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Institutsleitung
Prof. Dr. Gerd Hauser
Prof. Dr. Klaus Sedlbauer

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Moisture buffering effects of interior linings made from wood or wood based products

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48 Pages
1 Table
55 Figures

Dr.-Ing. H. M. Künzel
Dr.-Ing. A. Holm
Prof. Dr. K. Sedlbauer
Dipl.-Ing. (FH) F. Antretter
Dipl.-Ing.(FH) M. Ellinger

Fraunhofer-Institut für Bauphysik
Nobelstraße 12 · D-70569 Stuttgart
Telefon +49 (0) 711/970-00
Telefax +49 (0) 711/970-3395
www.ibp.fraunhofer.de

Institutsteil Holzkirchen
Fraunhoferstr. 10 · D-83626 Valley
Telefon +49 (0) 8024/643-0
Telefax +49 (0) 8024/643-66
www.bauphysik.de

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1 Introduction

A uniform indoor climate with minor variations in temperature and relative humidity contributes to establish a healthy and comfortable environment for the occupants. It is a well-known fact that the thermal mass of the building envelope counteracts strong changes in temperature (e.g. due to solar radiation). The fact that there is also something like a 'hygric mass', antagonising strong variations of moisture, is however less common. Here, 'hygric mass' means the vapour absorption capacity of the enclosing surfaces which is capable of buffering moisture variations inside a space. This would be beneficial in rooms where the generation of moisture (e.g. due to human activities) and the extraction of moisture (by way of ventilation) do not coincide. Concerning this issue, VTT (Finland) conducted numerical investigations [1], which proved timber lining to have a favourable effect on the relative humidity in bedrooms that are ventilated during the daytime only.

To validate the interpretation of these calculations, and to obtain some practice-oriented quantification of moisture buffering effects of different types of internal linings (based on wooden products or cellulose fibres) under defined boundary conditions, a series of comparative field tests was conceived by the Fraunhofer Institute of Building Physics (IBP) at Holzkirchen, Germany. Execution and results of these tests will be presented in the following.

2 Concept of the experimental investigations

The moisture behaviour of living spaces is influenced by a great variety of parameters. Apart from indoor air temperature control, inter-space air exchange, supply of outdoor air and its temperature and humidity, generation of moisture by the occupants and last, the moisture buffering effects of the building envelope as well as the home furnishings are also important. As all of these parameters are usually subject to strong temporary fluctuations, it is necessary to clearly reduce the number of parameters and their transient changes in order to obtain interpretable test results.

First, the air exchange between adjoining spaces should be reduced down to a minimum. The supply of outdoor air must be clearly defined, i.e. air infiltration through joints and building connections should be as low as possible. Besides, it is advisable to keep constant the indoor air temperature and one of the two moisture load factors. The moisture load (= the difference between the water vapour concentration inside the room and the outdoor air) is the ratio of moisture production and air change in a space. In buildings with natural ventilation (window ventilation), the moisture load will drop as the outdoor air temperature is increasing, because windows will be opened for a longer period when the weather is warm [2]. Under winter conditions, with temperatures ranging around the freezing point, the normal moisture load in habitable rooms amounts to an average of 4 g/m³ according to investigations mentioned in [3]. Assuming the minimum air change required for reasons of hygiene (0.5 h^{-1}) according to German standard DIN 4108-2 [4], an average moisture generation of 2 g/m³h or 48 g/m³d will result. For a household with 3 persons and a floor area of 65 m² (clear height 2.5 m) this corresponds to 7.8 kg/d, which is precisely the quantity that is suggested in [5] as a new, realistic proposal for indoor moisture production as a basis for the design of residential ventilation.

Due to human activities, the generation of moisture is subject to stronger variations during the day than is ventilation. This is why the air change rate will be kept constant in the present concept of investigations. To differentiate between the short-term and the long-term moisture buffering effects of the enclosing surfaces, a daily recurring, close-to-practice moisture production cycle was chosen, the peaks of which are short but intensive in the morning hours and longer and less intensive in the evening hours.

This makes the water vapour concentration of the outside air the only test parameter that cannot be determined in advance. As several tests have to be carried out successively with different types of lining, and the test results are liable to be influenced by the weather conditions, the comparison to a reference case is indispensable. This means that parallel tests will be performed in two identical spaces under identical boundary conditions; the different types of test room surfacing will be the only distinction. A customary mineral interior plaster with paint is used as reference surfacing material.

The variation of the relative indoor air humidity is the decisive quantity to be measured in order to quantify the moisture buffering capacities of the surfacing material. If one compares the profile of the daily indoor air humidity amplitudes with the reference case, an amplitude reduction will indicate an improvement of the buffering capacity as compared to the normal case. A quantitative comparison of the situation in both test rooms may also be achieved by defining tolerance limits for the indoor air humidity that shall be observed for reasons of hygiene or comfort. According to ASHRAE standard 55 [6], the comfortable range is between 30 % and 60 % RH. Under aspects of hygiene, the most favourable range is between 30 % and 55 % RH (see Fig. 1).

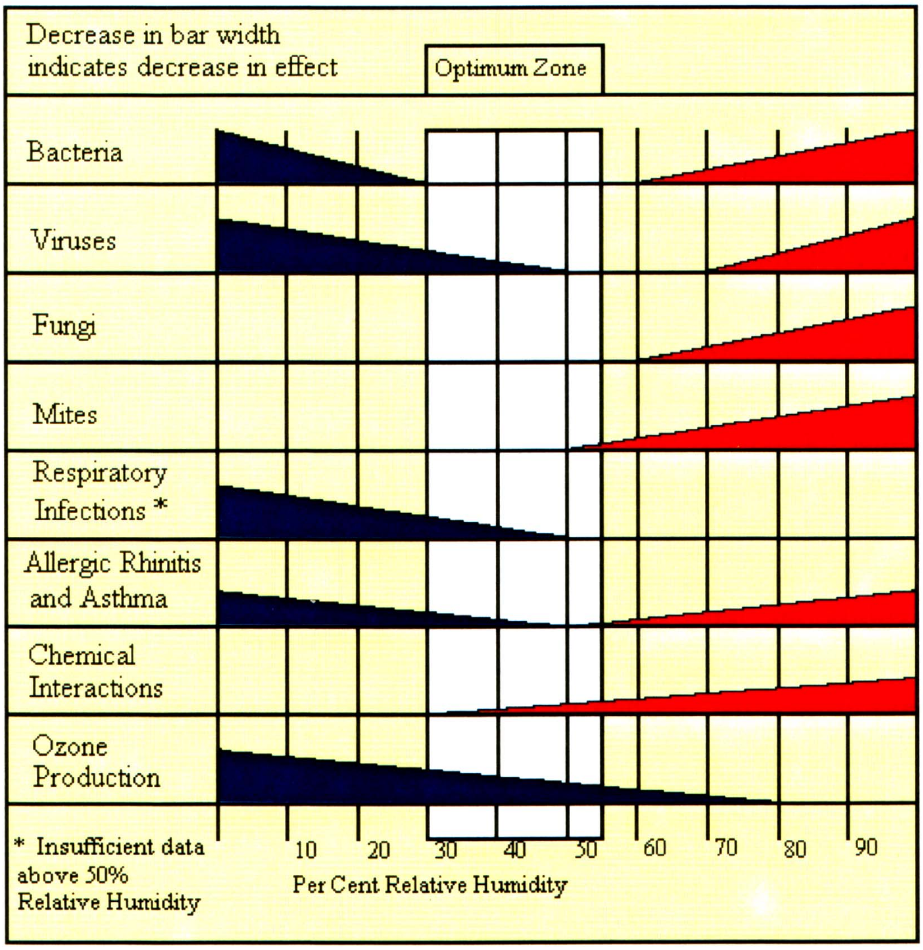

Fig. 1: Factors influencing hygiene and health as a function of the relative indoor air humidity according to [1]. The most favourable range of relative humidity is between 30 % and 55 %.

3 Performance of tests

The experiments were performed in two identical test rooms in a test building located on the IBP field testing facility at Holzkirchen between December 2002 and February 2004. During the entire test period, outdoor climate data were recorded by the IBP on-site weather station.

3.1 Test set-up and system control

3.1.1 Design and properties of the test rooms

The test rooms are situated in a building which was raised in the eighties on the field test site of the Fraunhofer Institute of Building Physics (IBP) at Holzkirchen, approximately 700 m above sea level (see Fig. 2). Originally, the building was used to perform measurements regarding the heat transmission properties of different types of wall constructions [7].

Fig. 2: IBP field test site at Holzkirchen.

The ground plan of the two test rooms is shown in Fig. 3. A U-value of 0.32 W/(m²K) results from the wall construction (240 mm brickwork with an external 100 mm polystyrene insulation). The south-oriented window (approx. 2 m²) has a U-value of 1.1 W/(m²K) and a g-value (total solar energy transmittance) of 0.6. In the adjoining rooms, there is a constant temperature of 20 °C, which practically prevents any heat flow through the partition walls and the ceiling. In the following sections, the room where the wall surfaces were coated with a conventional, painted interior plaster will be referred to as the 'reference room'. Geometry and dimensions of the test room and the reference room are identical. In distinction to the reference room, the surfaces of the test room were foiled with aluminium. This is why the interior surfaces of the test room have no sorption capacities. The vapour barrier ensures that the room's moisture balance will not be affected by the original plaster applied beneath the aluminium foil. Thus, only the effects of the newly applied surfacing materials will be determined. In both rooms, the floor is covered with a PVC coating, which is likewise to be considered as inactive in terms of moisture. Each room has a volume of 50 m³ and an interior surface area (floor, window and door excluded) of 67 m².

For interior views of the test room and the reference room see Fig. 4 and Fig. 5.

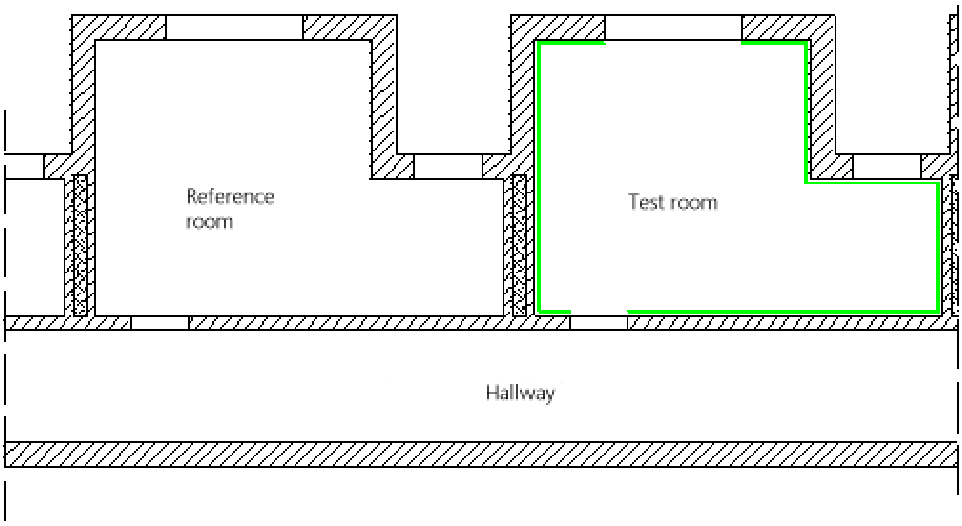

Fig. 3: Ground plan of the experimental rooms.

Fig. 4: Interior view of test room.

Fig. 5: Interior view of reference room.

3.1.2 Air-tightness of the experimental rooms

The blower-door method is a standard test procedure used in the energetic assessment of buildings. This method is also an appropriate procedure for testing the air tightness of spaces in a building: the higher the air tightness of the experimental rooms, the smaller the effects of undefined airflows onto the system. The method of measuring the air tightness is based on the Pitot tube principle. A frame is inserted into the test room door and covered with a piece of cloth. Then a fan is installed in an aperture of the cloth by means of an elastic element. The fan will generate a positive or a negative pressure inside the tested room (depending on the type of test) in relation to the ambient pressure outside the room (see Fig. 6). The air is conveyed through an orifice of a specified dimension. Before and behind this orifice the static pressure is recorded by a measuring device. The conveyed volume flow can be computed on the basis of the pressure difference recorded at the points of measurement. This air volume is drawn from the outside through unintended leaks of the building envelope into the room at a pressure difference of 50 Pa. Prior to the blower-door measurements, the window and door joints were carefully sealed with adhesive tape. The measurement results were $n_{50} = 0.56\ h^{-1}$ for the reference room and $n_{50} = 0.43\ h^{-1}$ for the test room. After conversion to the air change by infiltration under normal pressure conditions, we obtain $n = 0.03\ h^{-1}$ for the test room and $n = 0.04\ h^{-1}$ for the reference room (multiplication of the value determined for $\Delta p = 50$ Pa with the factor 0.07). Within the scope of the expected accuracy of ventilation control, these values are regarded as acceptable for the spaces' air tightness.

Fig. 6: Blower-door measurements.

3.1.3 Ventilation control

As initially mentioned, it is convenient to keep the air change rate of the spaces constant during the experiments on account of the great number of influential factors present. This is why an air change rate of $n = 0.5\ h^{-1}$ (minimum air change according to German standard DIN 4108-3 [4]) was selected for the mechanical ventilation of the experimental rooms. Accordingly, a volume flow of fresh air of 25 m³/h has to be implemented. The blowers that are installed inside the spaces are represented in Fig. 7. As their maximum output ranges between 56 and 48 m³/h, they are well suited for this purpose.

Fig. 7: Blowers for maintaining continuous ventilation rate of 25 m³/h.

However, a constant flow resistance does not suffice to limit the air supply to 25 m³/h, as the influence of pressure differences due to wind or stack was found to be too strong. Even with a low wind force, the air volume flowing inside the blower pipes was strong enough to blow out a candle while the fan was switched off. For this reason, volume-flow control units were installed in the ventilation systems that are capable of maintaining a continuous volume flow in a differential pressure range of up to 240 Pa. These control units are operated by motor-actuated valves, the current volume flow being determined by the Pitot tube principle. The adjustable volume flow ranges from 25 to 75 m³/h. The required volume is determined by an equivalent control variable, a voltage of 0 – 10 volt. The accuracy of the volume flow control is at ±15 %, and from this follows an actual air change in the rooms between 0.43 and 0.57 h^{-1}.

3.1.4 Moisture production control

As mentioned earlier, an amount of 48 g/m³d of evaporated water is considered as a representative value for the production of moisture in habitable rooms. For the total generation of moisture in the experimental rooms (volume 50 m³) this means that 2.4 kg of water have to be introduced per room and per day. In real life, the moisture production is not uniformly distributed over the day, but is marked by pronounced peaks. The upper part of Fig. 8 presents the diurnal moisture production pattern that was selected for the tests. The permanently present basic humidity production that is due to plants or pets, for instance, amounts to 25 g/h. In the early morning hours between 6 am and 8 am, this value is increased to a peak level of 400 g/h in order to simulate human activities, like having a shower and washing, for instance. Subsequently, the moisture production will drop back to the basic rate of production. In the late afternoon the moisture production will increase again to a moderate level (200 g/h) until the evening hours (4 pm until 10 pm) which is to simulate certain activities like cooking, cleaning or doing the laundry.

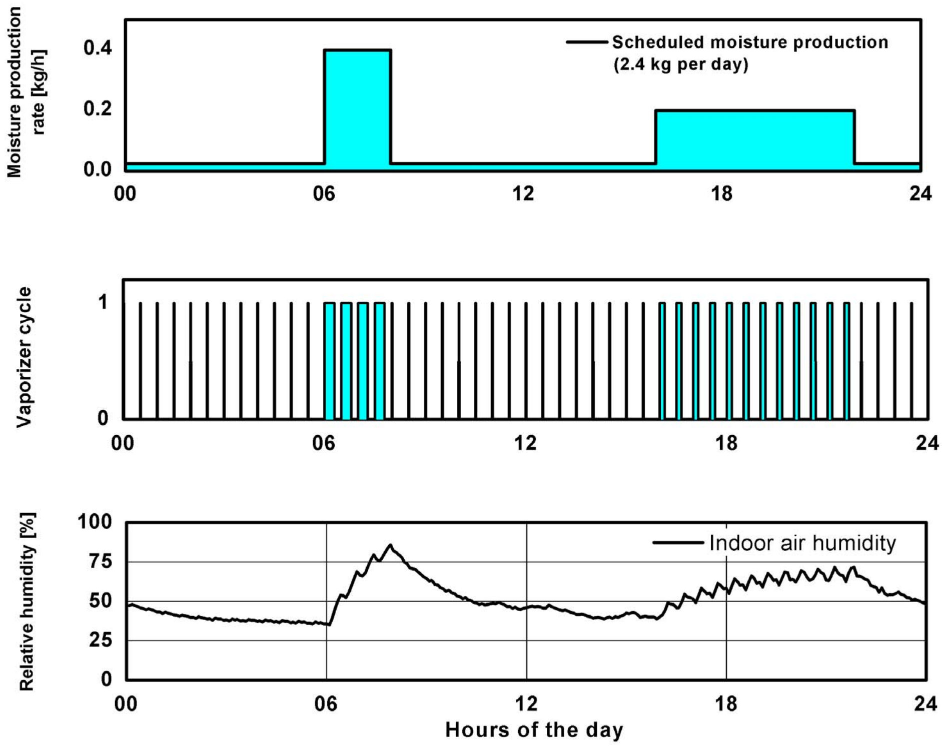

Fig. 8: Diurnal moisture production pattern in the experimental rooms

Curve #1: Target profile of moisture production
Curve #2: The clock timer transforms this signal into a digital signal
Curve #3: The indoor relative humidity reacts with a 'saw-tooth' pattern

Fig. 9: Vaporizer during moisture production.

The required amount of moisture is generated by means of ultrasonic vaporizers (see Fig. 9), namely by customary humidifiers producing cold mist. This input method implies the advantage of a low energy entry (50 W) into the experimental rooms. In this way, any additional undefined heat sources (like a heating coil, for instance) are excluded. To achieve ultrasonic vaporisation, a small metal membrane causes high-frequency vibrations of the water, thus vaporising it. For system-related reasons, it is however not possible to reduce the devices' rate of vaporisation. This is why vaporisation was 'digitalised', i.e. the devices were controlled by means of a clock timer. This timer enables individual activation of two channels with mains voltage and provides 345 switching operations. The smallest interval is one second. The resulting step functions of the humidity production are shown in Fig. 8, centre. Accordingly, the humidification of the indoor is effected batch-wise in a 30 minute time period. On the one hand, the length of the switching cycles is adapted to the moisture load to be simulated, and on the other hand to the output quantity of the appliance. To a certain extent, the discontinuous moisture production patterns are also reflected in the time profile of the indoor air humidity, as is evident in the lower part of Fig. 8. To facilitate comparability of results, the profiles presented in the following illustrations will be 'smoothed' by giving their moving average.

Prior to installation into the experimental rooms, there was a detailed analysis of the start-up performance, the evaporating quantities, and the long-term stability of the vaporizer. As the output of some appliances may deteriorate due to deposit in the course of time, the appliances had to be checked during the test series, as well. For this purpose, the evaporated quantity was determined by weighing and reweighing the water storage tanks before and after a test. In order to prevent any temperature stratification in the test rooms and to ensure uniform distribution of the humidity emitted from the vaporizers, pivoted blowers were operated throughout the test series.

3.1.5 Acquisition of measured data and sensor technology

Sensors were installed in the experimental rooms to continuously record the following parameters: temperature at the wall surfaces and in the centre of the room (with height profile), relative humidity in the centre of the space, heat flow through external walls and partition walls, and the energy consumption of the electrical heating system. For a further evaluation of the tests, only the measured parameters temperature and relative humidity are considered here.

The installed temperature sensors 'PT100' comply with German standard DIN IEC 60751 1/3 Class B. They have a measuring precision of ±0.5 K. The output signal is a voltage of 0 – 1 V (corresponding to -40 to +60 °C). The indoor temperature is kept at 20 °C by means of a SPC-control that regulates an electrical radiator. The relative humidity is measured in the centre of the room at a height of 1.30 m and, additionally, in the supply air of the fans. The physical measurement principle of the humidity sensors (see Fig. 10) is based on the electric signal of a condenser with a highly hygroscopic dielectric medium. Any change of humidity will therefore cause a proportional change in the capacitance. The signal emitted ranges between 0 and 1 V, which corresponds to the measuring range of 0 – 100 % RH.

Fig. 10: Humidity and temperature sensors in the centre of the room.

The electrical signals emitted by the temperature and humidity sensors were recorded by means of the Imedas® data acquisition system. This system combines the options of a direct transfer of measured data to a database and graphical representation of the data. Each individual sensor is recorded on one channel. Measurement cycles and intervals can be selected as required. Depending on the required applications, specified channels can be compiled online. Moreover, the system offers the option of stating either interval means or absolute values measured at certain instants. The measured values may be provided directly as an ASCII-file and can be exported to EXCEL. The selected series of readings will be immediately visualised, thus making it easy to quickly check on the way a measurement is developing. As both test rooms are displayed simultaneously, a direct comparison of all measured parameters is also possible (see Fig. 11).

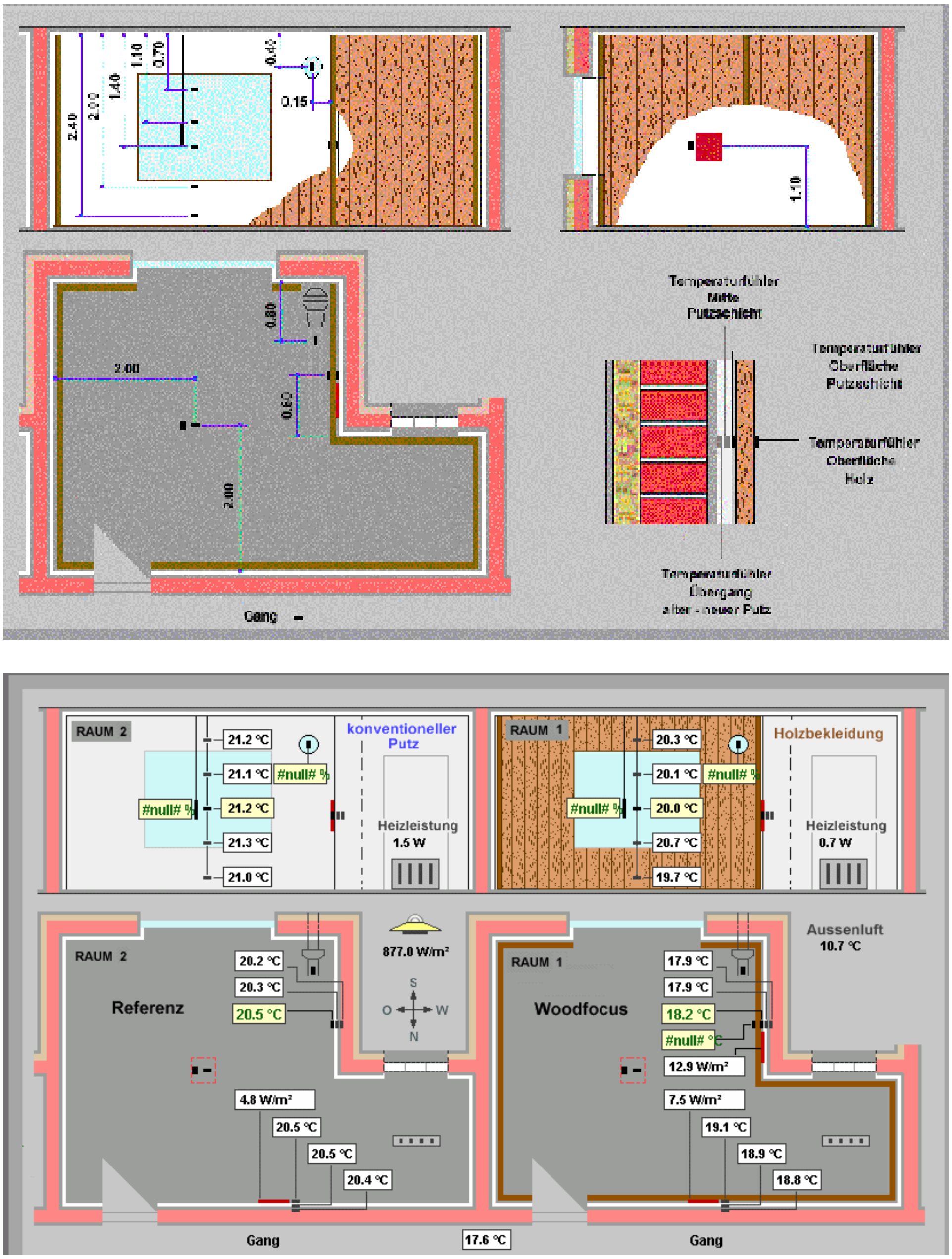

Fig. 11: Visualisation of the experimental rooms; location of sensors and representation of measured data.

3.2 Preconditioning of the interior linings

Comparative investigations of water vapour sorption characteristics of building materials require the preparation of a precisely defined initial state. This is why the supplied interior linings were stored in an air-conditioned space at 20 °C and 50 % RH for at least four weeks. During storage, the lining panels or other lining elements were positioned in such a way that the surfaces of the material were exposed to the ambient air. Figure 12 illustrates the material storage upon stacking strips, similar to stacking timber for drying purposes. Subsequent to the installation of the lining elements in the test room and prior to the actual test, a settling phase for material acclimatisation was allowed for during which the same moisture cycles were run as in the measurements to follow.

Fig. 12: Storage of spruce panels during the preconditioning phase.

3.3 Experimental investigations of the moisture buffering behaviour

The investigations concentrated on the effects of the room-enclosing materials regarding the evolution of the relative humidity inside the test rooms. The tests were performed in parallel in both test rooms under identical boundary conditions. The room temperature remained constant at 20 °C with the exception of a few days, when this temperature was exceeded for some hours due to intensive solar radiation. In both test rooms, the air supply was maintained at an air change rate of 0.5 h^{-1} by the ventilation control, and the moisture production cycles conformed to the information stated in Figure 8.

3.3.1 Preliminary tests without interior linings

The first tests were performed in the test room without any interior linings, which means that the enclosure of the space has practically no hygric storage capacity due to its aluminium foil surfacing. Initially, the reference room is merely coated with a rough, slightly grey lime-gypsum interior plaster. Before a second preliminary test, a conventional white finish coat was applied to this plaster layer. As the water vapour permeability of this coat will affect the hygric behaviour of the enclosing surfaces, the diffusion resistance (s_d-value) of this coating layer is also going to be determined in the laboratory. Figure 13 illustrates the diffusion measurement according to EN ISO 12572 [8] in the humidity range of 50 % and 93 % RH. This range was chosen because, in practice, the moisture buffering effect is of major importance in a range above 50 % RH due to possible mould growth. These measurements resulted in an s_d-value of 0.15 m, with a given application quantity of 150 ml/m² (according to the manufacturer's specifications for application). Accordingly, the coat may be classified as relatively open to diffusion, which in actual practice - particularly with repeated coating - might not always be the case. However, the conditions inside the reference room should not be particularly unfavourable, in order to allow for some realistic comparison to the lining materials under test.

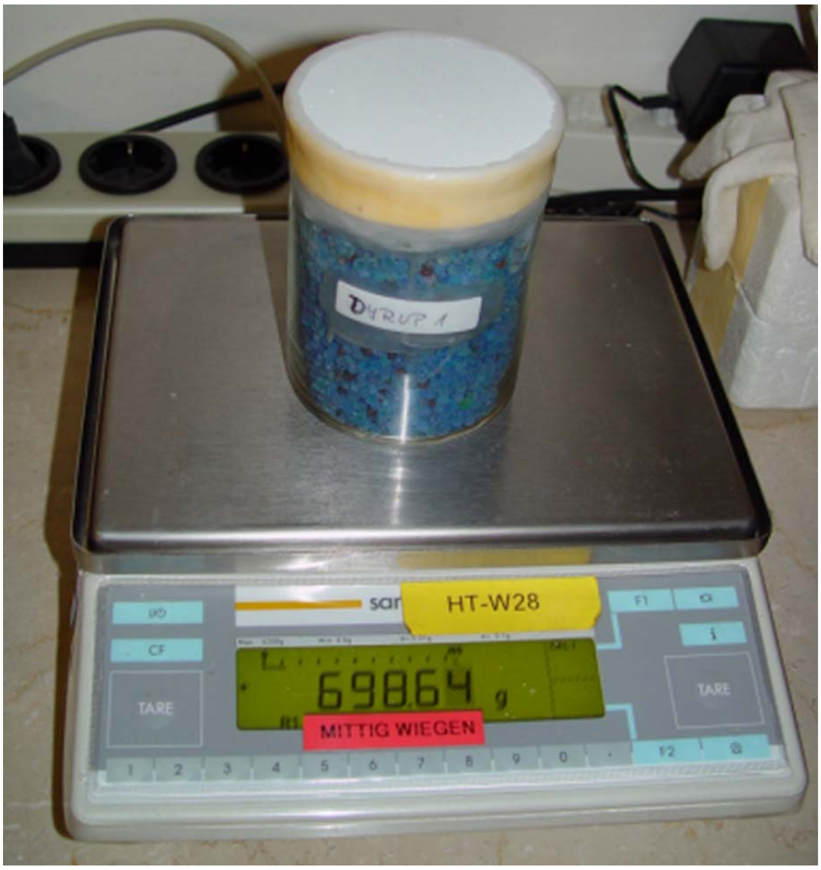

Fig. 13: Weighing a plaster sample to determine the s_d-value of the paint

3.3.2 Investigations with regard to the moisture buffering effects of wood-based linings

In the following tests, various types of linings (either wood or wood based products) were successively installed in the empty test room. Then, their influence on the indoor air humidity was determined and compared to the situation in the reference room (with the painted interior plaster). By sealing the back side of the lining units with aluminium foil or polyethylene film, it was ensured that the backside surfaces would not affect the measurements. Though it seems possible that these offside surfaces might also contribute to moisture buffering in real applications due to backside air infiltration, this phenomenon was excluded for the current tests, as it is governed by several, hardly appreciable factors (air flows through joints etc.).

The investigated linings and their installation surfaces are compiled in Table 1. Unlike the other linings, the round-logs used in log cabin construction could not be fully installed at the walls and ceiling of the test room due to their dimensions. They were placed inside the room in such a way that the indoor air could freely flow around them. In distinction to the other kinds of lining, their projected surface (due to the round shape the actual, active surface is correspondingly larger) amounts to 41 m² only (see Table 1). A detailed description and representation of the various lining units will be given along with the presentation of measurement results.

Table 1 Projected surface of the materials under test

Interior linings of walls and ceiling	Projected surface [m²]
Spruce panels	67
Acoustic elements	67
Insulating elements	67
Pine log wall elements	41
Wood fibreboard	67
Interior wall plaster (reference room)	67

3.3.3 Investigations of moisture buffering effects of textile materials

Investigations referred to in [9] have shown textile materials (as used for furniture or curtains) to have quite a good moisture buffering capacity, too. This is why two tests were run on textiles commonly known to be strongly hygroscopic. To this end, untreated woollen blankets sized 2.0m x 1.4 m (2.8 m²) were chosen. Six of these blankets (16.8 m²) were suspended inside the test room in such a way that the indoor air could freely circulate and flow around them from all sides. In the first test, the woollen blankets were suspended in the empty aluminium-foiled test room.

4 Test results

After the test rooms had been calibrated and equipped with the required measuring instrumentation in the autumn of 2002, the experimental investigations were performed between December 2002 and February 2004. Due to the higher outdoor air temperatures (> 5°C) prevailing during the tests that were carried out in May and in June, these results can be compared to those obtained in the rest of the test period to a limited extent, only. Since the moisture load in the spaces (the quotient of moisture production and air change) was defined for winter conditions, the indoor-air humidity values measured for these months are clearly above conditions encountered in practice. This context should be considered regarding the detailed presentation and analysis resp. interpretation of the results given in the following.

4.1 Preliminary tests

During the preliminary tests, the reference room remained unpainted at first, being covered with a rough interior plaster only. Fig. 14 presents the reaction of the indoor air humidity to the 24-hour moisture production cycle in both test rooms (see Fig. 8) on a typical winter's day, along with the exterior climatic boundary conditions. The humidity fluctuation range in the reference room clad with the rough interior wall plaster is distinctly lower than the range in the aluminium-foiled test room. The moisture-buffering capacity of the interior plaster prevents the indoor air humidity from rising above 65 % RH, whereas the relative humidity exceeds 80 % in the empty test room.

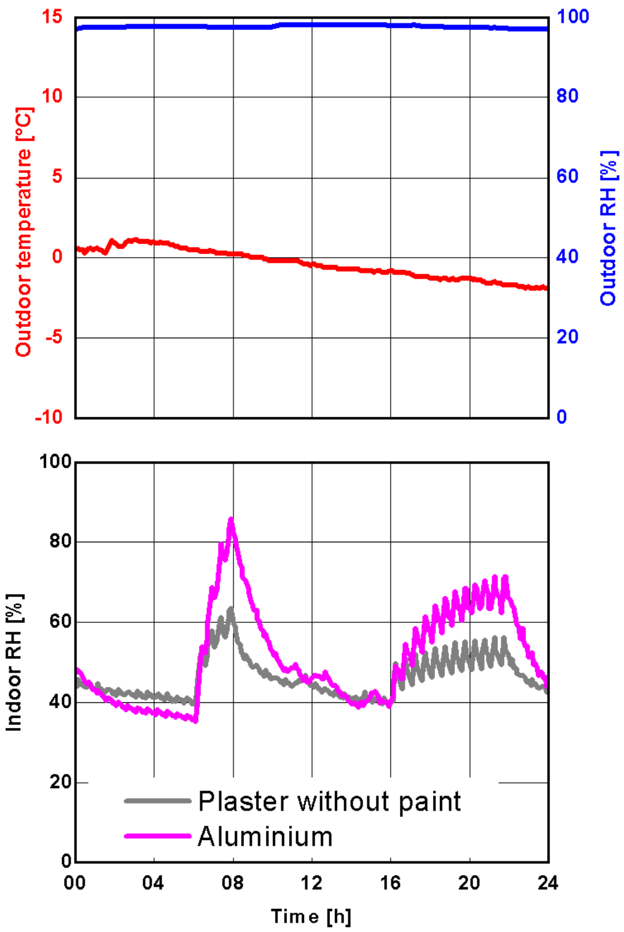

Fig. 14: Measured time profiles of the indoor air humidity in the non-hygroscopic test room and in the reference room (unpainted interior wall plaster).

If the interior wall plaster is painted (as is usual practise in habitable rooms), the space's moisture buffering effect will clearly deteriorate (see Fig. 15 for the moisture curves in the reference room before and after painting the wall plaster). A direct comparison is permissible to a limited extent only, as the moisture patterns inside the room are also depending on the outdoor air conditions. This is why the results were chosen carefully to make sure that the weather conditions in the survey period (see Fig. 16) were not too diverging.

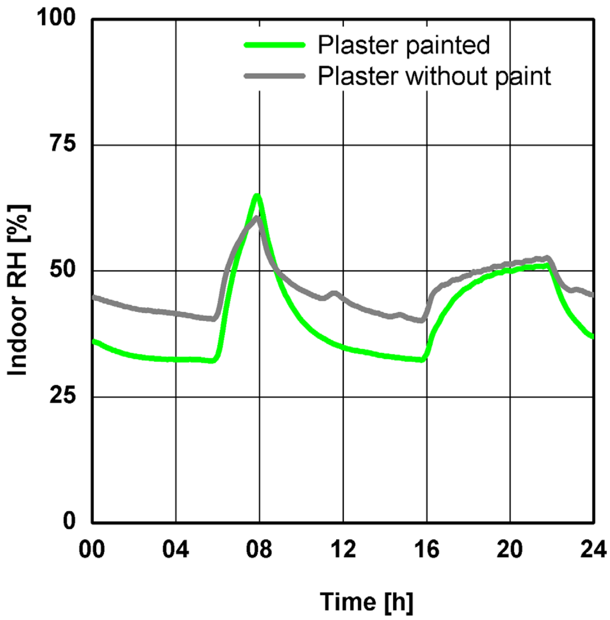

Fig. 15: Measured curves of the indoor air humidity (smoothed) in the reference room before and after coating the interior plaster with vapour permeable wall paint.

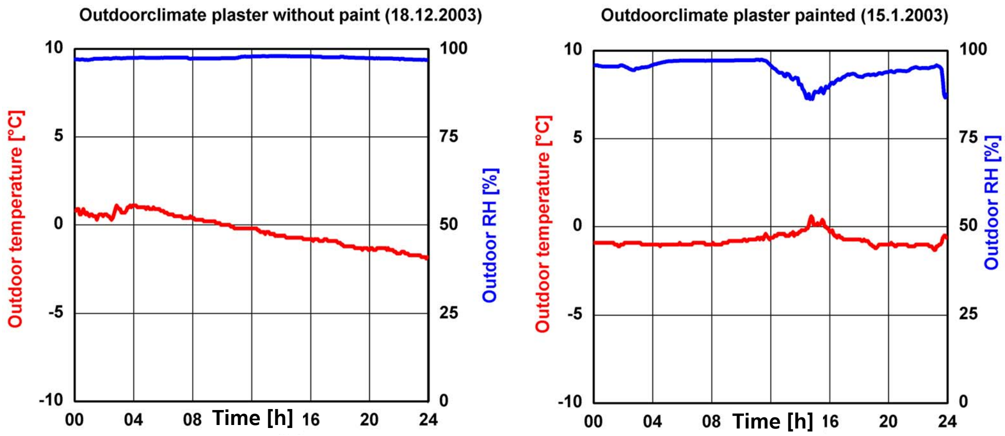

Fig. 16: Measured curves of the outside air conditions on winter days that were selected to compare the moisture buffering effects of the interior plaster in the reference room before and after painting.

The wall construction of the reference room (painted interior plaster on brickwork) is representative for an average dwelling in Germany. All of the further test results will therefore be related to the situation in this room. First, the performance of the non-hygroscopic (walls and ceiling were foiled with aluminium) empty test room is analysed in comparison with the reference room. These "empty space" tests preceded the actual tests that were performed with installations in the test room. Fig. 17 illustrates the indoor air humidity curves in the autumn of 2003 and the corresponding exterior climatic boundary conditions. The pattern of the relative indoor air humidity reflects the moisture production cycles. Evidently, the moisture production inside the space substantially affects the indoor-air humidity development, while the outdoor-air humidity entered by ventilation tends to determine the average level of the relative humidity.

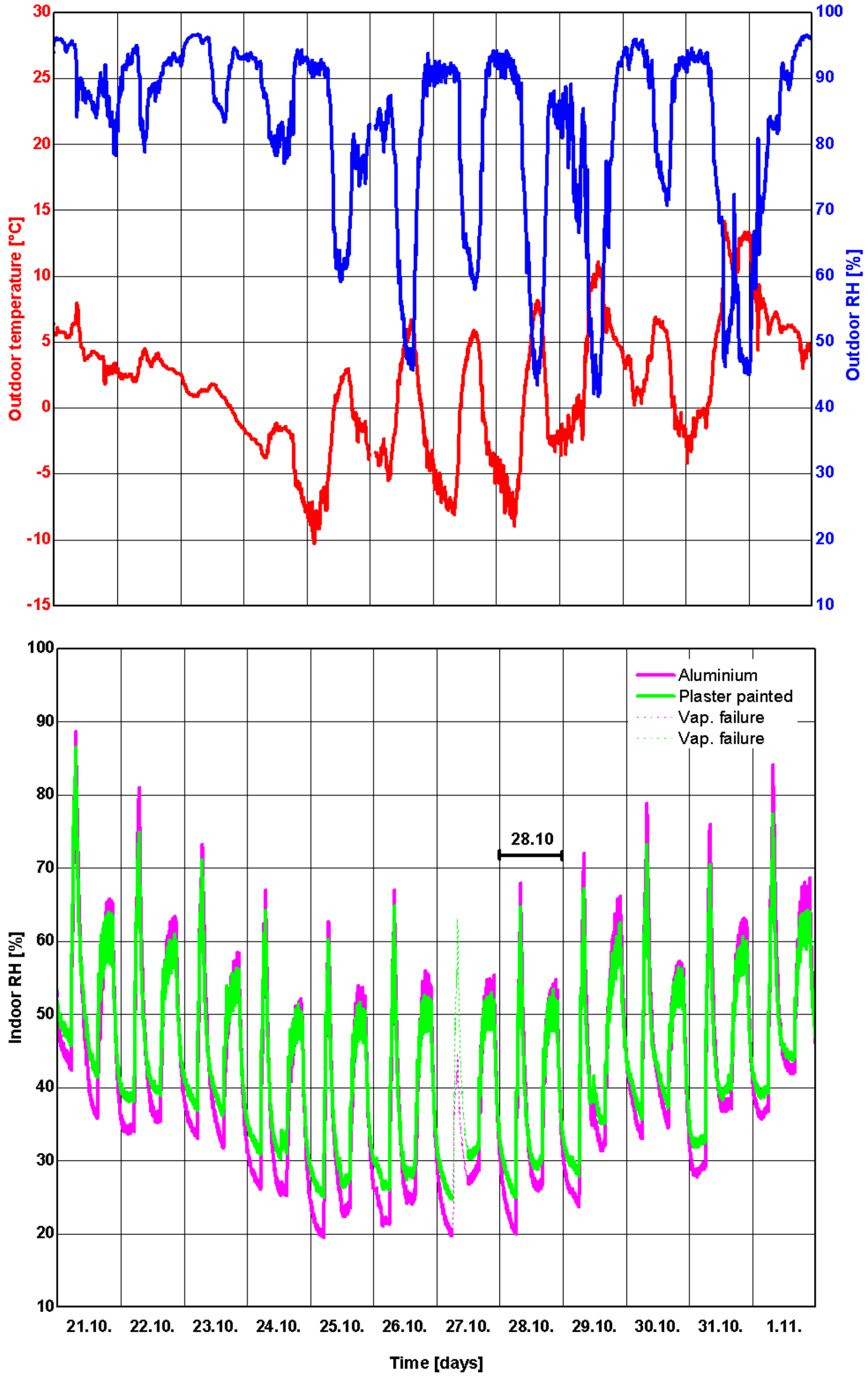

Fig. 17: Patterns of the exterior climatic boundary conditions (top) and the indoor air humidity in the test rooms (bottom).

Fig. 18 presents the time profiles of the relative humidity in both rooms on a representative day. Though the humidity curves in both rooms differ only slightly, there is yet some moisture buffering effect of the interior plaster to be clearly distinguished.

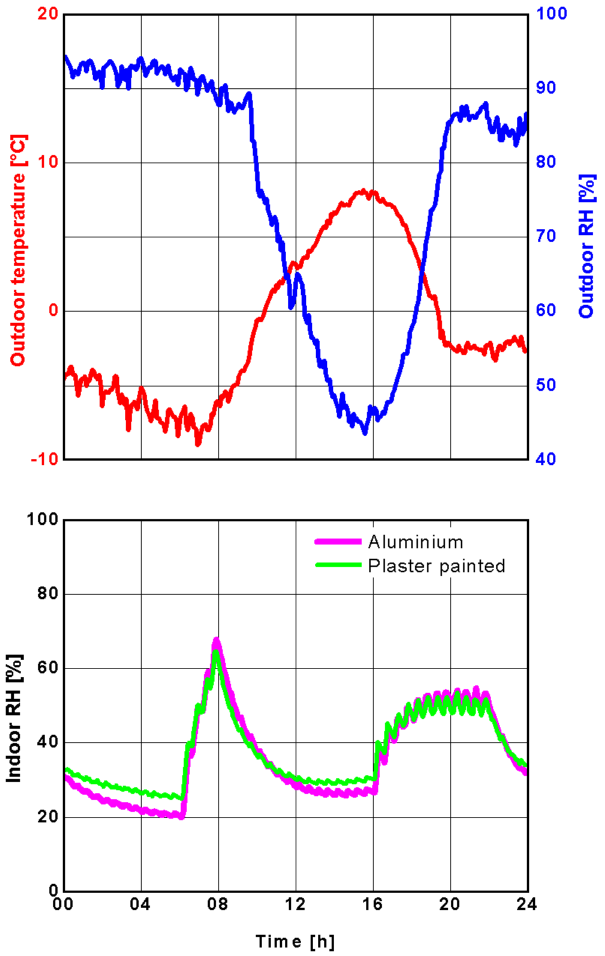

Fig. 18: Time profiles of the exterior climatic boundary conditions (top) and the indoor air humidity in the test rooms (below) on a representative day.

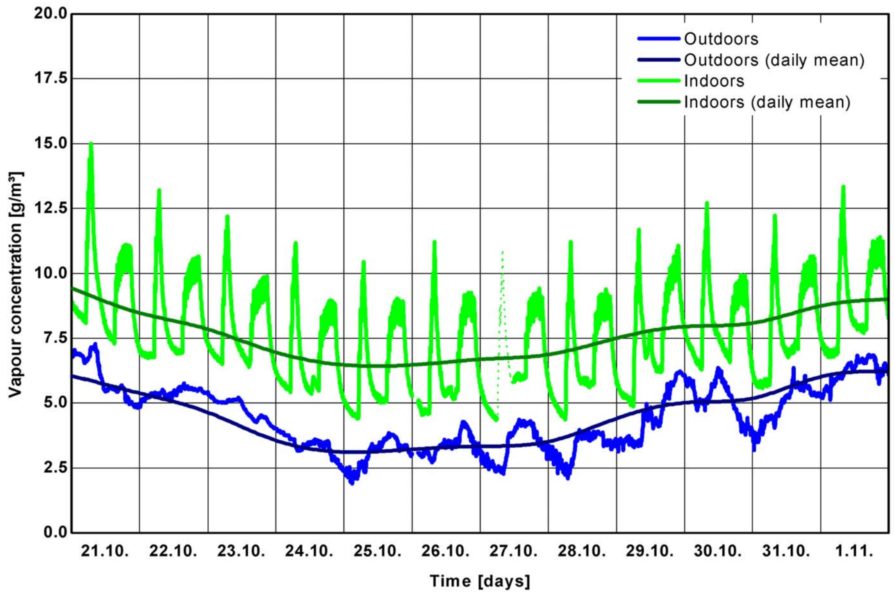

Fig. 19: Pattern of the absolute moisture profile in the reference room (green) versus outdoor air conditions (blue.)

Fig. 19 shows the indoor-air humidity situation in the reference room along with the absolute outdoor-air humidity, both as instantaneous values and as daily means for a 12-day period. Evidently, the indoor-air humidity fluctuates around the daily means (due to moisture production), which largely follow the development of the outdoor air humidity with a shift or an offset of 3.1 g/m³ (this corresponds to the mean indoor moisture load). The average moisture production amounted to 46 g/m³d in the same time span. From this, a mean air change of 0.6 h^{-1} can be derived, which is about 20 % above the target value. The indoor-air humidity peaks in the morning and in the afternoon are connected with the moisture production cycle that is repeated every day. The amplitude of these deflections is a measure for the room's humidity response to the moisture production peaks and thus also for the buffering effect of its enclosing surfaces. The quantification of these humidity peaks is demonstrated for the example of the reference room in Fig. 20. Here, the difference of the relative indoor humidity is determined twice a day, namely at the beginning and at the end of both daily repeated moisture production peaks. The humidity peaks that were determined by way of this method in the reference room also serve as reference values for the humidity variations in the test room, i.e. the humidity peaks in the test room will be compared to the peaks that were measured in parallel in the reference room.

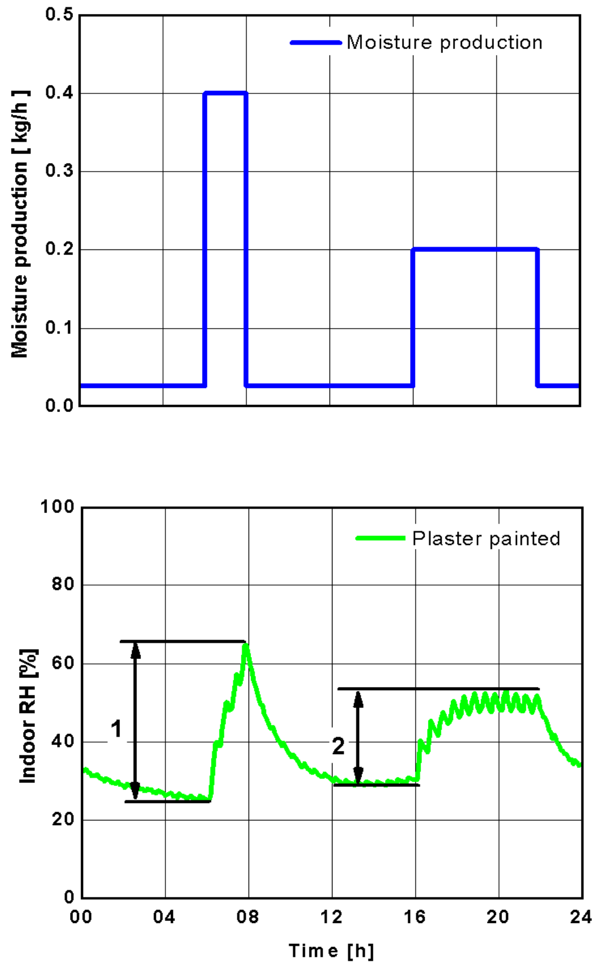

Fig. 20: Indoor-air humidity changes due to moisture production; first peak 6 - 8 am; second peak 4 - 10 pm.

By calculating the difference of the indoor-air humidity measured between 6 am and 8 am and the values measured between 4 pm and 10 pm, one obtains the amounts that are presented in Fig. 21 (top) for both test rooms; due to the influence of exterior climatic conditions, these values may vary slightly from day to day. As was expected, the short but intensive moisture-production cycle in the morning induces a stronger peak of indoor-air humidity than the longer lasting evening moisture-production cycle, which is only half as strong. The phenomenon of moisture buffering can be clarified if one relates the humidity amplitudes of the empty test room to the moisture fluctuations in the reference room (as shown in Fig. 21, bottom). Fig. 22 presents the values that were averaged over the 12-day test period. After the morning cycle, the humidity level in the empty test room will rise by more than 25 % compared to the reference room; after the longer lasting evening moisture-production cycle, the relative difference will be almost 40 %. Thus, the moisture buffering effect of the painted interior plaster in the reference room becomes more noticeable after a longer moisture-production cycle than after short-time moisture production peaks.

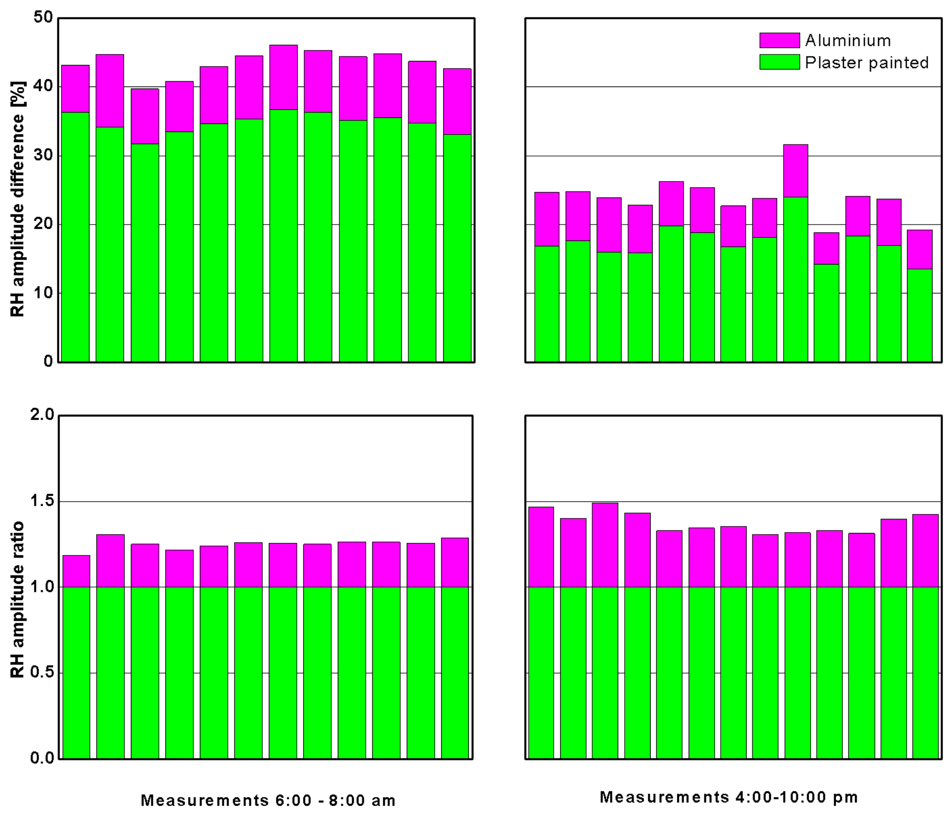

Fig. 21: Humidity peaks in the test rooms (top) and their amounts, related to the humidity variations in the reference room (bottom) induced by the cyclic moisture production in the morning (left hand) and in the evening (right hand).

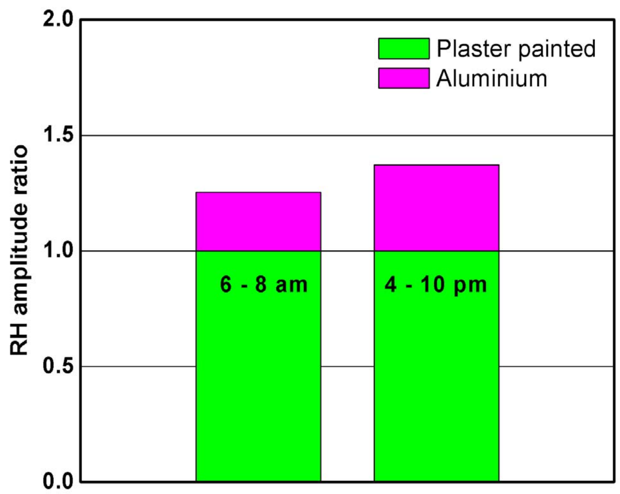

Fig. 22: Average of the related humidity peaks from Fig. 21 during the 12-day test period.

The evaluation of the hygienic compatibility (according to the classification given in Fig. 1) can be based on the humidity conditions measured in the test rooms (see Fig. 17). The periods during which the indoor air humidity exceeds the upper limit of the optimum range (55 % RH) are related to the overall test period. By analogy, the same holds for periods during which values fall below the lower limit of the optimum range (30 % RH). The result of this evaluation is presented in Fig. 23 for the aluminium-foiled test room and for the reference room.

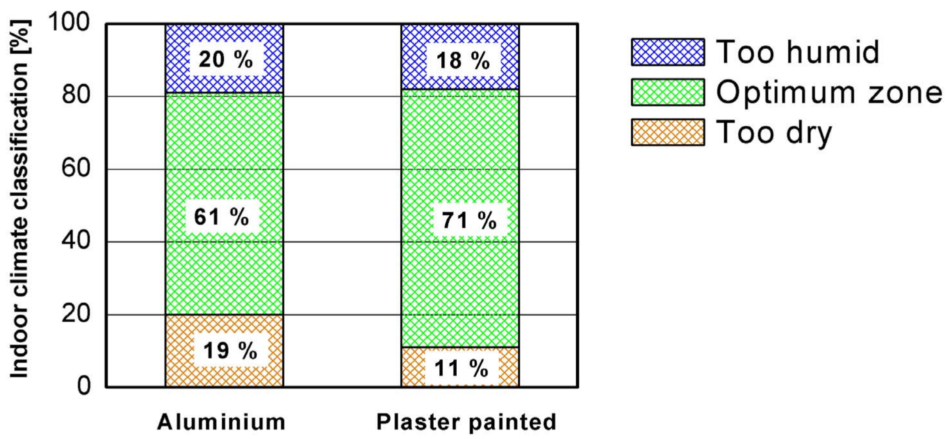

Fig. 23: Classification of the humidity conditions prevailing in the test room (aluminium foils) and in the reference room (plastered) after remaining in the optimum humidity range (30 - 55 % RH), respectively above it (too humid) and below it (too dry), according to Fig. 1.

4.2 Moisture buffering effects of wood-based linings

The following results present the moisture buffering effects of different types of wood-based linings in the test room compared to the conditions in the plastered reference room. An overview of the individual tests is given in Fig. 24 by a survey of the indoor air humidity measurements that were performed in the test period. As the moisture production cycle and the air change remained unaltered throughout the entire period, the average indoor air humidity strongly increases in the warm season of the year. The periods with daily mean temperatures exceeding 5 °C (shaded are in Fig. 24) were only considered when evaluating the moisture buffering effects. There is no classification of the indoor-air humidity conditions according to Fig. 1, as the air change rate for dwellings under summer conditions is unrealistically low; consequently, an increased air humidity (which would not occur in practice) will result inside the test rooms.

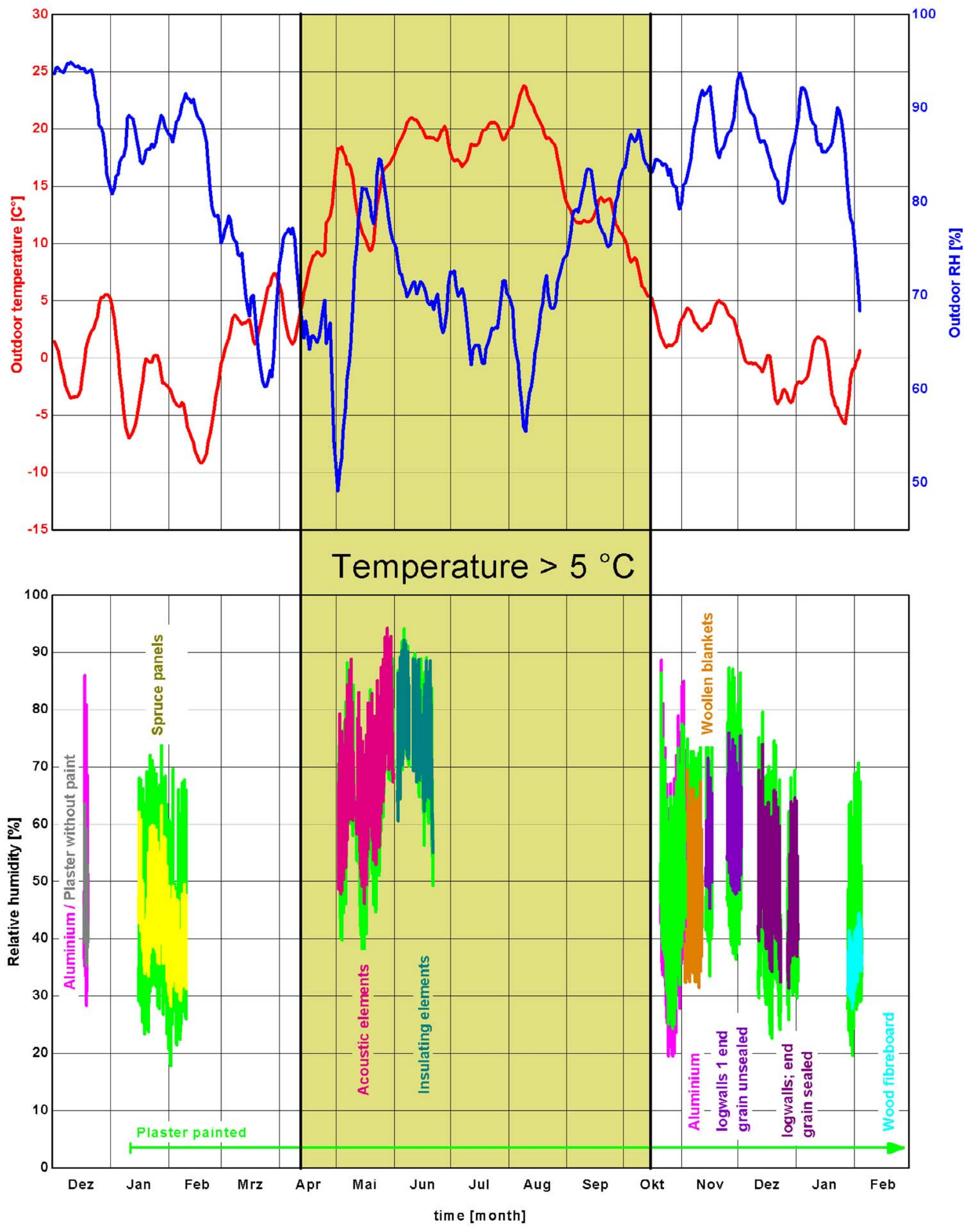

Fig. 24: Overall survey of the test period. The recorded exterior climatic boundary conditions are presented as floating decade mean.

4.2.1 Test room lining: Spruce panels

Figure 25 shows the test room with the installed decorative panels made of tongue-and-groove spruce boards. The front side of the panels remained untreated; the backside was foiled with aluminium. The patterns plotted in Fig. 26 present the exterior climatic boundary conditions measured during the test period and the relative humidity in the test room compared to the reference room conditions.

Fig. 25: Test room with spruce panels.

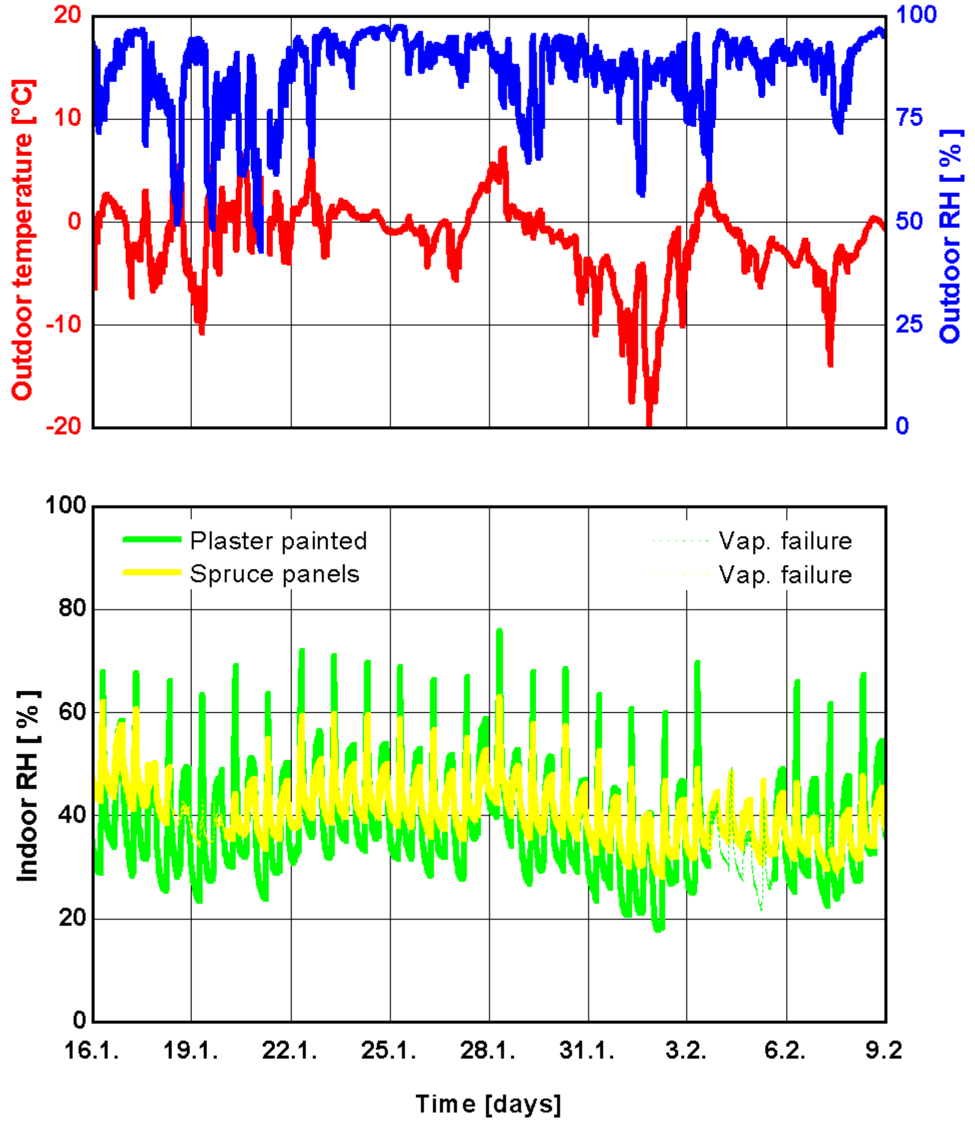

Fig. 26: Patterns of the exterior climatic boundary conditions and relative humidity in the test rooms during the measurement period.

Taking the representative day as an example (see Fig. 27), the impact of the spruce panels on the test room's moisture behaviour becomes even more apparent. The indoor-air humidity changes that were induced by the two moisture production intervals are shown in Fig. 28. Figure 29 displays the humidity amplitudes (from Fig. 28) that were related to the conditions in the reference room and averaged over all test days. Evidently, the humidity amplitudes in the test room are less than half of the amplitudes measured in the reference room. Thus, the moisture-buffering capacities of the untreated spruce panels will reduce the indoor-air humidity fluctuations by more than 50 % compared to the sorptive capacity of conventional interior plaster. In addition, this keeps the indoor-air humidity for a longer period in the initially defined optimum range of 30 % to 55 % relative humidity (see Fig. 30).

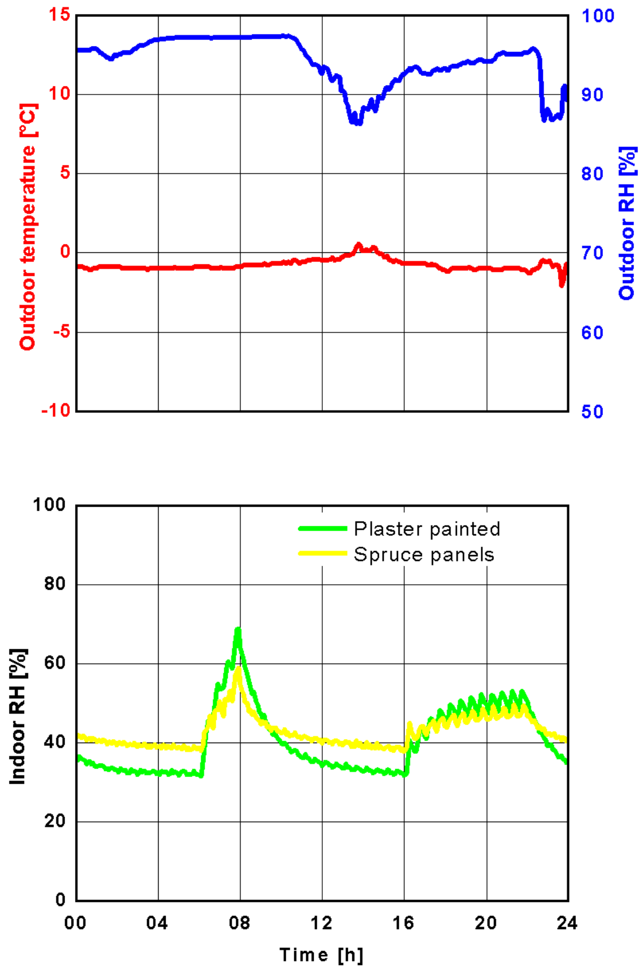

Fig. 27: Time profile of the exterior climatic conditions and of the air humidity in the test rooms lined with spruce panels or interior plaster during a representative day.

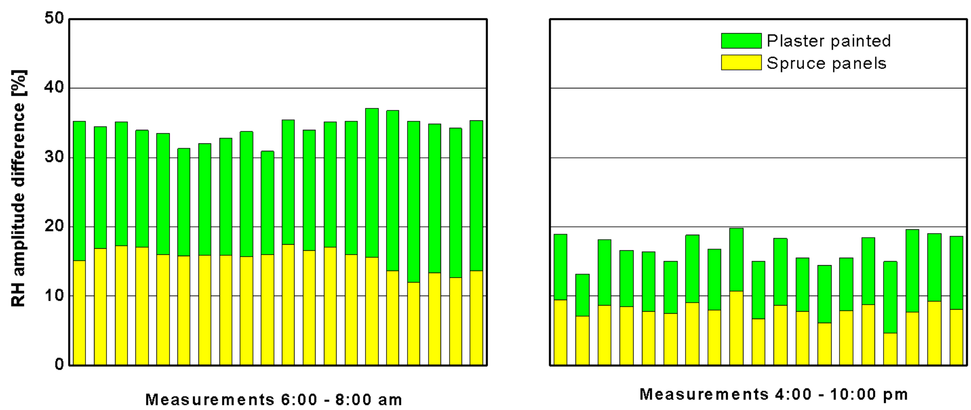

Fig. 28: Indoor air humidity amplitudes on particular test days in the experimental rooms containing spruce panels or interior plaster, during the moisture-production peaks in the morning (left hand) and in the evening (right hand).

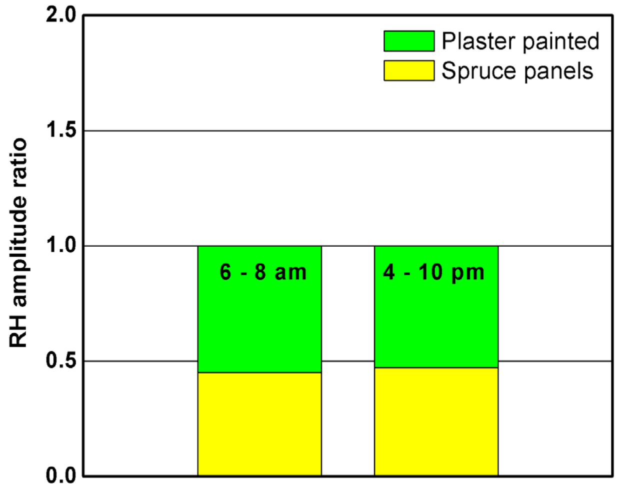

Fig. 29: Mean indoor air humidity amplitudes in the test room with spruce panels, related to the conditions in the reference room during the moisture production peaks in the morning (left hand) and in the evening (right hand).

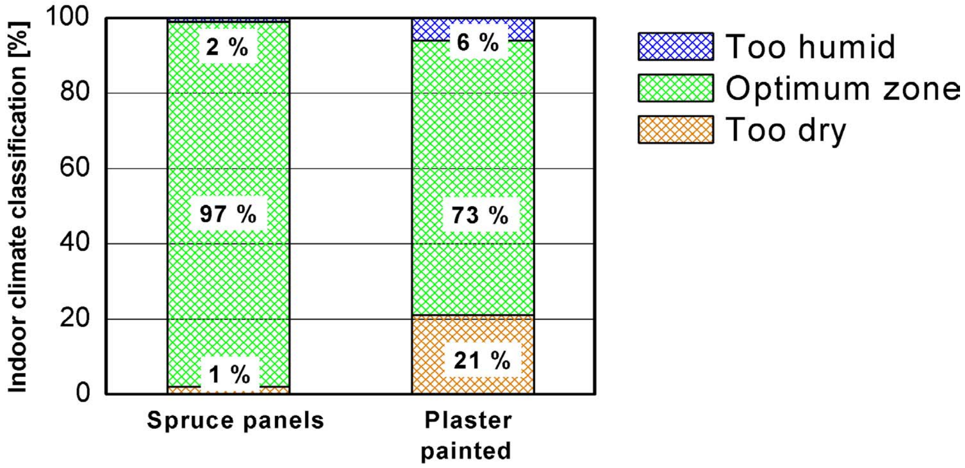

Fig. 30: Classification of moisture conditions in the test room lined with spruce panels and in the reference room (plastered) according to Fig. 1.

4.2.2 Test-room lining: Acoustic elements

Figure 31 shows a photograph of the acoustic elements; Figure 32 presents a section through these units. The acoustic elements are made of 9 mm birch plywood with drill holes (diameter: 8 mm). The outer surface of the plywood panel is coated with varnish, whereas the backside remained untreated. The plywood panel is attached to an 18 mm wood frame. Below the frame, there is a 12 mm sheet of wood fibreboard. The rear side of the fibreboard was rendered vapour-tight (like all of the other test-room linings) by applying spray-bonded aluminium foils. During the tests involving the acoustic elements, the outdoor temperatures were somewhat higher (see values in Fig. 33). Consequently, the mean level of the indoor air humidity was also somewhat higher than in the previous tests.

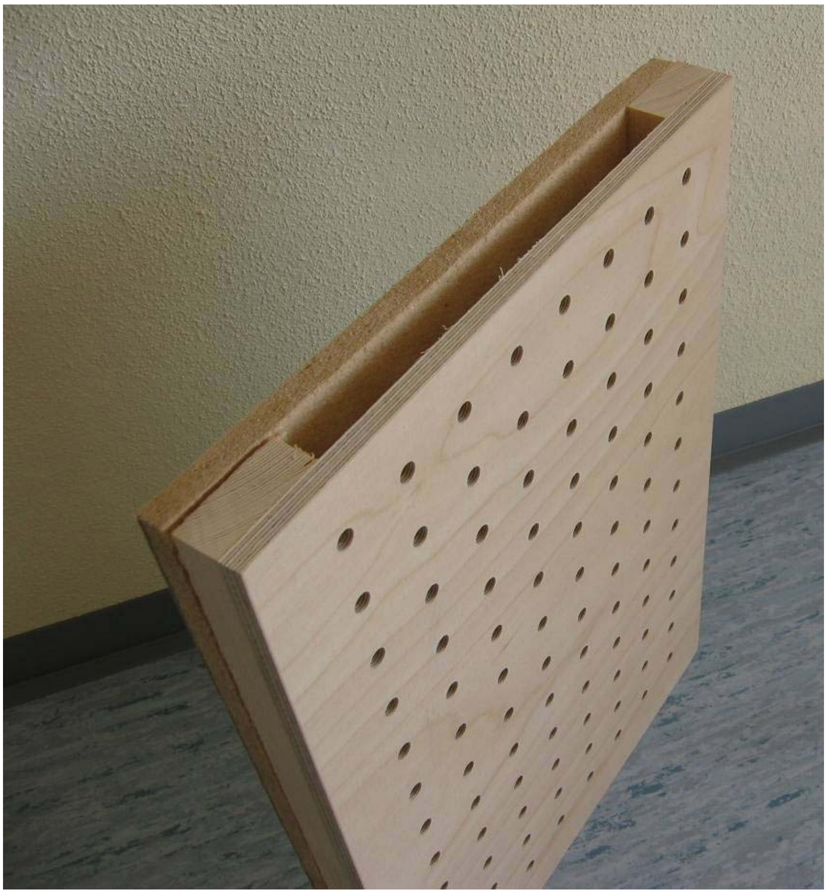

Fig. 31: Photograph of an acoustic element.

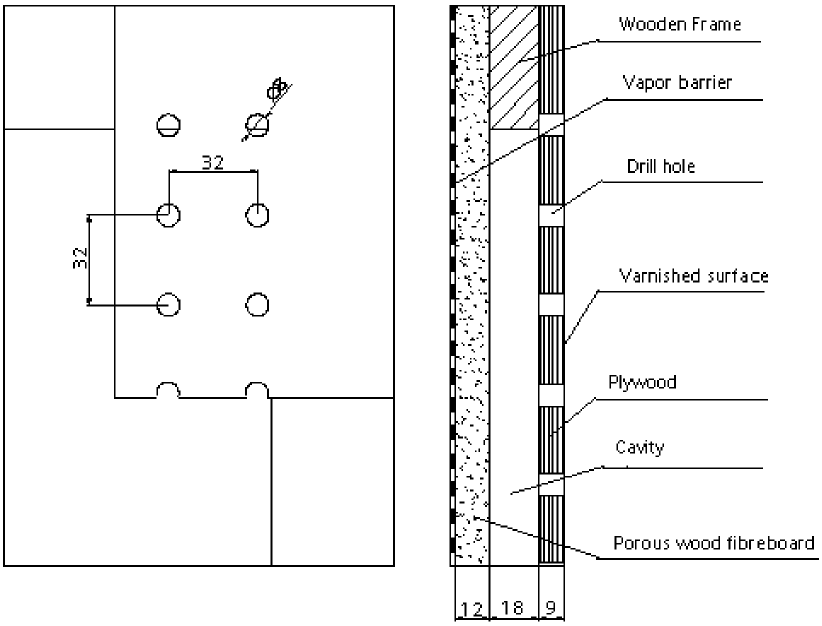

Fig. 32: Detailed drawing of an acoustic element.

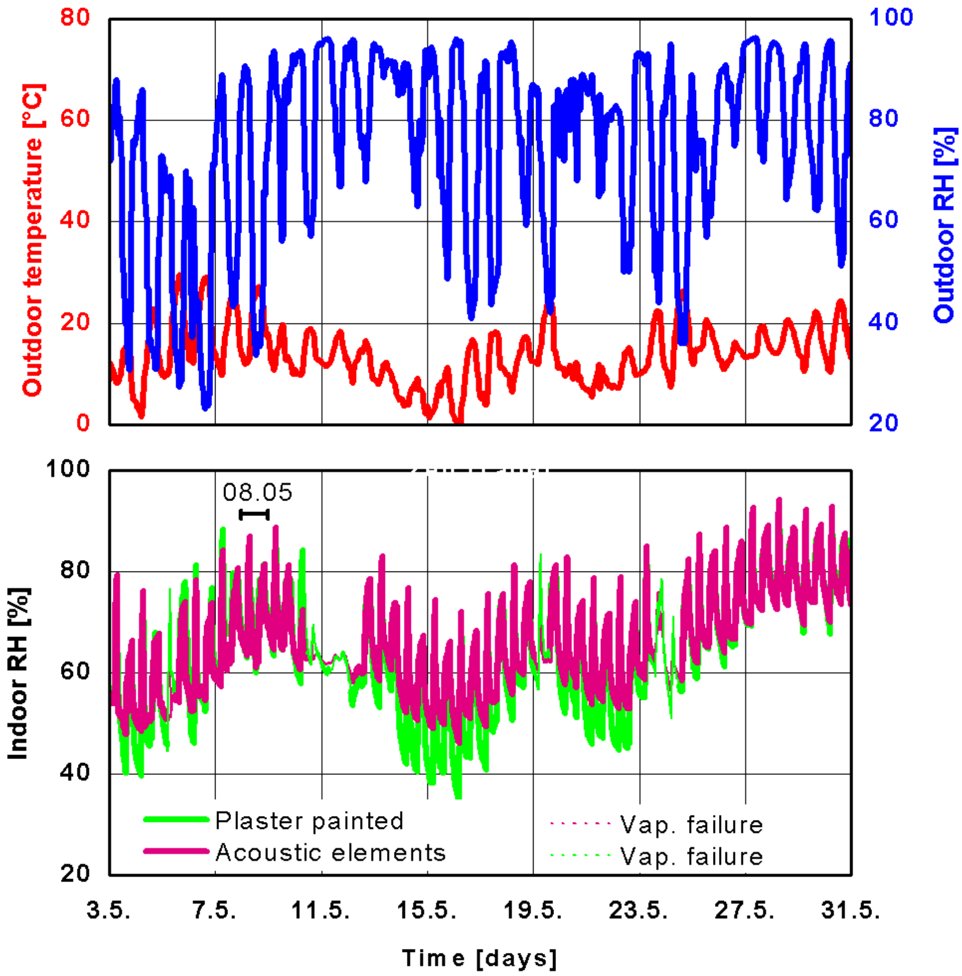

Fig. 33: Patterns of the recorded exterior climatic conditions and of the relative humidity in the test rooms during the measurement period.

In spite of the higher indoor-air humidity level, the moisture buffering effect of the acoustic panels can yet be quantified, as the same conditions were prevailing in the reference room, too. Figure 34 presents the comparative analysis of the indoor air humidity amplitudes following the morning and evening moisture-production peaks in the test room and in the reference room, for all of the test days. Arising vaporizer disturbances produced an untypical pattern on some days, which is why these results were not included in the average given in Fig. 35. The humidity reduction that was achieved by the acoustic elements amounts to 30 % approximately and is thus slightly less than the performance of the spruce panels.

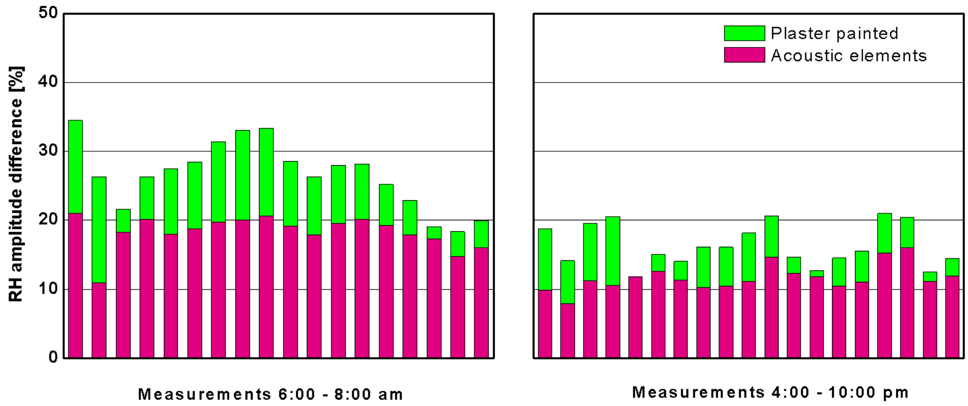

Fig. 34: Indoor air humidity amplitudes in the test rooms containing acoustic elements resp. interior plaster during the moisture-production peaks in the morning (left hand) and in the evening (right hand).

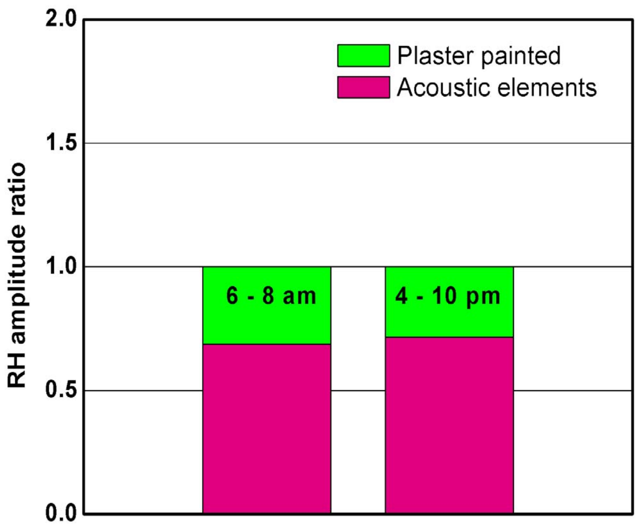

Fig. 35: Mean indoor air humidity amplitudes in the test room containing acoustic elements, related to the conditions in the reference room during the moisture-production peaks in the morning (left hand) and in the evening (right hand).

4.2.3 Test room lining: Insulating elements

Insulating elements with gypsum plasterboard were also tested with regard to their effect on the indoor climate during a comparatively warm period in 2003, from June 10 through June 24. These insulating elements (see Fig. 36) consist of a 45 mm wood frame the front side of which is covered with 12 mm plasterboard. The backside of the element is covered with a 12 mm plywood board. The intermediate space between the two boards was filled with 45 mm of cellulose fibre insulation. By covering the backside of the elements with a PE-film, any vapour sorption from the rear side was excluded, like in all the other test setups.

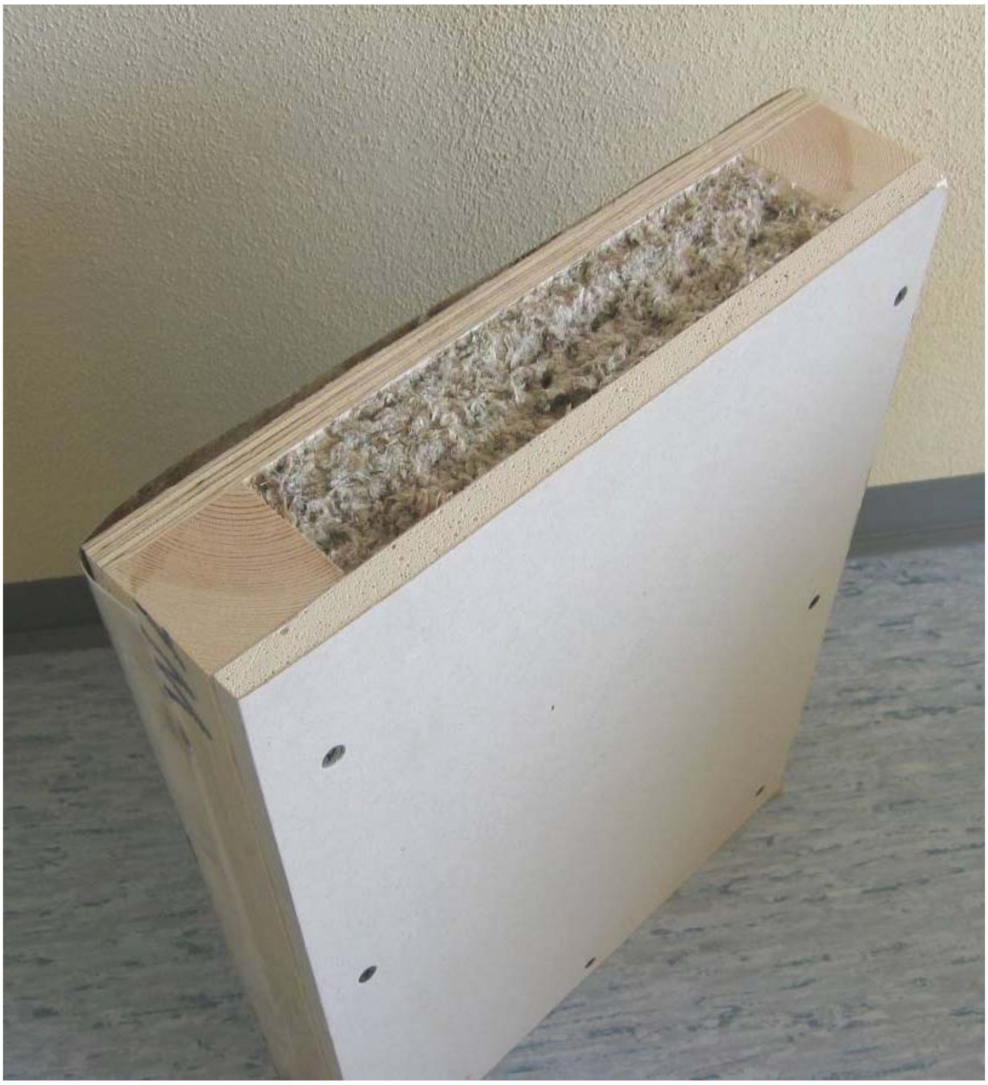

Fig. 36: Photograph of the insulating units under test

Figure 37 presents the exterior climatic conditions and the relative humidity in both test rooms in the measurement period. Because of the warm weather with a high level of absolute humidity, the indoor-air humidity is in the range of 60 % – 95 % RH. The comparison between the indoor-air moisture buffering effect in Fig. 38 and Fig. 39 does not show great differences between the test room and the reference room. Obviously, the gypsum plasterboard, which is in contact with the indoor air, has sorptive capacities similar to those of the gypsum-based painted interior plaster. The cellulose fibre insulation that was applied behind the plasterboard will only show some effect after a longer-lasting moisture production cycle. This is why the relative moisture buffer of the insulating units is slightly higher during the evening moisture production than in the morning (Fig. 39).

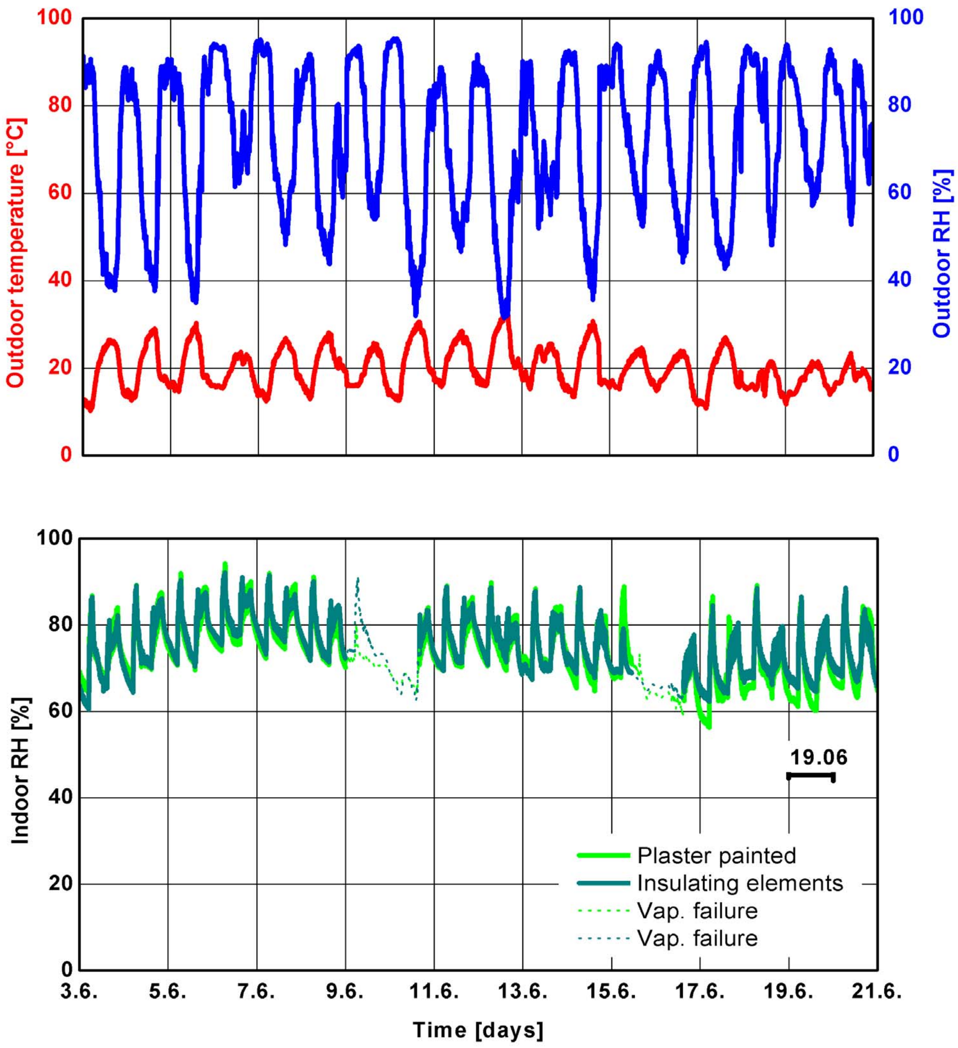

Fig. 37: Curves of exterior climatic conditions and relative humidity in the test room containing insulating units and in the reference room during the measurement cycle.

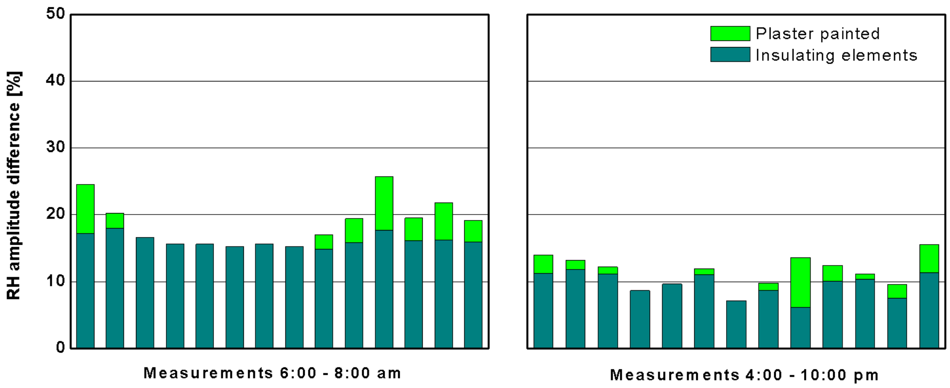

Fig. 38: Indoor air humidity amplitudes on particular test days in the test rooms containing insulating units or interior plaster, during morning (left hand) and evening (right hand) moisture-production peaks.

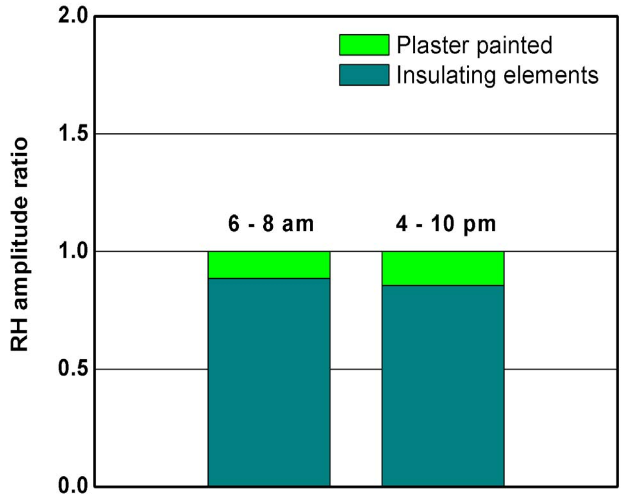

Fig. 39: Mean indoor air humidity amplitudes in the test room containing insulating units, related to the conditions prevailing in the reference room during the peaks of moisture production in the morning (left hand) and in the evening hours (right hand).

4.2.4 Test room lining: Round-log walls

The moisture buffering capacity of round-log walls was investigated in another test. For this purpose, unconditioned wall units made of pine logs were used (the kind that is used for log-cabin construction in Finland, for instance). These round logs have a diameter of 166 mm. Due to the wall units' geometry, it was not possible to line the test room completely with round logs. The logs were installed in the test room in such a way that all surfaces could be freely circulated by the indoor air (see Fig. 40). To ensure the uniform distribution of moisture in the room, the walls do not extend to the ceiling. In this way, the air can circulate above them. The logs have many drying cracks that are mainly due to the fact that the pith had not been removed. The projected total surface of the wall units amounts to 20.7 m². As the indoor air is flowing around them from both sides, this corresponds to a log-cabin wall area of twice this size (41.4 m²). Due to the round shape, the actual surface area increases by 10 m² to 51 m², though.

The sorption-active surface area of the round logs is somewhat larger because of the existing shrinkage cracks. Assuming an average crack length of 3 m and a depth of 30 mm, a crack surface area of approximately 17 m² results for the wall units under test. It is however uncertain whether the moisture sorption processes occurring between wood and air inside the cracks can be evaluated in the same way as those occurring at the exterior surface. The air inside the cracks will not change as fast as will the air at the external surface of the logs, neither by natural convection nor by forced air flow due to fans. Therefore, the air inside the cracks takes on the indoor air humidity only after a certain delay, and thus the crack surfaces cannot simply be added to the total surface area. Anyway, these considerations are not relevant for the comparison with other types of wall linings. Here, only the projected surfaces as compiled in Table 1 can be compared to each other.

The first test series was performed with free ends of the round-log walls (see Fig. 40). One half of the ends were exposed to the indoor air. The other half was mounted flush with the aluminium-lined test room wall to prevent any (or low) air circulation. This is the case in practical applications, as well. There are similar situations, for instance at corners of interior walls or at door apertures that are concealed by door frames (without being absolutely airtight).

Fig. 40: Photograph of the round-log walls mounted in the test room.

Figure 41 (top) presents the exterior climatic boundary conditions in the test period and the corresponding curves of the relative indoor-air humidity (bottom). The humidity profile of the test room lined with the round-log wall units appears to be dampened very strongly when compared to the reference room.

The mean humidity peaks determined from the curves in Fig. 41 were again related to the conditions in the reference room (see Fig. 42). During the comparatively short (but intensive) morning moisture-production peak between 6 am and 8 am, the amplitude reduction due to the effect of the round logs amounts to 52 %. During the longer (but moderate) moisture-production peak between 4 pm and 10 pm, the reduction even reaches 63 %.

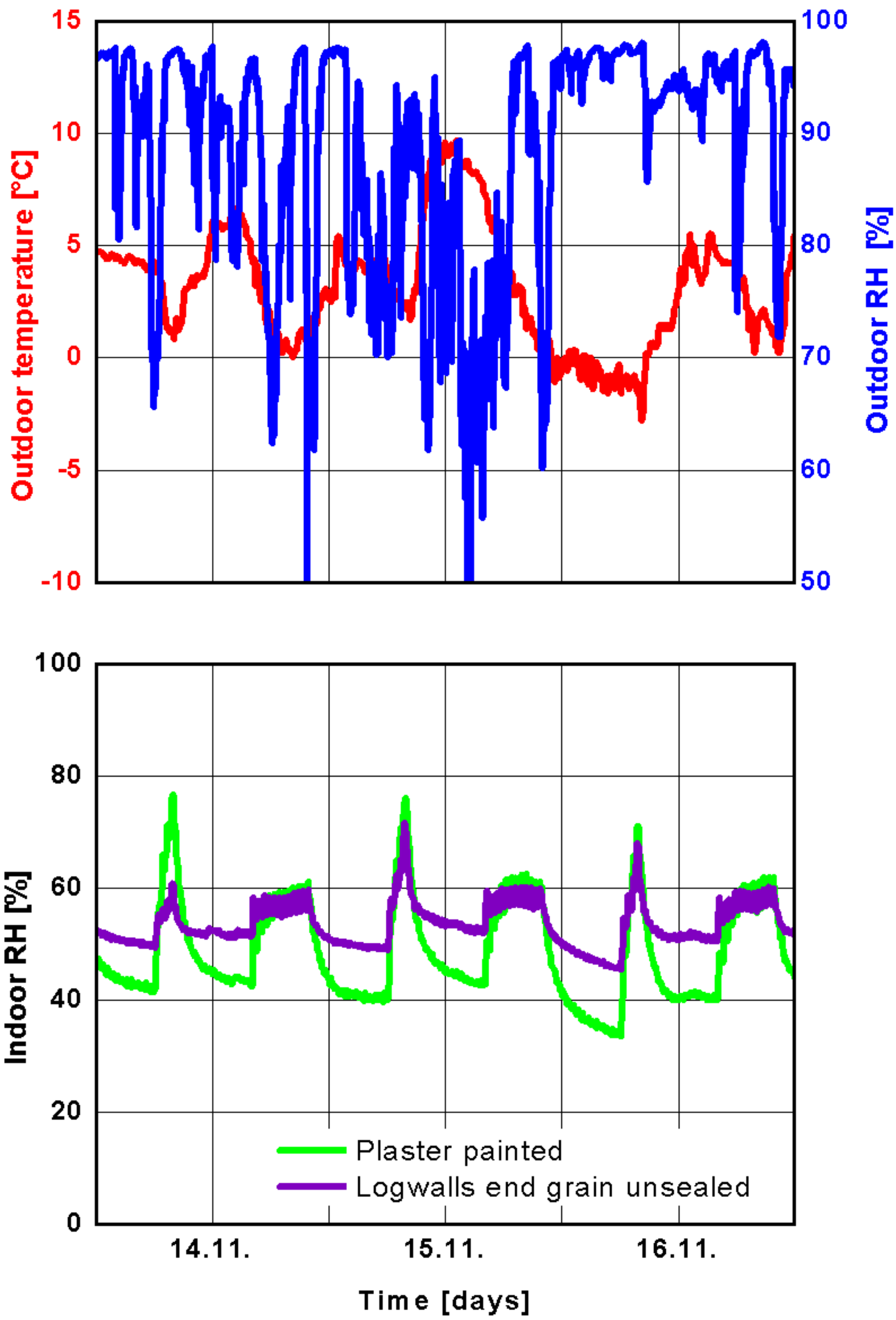

Fig. 41: Time profiles of the exterior climatic conditions and of the relative humidity in the test room lined with round-log units and in the reference room during the test period.

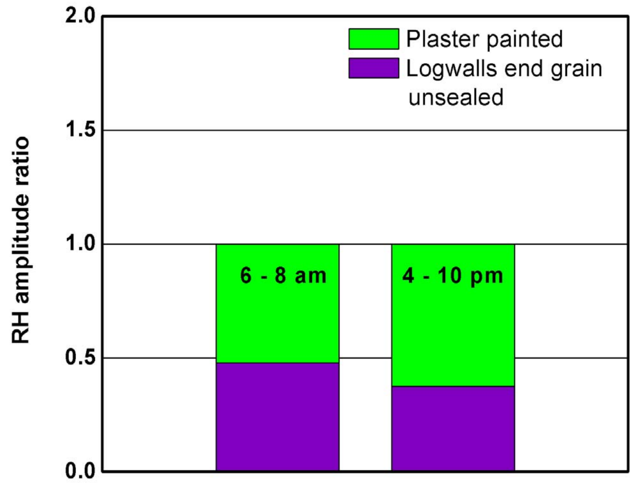

Fig. 42: Mean indoor air humidity peaks in the test room lined with round logs, related to the conditions prevailing in the reference room during the moisture production peaks in the morning hours (left hand) and in the evening hours (right hand).

Fig. 43: Photograph of the round logs with their ends tightly sealed.

Subsequent to the test series allowing free air circulation around the open faces of the round-log units, some further tests were performed, the interior face of the round-log walls now having been foiled with aluminium (see Fig. 43).

The time profiles of the outside air conditions and of the relative humidity in the test room and in the reference room are plotted in Fig. 44 for the 11-day test period. Like in the previous tests, the humidity fluctuations in the test room are clearly smaller than in the reference room.

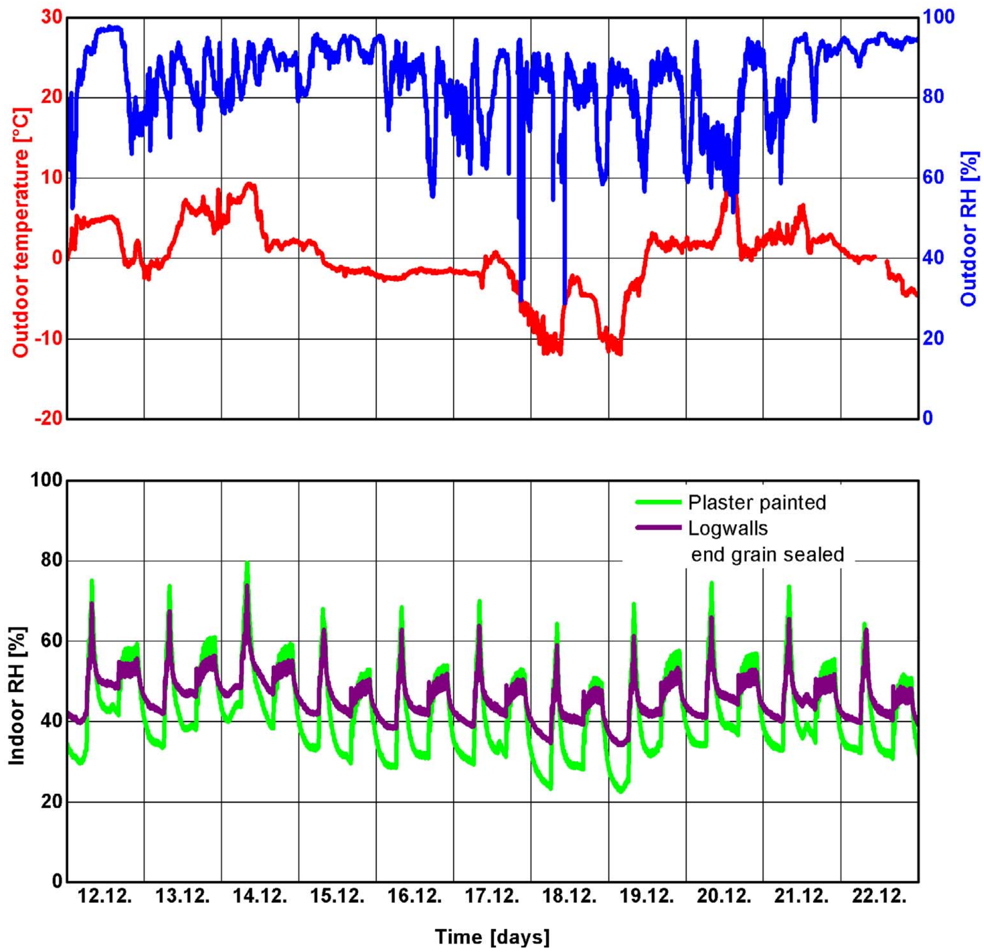

Fig. 44: Time profiles of the exterior climatic conditions and of the relative humidity in the test room lined with round-log units (ends sealed) and in the reference room during the test period.

Figure 45 shows the mean indoor air humidity amplitudes in the test room lined with round logs, related to the situation in the reference room. The amplitude reduction in the test room is about 44 % in the morning and 63 % in the evening. By comparison, the reduction amounted to 52 % and 63 %, respectively, when the ends were left unsealed. Obviously, sealing the ends does not seriously affect the moisture buffer capacity of round logs, at least not in the case of a longer moisture production cycle, that is. In Figure 46 the indoor air humidity is again classified according to Fig. 1 for the 11-day test period. Compared to the plastered wall, the round logs are keeping the indoor air humidity level in the optimum humidity range for a longer period. Their moisture-buffering effect thus corresponds approximately to the performance of the spruce panels.

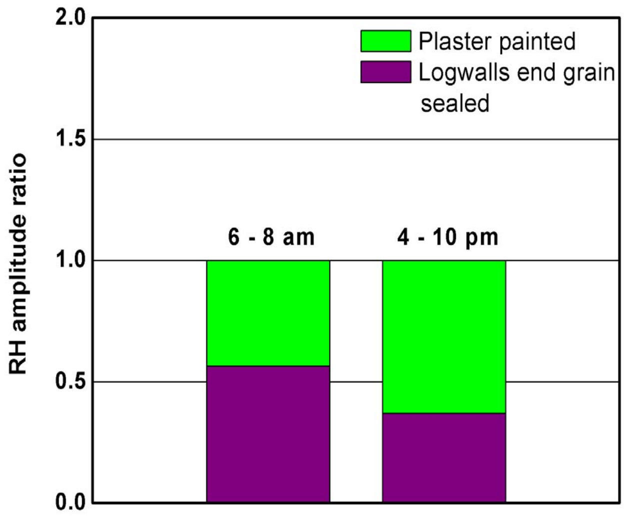

Fig. 45: Mean indoor-air humidity amplitudes in the test room supplied with the round-log units (ends sealed), related to the conditions in the reference room during the moisture production peaks in the morning (left hand) and in the evening hours (right hand).

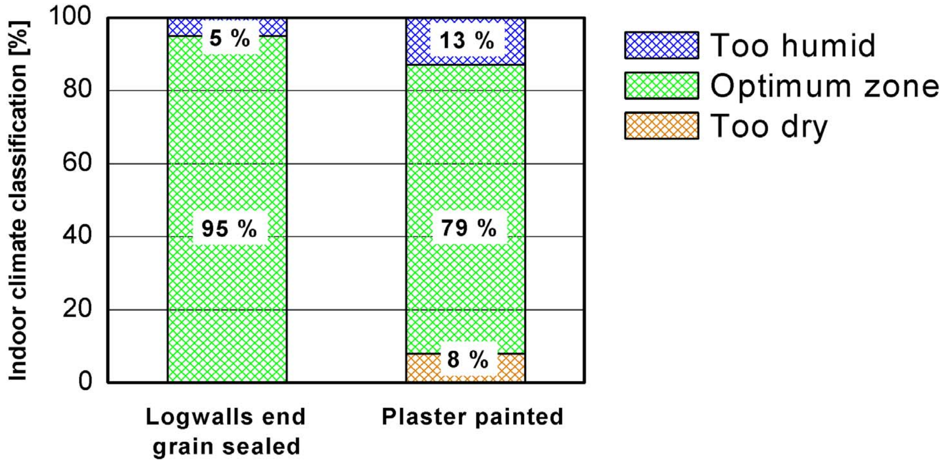

Fig. 46: Classification of the moisture conditions in the test room supplied with round-log wall units (ends sealed) and in the reference room (plastered) according to Fig. 1.

4.2.5 Test room lining: Wood fibreboard

Wood fibreboard is manufactured from cellulose fibres in a wet process. The setting process or bonding is based on the felting of the fibres and on the inherent bonding property. Because of its rough, mostly dark-coloured surface (see Fig. 47) wood fibreboard is usually not chosen for interior linings. However, as they were expected to produce a strong moisture buffering effect because of the high water vapour permeability in conjunction with an important sorption capacity of the wood fibres, it was decided to include them in the investigations. Here, untreated sheets of wood fibreboard (thickness: 22 mm) were used for the test room lining. The backside was made vapour tight (like all other test room linings, too) by applying a spray-bonded aluminium foil.

Fig. 47: Photograph of the employed fibreboard sheets (front and backside).

Figure 48 (top) presents the exterior climatic conditions of the measurement period. The lower part of the figure shows the relative humidity profiles for both rooms. Compared to the situation in the plastered reference room, the fibreboard lining causes a strong reduction of the indoor air humidity fluctuations in the test room. The daily humidity amplitudes that were induced by the moisture production peaks in both experimental rooms are presented in Fig. 49. The differences in the humidity amplitudes present a uniform image throughout the measurement period, i.e. the strong moisture buffering effect of the fibreboard lining does not degrade as time goes by. The mean humidity amplitudes shown in Fig. 50 were obtained by averaging the single results from Fig. and by relating them to the situation in the reference room. It turns out that the morning moisture production peak is reduced by 80 % and the evening peak by 75 %. Thus, the fibreboard lining is found to have the best moisture buffering capacity of all lining materials included in the test. Due to this strong moisture buffering effect the indoor air humidity remains in the optimum range for a significantly longer period, compared to the situation in the reference room (see Fig. 51).

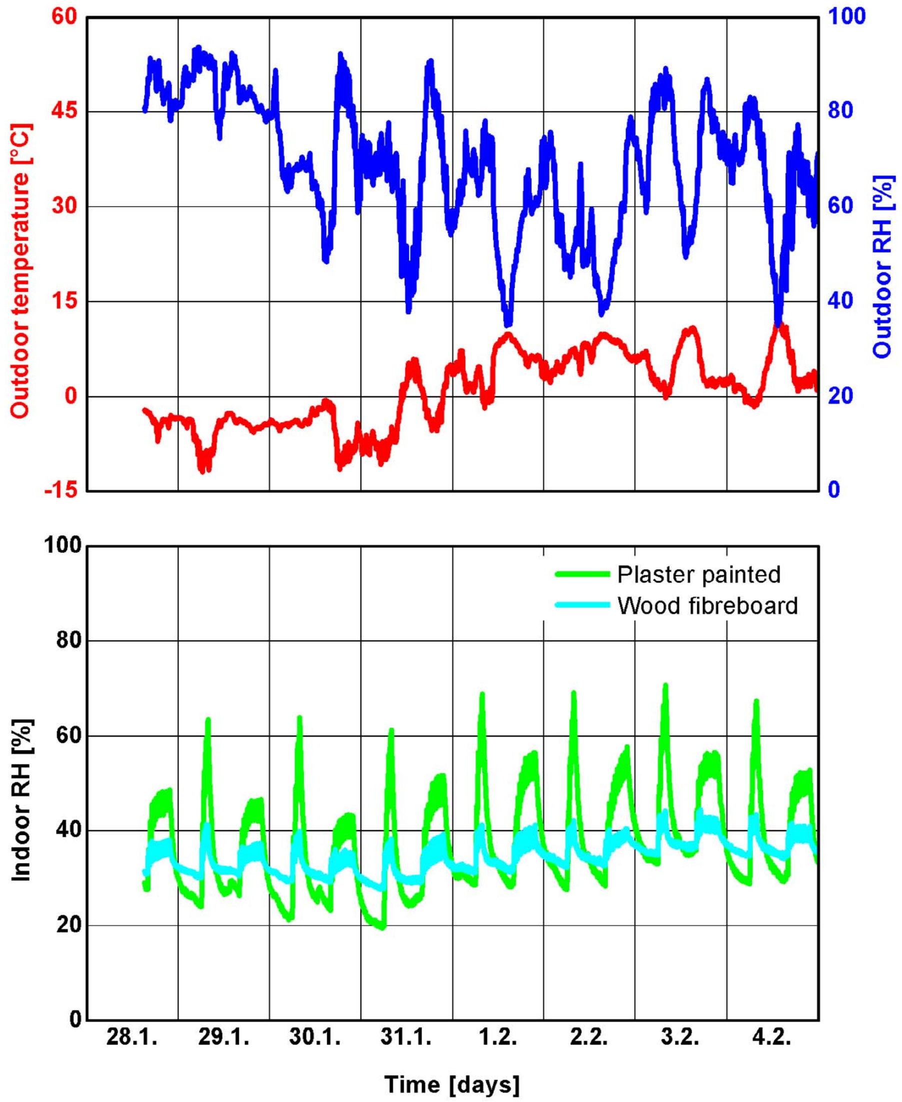

Fig. 48: Time profiles of the exterior climatic conditions and of the relative humidity in the test rooms during the measurement period.

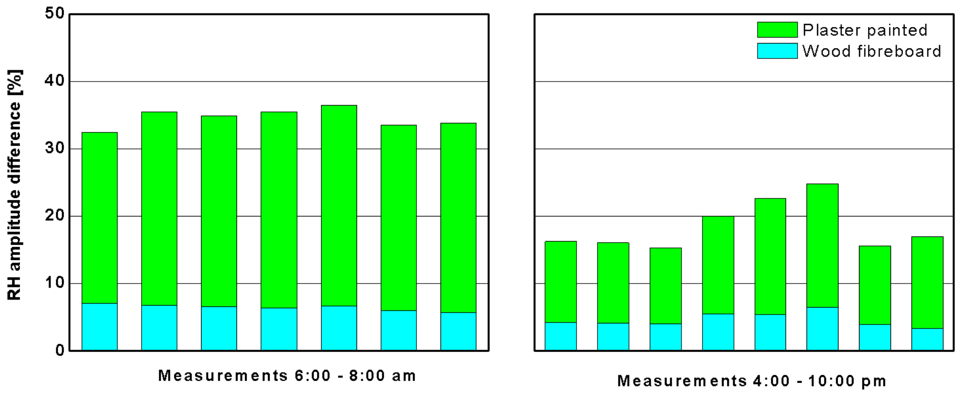

Fig. 49: Indoor air humidity amplitudes on particular test days in the experimental rooms lined with fibreboard sheets or interior plaster during the moisture production peaks in the morning (left hand) and in the evening (right hand).

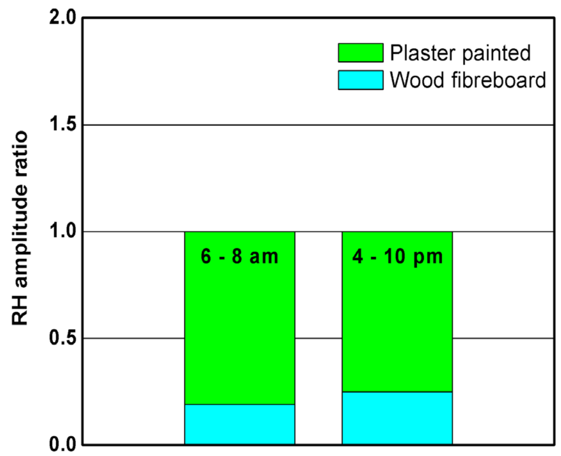

Fig. 50: Mean indoor air humidity amplitudes in the test room covered with fibreboard lining, related to the conditions in the reference room during the moisture production peaks in the morning (left hand) and in the evening (right hand).

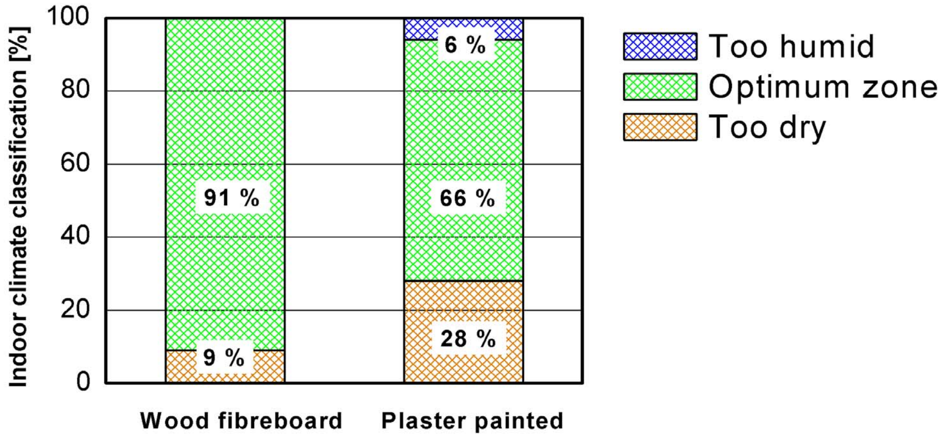

Fig. 51: Classification of the humidity conditions in the test room lined with fibreboard sheets and in the reference room (plastered) according to Fig. 1.

4.2.6 Comparison of the moisture buffering effect of the investigated interior linings

The reduction of the moisture production induced amplitudes of the indoor air humidity in the test room (in relation to the situation in the plastered reference room) is a measure for the moisture buffering effect of the test room linings. In order to be able to compare the moisture buffering by the different lining systems, the surface area of the linings in the test room should be equal in size. Except for the round-log walls, this is the case with all of the lining materials under test. As the projected area of the round-log walls is only a bit more than 60 % of the standard lining area, the amplitude ratio is correspondingly corrected in the compilation in Fig. 52. This results in a calculated humidity peak reduction of 65% (6:00 – 8:00 a.m.) res. 78% (4:00 – 10:00) provided by the log walls with sealed end grain and it allows for a direct comparison of the various test-room linings to the plastered reference-room wall and ceiling surface area of equal size.

Since the unlined test room has practically no hygroscopic moisture buffering capacity, the humidity amplitudes are larger there than in the plastered reference room. All the linings under test share a higher moisture buffering capacity than the painted interior plaster. Comparing the short-term moisture buffering to the somewhat longer-term buffering, it is found that the maximum buffer capacities of the various lining materials are not equally great. For example, the log walls seem to have advantages during prolonged moisture production periods, whereas the other lining materials tend to have a greater effect during short-term production peaks, when compared to the interior plaster.

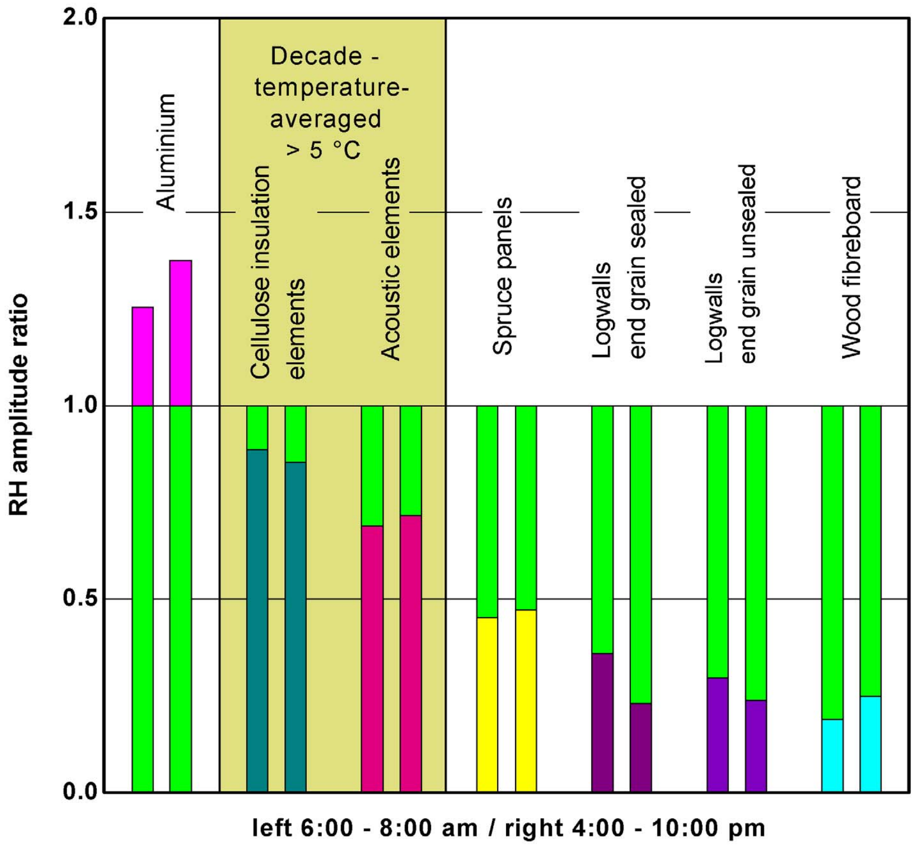

Fig. 52: Compilation of the determined mean humidity amplitude in the test room, related to the situation in the reference room and considering the respective projected surface area of the test room linings.

4.3 Effects of textile materials on the indoor climate

As most residential rooms contain textiles or other moisture absorbing objects in addition to the linings of walls and ceilings, their impact on indoor humidity fluctuations was investigated by suspending woollen blankets in the test room. The humidity time profiles measured in the unlined test room containing several woollen blankets (total surface area approx. 17 m²) and in the reference room are given in Fig. 53 along with the exterior climatic conditions. The woollen blankets obviously reduce the humidity variations in the test room. This reduction approximately corresponds to the situation in the reference room, with a somewhat stronger effect during the short-term moisture production peaks in the morning. This also becomes evident when looking at the profiles of a representative day in Fig. 54.

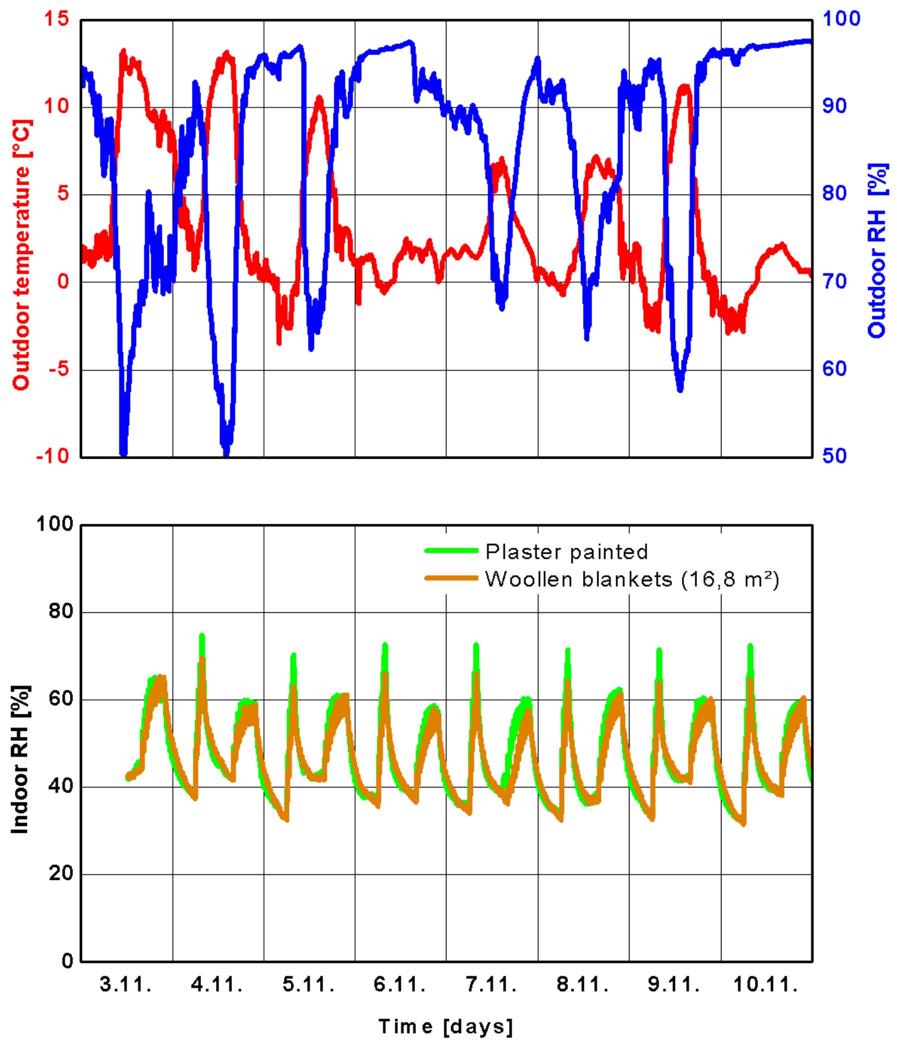

Fig. 53: Time-profiles of exterior climatic conditions and relative humidity in the unlined test room containing woollen blankets and in the plastered reference room during the 8-day measurement period.

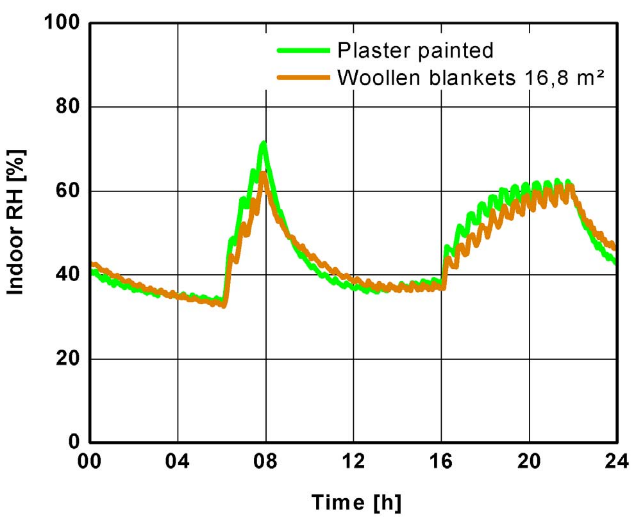

Fig. 54: Detail of a representative day in the period of measurement presented in Fig. 53

In spite of the smaller surface area of the woollen blankets, the active surface (33.6 m²) actually amounts to about half of the surface area of the plaster in the reference room only, the short-term moisture buffering effect is slightly better than with the interior plaster. This becomes evident when looking at the amplitudes shown in Fig. 55. This relationship will, however, become reversed if the moisture production continues for a longer period. Moisture buffering inside the reference room is now better than in the test room because the vapour storage capacity of the woollen blankets is exhausted more rapidly than that of the interior plaster.

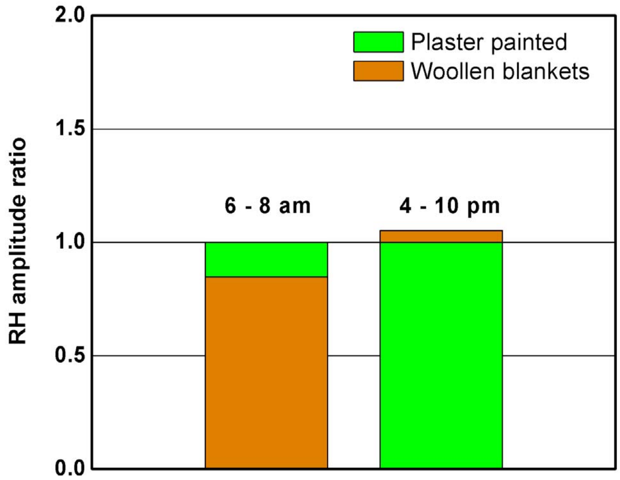

Fig. 55: Mean indoor air humidity amplitudes in the unlined test room with suspended woollen blankets, related to the conditions in the plastered reference room during the moisture production peaks in the morning (left hand) and evening hours (right hand).

5 Summary and Conclusions

A series of experimental investigations was performed at the outdoor testing facilities of the Fraunhofer Institute of Building Physics (IBP) in Holzkirchen, Germany in order to determine the moisture buffering effects of internal linings made from wood or wood based building products in comparison to the performance of an interior plaster customary in German residential buildings. For this purpose, two identical test rooms located in an existing test hall were carefully sealed and provided with a calibrated ventilation system. The reference room was coated with a conventional lime-gypsum interior plaster and a vapour permeable paint. The test room was lined all over with aluminium foil to exclude any disturbing influences. The floors in both test rooms were covered with a vapour-tight PVC-surfacing. The daily repeated moisture-production cycle that was run in both spaces is typical of the conditions in living spaces. It was generated by means of ultrasonic humidifiers. Humidity and temperature sensors measured the indoor climate data in both experimental rooms. These data were continuously recorded by the data acquisition system. Due to the outdoor climate's effects on the indoor humidity level, all measurements were always performed in parallel, ensuring that ventilation and humidification were the same in the test room and in the reference room. To determine the moisture buffering capacities of various interior linings, the test room (that had been made inert with regard to moisture) was covered with untreated linings consisting of spruce panels made from tongue-and-groove boards, acoustic elements, cellulose fibre insulation units, solid round logs made of Scandinavian pine and wood fibreboard sheets. By comparing the indoor-air humidity amplitudes resultant during a moisture production peak in the lined test room and in the plastered reference room, the moisture buffering capacities of the various surfacing materials under test could be quantified.

It was found that all of the investigated linings show a moisture buffering capacity superior to that of the conventional interior plaster. This helps to keep the indoor air humidity in the hygienically optimal humidity range for extended periods of time. However, the investigated interior linings were also found to differ greatly in their effects. Whereas the untreated spruce panels reduce the indoor-air humidity fluctuations by more than 50 %, the Scandinavian pine logs have the ability to enhance the buffering capacity even more if they cover the same wall surface area (65% - 80%). In contrast, the insulating units and the acoustic elements will achieve a humidity reduction which is only 15 % to 30 % better than the reduction due to an interior plaster. In the latter cases, this is due to the fact that the sorptive material layers are not directly exposed to the indoor air. In the case of the insulating elements, the water vapour must first diffuse through the plasterboard sheet before being absorbed by the cellulose fibres. In the case of the acoustic elements, the water vapour must pass through small holes before reaching the sorptive wood fibreboard and the backside of the plywood sheet. In the latter case, however, some improvement could be achieved by simply designing the apertures in the plywood sheet such as to allow for some air circulation through the acoustic units under living space boundary conditions.

While the log walls had the best long-term buffering capacity, the best short-term moisture buffering effect was achieved by wood fibreboard. With an amplitude reduction of almost 80 % they excel all other linings in the test. This outcome is of purely academic interest, however, as in practice they will hardly be used for interior linings without adding some surface finish. It should also be considered in this context that all other linings, too, will only reach the full moisture-buffering capacity determined in the test if they do not receive any surface treatment. As was found in experiments presented in [10], surface coating will reduce the water vapour absorption by the base material, which will become clearly apparent with coatings or with wax layers, in particular.

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