TKB-Report 2

Published: July 2013

(English translation of the German TKB-Bericht 2)

Industrieverband Klebstoffe e.V.

Readiness for Installation of Floor Coverings and Moisture

The KRL*-Method to determine Moisture State of Screeds

* KRL = korrespondierende relative Luftfeuchte / corresponding relative humidity

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1. Introduction

The moisture content of substrates is an important criterion for readiness for installation, i.e. the condition a subfloor must have achieved in order to be ready to receive floor coverings or parquet.

In the German-speaking regions, the moisture condition of a substrate is normally almost exclusively described by "water content in Darr-%" or "water content in CM-%". Outside of the German-speaking regions, moisture condition is often described with the term "corresponding relative humidity". This description has the advantage that it applies irrespective of the composition of a substance (wood, concrete, cement screeds, calcium sulphate screeds....) and makes simple statements regarding a state of equilibrium. In case of non-existence of an equilibrium the corresponding relative humidity indicates in which direction a change will happen (e.g. from high humidity to low humidity).

However, so far there is no standard, measuring instruction or threshold/limit for measurement and assessment of the factor "corresponding relative humidity (KRL)" in screeds common in these regions.

This report summarizes the TKB experiences regarding measurement and assessment of KRL and offers the industry a uniform basis for the collection of further experience.

The KRL measuring method and the proposed thresholds however are not supposed to replace the measurement and assessment of the current factors applied (Darr-%, CM-%,). It shall rather provide supplementary information, for example in the event that the composition of a screed is unknown or doubts exist regarding the composition.

In chapter 4 "Theoretical Principles" the above relationships and terms are explained from a physics viewpoint.

Chapter 5 contains answers to questions which during the draft phase were often asked by the proofreaders.

2. Work Instruction for Measurement of Corresponding Relative Humidity (KRL measurement) of samples taken from cement or calcium sulphate screeds

Preliminary remark

Measurement of the corresponding relative humidity (KRL measurement) is used to determine the material climate and provides an indicator for assessment of readiness for installation. In Germany and some other countries, currently the recognized rule of technology for assessment of readiness for installation of a subfloor is the CM measurement. The method presented here is supplementary to the CM measurement. The taking of samples is identical for both methods. The KRL measurement is recommended for cases where the composition or the drying behaviour of the screed is unclear.

Taking and preparation of samples

For sample taking and processing of the test material before the actual measurement, the procedures for CM measurement have been tried and tested. Therefore, the first steps of this work instruction are identical with work instruction for CM measurement. The two tests may be combined.

Basically, as with other moisture test methods, it has to be ensured that moisture is not lost or introduced from the outside during sample preparation.
It therefore follows that:

- Sample taking and preparation must be performed as quickly as possible.
- For sample taking, do not use procedures entailing high heat built-up such as drilling or cutting and avoid water permeation.
- Protect sample taking and preparation process from direct sunlight and drafts.
- Only pre-crush sample including aggregates to a size that the final test material has a granulation of smaller than 8 mm.

Before taking the sample take the following steps:

- Inspect the probes. The sensor and the protective cap shall be free of dust and adhesions. Contamination of the sensor with fine screed dust will result in incorrect measurements.
- Devices shall be calibrated according to manufacturer's instructions. In the event of doubtful measurement results, proper functioning of the device shall be checked with calibration/verification measurements.
- Have scales ready.
- Prepare bowl, hammer, chisel and spoon.
- Prepare a lidded, clean and dry receptacle (successfully tested: PE freezer bags with volume of 3 litres, CM flasks, PE flasks with volume of approx. 250 ml), adhesive tape.
- Fill in the protocol (specification of construction site, floor, room, date of test, tester and test result).

Performance of test

The sample to be tested shall be taken evenly over the lower half of the screed.

1. Only pre-crush sample including aggregates to a size that the final test material has a granulation of smaller than 8 mm.
2. Fill device with approx. 100 to 200 g of test material. Exact weighing of test material is not required (exception: combined measurement in CM flask, sample weight 50 g).[1]
3. Carefully insert probe into device and place on top of coarse grain of test material. Preferably, use probes with dust filters.

[1] Unlike with CM measurement, exact weighing is not required, since not the absolute water content of the test material is determined, but only the relative humidity formed in equilibrium. For cement and calcium sulphate screeds the same amount of test material is needed.

4. When using bags, squeeze as much air as possible out with your hands. Then place the bag opening tightly around the rod of the probe and close it with adhesive tape (tape the edge of the bag to the probe rod).[2] Solid containers shall preferably be filled right to the edge and then closed with a matching lid with built-in sensor.
5. Store the container with test material and probe at a steady temperature on the floor until equilibrium is reached. Protect the container from direct sunlight, draft and other influences which may result in temperature fluctuations. Do not hold the container in your hands for long since the sample may warm up otherwise.[3]
6. Reading the equilibrium moisture content off the measuring device at the earliest after 30 minutes (duration until equilibrium is reached varies depending on device type). Equilibrium is reached once the indicated measured value does not significantly change in a timeframe of 3 minutes (+/- 1 % RH).
7. Recording of measurement: Measurement is documented in protocol attached to this work instruction.

Checking the sensor
Some measuring device manufacturers offer "calibration sets". For example, test pipes with an air humidity in the range of 75 to 95 % rLF/RH are suitable options.[4]

Notes regarding measuring systems
Suppliers of suitable systems for KRL measurements are, among others (in alphabetical order):

- Gann Mess- und Regeltechnik GmbH, Gerlingen
- Protimeter, GE Sensing & Inspection Technologies GmbH, Pforzheim
- Dr. Radtke CPM AG, Baar, Schweiz
- Testo AG, Lenzkirch
- Trotec GmbH & Co. KG, Heinsberg
- Vaisala GmbH, Hamburg

After the publication of the German version of this text, the TKB published a 3rd report on an evaluation of measurement instruments by the Technische Universität Hamburg-Harburg.

[2] The period until equilibrium of the corresponding relative humidity is reached depends on the ratio between test material and air volume in the container. In order to reach equilibrium quickly, the container must be filled with test material to capacity.

[3] Basically, the measurement shall be performed under stationary conditions. Temperature fluctuations shall be avoided.

[4] e.g.: Saturated NaCl solution (75.5 % RH at 20 °C), saturated KNO3 solution (93.2 % RH at 20 °C). The corresponding relative humidity is measured above the saline solution.

3. Documentation and Thresholds for Assessment of Measurement Result

(PROTOCOL FOR KRL MEASUREMENT ACCORDING TO WORK INSTRUCTION)

Customer: ____

Building /
Property: ____

Construction section
Floor/apartment: ____

Information regarding screed and measurement

Room No.						
Type of screed (binding agent)						
Construction						
– Screed on separating layer						
– Screed on insulating layer						
– Composite screed						
– Heated screed						
Nominal thickness (cm)						
Date of installation						
Tester						
Date						
Test result						
Room temperature (°C)						
Floor temperature (°C)						
Measurement No.	1	2	3	4	5	6
Screed thickness (mm)						
KRL						
– sample weight (g)						
– Temperature in container (°C)						
– KRL (% RH)						
CM measurement						
– sample weight (g)						
– Manometer reading (bar)						
– - Water content (CM-%)						

On the basis of current information, as far as readiness for installation is concerned, you generally arrive at readings below 75% relative humidity for unheated screeds and below 65% relative humidity for heated screeds.

Confirmation

______________________ ______________________________

Place/Date

Top floor installer (tester)
Stamp/Signature

4. Theoretical Principles

4.1 Moisture from a thermo-dynamical viewpoint

"The term **humidity** or **moisture** characterizes the presence of water in or on a substance or in a gas or a room (e.g. the basement of a building). In physics and material sciences you generally speak of **water content**."[5]

Quantitatively, moisture or water content respectively can be described by means of thermodynamics.

Basically, thermodynamic states can be described with different but equally valid variables. These include either

- **intensive** (variables independent of substance quantity, for example pressure or temperature) or
- **extensive** (variables dependent on substance quantity, e.g. mass, volume ...) **properties**.[6]

As regards the water content or moisture, a typical intensive property is the so-called **"vapour pressure"** of water, which for measurements exists as **partial pressure**[7] in the air. This partial pressure is often not measured as a pressure but rather as **"relative humidity"** in % of the **saturation vapour pressure**[8] of the pure substance water in the air using special sensors.

Accordingly, the "corresponding relative humidity" is the humidity present in a relatively small volume of air around a "moist" object which can be measured with appropriate sensors.

A typical extensive property of moisture is, for example, the amount of water in a given sample which is then converted to mass related % or volume related %. Since different values for water content in mass-% are obtained depending on measuring method, the readings are often given with indication of measurement method used. Darr-% is an information in mass related % after kiln-drying, referring to the kiln-dried condition of the sample, often complemented by indication of the temperature present during the test, e.g. temperatures of 105 °C or 40 °C typical for screeds.

It is generally advantageous to use intensive properties when statements regarding the equilibrium of a system are required. Intensive properties must be equal in 2 or more phases in contact equilibrium, extensive properties are not equal or if they are, this is accidental.

For example: If two objects have the same temperature, they are in a thermal equilibrium and you can be sure that heat can not be transferred from one object to the other. When two objects have the same amount of heat, no statement can be made whether the heat can flow from one object to the other.

When three materials containing water, e.g. screed, air and wood are in equilibrium in a closed system (e.g. in a tight stainless steel box), all three phases (wood, air and screed) will have the same vapour pressure relating to the substance water. This vapour pressure can easily be determined via measurement of the relative humidity, which for the screed or the wood is then the "corresponding relative humidity". The process parallels the temperature measurement in contact equilibrium.

Once the intensive metrics are known, a direct statement can be made regarding the direction a "flow" will take. For calculation of the new equilibrium condition however, extensive properties are also required, which can be determined from the intensive properties (see below, 4.2. sorption isotherms).

4.2 Sorption isotherms

In principle, a relation between intensive and extensive properties can be derived. With regard to moisture, this relation is traditionally displayed as sorption isotherms[9], with mostly Darr moisture used as the extensive property and relative humidity as the intensive property.

Frequently, sorption isotherms are no simple functions but rather relations and show a more or less pronounced hysteresis for absorption or desorption. In particular, this applies to many materials used in the construction industry. In many practical cases which require a drying process however, knowledge of the desorption function is sufficient.

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[5] See: http://de.wikipedia.org/wiki/Feuchte, copied 2012-11-20.

[6] H. Weingärtner, Chemische Thermodynamik, B.G. Teubner Verlag, 1. Aufl., Wiesbaden 2003.

[7] "The partial pressure is the pressure that can be assigned to an individual gas component in a mixture of ideal gases. The partial pressure is the pressure exerted by a gas component in a certain volume of a gas mixture, if it would be the only component present. " See: http://de.wikipedia.org/wiki/Partial Pressure, copied 2013-02-16.

[8] „The saturation vapor pressure (also equilibrium vapor pressure) is the pressure exerted by the vapor phase of a substance, when the liquid and vapour phases are in equilibrium." See: http://de.wikipedia.org/wiki/Vapor pressure. Copied 2013-02-16

[9] In thermodynamics, the absorbed heat q is not directly given as q = q(T), where T = temperature; rather as a differential equation dq = C dT, where C = C(T), heat capacity. The "storage capacity" for moisture then equals the derivation of the sorption isotherms.

In many cases, the sorption theory by Brunauer, Emmett and Teller (BET-isotherms)[10] can be used for description or modelling of sorption measurement data.

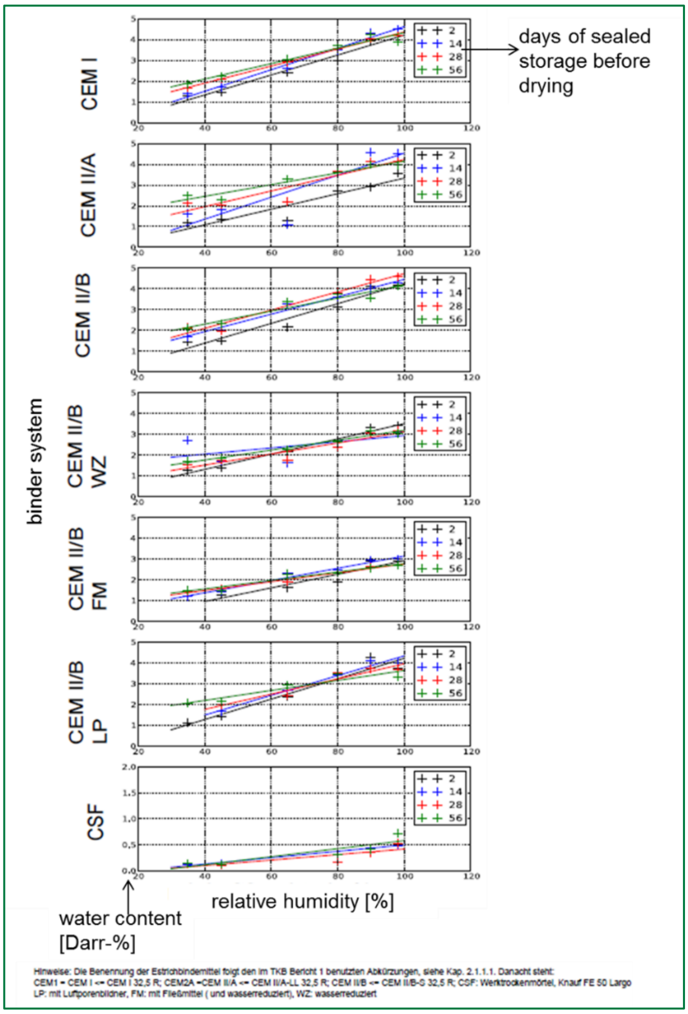
Sorption isotherms are dependent on the actual composition of a substance as well as on its microscopic and macroscopic structure, however, all these parameters may change as a result of the ageing processes.

Within the framework of the TKB project "Readiness for installation and Moisture", desorption isotherms for relative humidity levels from 35 to 98% were determined for some screed mixtures with an aggregate-cement ratio of 6.0 and a water cement value of 0.55 or 0.40 depending on age of the mixtures before the drying started.[11] Graph 1 shows the data found in Darr-%, graph 2 shows the findings in CM-%; the graph lines show the regression line of the measuring points.

For the isotherms of W. Schnell[12], often cited in the literature, the exact composition of the screeds is unfortunately not given, however, it is noted: "Strictly speaking, the equilibrium moisture content only applies for a specific screed with a specific composition and compression at specific ambient conditions. However, it has been proven that for the usual composition of screeds in residential and commercial construction, distinction by binding agents is normally sufficient....".[13]

The Schnell isotherms for cement screed and calcium sulphate screed for relative humidity levels > 80 % poorly match the data presented by TKB in this report and for cement screeds also do not match the data collected at the first TKB ring trial.[14] For cement screeds, an analysis of other data published by W. Schnell, especially the drying curves[15] shows that the determined isotherms only comply with the data in the lower part. The drying curves established by W. Schnell better match the TKB data.

Graph 1: Desorption Isotherms: Relative Humidity vs. Water Content [Darr-%]



[10] Application of the BET theory for construction materials for example has been discussed and explained by H. Klopfer in "H.-M. Fischer et. al., Lehrbuch der Bauphysik, 4. Aufl., B. G. Teubner, Stuttgart 1997" on pages 332 and following.

[11] TKB Bericht 1, Belegreife und Feuchte – Versuche zur Trocknung von Estrichen, März 2012.

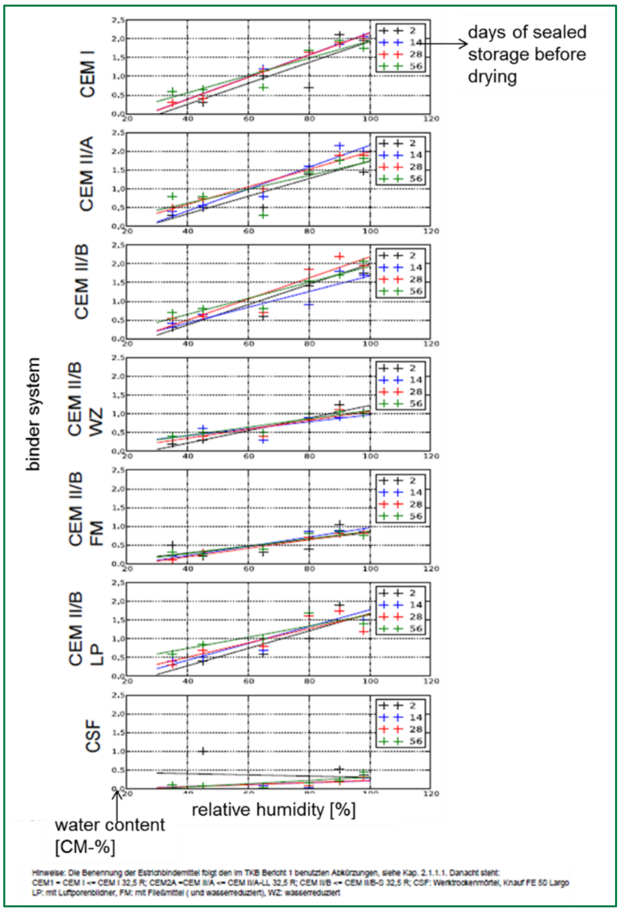
[12] Werner Schnell, Das Trocknungsverhalten von Estrichen – Beurteilung und Schlussfolgerungen für die Praxis, in: Rainer Oswald (Hrsg.), „Aachener Bausachverständigentage 1994", Neubauprobleme – Feuchtigkeit und Wärmeschutz, AIBau, Bauverlag GmbH, Wiesbaden 1994.

[13] See footnote 12, p.86, chapter 3, also see p. 88, chapter 5.

[14] 26. TKB Fachtagung 2010, Th. Brokamp et al., Verlegereife und Feuchte – Vorschläge der TKB zur Messung der korr. rel. Luftfeuchte.

[15] Handbuch für das Estrich- und Belaggewerbe, Hrsg. Bundesverband Estrich und Belag, Köln, R. Müller 1997, There: Zur Ermittlung von Belegereife und Ausgleichsfeuchte von mineralisch gebundenen Estrichen, W. Schnell, reprint of the original from Boden/Wand/Decke 1/1985, in addition footnote 12.

Graph 2: Desorption Isotherms: Relative Humidity vs. Water Content [CM-%]



4.3 The KRL measurement result and assessment of readiness for installation

4.3.1 Readiness for installation

A definition of the term "Readiness for installation" can be found for example at W. Schnell:

"Readiness for installation is the threshold moisture content of the screed which must be reached before a specific floor covering can be installed on the screed. ... As a general rule, the threshold moisture content at readiness for installation is higher than the moisture content in the state of equilibrium with the long term room climate."[16]

The equilibrium moisture content is considered to be related to an ambient climate of 22°C and 50% RH.[17] Unfortunately, the difference between moisture at readiness for installation und equilibrium moisture content remains unclear and can only be deduced indirectly from the context (see below, chapter 4.3.2.).

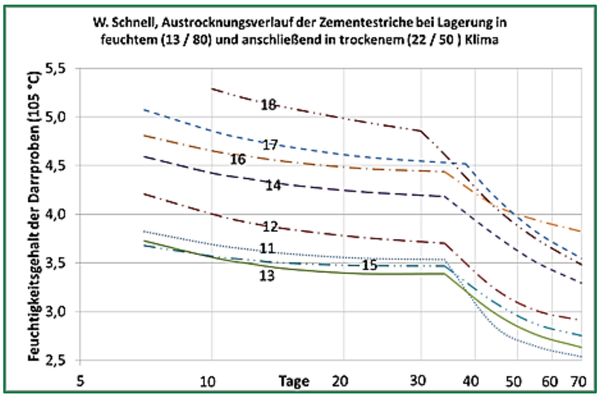
In general, readiness for installation assumes that floor covering can be installed without damage with regard to negative effects caused by moisture. Unfortunately however, there is only limited data regarding the degree of moisture which may cause damage. Some damage mechanisms however start at a relative humidity between 70 to 80 %.[18] This would confirm the above assumption that conditions at time of readiness for installation significantly exceed the equilibrium moisture content.

4.3.2 Determination of readiness for installation based on extensive properties

Older information regarding readiness for installation based on extensive properties can be found at W. Schnell, 1985.[19] The thresholds/limits for cement screed cited there

Darr-%	CM-%	Readiness for installation
≤ 4,5	≤ 3,0	Generally for floor coverings **insensitive** to moisture
≤ 4,0	≤ 2,5	Generally for floor coverings sensitive to moisture
≤ 3,5	≤ 2,0	For vapour proof floor coverings

in good approximation correspond to the equilibrium water content found by him at a climate of 13 °C and 80 % relative humidity during the first part of his storage experiments:



(according: W. Schnell[20])

The same relationship exists for the calcium sulphate screeds he tested, however in this case the first storage experiment was performed at 10 °C and 75 % rel. humidity (see image 2, table 5 cites „~ 13 / 80“ in deviation).[21]

[16] See footnote 12, p. 87, chapter 3.

[17] See footnote 12, p. 87, chapter 3.

[18] 25. TKB Fachtagung, Th. Brokamp, Verlegereife und Feuchte - Grundlagen.

[19] See footnote 15, table 5 and image 4.

[20] See footnote 15, image 4.

[21] See footnote 15.

From today's viewpoint, the data for extensive properties appears relatively high. A more recent comment[22] regarding floor coverings (for parquet and wood blocks see[23]) cites the following information:

“As a rule, "readiness for installation" of the individual screeds is achieved at the following moisture content:

Cement screeds <= 2.0 CM-%

as heated screeds <= 1.8 CM-%

Calcium sulphate screeds <= 0.5 CM-%

as heated screeds <= 0.3 CM-%

The cited CM-% values refer to a cross section sampling and measurement of the screeds, irrespective of the common types of screed construction.

For safety reasons, the parquet layer industry recommends sample taking from the lower and medium sections of the screed. This approach can be supported, especially for screeds with thicknesses of 8 cm and more."

On account of negative experience in the field, the originally proposed values have been adjusted and unified with the values for vapour proof floor coverings.

However, it should be noted that the equilibrium moisture is defined by intensive properties ("22 °C and 50 % rel. humidity“).

4.3.3 Readiness for installation based on intensive properties

Once the moisture status is known based on the intensive property "corresponding relative humidity", it can therefore immediately be concluded:

- Has an equilibrium state already been achieved in good approximation?
- In which direction will moisture flow?
- Once certain thresholds are exceeded, certain damage is predictable.

In many countries, determination of readiness for installation via measurement of the corresponding relative humidity is "state-of-the-art".

Roughly, you can differentiate between 3 measurement principles:

a) measurement close to top (BS5325)

b) measurement in drill hole (NT Build 439, ASTM 2170)

c) measurement of samples taken from screed (NT Build 490)

An overview of current standards and thresholds for methods a) and b) can be found at Kanare[24], some typical values are summarized below:

Standard	Upper limit in % rel. humidity.
BS5325, BS8203	75
Nordtest NT Build 439, 1995	Sweden, HusAMA83: 80: wood and wood-based floors, PVC with bio-degradable backings, cork. 85: Homogenous PVC, cork with PVC backing. 90: Floor coverings where the required adhesive can degrade under the influence of alkalis.
Nordtest NT Build 439, 1995	Finland, SisaRYL 2000: 60: parquet elements without moisture barrier. 80: Mosaic parquet. 85: PVC elements, cork with plastic backing, carpet. 90: PVC tiles, PVC sheets without fleece, linoleum.
ASTM F2170	Depending on floor type between <= 75 to 90.

The limit of <= 75 % rel. humidity proposed in chapter 3 is in the lower range of the values listed in the table and takes into account the experience made so far in Germany with the method described here.

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[22] H.-H. Kaulen, N. Strehle, R. Kille, Kommentar und Erläuterungen VOB DIN 18365 Bodenbelagsarbeiten, 7. Aufl., Holzmann Medien, Bad Wörishofen, 2010, dort: S. 113.

[23] J. Barth, W. Schmidt, N. Strehle, Kommentar zur DIN 18356 Parkettarbeiten und DIN 18367 Holzpflasterarbeiten, SN-Verlag, Hamburg 2011, here: see p. 125.

Readiness for installation of screeds in CM-%		
Type of substrate	Unheated substrate	Heated substrate
Cement screeds	< 2.0	< 1.8
Calcium sulphate screeds	< 0.5	< 0.3

[24] H. M. Kanare, Concrete Floors and Moisture, 2nd. Edition, Portland Cement Association, Skokie, Ilinois, and National Ready Mixed Concrete Association, Silver Springs, Maryland, USA, 2008.

5. Questions and Answers

1. Why does the TKB propose an "indicative value" and not a "threshold/limit"?

The method is relatively new in German-speaking regions and therefore there is no extensive on-site experience. An indicative value therefore serves as a point of reference. However, this indicative value must still be confirmed by more field experience and may then become a threshold/limit value.

2. Is an indicative value of 75 % KRL too low?

Indeed there is some evidence (for example take discussion in chapter 4.3.2 and the graph by W. Schnell), that a threshold may be higher – or lower. Internationally, over the past years values between 75 and 90 % rel. humidity have been cited. The value of 75 % has been proven as especially reliable, therefore it was decided to use it as a basis.

3. Is a KRL measurement mandatory to prove readiness for installation?

Not in Germany. TKB recommends to use this method as a supporting instrument in doubtful cases, for example in case CM or Darr values seem implausible.

4. Why is it so difficult to determine readiness for installation with only one measurement value?

Readiness for installation means that after installation a floor covering will properly stay on the substrate without damage. In principle, moisture can only cause damage when the required vapour pressure and the amount of water exceed the limits in a potential damage area. In order to make precise predictions, it must be known what amount of water with which vapour pressure (as an approximation for the activity) will be present when and where. To this end, data regarding vapour pressure or relative humidity, amount of water, sorption isotherms, density and diffusion conductivity must be collected. Generally, these data are difficult to assess and therefore, in the field, one mostly relies on the parameter which is most significant in practice - and this is the corresponding relative humidity.

5. What is the advantage of the KRL method compared to the Darr or CM methods?

This question is most easily answered with an analogous situation from the field of physics, which is familiar to everyone.
You are faced with the question whether you can touch a series of objects with an unknown quantity of heat contained without "burning your fingers". Most people would simply take the temperature of the objects and when the temperature is within a range from 5 to 45 °C, touching of the objects should not be a problem. However, if the objects are very cold or very hot, problems are to be expected.
However, you have to take into consideration that in some situations also the heat quantity can play a role: e.g. you can touch a bird feather heated to 100 °C without problems, while touching a metal object heated to 100 °C may cause burns.
Relating to moisture, the counterpart of temperature is KRL, the counterpart of Darr or CM value the amount of heat.

Additional advantages for the contractor are:

- Weighing mistakes are avoided since test samples do not need to be weighed precisely.
- The method is independent of the material of the test sample, in particular of the screed binding agent.
- After a minimum waiting period, the time of measurement can be selected at will.
- Test is easy to perform, no shaking at certain intervals, easily repeatable.
- No subsequent inspection of the ground material.
- No need for handling of hazardous carbide, breakable vials and acetylene.