Classification and simplified design rules concerning the moisture performance of capillary active insulation materials

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Abstract. Conventional interior insulation systems protect the wall from condensation in winter by the help of vapor barriers or vapor retarding insulation materials. However, these solutions also reduce the drying potential of the walls towards the inside. This can be a disadvantage if wetting from the outside due to rain or other influences takes place and the drying potential to the outside is not sufficient. In such cases, so called capillary active materials can be an alternative, because they provide additional drying potential to the inside in summer thanks to a rather low vapor diffusion resistance. In winter they work without vapor retarders because they can store and wick water away from the condensation plane back towards the interior by capillary action. In practice, there are currently many different materials under the label "capillary active" with a correspondingly wide range in terms of moisture storage, liquid transport and vapor diffusion resistance and it is difficult to decide, whether material is suitable for an application or not. There is still missing a common definition of the performance of such materials. While for most other materials already simplified design and application rules for the application as interior insulation are available, capillary active interior insulation materials still require an individual design, normally by the help of hygrothermal simulation. In order to simplify also their practice application, a classification of the moisture performance of capillary active interior insulation, considering the influencing parameters of relevance on the moisture level at the critical interface between wall and interior insulation was developed. On this basis, also a simplified verification process as well as design rules for the main practical application fields become possible, which allows designers to choose an appropriate system for the specific situation.

1. Introduction

Energetic refurbishment of exterior walls is one of the most important steps to reduce the energy demand of the existing building stock under Central European climatic conditions. In some old buildings, interior insulation is the only option for insulating the exterior walls. This is particularly the case when valuable or heritage facades are subject of energy retrofit. When buildings are used only temporarily, the use of interior insulation can also offer benefits, as it enables a significantly faster and more cost-effective conditioning of single rooms or the whole building.

In autumn 2022 the adjusted *Energy Performance of Buildings Directive* (EPBD) [1] passed the European commission. The commission stated that, the building sector is responsible for round about 40 % of the energy consumption and for 36 % of the greenhouse gas emissions. With the new directive [1] the commission focuses on the refurbishment of the building stock for residential buildings. The target corridor is an overall energy efficiency level of the whole building stock of at least class D. For

Germany on example class D means a primary energy consumption of 100 -130 kWh/m²a. But there is no obligation of renovation for existing residential buildings, even for the worst performing buildings (WPS) of the building stock. However, the yearly refurbishment rate for Germany as an example is with round about 1 % [2] significantly too low to achieve the goals mentioned above. Therefore it is also necessary to apply more interior insulations, whose potential was highlighted by various research projects in the past years [2] [3] [4].

Conventional interior insulation systems protect the wall from condensation in winter by the help of vapor barriers or vapor retarding insulation materials. However, such systems also reduce the drying potential of the walls towards the inside. This can be a disadvantage if wetting from the outside due to rain or other influences takes place and the drying potential to the outside is not sufficient. In such cases, at least in many European countries, so called capillary active interior insulations are used, which maintain the drying potential to the inside in summer due their rather low vapor diffusion resistance. In winter they work without vapor retarders because they can store and wick water away from the condensation plane back towards the interior by capillary action. In practice, there are currently many different materials under the label "capillary active" with a correspondingly wide range in terms of moisture storage, liquid transport and vapor diffusion resistance and it is difficult to decide which material is suitable for which application. There is still missing a definition of the performance of these materials. While for most other interior insulations already simplified design and application rules are available, like for example in [10], capillary active interior insulation materials normally still require an individual design, for example according to [5]. For the determination of the capillarity of insulation materials, already different measurement procedures are available e.g. [6]. However, this test only allows for an evaluation of the liquid back transport of the insulation material itself, while in reality also other factors can become crucial. In order to simplify also the application of these materials, a classification of the moisture performance of capillary active interior insulations was developed, which considers the most important influencing factors. On this basis also a simplified verification process and design rules for practice become possible.

2. Influencing factors on the moisture performance of capillary active interior insulations

The schematic drawing in **Figure 1** shows in a simplified way the transport and storage processes occurring in a wall with capillary interior insulation under Central European winter conditions. The vapor flux is directed from the indoor climate to the outside and leads to a rising humidity level at the cold side of the insulation and the inner part of the substrate masonry. The moisture is absorbed by the two adjacent materials and to a certain extent transported back to the inside and further to the outside by capillary flow. These effects limit the increase of moisture between interior insulation and cold wall. The material properties and performance of capillary active interior insulations are described much more in detail in [6]. However, a detailed recapitulation would go beyond the scope of this paper.

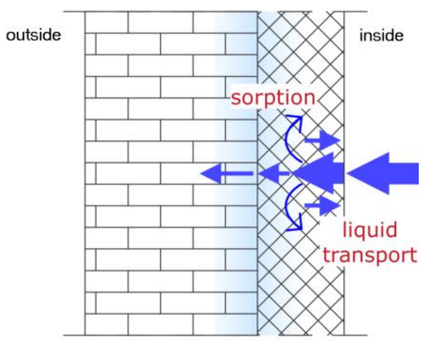

Figure 1: Schematic illustration of the moisture conditions in a wall with vapour permeable capillary active interior insulation under Central European winter conditions (without rain water influence)

The functionality of such interior insulation systems is influenced by various factors; which are summarized in **Figure 2**. On the one hand, the material properties of the interior insulation respectively the insulation system itself and on the other hand the boundary conditions are crucial for the development of the moisture level in the insulated wall.

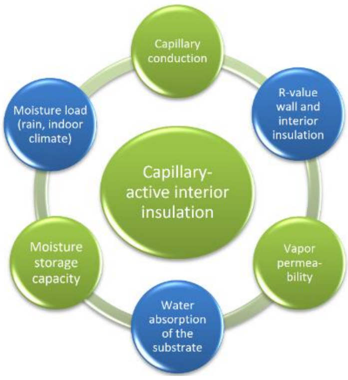

Figure 2 : Influencing factors for the moisture performance of capillary active insulation materials. Green are parameters of the insulation material or system and blue factors of the boundary conditions or the substrate wall.

According to [5] the critical position of a construction with interior insulation is the interface between the already existing wall and the newly applied interior insulation. If the moisture level at this interface remains below 95 % RH, no damages have to be feared. If this threshold is exceeded, the materials present in that area need to be correspondingly moisture resistant. If conditions above approx. 99 % to 100 % RH arise, the risk of dew water cannot be excluded any more.

3. Classification and simplified evaluation of interior insulation systems

Laboratory tests and computational investigations with the hygrothermal simulation tool WUFI® [7] within [8] have shown that a classification of capillary active interior insulations based on the material parameters of the insulation material alone is not meaningful. I case of an assessment of only the insulation materials without other wall layers, all investigated materials fail under critical boundary conditions, as the moisture levels on the cold side of the insulations clearly exceed 95 % RH in all cases, while under mild conditions sometimes even materials without any capillarity perform well. Especially the moisture buffering of the substrate material plays an important role for operation in reality, while it is missing, if only the insulation material itself is evaluated in a laboratory test on a vapor and water tight substrate. Therefore, the combination of material properties of the insulation material respectively the insulation system with typical application situations under defined boundary conditions seemed to be necessary in order to be able to evaluate the moisture performance of the insulated wall in a realistic way.

3.1 Reference simulation for different application areas

The three exterior influencing factors represented in blue within **Figure 2**, are therefore eliminated by appropriate application limits to be able to focus on the insulation and system parameters. As the rainwater absorption varies significantly at different locations and normally dominates the moisture level of walls with interior insulations, only situations without rain load or with good rain water protection can be considered for a simplified evaluation. Thus, the boundary conditions are similar to the ones for the already existing simplified evaluation method for normal interior insulation materials in WTA Guideline 6-4 [9]:

- No rain load or good driving rain protection of the existing wall
- Interior climate with low or normal moisture load according to WTA Guideline 6-2[10]
- R-value improvement of interior insulation $\Delta R \leq 2.5$ m²·K/W
- R-value of the existing wall $R \geq 0.4$ m²·K/W
- Average annual temperature of the outdoor climate ≥ 7 °C

The remaining factor, water absorption coefficient of the interior wall surface beneath the interior insulation, is considered in two levels: moderately absorbing surfaces with an A-value ≥ 0.2 kg/m²√h, which still covers almost all unsealed wall formers and even concretes, or well absorbing surfaces with an A-value ≥ 1.0 kg/m²√h, which represents raw brick surfaces or most unpainted interior plasters. In case of doubt, the A-value must be determined on site. Weakly absorbent substrates with an A-value < 0.2 kg/m²√h always require an individual verification – however, they are generally less suitable for an application of capillary active interior insulation. The different prerequisites result in the application areas summarized in **Table 1.**

Table 1: Possible areas of application for a vapor permeable capillary active internal insulation system following the simple verification process.

	Application area		
	I	II	III
Moisture load acc. to WTA 6-2	low	low	normal
Absorbency of the existing wall surface (comparable to WTA 6-4 [])	Well absorbent A ≥ 1.0 kg/m²√h	Moderate absorb. A ≥ 0.2 kg/m²√h	Well absorbent A ≥ 1.0 kg/m²√h

The evaluation is again performed by the help of hygrothermal simulations with the simulation model WUFI®. Firstly, many transient simulations under critical but realistic boundary conditions were performed. However, a clear classification proved to be hardly possible under varying conditions and the results were very difficult to visualize. Therefore, it seemed to be better to do this visualization by a hygrothermal simulation with calibrated and verified constant boundary conditions, whose results were verified by transient simulations in order to well represent the transient winter situation and to lead to the same maximum moisture values. The simulation is performed for the different interior insulation systems on a critical representative standard wall structure with concrete shown in **Figure 3**, which just fulfills the requirements mentioned above and thus represents the respective worst case. The R-value of the interior insulation is assumed to be 2.5 m²K/W and the R -value of the existing wall amounts to 0.4 m²K/W - both values are based on the application limits from the WTA Guideline 6-4 [9].

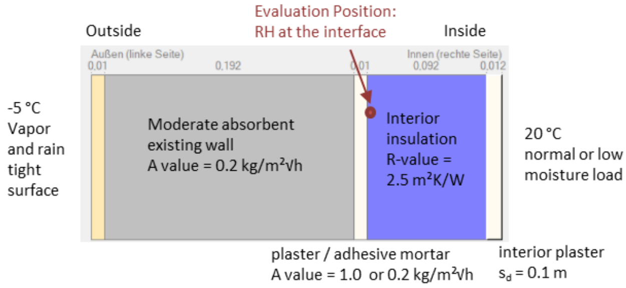

Figure 3 : Critical representative reference wall under Central European Winter Conditions

The used material properties of the reference construction are listed in **Table *2***.

Table 2: Material properties of the different layers of the reference construction.

Material	Thickness (mm)	Density (kg/m³)	Thermal conductivity (W/mK)	μ-value Dry-Cup (-)	A-value (kg/m²√h)	Reference water content (kg/m³)	Free saturation (kg/m³)
Exterior plaster	10	1900	0.8	25	0.1	45	210
Concrete	192	1200	0.48	10.9	0.2	30.2	206
Lime cement plaster	10	1900	0.8	19	1.0 or 0.2	45	210
Interior plaster	12	850	0.2	8.3	17	6.3	400

In order to ensure a good comparability, the simulations are performed over three months at steady state Central European winter conditions. As outdoor conditions -5 °C and 80 % RH according to the steady state evaluation method from the German DIN 4108-3 [11] are used. This assumption is on the safe side, as even in Holzkirchen as critical location for Germany, the average temperature in the months December to February falls only to about -3 °C in cold years. For the indoor climate constant conditions with 20 °C and RH values for normal (40 % RH) or low moisture load (33 % RH) according to the indoor climate model from [11] for the resp. outdoor temperature were chosen and slightly adapted to agree concerning the moisture level in the wall with transient simulations at Holzkirchen, Germany, a location which can be seen as critical representative for Central European climate conditions. In order to keep the focus of the evaluation on moisture influence from the indoor climate, no moisture exchange with the outdoor climate is considered. This is achieved by a vapor and rain tight exterior surface of the wall. The initial moisture content of the wall is taken into account with an equivalent moisture content at 70 % RH.

The comparison of the moisture level in the reference simulation with the one from the simulation in Holzkirchen for the different application areas is shown in **Figure 4**. It shows that the two scales agree very well, so that the points lie directly on or very near to the straight line. The results of the steady state reference simulation tend to be slightly above the straight line, which leads to results on the safe side compared to the transient simulation with the real climate conditions.

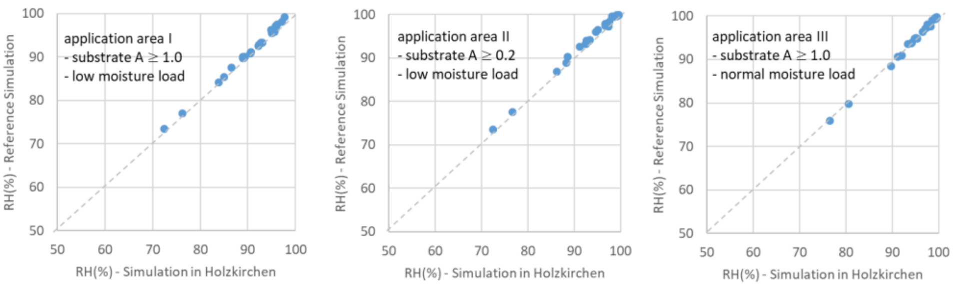

Figure 4: Comparison of the resulting RH at the interface between interior insulation and existing wall of the construction between the reference simulation on the y-axis and the transient hygrothermal simulation with measured climate date for Holzkirchen on the x-axis. The results comprise values for in total 23 different insulation materials.

3.2 Classification of the investigated interior insulation systems

The classification of the materials is based on the moisture level that occurs at the boundary layer on the cold side of the insulation. Under a favorable combination of material parameters like vapor diffusion resistance, moisture capacity and liquid transport, the RH at the boundary layer remains below 95 % RH within the three months calculation period. In these cases the system can be used in the corresponding application area without restrictions and is thus classified in category A: generally functional.

Table 3: Classification criteria of capillary active interior insulation systems.

Classification Category	A	B	No classification
Maximum relative humidity at the boundary layer	≤ 95 %	≤ 99 %	> 99 %
Required persistence of the masonry and the internal insulation system at the boundary layer area	Moisture resistant till 95 % RH	Moisture-, Frost and Rot resistant till 99 % RH	Individual verification necessary

However, the materials used in that area need to be moisture resistant up to 95 % RH – so certain particularly sensitive natural material may be not suitable. However, below 95 % RH, no other problems are to be expected apart from mold growth, which is prevented by avoiding air flow behind the insulation materials – normally by a mostly complete adhesion to the substrate. According to WTA Guideline 6-5 [5], also wood and sensitive pure gypsum materials (which are often used for interior plasters) can tolerate these conditions without damages in combination with winter temperatures below approximately 10 °C. If the moisture level exceeds 95 % RH, but remains in the range up to max. 99 % RH, the insulation material or system can be classified in category B: functional, if moisture resistant. If the RH increases above 99 %, dew water formation cannot be ruled out and a general approval within the simplified evaluation is not possible.

The course of the relative humidity is plotted over the three months period. The maximum value reached at the end of this period is decisive for the classification. For better illustration, this is shown as an example for application area II (poorly absorbent substrate with normal moisture load) in **Figure 5**.

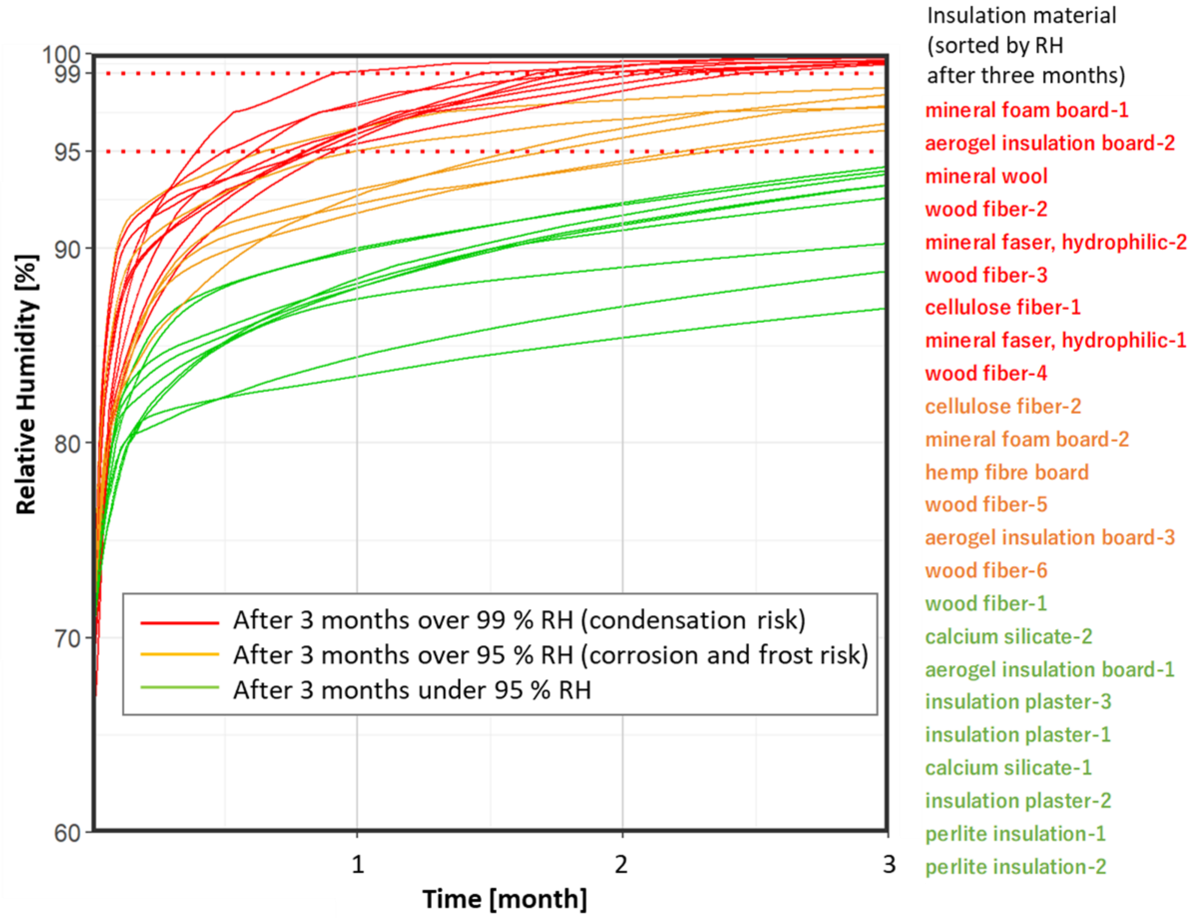

Figure 5: Increase of the RH at the interface between interior insulation and existing wall for the critical reference construction, based on a simulation of standard constant winter conditions. The figure shows as clearly as possible the principle moisture performance of the insulation material on a moderate absorbent substrate and operation as residential building with low occupation. The materials indicated in red result in a moisture level above 99 % RH and risk of dew water formation at the end of the three winter months, the ones indicated in yellow remain between 95 and 99 % RH and require frost and rot resistant materials, while the green ones do not exceed 95 % RH and are therefore uncritical without additional requirements.

The relative humidity curves of the individual materials are plotted in different colors according to the categorization achieved in each case: green for category A, yellow for category B and red for all other materials or systems. In **Table 4** the classification of all 23 different vapor permeable, capillary active insulation materials is summarized. For application area I with normal absorbent substrate, low indoor moisture load and a normal gypsum plaster with 0.1 m s_d-value, 13 of 23 materials can be classified in category A without further requirements and 10 into category B, which means, that they can be used without individual proof, as far as substrate and system materials are moisture, frost and rot resistant. However, additional simulations showed, that it is not always beneficial, to ensure an extremely low vapor diffusion resistance on the inside. Increasing the interior s_d value only slightly to 0.2 m allows to classify all systems into category A.

For application area II the substrate absorbency is only 0.2 kg/m²√h with otherwise identical boundary conditions. Here the lower A value of the substrate increases the moisture level at the evaluation positon. In application area III, the higher absorbency from area I is kept, but the indoor moisture load is now normal instead of low. For both application areas II and III with the normal inner s_d value of 0.1 m, 9 systems are classified in category A, 6 in category B and 8 require an individual proof. Also here an increase of the interior s_d-value improves the situation. However, to reach again an A classification of all investigated systems, a slightly stronger increase to 0.5 m is necessary, which is just the upper end of the bandwidth for a still "vapor permeable" system. This is no problem, as far as no moisture entry from the outside occurs. However, in case of rain water absorption or moisture entry from the outside, always an individual verification of the system is necessary, as rain water absorption can easily dominate the moisture performance.

It becomes evident, that even materials of the same type can perform very differently. For application area II for example, the three aerogel insulations are all landing in a different category – it is therefore hardly possible to draw conclusions from one representative of a material group to another one. Therefore an individual evaluation and classification of specific materials or systems is generally required.

Table 4: Exemplarily categorization of different capillary active insulation materials. Category A (red) means functional, category B (yellow) functional if the materials in the boundary layer are moisture resistant. No category (red) means an individual verification required.

Material	Application area					
	I		II		III	
	well absorbent substrate (A ≥ 1.0 kg/m²√h) and low moisture load (WTA 6-2)		moderate absorbent substrate (A ≥ 0.2 kg/m²√h) and low moisture load (WTA 6-2)		well absorbent substrate (A ≥ 1.0 kg/m²√h) and normal moisture load (WTA 6-2)	
	sdi = 0.1 m	sdi = 0.2 m	sdi = 0.1 m	sdi = 0.5 m	sdi = 0.1 m	sdi = 0.5 m
aerogel insulation board-1	🟢	🟢	🟢	🟢	🟢	🟢
aerogel insulation board-2	🟡	🟢	🔴	🟢	🔴	🟢
aerogel insulation board-3	🟢	🟢	🟡	🟢	🟡	🟢
calcium silicate-1	🟢	🟢	🟢	🟢	🟢	🟢
calcium silicate-2	🟢	🟢	🟢	🟢	🟢	🟢
cellulose fiber-1	🟡	🟢	🔴	🟢	🔴	🟢
cellulose fiber-2	🟡	🟢	🟡	🟢	🔴	🟢
hemp fibre board	🟢	🟢	🟡	🟢	🟡	🟢
insulation plaster-1	🟢	🟢	🟢	🟢	🟢	🟢
insulation plaster-2	🟢	🟢	🟢	🟢	🟢	🟢
insulation plaster-3	🟢	🟢	🟢	🟢	🟢	🟢
mineral faser, hydrophilic-1	🔴	🟢	🔴	🟢	🔴	🟢
mineral faser, hydrophilic-2	🟡	🟢	🔴	🟢	🔴	🟢
mineral foam board-1	🟡	🟢	🔴	🟢	🔴	🟢
mineral foam board-2	🟢	🟢	🟡	🟢	🟡	🟢
perlite insulation-1	🟢	🟢	🟢	🟢	🟢	🟢
perlite insulation-2	🟢	🟢	🟢	🟢	🟢	🟢
wood fiber-1	🟢	🟢	🟢	🟢	🟢	🟢
wood fiber-2	🟡	🟢	🔴	🟢	🔴	🟢
wood fiber-3	🟡	🟢	🔴	🟢	🔴	🟢
wood fiber-4	🟡	🟢	🔴	🟢	🔴	🟢
wood fiber-5	🟡	🟢	🟡	🟢	🟡	🟢
wood fiber-6	🟢	🟢	🟡	🟢	🟡	🟢

🟢 Functional (category A)
🟡 Functional if insulation system and substrate moisture, frost and rot resistent (category B)
🔴 Condensation possible. Individual verification required.

4. Summary

The presented classification of capillary active interior insulation materials and systems is valid for climate conditions in Central Europe and allows both, a comparison and simplified choice of an appropriate product for building practitioners and an optimization and definition of the application field for the manufacturers.

A prerequisite for a realistic classification are adequately determined hygrothermal material parameters including capillary or condensation test e.g. according to [6]. Due to the strong influence of the boundary conditions on the hygrothermal performance of walls with interior insulations, the simplified evaluation is only possible under clearly defined application areas considering level of rain water protection, moisture load in the indoor and temperature level in the outdoor climate as well as R-values of both, the existing wall and the newly applied interior insulation system. Capillary active interior insulations are mainly used in older or historic buildings which often provide an operation with low or normal moisture load as well as wall materials with a certain absorbency. Therefore, the defined application areas I to III cover a large part of the practical situations in which capillary active interior insulation can be usefully employed. If no classification of a product or system can be reached or the application differs from the defined conditions it is of course always possible to do an individual hygrothermal evaluation e.g. according to [5].

Manufacturers as well as building practitioners often assume, that the performance of a capillary active interior insulation should be as vapor permeable as possible. This is not always true. Especially in case of no or only little rain influence, a moderate increase of the inner s_d value by a more vapour retarding render or painting to the upper end of the "vapour permeable" range, can clearly reduce the RH level at the interface between insulation and wall and thus improve the moisture performance of the whole system. In case of the 23 insulation materials investigated in [8] an increase of s_{di} by 0.2 m for application area I and by 0.5 m for application area II and III allows a classification of all systems into category A.

Acknowledgement
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