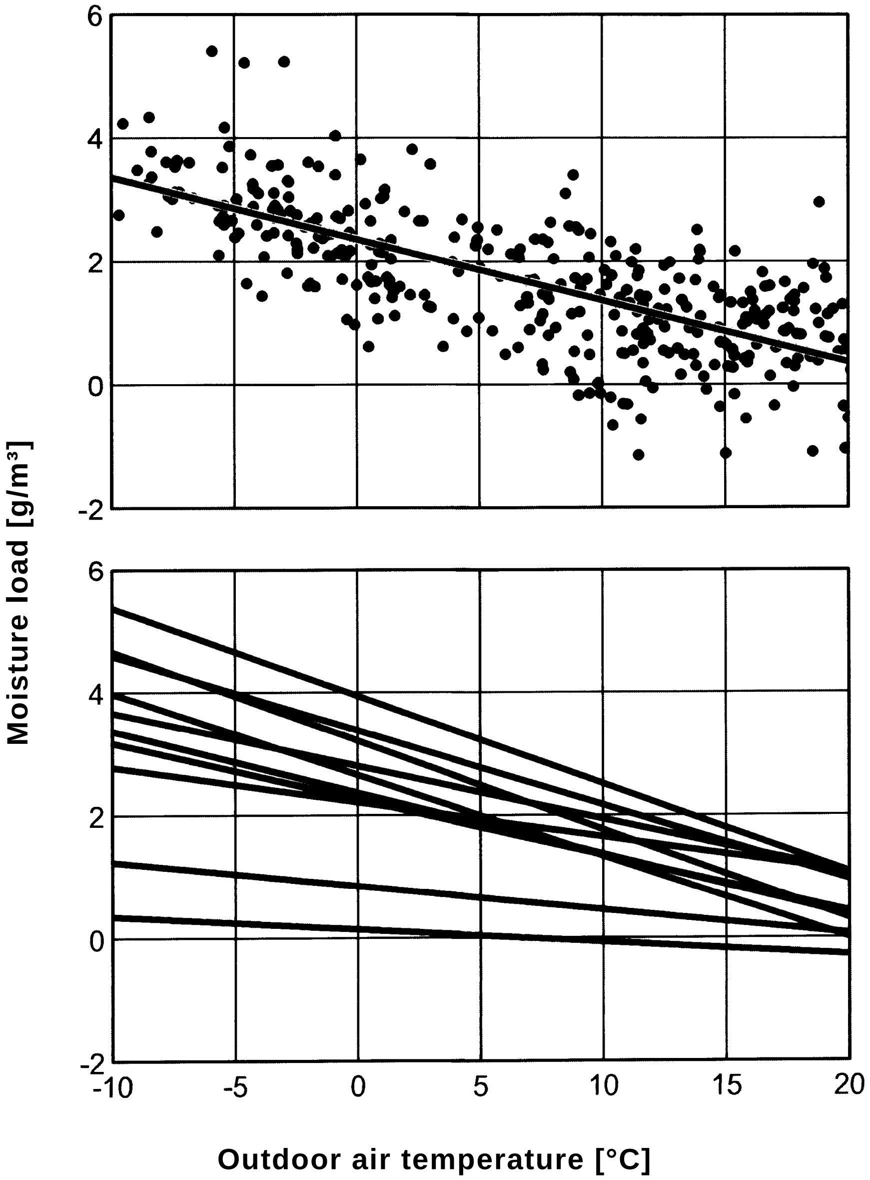

Fig. 7, above: daily mean value of measured moisture load (difference of the indoor and outdoor water vapour concentration) for a living room represented in dependence of outdoor air temperature and evaluation by linear regression.
below: representation of regression lines for all investigated homes.

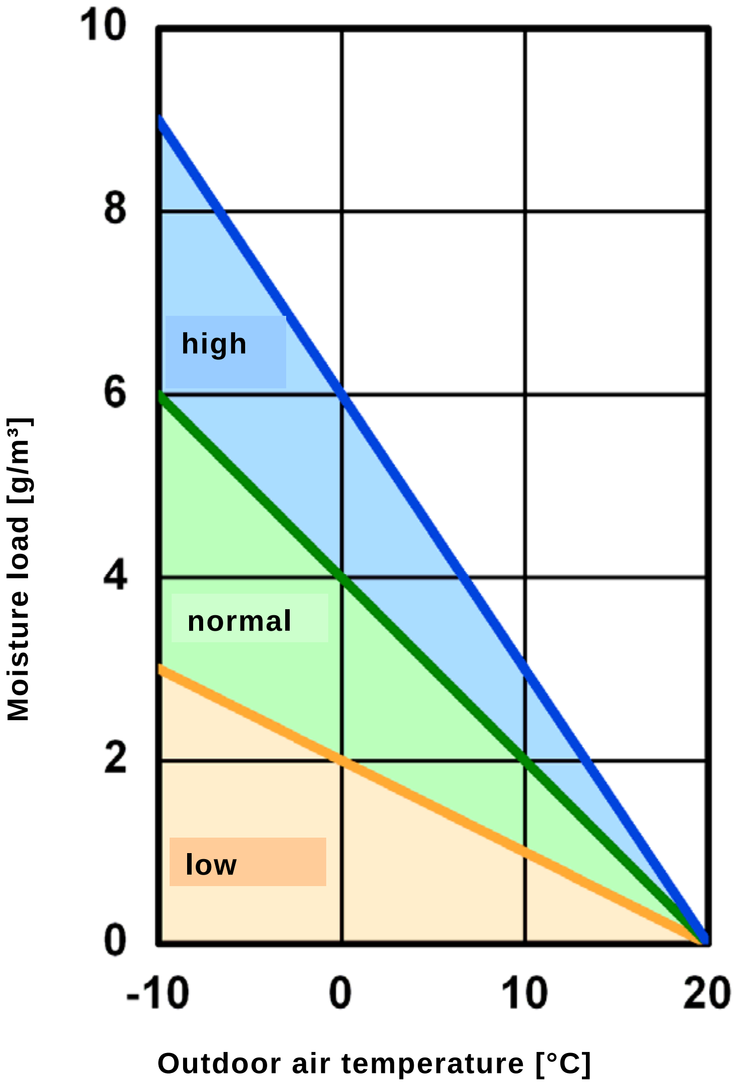

Fig. 8: classification of the moisture load in living spaces in dependence of the outdoor temperature according to [18]

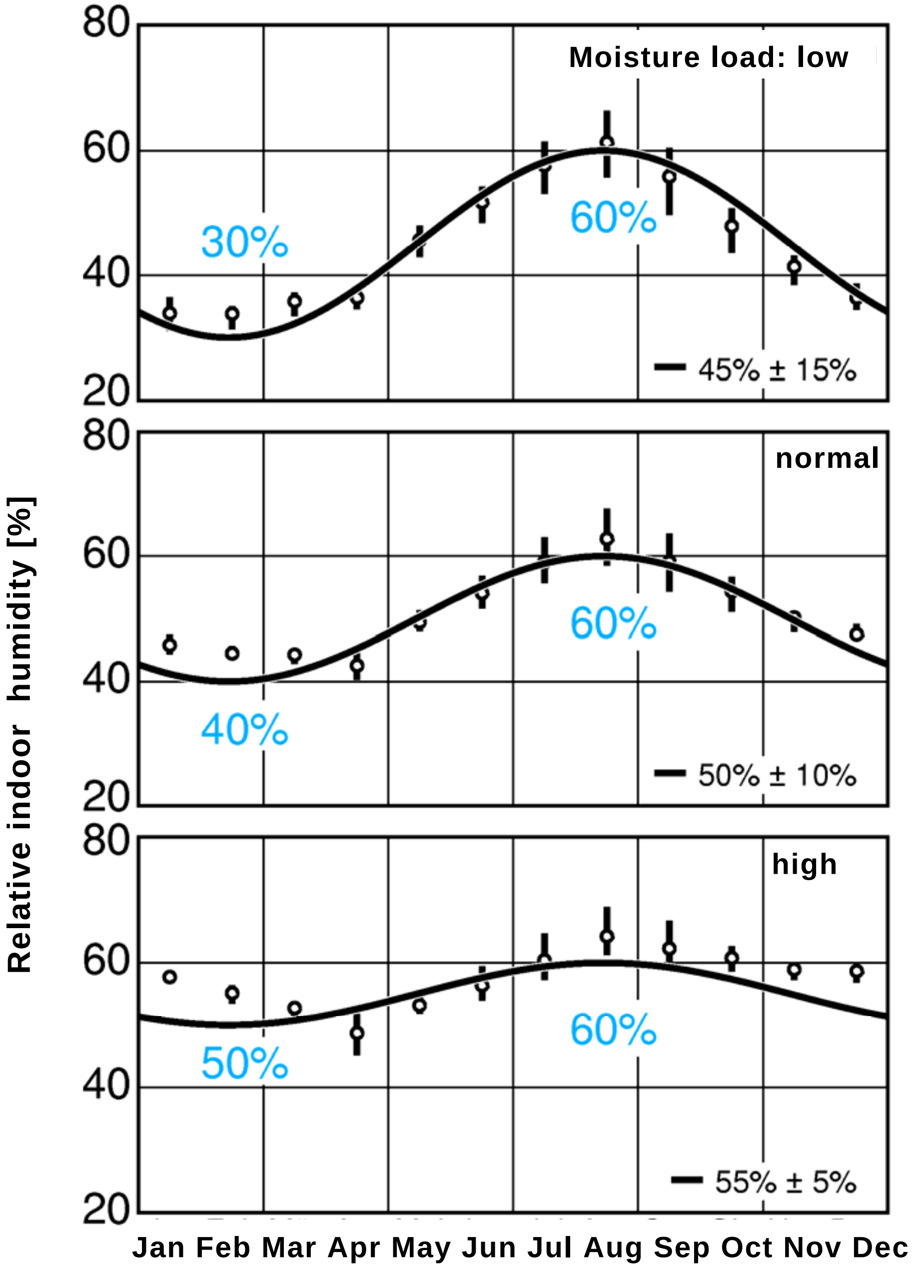

Fig. 9: Indoor humidity (monthly mean values) determined by sinusoidal regression by means of moisture load ranges in Fig. 8 from the German outdoor climate conditions (see Fig. 4) according to equation (2)

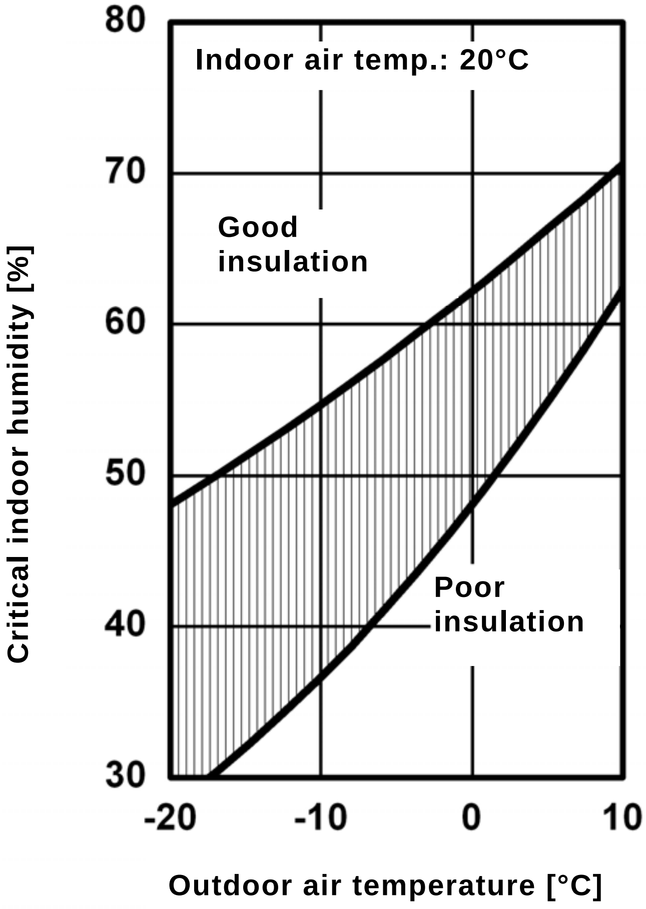

Fig. 10: Critical limit curves for indoor humidity with well insulated (R = 1.8 m²K/W corresponds to a U-value of 0.5 W/m²K) and poorly insulated (R = 0.55 m²K/W, U = 1.4 W/m²K) external walls which should mot exceeded in order to prevent mould growth. Appropriate interpolation must be performed for buildings with intermediate U-values.

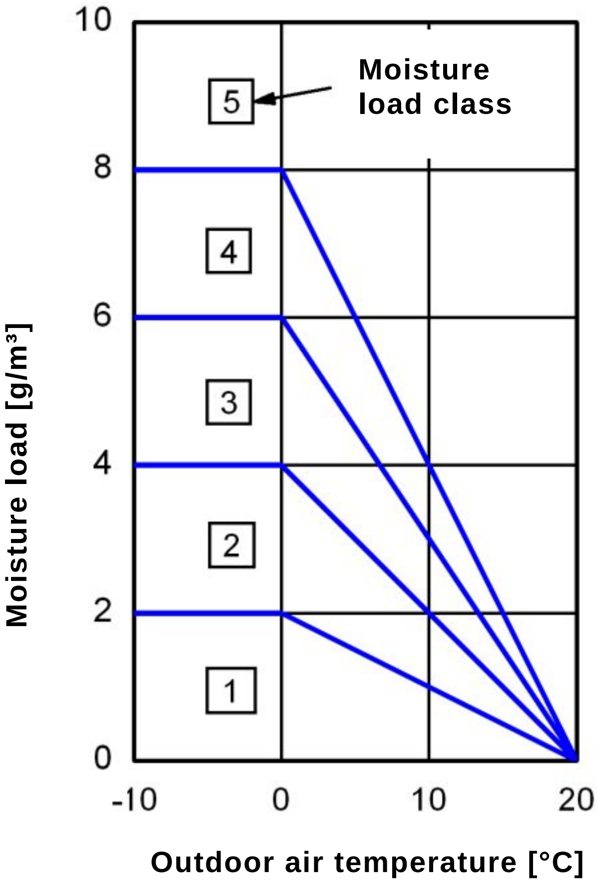

Fig. 11: moisture load classed according to EN ISO 13788 [23]

class 1:	storage
class 2:	offices, shops
class 3:	residential buildings with low occupancy
class 4:	residential buildings with high occupancy, sports halls, kitchens, canteens, buildings with un-flued gas heaters
class 5:	special buildings, e.g. laundries, breweries, swimming pools

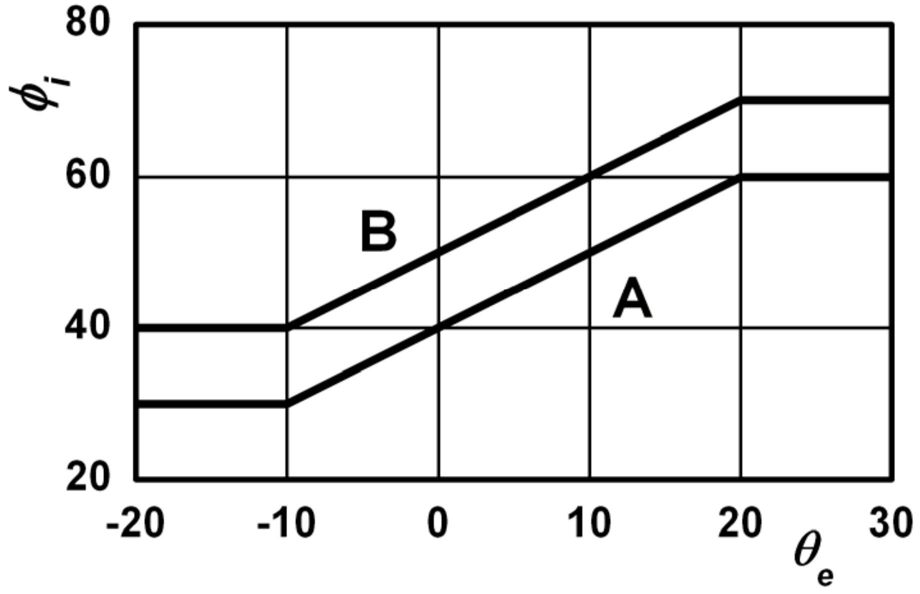

Fig. 12: Diagram to determine indoor humidity Φ_i in dependence of outdoor air temperature θ_e in Annex B of EN 15026 [24].

A: normal occupancy
B: high occupancy

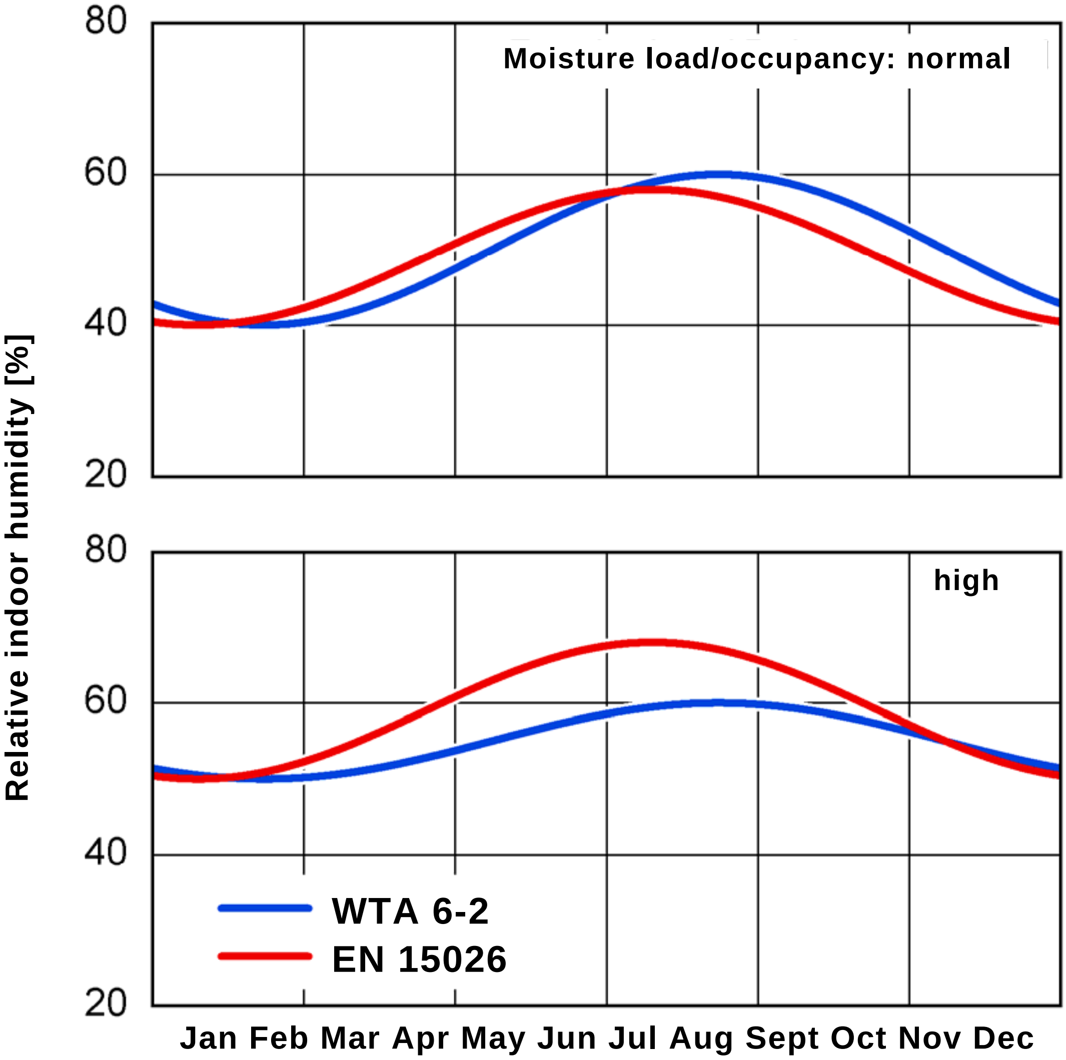

Fig. 13 Comparison of the boundary conditions for relative humidity in living spaces according to the specifications of the WTA guideline 6-2 [13] and EN 15026 [24] under German climate conditions.