Keeping risks at bay – improving a test method to reliably quantify the capability of capillary active interior insulation

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SUMMARY:
Conventional laboratory tests for the determination of liquid transport are not fully appropriate for interior insulation purposes, as they tend to overrate the transport ability under non-isothermal conditions in the hygroscopic region, and, in some cases, are not possible at all. A new test method, the Capillary Condensation Redistribution test, has recently been developed by Fraunhofer IBP. This test is specifically designed for the needs of interior insulation and is also appropriate for moisture-sensitive materials. Via hygrothermal simulation, transport characteristics are determined, enabling a close reproduction of CCR-measurement results. The data is cross-checked (where possible) by numerically simulating standard drying tests. While the results of both tests can be simulated with good correlation each, comparisons show that the drying test parameters overestimate the redistribution process of interior insulation. At the same time, the CCR-test parameters partially underestimate the isothermal drying process. To provide a single set of material parameters for hygrothermal simulation, a consolidation of transport characteristics derived from both tests is done. Numerical reproductions of field tests prove the validity and reliability of CCR and combined parameters.

1. Introduction

Interior insulation systems sometimes are met with reservations still by planners and builders (Worch 2010). Due to their complex hygrothermal behaviour, a thorough analysis of all hygrothermal processes is necessary (Worch et al. 2012) in order to keep harm from the construction. For this, transient hygrothermal simulations have proven valuable and are recommended by building physicists (Scheffler & Schoch 2013, Engel 2012, Binder at al. 2012) as well as national and international standards and guidelines (DIN 4108-3:2012, WTA-Guidelines 6-4: 2009 & 6-5:2013, EN ISO 15026:2007). The reliability of the respective simulation results hereby strongly depends on the quality of input parameters such as specific material properties.

In contrast to conventional systems with vapour retarders, capillary active insulation systems utilize the materials ability to store and transport liquid moisture inside their pore system in order to balance the construction moisture content. For this, the specific liquid transport of the insulation material is important; however, the measurement of this characteristic tends to be challenging due to the complex nature of both the materials pore system and the moisture transport processes in general.

For interior insulation, the relevant boundary conditions are non-isothermal, inducing counteracting mass transfer (liquid and vapour). Also, humidification predominantly occurs as a result of water vapour diffusion from the interior air towards the cooler parts of the construction. Here, transport processes are dominated by the rather slow suction velocity inside smaller pores.

This situation cannot be reflected by conventional tests (EN ISO 15148:2003, Holm & Krus 1998). Developed and valid for material in contact with natural weathering, they are not fully appropriate for interior insulation purposes: As the isothermal conditions here produce rectified transport processes, the measured liquid transport may exceed the real one. The high amounts of water applied to the samples additionally lead to an overestimation of the liquid transport, as here, the transport is dominated by the rather high suction velocity inside larger pores. Evidence for this has been found in the context of internal research at IBP and is also supported by external data: Kloseiko et al. (2013) have shown that the results of numerical reproduction of the measured moisture content of interior insulation constructions undercut measurement values. Furthermore, for materials sensitive to liquid moisture, e.g. fibre insulations, the conventional tests sometimes cannot be evaluated at all, as they result in agglutinated or slumped material samples.

Hence, the Fraunhofer-Institute for Building Physics has developed a new laboratory method considering the specific needs and boundary conditions of interior insulation materials. Via numerically simulating the measurement results, liquid transport characteristics for the hygroscopic region are determined. Simulations with respective characteristics have shown good correlation of both measurement and simulation results (Binder et al. 2010) and are valid for these moisture regions and circumstances. Although the respective boundary conditions and transport characteristics clearly are the dominant ones concerning interior insulation and, technically, higher moisture contents should not be reached at all inside interior insulation materials, it cannot be ruled out that sometimes, higher moisture contents or different humidification processes may occur. In order to reliably predict the moisture behaviour of a material, its liquid transport characteristics should therefore also cover the drying behaviour under isothermal conditions as good as possible.

2. Capillary Condensation Redistribution test

2.1 Test concept and procedure

The new method, the Capillary Condensation Redistribution (CCR) test, considers the specific conditions of interior insulation (Binder et al. 2010, Zirkelbach & Binder 2011). In imitation of the real-life boundary conditions of interior insulation, the CCR-test works with non-isothermal conditions and opposing liquid moisture and water vapor flows, with humidification only by vapor diffusion.

In the first phase of testing, the testing device was aligned horizontally, providing for horizontal moisture flows similar to real ones. Experience showed, however, that this may distort the moisture behaviour (Binder et al. 2010), as a runoff of condensation moisture can occur. In continuation of the original idea, the device was modified to vertical orientation. As liquid transport works independent of orientation, unaltered liquid transport characteristics can be expected. Figure 1 shows the set-up of the test.

Under laboratory conditions, a dew-point undercut is applied to one side of a laterally sealed material sample. This produces temperature and partial pressure gradients, and, consequently, vapour diffusion into the material. The adsorbed moisture is condensing at the sealed back side of the material, where it causes an increase of relative humidity. Hence, the moisture content inside the material sample rises. Due to the increasing gradient of relative humidity, a liquid transport back to the front surface of the sample sets in. Eventually, the opposing moisture fluxes will reach dynamic equilibrium. To reveal the hygrothermal behaviour of the material samples during testing, two modes of measuring are taken: Through periodic gravimetrical measurements, the moisture gain is analysed and documented for the entire test period. The moisture distribution in the samples cross-section is measured periodically by using nuclear magnetic resonance spectroscopy. By recomputing both the measured moisture distribution as well as the moisture gain via numerical simulation, highly detailed parameters for the moisture transport in the hygroscopic region are determined.

The tests are executed in a climate chamber with steady-state conditions. The dried and sealed material samples are applied to a carrier plate with heat conductive paste. All boundary conditions are measured and documented for the testing period. Regularly, the samples are removed from the test setup in order to measure their moisture content; the moisture distribution is measured at the beginning and end of the test period, as well as at certain times during test period.

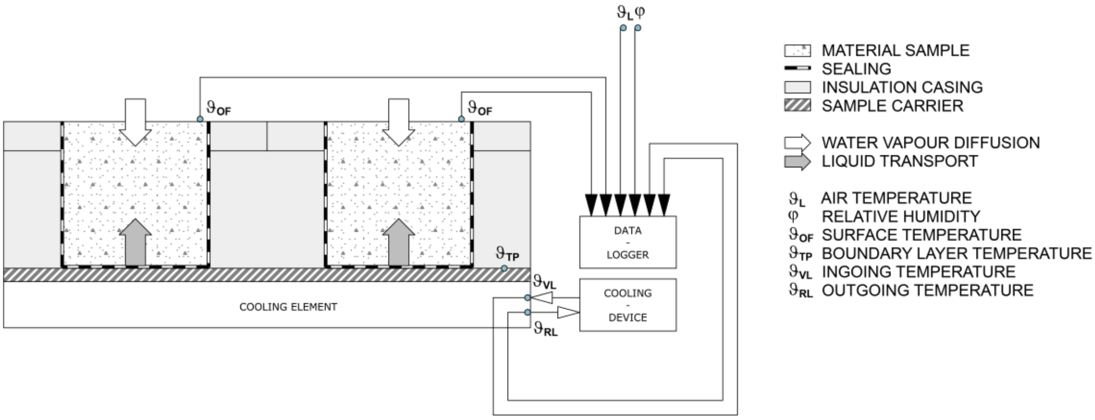

FIG 1. Setup of the new Capillary Condensation Redistribution (CCR) test developed for the measurement of liquid transport inside capillary active insulation material.

2.2 Test results

As an example of conventional capillary active materials, figure 2 shows the moisture development of calcium silicate samples during CCR test. To the right, the moisture content (MC) of three samples is shown for the entire test period of 5 weeks; to the left, the measured moisture distribution (MD) at different points of time (left) is shown for one of the samples. The tests were executed under climate conditions of 72 % RH and 22.7 °C and rear temperatures of 12.0 °C. Starting from sorption moisture content, samples gain weight fast at the beginning of the experiment, with vapour diffusion still taking place to its full extent. With time advancing, the moisture gain is decelerated by an insetting liquid transport (surface diffusion and capillary suction). After 4 weeks, a maximum MC of approximately 50 kg/m³ is reached. Now, there is only little discrepancy to be seen between the results of the different samples. The MD shows steady development: From an even distribution at start of the tests, moisture increases with time advancing, always showing a maximum at the sealed, cool back side of the sample. Towards the open-faced front surface, a comparatively even decrease of moisture is exhibited.

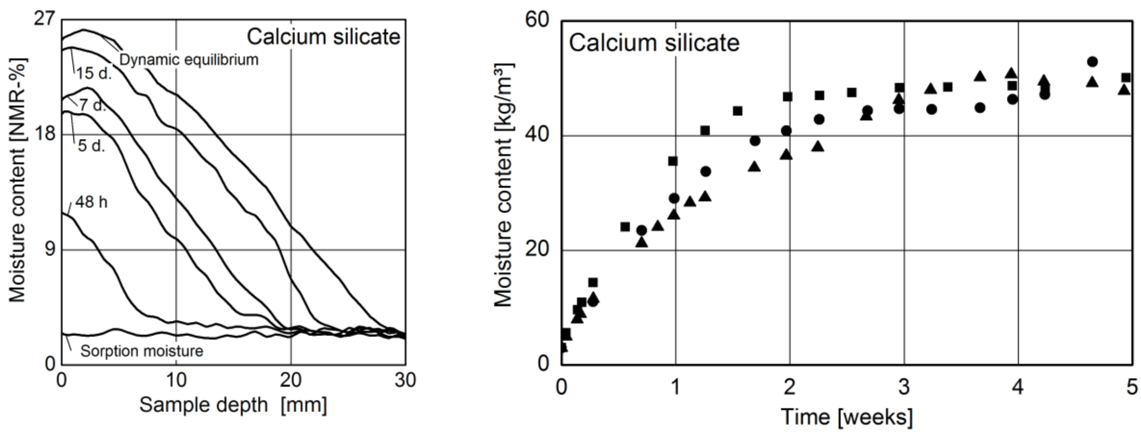

FIG 2. Results of CCR measurements for calcium silicate. Left: moisture distribution at different points of time; right: development of the moisture content for the entire test period

2.3 Determination of transport characteristics

The transport coefficients are determined by numerical simulation with WUFI® (Künzel 1994). For this purpose, the measurement results are processed prior to their implementation into the software, exporting the moisture gain characteristics for the entire test period and the MD at dynamic equilibrium (or at the end of testing). Simple values, based on the A-Value, as described by Holm and Krus (1998), serve as initial values. Step-by-step, these values are adapted in order to gain a good correlation of calculated and measured moisture gain and distribution. Figure 3 shows the measurement results of the CCR test for autoclaved aerated concrete (AAC) compared to simulation results (chain dotted line). When calculated with CCR-test parameters, good correlation can be reached for both moisture distribution (left) and gains (right); only slight deviations can be detected in lower moisture regions. After 12 weeks of testing, still no dynamic equilibrium could be reached; the MC measures up to app. 38 kg/m³. At the rear side of the sample, a maximum MC of app. 110 kg/m³ can be detected, equivalent to a RH level of almost 100 %.

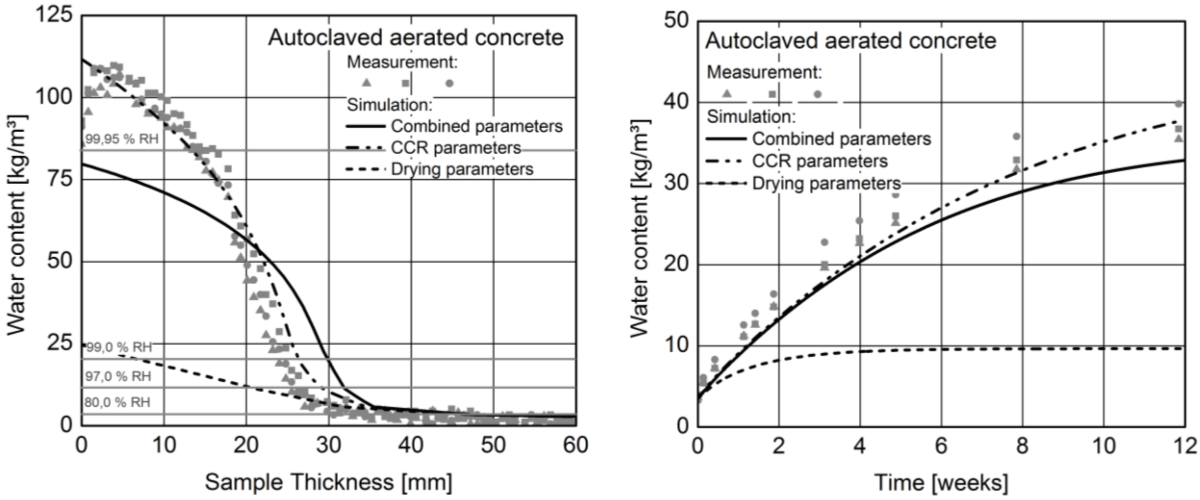

FIG 3. Results of CCR measurements for AAC compared to simulation results with different sets of liquid transport parameters. Left: moisture distribution at different points of time; right: moisture gradient for the entire test period

As mentioned before, the material properties shall enable also a realistic reproduction of the materials drying behaviour. The output of conventional drying tests (where possible/applicable) is reproduced in numerical simulation hence to verify the liquid transport coefficients. Respective results for the AAC material are shown in figure 4. With unaltered CCR parameters (chain dotted line), the drying process is underestimated. After a period of 600 h, the calculated moisture content still outruns the measured values. A cross-check of the drying parameters (dashed line), however, shows that these, on the other hand, do not reflect the measurement results of the CCR test (app. 75 % lower), showing good correlation for the drying test itself, though.

This proves that, while reaching good results in their respective area of implementation, neither of the methods solely is able to reproduce both drying (rectified) and redistribution (counteracting) moisture transport processes. Thus, in an additional step, hence, liquid transport parameters are adapted further, coupling the results of both tests. It showed, however, that it is hardly possible to perfectly reproduce both processes with one single set of combined parameters. This is due on the one hand to the diverging moisture transport processes and boundary conditions, on the other hand to the inevitable simplifications generally needed in simulation tools in order to transform a complex real material into a material data set.

Compromising both tests as good as possible, figures 3 and 4 show the results of simulation (solid line) with combined parameters. Compared to measurements and the “ideal” simulation with separately determined DW_Ws, simulation results still show deviations; however, these deviations are considerably lower than with the respective other parameters (drying and CCR). The selection of the specific parameter set thereby is, to a certain extent, an arbitrary act; however, in consideration of its rather close conformance with real conditions, the reproduction of CCR-test results should be granted priority to that of rectified drying processes.

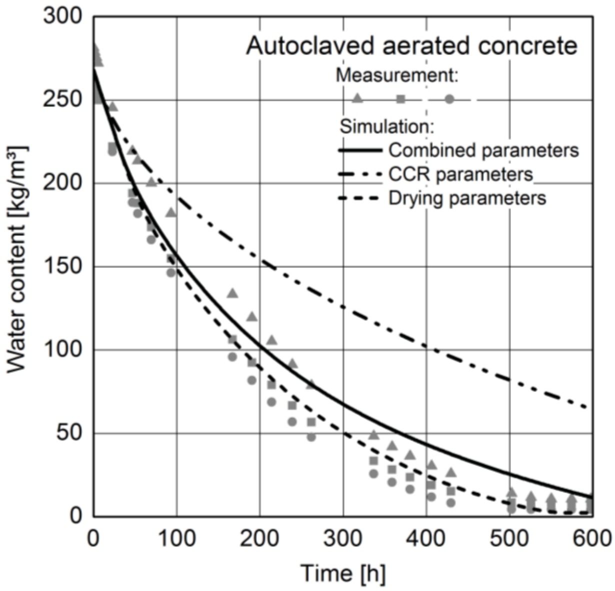

FIG 4. Results of drying tests for AAC compared to simulation results with different sets of liquid transport parameters.

3. Validation & comparison

3.1 Test concept and procedure

To validate both concept and procedures of the CCR test, a field test is done at the facilities in Holzkirchen. In a partitioned test façade (interior climate 25 °C, 50 % RH), an interior insulation assembly is installed into wooden framework with 500 x 500 mm diameter. The basic composition (from the exterior) is 20 mm lime-cement render, 240 mm solid brick and 20 mm plaster (to create an even surface for the insulation layer). The AAC material used for interior insulation is sealed laterally to inhibit any side influences. At the rear side, aluminium foil is applied. Naturally, this is an addition not reflecting the actual situation, but is providing for measurement results that solely reflect the materials hygric behaviour in itself without any manipulation from possible suction processes of backing material. At the interface of insulation and aluminium foil, both temperature and relative humidity are continuously recorded. As traditionally, RH measurement at higher moisture regions is somewhat challenging, additionally, thin wooden plates equipped with wood-moisture probes are embedded. All exterior climate parameters are measured by the IBPs weather station; for interior climate, temperature and relative humidity are measured.

3.2 Test and calculation results

The experiment started in November 2011. As the materials were implemented into the structure without preceding conditioning, their initial moisture contents were not equal. A period of adjustment therefore marks the first weeks of the test period. The following paragraphs only refer to the period after comparable moisture contents have been reached (1.2.2012 – 31.1.2013). Figure 5 shows the temperature of the exterior air and at the rear side of AAC. Starting at around 5 °C (interface) and -7 °C (exteriorly), temperatures drop in the first days of February and start rising in the 2nd half of February, with maxima showing from late June to August. While larger temperature differences between outside and interface can be detected during winter, towards summer, values are closer.

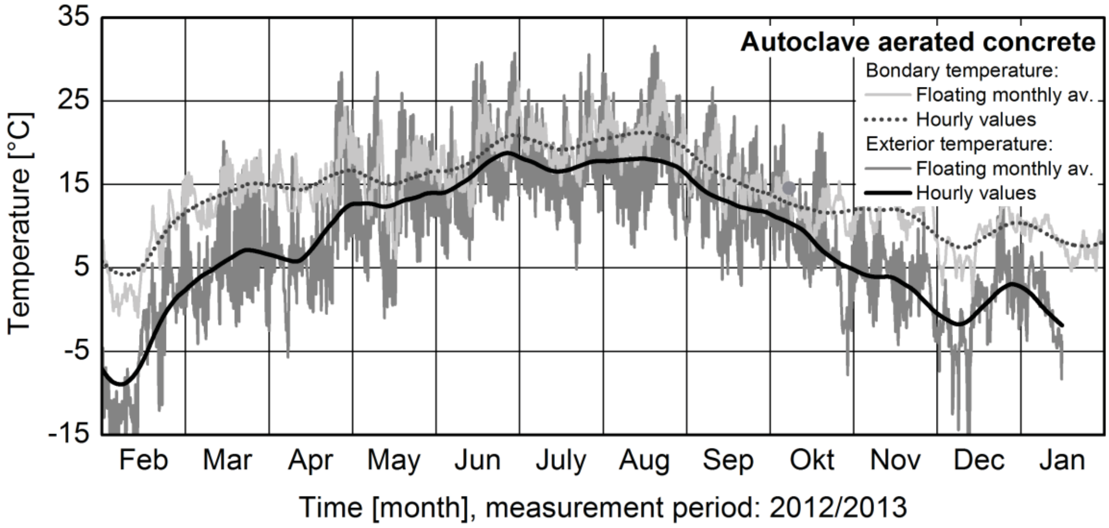

FIG 5. Results of a field test of interior insulation assemblies in Holzkirchen. Temperatures of the exterior air and at the rear side of AAC interior insulation according to measurements.

Figure 6 shows the development of RH at the rear side of AAC. During winter time, approximately 100 % RH are reached, as the moisture settles at the rear side of the insulation. With rising temperatures, redistribution and drying processes (both diffusion and liquid transport) set in; consequently, RH levels fall (starting in April). In autumn, the decrease of temperatures is followed by rising RH levels, reaching 100 % RH again in December.

The graph also shows the results of numerical simulation for the different parameter sets described above. With drying parameters, the rather fast drying process (during spring) can be retraced with good concordance. However, it is not possible to reproduce the high RH levels measured during winter: calculated maxima are approximately 15 % lower than actual ones. Both with CCR as well as with combined parameters, however, 100 % RH are reached during winter time, reflecting the measurements very closely. The rather fast decrease of moisture during spring can be retraced with a setback of approximately one week with combined parameters and two weeks with CCR parameters. With all three parameter sets, RH levels during summer generally can be reproduced with good accordance, levelling out any extremes to a certain extent, however.

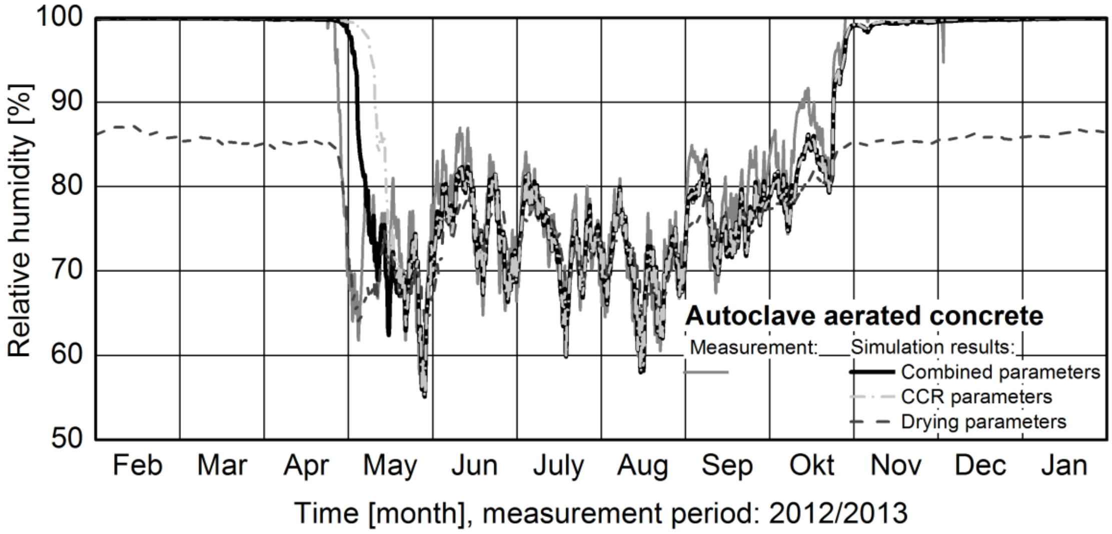

FIG 6. Results of a field test of interior insulation assemblies in Holzkirchen. Level of relative humidity at the rear side of AAC-interior insulation according to measurements and numerical simulation based on different sets of liquid transport parameters.

4. Conclusion

In context with the swiftly developing market of capillary active interior insulation, a reliable data basis of their respective liquid transport ability is important to secure an acceptable performance. Experience has shown that conventional tests, originally developed for materials under influence of natural weathering, are not fully appropriate for interior insulation purposes, tending to overestimate the materials liquid transport abilities and possibly not realizable for moisture sensitive materials. With the development of the CCR-test, the Fraunhofer IBP delivers a test that is especially designed and appropriate for the boundary conditions of interior insulation and also provides a method to determine the liquid transport ability of materials not measureable before.

Showing promising results, the test and its results have been undertaken further cross-checking and validation. The comparison with conventional tests showed that while each test (drying and CCR) delivers good correlation in its respective area of implementation, neither method solely seems to be able to reproduce the respective other test results. Hence, in the desire to cover as best as possible all drying and redistribution processes with just one set of parameters, further processing of the coefficients has been done, compromising the resulting moisture gain and distribution of both tests.

Experience shows that simulations with combined parameters lead to good correlation with results of all tests. The field test done for validation purposes proves the reliability of the respective parameter set, retracing both winterly maxima and summerly minima of RH. The aluminium foil that is used for sealing reasons in the field test adds somewhat to extreme values, as it prohibits any equalizing effects the render or masonry might have on the moisture levels at the interface. Actual MCs may therefore be lower than in this test. However, the large distance between measured results and those of numerical simulation with drying parameters clearly shows the limited adequacy of conventionally determined liquid transport parameters for interior insulation assemblies.

Thus, the new combination method provides reliable and realistic information about the specific liquid transport ability of interior insulation materials both in higher and lower moisture regions under for non-isothermal as well isothermal conditions.

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