
MOISTURE TRANSFER THROUGH FACADES COVERED WITH ORGANIC BINDER RENDERS

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ABSTRACT

Year after year we witness the negative effect of water over buildings, caused by direct or indirect actions. This situation is obvious in case of old, historical building, subjected to this aggression for a long period of time, but new buildings are also affected. Moisture in building materials causes not only structural damage, but also reduces the thermal insulation capacity of building components.

Materials like plasters or paints have been used historically for a long period of time, fulfilling two basics functions: Decoration and Protection. The most acute demands are made on exterior plasters, as they, besides being an important decorative element for the facade, must perform two different functions simultaneously: protect the substrate against weathering and moisture without sealing, providing it a certain ability to "breathe" (Heilen, 2005). In order to accomplish this aim, the first step is to understand the hygrothermal behavior of coating and substrate and define the fundamental principles of moisture transfer; According to Künzels Facade Protection Theory, two material properties play the most important role: Water absorption and Vapor permeability.

In the context of recently adoption (2009) of the "harmonized" European standard EN 15824 – „Specifications for external renders and internal plasters based on organic binders”, this paper deals extensively with the interaction of the two mentioned above properties for the coating materials, covered by EN 15824.

Keywords: Moisture transfer, organic binder renders; Water absorption; Vapor permeability.

REZUMAT

An de an asistăm la efectul negativ, direct sau indirect, pe care umezeala îl are asupra clădirilor. În cazul clădirilor istorice, supuse agresiunii apei pe perioade îndelungate, efectul este foarte vizibil, dar clădirile noi sunt de asemenea afectate. Umezeala nu provoacă doar daune structurale, dar de asemenea, reduce capacitatea de izolare termică a elementelor de construcție.

Tencuielile sau vopsele au fost utilizate de-a lungul timpului ca și materiale de finisare, îndeplinind două funcții de bază: decorativă și de protecție. Cerințele cele mai acute sunt aplicate tencuielilor exterioare, materiale care pe lângă rolul decorativ trebuie să satisfacă două funcții simultane: să protejeze substratul împotriva intemperiilor și umidității fără a-l „sigila”, conferindu-i abilitatea de a „respira” (Heilen, 2005). Pentru a realiza acest obiectiv, primul pas este înțelegerea comportamentului higrotermic al stratului de finisare și al substratului și definirea principiilor fundamentale ale transferului de umiditate; Conform teoriei lui Künzels de protecție a fațadelor, două proprietăți ale materialului joacă rolul esențial: Absorbția de apă și Permeabilitatea la vapori.

În contextul adoptării recente (2009) a "standardului armonizat" european EN 15824 - "Specificații pentru tencuieli exterioare și interioare pe bază de lianți organici", prezenta lucrare se ocupă cu interacțiunea celor două proprietăți higrice esențiale anterior menționate.

Cuvinte cheie: transfer de umiditate, tencuieli cu lianți organici; absorbție de apă; permeabilitate la vapori.

1. INTRODUCTION

Structural damage and reducing the thermal insulation capacity are the most significant deteriorations that can occur in building components due to moisture excess,

thus leading to poor hygienic indoor conditions. (Künzel, 1994; 1998). Because of their pore and capillary structure, mineral building materials absorb moisture on contact with water often causing visible and invisible damage, produced either by water itself or by

inside processes initiated or sustained by water: propagation of algae, fungi or spores, salt efflorescence, degradation of insulating effect, coating exfoliation and frost damage.

Special attention must be paid to fungus infestation and therefore a strategy that focuses on the growth conditions for mould fungi and also considers the complex transient processes of building physics has to be set up at IBP (Fraunhofer Institute of Building Physics), Germany (Sedlbauer and Breuer, 2003). Specially formulated organic coatings, preferably waterborne, which are also more environmental friendly, may have the effect of balancing the moisture transport in gypsum based materials and consequently decrease risks of fungal growth. Experimental testing and description of moisture transport in the combined system of coating and base material were performed for subsequent development of such coating systems (Van der Wel and Adan, 1999b).

The most important objective is therefore to keep away the water from building components or to reduce as much as possible the water content to a level where the detrimental effect is considerable low. In order to accomplish this task, first we have to clarify the illness process (how moisture penetrates and travels through building material elements), then the cure (choosing the appropriate coating materials or systems for facades optimum protection). Around 2,000 years ago, the coating solution consisted in simple lime plasters, then natural oils and fats were used for this matter, then waxes and in the latest years the silicon derivatives as fats, resins or rubbers became the main hydrophobes, satisfying more sophisticated demands.

The European standard EN 15824 appeared in October 2009, which also applies in Romania, refers to external renders and internal plasters based on organic binders. This implies that such products, based on good coating performances and also satisfying economic considerations, are gaining step by step the facades market, so that solid performance criteria and also testing methods must be clearly established.

Organic binders, such as bitumen or synthetic resins (polymers), so-called because their organic molecules, are historically known to human kind; nowadays they are certainly better known than in the past, but for certainly their chemistry have not yet revealed all their secrets. W. Heilen (Heilen, 2009) offers a clear and complex perspective over these materials as key components in external coatings.

2. MECHANISMS OF MOISTURE TRANSPORT THROUGH BUILDING ELEMENTS

In order to design high performance coating materials, preventing facades deterioration and improving their protection we must first clarify the basic and major processes that govern the mechanisms of moisture transport through building elements.

H. M. Künzle (Künzel, 1994), in his PhD thesis „Simultaneous Heat and Moisture Transport in Building Components”, presents a detailed analysis of this complex phenomenon. Depending on environmental conditions, water in building materials can be found in liquid form, solid form (ice), or vaporous form, respectively in some intermediate state as absorbed phase on the pore walls (Künzel and Kiessl, 1997). Künzel (Künzel, 1994) summarizes the main moisture transport mechanisms, characterizing majority of building materials as porous capillary active products:

- Regarding the vapor transport, he mentions as main transport mechanisms: **gas diffusion**, **molecular transport (effusion)** and **solution diffusion** (caused by vapor pressure, and characteristic to organic polymers used in buildings like seals or coatings as vapor barriers or underlays);
- Considering the liquid transport, in his study he focuses on **capillary conduction** (having as cause or transport potential the capillary suction stress) and also on **surface diffusion** (caused by relative humidity).

2.1. Basic Hygric definitions

A building material is considered dry when it contains no water or only chemically

bonded water; this state can be obtained by drying to constant weight

Non-hygroscopic materials remain dry in contact with moist air, while **hygroscopic** materials retain water molecules at the inner surfaces of their porous structure, until an equilibrium state of water content related to the humidity of ambient air is reached.

A surface is described as **hydrophobic** if it is or is not completely wetted by droplets. The parameter relevant for hydrophobicity of a surface is **the contact angle**, which can be determined by using specific equipment (Heilen, 2009).

Capillary-active materials (hydrophilic materials) means moisture absorption by capillary suction in case of direct material contact with liquid water; the opposite are the water impenetrable materials, also called hydrophobic materials.

2.2. Moisture storage in building materials

In theory a building material can absorb moisture until all its pores are saturated, reaching the so called free water saturation or **capillary saturation state**; beyond this state, increasing of water content can occur only by applying pressure or by water vapor diffusion in a temperature gradient. For hygroscopic materials, capillary saturation is an important material coefficient, placed below the maximum possible water content, in the open pore space (this being caused by entrapped air presence in some pores (Krus and Kiessl, 1998), but it does not offer enough information about its real moisture storage capacity under natural conditions. In order to establish a mathematical model valid for the one and two dimensional calculation of the simultaneous heat and moisture transport in building components, H. M. Künzle is concerned in determining the relation between water content of a building material and the ambient conditions, the most decisive one being the relative humidity (RH) (Künzel, 1994). Recent hygrothermal models consider as well RH and its corresponding capillary pressure, as the driving force for the basic moisture transient processes: vapor and liquid transport (Holm and Künzle, 2000).

H. M. Künzle (Künzel, 1994) identifies three moisture regions, graphically presented in Fig. 1 that can appear in a hygroscopic, capillary active material due to ambient intensively rising moisture.

Region A (hygroscopic region) – characterized by adsorption from the ambient moist air, it ranges from the dry state to equilibrium moisture of about 95% relative humidity; Krus (Krus and Kiessl, 1998) mentions that for hygroscopic porous materials under isothermal conditions, the sorption isotherms, which define the relationship between the volume of accumulated moisture and RH, have a typical S - shape profile (Fig. 2) and are often subjected to a hysteresis effect between absorption and desorption. According to H. M. Künzle (Künzel and Kiessl, 1997), the hysteresis between absorption and desorption is not very distinct and for majority of building materials and consequently the absorption curve is enough to define moisture retention in this region. In case of distinct hysteresis, a mean value can be taken into account for moisture behaviour calculation.

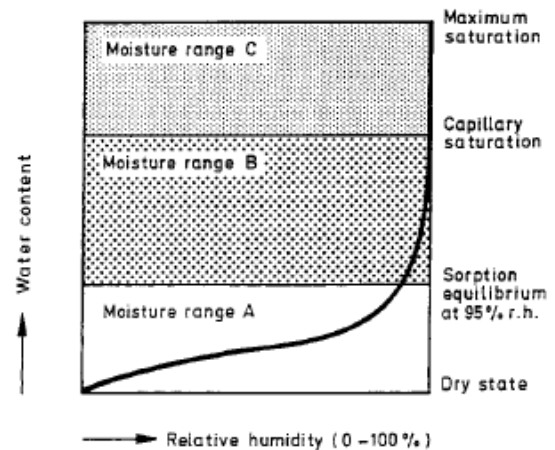


Figure 1. Schematic diagram of the moisture storage function of a hygroscopic capillary active building material

Region B (capillary water region) – According to Krus (Krus and Kiessl, 1998), this region is characterized by the property of capillary porous hygroscopic material to absorb water until the equilibrium state of capillary saturation is reached. Materials with smaller capillaries possess greater suction

forces, meaning that, in this equilibrium state, the water contents of two materials connected by capillary action are not equal. The sorption isotherm for this region, where RH exceeds 95%, rises abruptly (Fig. 2)

Region C (supersaturated region) – ranges from the free water saturation and goes to filling up all the cavities; in practice it can be achieved by some methods like applying external pressure or inducing vacuum in order to eliminate the entrapped air or by forced condensation; along this region, as tests revealed, no equilibrium state is reached.

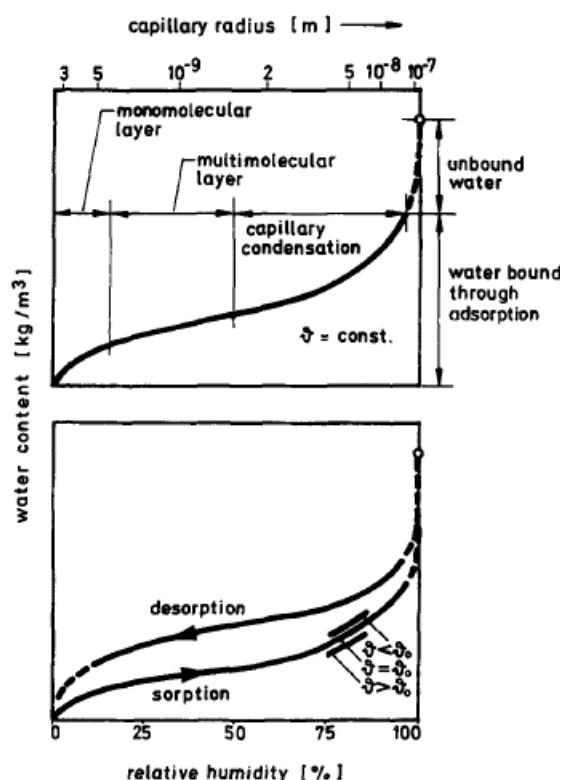


Figure 2. Schematic representation of a typical isotherm for hygroscopic porous building material (Krus and Kiessl, 1998)

2.3. Mechanisms of moisture transport

H. M. Künzeli (Künzel, 1994) considers that the most relevant moisture transport mechanisms for building elements are:

I. **Water vapor transport** – mainly vapor diffusion;

II. **Liquid transport** (with its distinct components: **surface diffusion** and **capillary conduction**).

First H. M. Künzeli insists upon them, aiming to define a relationship between the

water content of a building material and the ambient condition, and then, together with Quenard (Quenard *et al.*, 1998) also underlines them, interested in another dependency: between material microstructure (defined by density, open porosity and pore size) and the transport properties of materials: air permeability, water vapor transport and liquid transport.

Considering the unit of time, water liquid transport permits tens of times more moisture carriage inside materials than diffusion (Krus and Holm, 1999); in order to provide a correct evaluation of liquid transport coefficients, wetting and drying must be regarded as distinct processes, meaning two distinct boundary conditions and consequently different transport coefficients.

Determination of liquid water transfer through porous building materials, due to moisture implication in buildings with huge economical involvement, is considered of international importance, being part of the “hamstad” project (Heat Air and Moisture Standards Development), initiated by European Commission (Adan *et al.*, 2004).

The above mentioned processes are generally independent of each other, as it is proved that vapor diffusion is a characteristic of large pores materials, while liquid transport by capillary suction is more active in small capillaries, as H.M. Künzeli remarks (Künzel and Kiessl, 1997): „Despite the fact that an interaction of liquid and vapor fluxes, especially under very humid conditions, cannot be excluded, they are treated as independent processes”. This hypothesis, confirmed by Krus and Kiessl (Krus and Kiessl, 1998), that the vapor and liquid transport do not have mutual influence, valid in the hygroscopic region of most building materials, represents the basis of his capillary model.

In order to offer a valid calculation model, Künzeli deals with the interaction of these two major mechanisms, taking into consideration the actual physical process, graphically exposed in Fig. 3.

Considering the winter conditions, the interior temperature and also vapor pressure

(due to interior moisture) are higher than those outside the building; on the other hand, the exterior humidity is considerably higher than the interior one (the annual mean of RH for Germany is 80%), and therefore the gradients of relative humidity (RH) and vapor pressure have opposite sense (fig. 3 a), representing non – isothermal conditions.

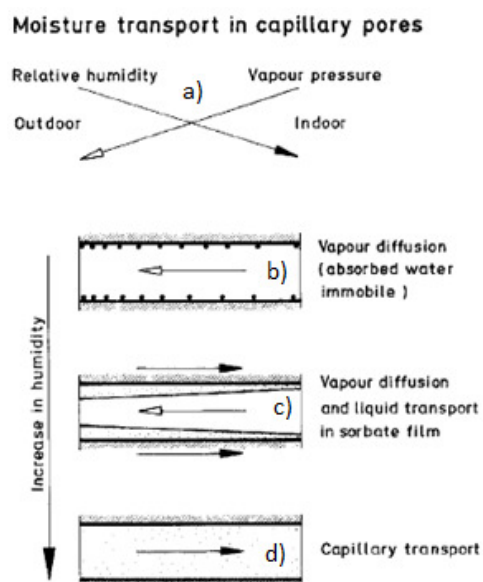


Figure 3. Kunzel's schematic diagram showing the moisture transport in a porous hygroscopic building material (winter conditions)

As long the building element is dry, the moisture flow by vapor diffusion in the capillary occurs only from the interior to the exterior side; because of high adhesive forces, the water absorbed in the walls remains still (fig. 3 b).

When rising of water content, the vapor diffusion is offset by liquid transport in sorbate film (this layer covers the pore walls and it is thicker on the outside because of exterior RH increased value); the mobility of water molecules depends to sorbate film thickness, travelling from the thicker section to the thinner one, in the process of surface diffusion (fig. 3 c). Having as driving gradient the suction stress or the relative humidity, this is a process related to the liquid transport and not of vapor diffusion, as it was wrong considered. In the capillary presented in Fig. 3, surface diffusion, having an opposite sense than vapor

diffusion, reduces moisture transport from the interior to exterior.

When the total humidity raises (fig. 3, d) capillary conduction occurs, reversing the initial moisture transport direction; the phenomenon happens only above the critical moisture.

Capillary conduction and surface diffusion occur almost simultaneously in liquid transport and experimentally they are determined together.

The process of diffusion, defined as „responsible for the movement of matter from one part of a system to another, mainly due to random molecular motions” (Masaro and Zhu, 1999), is fast in gases (10 cm/min) and much slower in liquids (0.05cm/min) and solids (0.00001 cm/min); as Masaro says, to define a valid diffusion through solids model can be difficult to achieve, because of diffusion coefficients which in this case can differ by more than a factor of 10^{10} .

3. RENDERS BASED ON ORGANIC BINDERS

3.1. General information

The European standard EN 15824 - Specifications for external renders and internal plasters based on organic binders”, appeared in October 2009, also applies in Romania and refers to coating products as, for example, final plaster coats, plaster undercoats and filler compounds, but not paints or coating materials, which are covered by the standards EN 1062-1 and EN 13300. EN 15824 defines a plaster or finish plaster as a mixture (paste or powder) of one or more binders (polymers), aggregates, (with predominant particle size ranging from 0.25 and 4 mm), pigments and other additives/adjuvants (rheology modifiers dispersion agents), all placed in water or other solvent (solvent-borne or water-borne coatings). As Van der Wel explains (Van der Wel and Adan, 1999a), each ingredient plays its distinct role in the admixture: the **polymer** represents the matrix for the other constituents, the **pigments** (dense inorganic particles or insoluble organic compounds) ensure the

colour and sometimes the corrosion inhibition, the **fillers** – cheap minerals like talc, clay, chalk and quartz- reduce the price of the final product and the **additives** improve some coating parameters, such as workability or stability.

Occurrence of EN 15824 as Harmonized European standards implies that in future these renders and plasters will therefore be marked with the CE symbol, in three different systems for attestation of conformity. This confirms that the products comply with the current European requirements for stability, fire protection and environmental protection and their performance criteria and the methods used evaluate them are clearly established.

Consequently, considering the standard's basic demands and also specifications resulted from organic binders research (Van der Wel and Adan, 1999b), the products must meet the following requirements:

- Good adhesion to the substrate (adequate tensile adhesive strength);
- Low water absorption (low coefficient of water absorption)
- Good drying characteristics (good water-vapor permeability, low S_d value)
- Low susceptibility to cracking (good relaxation behavior), this implying a good durability resistance

Regarding liquid water absorption and vapor permeability, organic binder products should obey the general Künzel's facade theory.

3.2. Facade protection theory

W. Heilen, (Heilen, 2009), provides us a complex study regarding the action mode and the properties, the use and also the proper choosing of additives in order to obtain optimum design of barrier coatings satisfying the required properties. His research, besides pertinent information regarding the chemistry of most commonly used hydrophobing agents (recently silicon derivatives – oils, fats, resins or rubbers), presents Künzel's facade protection theory, formulated in the 1960's.

According to this theory, the solution of sealing completely the facades against water using waterproof material is not proper: on one

hand, there are several entrance points for water in a facade, besides coating hydrophilic potential: cracks or other coating faults, damage in roof drainage or dampness from the interior; on the other hand, protection of a facade can be achieved by providing it „a functioning moisture management” (Heilen, 2009), moisture resisting and breathing in the same time. The hydrophobic capacity of the plaster must be achieved (reduction of capillary water absorption) without affecting water-vapor permeability.

This complex condition is obtained satisfying the requested values of two parameters above mentioned, as key elements in moisture transfer thorough building materials and elements:

- a) Water absorption capacity (w-value);
- b) Vapor permeability (V-value or S_d -value).

The water permeability of organic binder renders is determined (as EN 15824 requires it) according to EN ISO 1062-3 standardized method; also called capillary water absorption, describes the amount of water which can be absorbed by capillary suction by a square meter of building material within a certain time interval. EN ISO 1062-1 and also EN 15824 contain three categories, (Table 1) of capillary water absorption (Kg of water uptake on one square meter in 24 hours).

Table 1. Water permeability classes, w – value, according to EN 15824

Category (class)		W – value Kg/(m ² d ^{0.5})
W ₁	High	>0,5
W ₂	Medium	≤0,5 >0,1
W ₃	Low	≤0,1

The water vapor transmission rate is determined, as EN 15824 requires it, according to EN ISO 7783-2 (recently replaced by EN ISO 7783:2011), two parameters being involved:

- **The V-value**, describing the amount of water vapor in grams which can diffuse in one day from a coating area of one square meter;
- **S_d -value** (which can be calculated from the V-value), describing the thickness of an

imaginary layer of still air which has the same resistance to water vapor diffusion as the coating.

Diffusion equivalent thickness of air (S_d -value) is given more often than water vapor transmission rate (V). The EN 15824 divides the S_d value into three categories (classes). Coatings with an S_d -value less than 0,14 m are assigned to the best class (class 1) and have very good water vapor transmission.

Table 2. Water vapor transmission rate V and S_d classes, according to EN 15824

Category (class)		Water vapor transmission rate V – value $\text{g}/(\text{m}^2\text{d})$	Diffusion equivalent thickness of air S_d – value
V_1	High	>150	$<0,14$
V_2	Medium	≤ 150	$\geq 0,14$
V_3	Low	>15	$\geq 0,14$

The testing method presented by EN ISO 7783-2 - the wet cup method – and also the dry cup method are lately contested (Pazera and Salonvaara, 2012) as accuracy of determination (due to instability of boundary conditions, by changes in vapor pressure and air velocity on either or both sides of the specimen) especially in case of thin, flexible, and highly permeable construction materials. The multilayer test method for water vapor transmission testing of construction materials is proposed, as a new testing approach for WVP (Water vapor transmission), improving the precision of the material property data: change in the weight of the system is automatically determined at predetermined time intervals, resulting the vapor fluxes, and simultaneous testing of multiple specimens provides greater statistical confidence.

The relationship of these parameters to each other is given in Künzels facade theory which states that, for the ideal coating, both w -value and the S_d -value should approach zero, meaning that hydrophobic character must be achieved without reducing water vapor permeability.

Figure 4 shows quantitatively the relationship of w - and S_d -values to each other. The yellow area shows the region in which the

product of w - and S_d -values is $0.1 \text{ kg}/(\text{m} \times \sqrt{\text{h}})$ or smaller. Silicone resin architectural coatings can now obtain w -values below 0.1 and S_d values below 0.14.

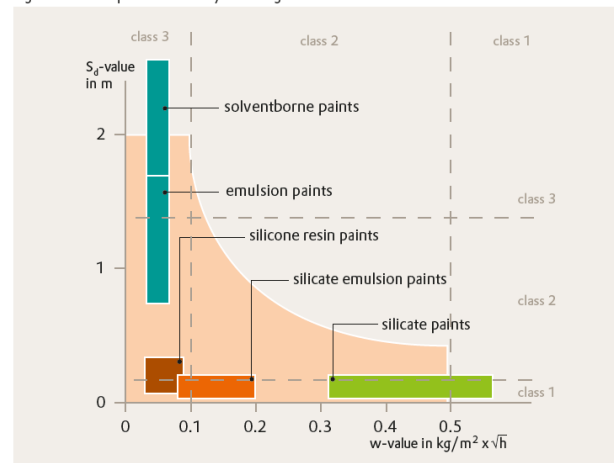


Figure 4. Facade protection theory according to Künzels

3.3. Open air tests

This theory was developed starting with 1960s open air tests carried out by Fraunhofer – Institute of Building Physics (Germany). By the means of experimental procedures upon driving rain protection of masonry wall, coated with organic binder renders (polymeric stuccos), the correlation between the water absorption and the vapor diffusion properties of coatings was proved (Künzel H. M *et al.*, 2004) and therefore it was introduced into the German Standard regarding exterior coating for regions subjected to high wind-driven rain load. The IBP (Fraunhofer Institute of Building Physics) extensive open air investigations concerning driving rain protection, were internationally appreciated (Blocken Hugo Hens) as important studies for this matter.

The relevant large scale field tests took place in Holzkirchen, a site created in 1951, closed to Bavarian Alps, characterized by severe temperature variation and high incidence of driving rain. Therefore the following relation was developed:

$$A \times S_d < C_{RP} \quad (1)$$

where:

A - water absorption coefficient [$\text{kg}/\text{m}^2\text{h}^{1/2}$];
 S_d – vapor diffusion resistance [m];
 C_{RP} – constant driving rain protection coefficient [$\text{kg}/(\text{mh}^{1/2})$]

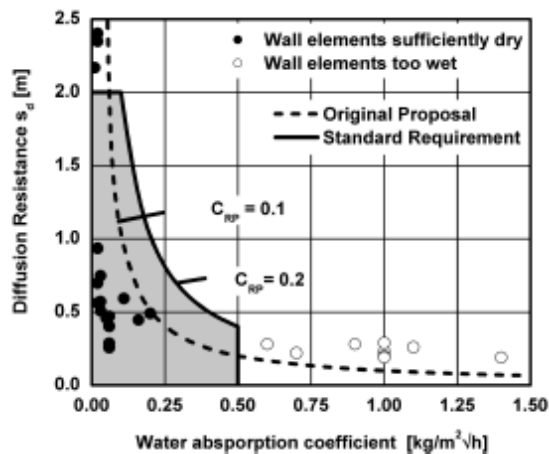


Figure 5. Measured hygrothermal parameters of coatings, Holzkirchen tests, (Künzel H. M et al., 2004)

The hyperbola $C_{RP} = 0.1 \text{ kg}/(\text{mh}^{1/2})$, defining the adequate performance criteria for waterprotection exterior renders, was increased to $0.2 \text{ kg}/(\text{mh}^{1/2})$ – all grey area – considering that the field condition in Holzkirchen, where from the necessary data were collected, are too severe in order to apply them generally.

In order to validate the above mentioned relations and specifications, hygrothermal simulations were performed in USA (costal climate of Boston and Seattle), the results confirming the Holzkirchen tendency.

A conclusive state of the art upon the matter of in situ tests and generally over The WDR (Wind-driven rain) as the most important moisture source affecting the performance of building facades, by Carmeliet and Blocken (Blocken and Carmeliet, 2004). Later on Janssen, Blocken and Carmeliet are introducing the WDR conditions as atmospheric boundary conditions for numerical hygrothermal models (Janssen and Blocken, 2007).

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4. CONCLUSIONS

In order to ensure development of high-performance organic coating systems, it is necessary to analyze the facades moisture transfer distinctly:

Firstly, as a complex phenomena, (referring mainly to substrate transient properties) through porous, capillary - active materials (generally, all building materials have these characteristics); relevant in this matter is the Kunzel approach (Künzel, 1994);

Secondly, as moisture transport through organic substances, as polymers represent the matrix constituents for fillers in composition of the organic coatings (George S. C., Thomas S., 2001). Referring to diffusion as important component in polymers moisture transport, this is a complex process, having a rate that should be placed between those in liquids and in solids. It depends mainly on the concentration and degree of swelling of polymers (Masaro and Zhu, 1999; George and Thomas, 2001);

Thirdly, as moisture transport in the combined system of coating and base material – facades systems (Van der Wel and Adan, 1999b). In 2011 Moon and Ryu are presenting their study, where investigating the effect of moisture transport on overall building performance: energy efficiency, thermal comfort, and IAQ (Indoor Air Quality) in built environments based on thermal and hygric simulation; they are measuring the hygrothermal properties of building materials forming a system (for instance, for exterior walls, they considered concrete, insulation and gypsum plaster); experimental data was used in for modelling the corresponding hygrothermic model (Moon and Ryu, 2011).

Summarizing, special coatings based on organic binders were developed starting with

the early 1960 in order to improve facade protection against excessive moisture, under general tendency of building elements width reducing which caused rainwater penetration problems. In order to improve the renders protective properties, moisture transport mechanism through building materials (including polymeric coatings), must be careful analyzed: two distinct parameters seems to be the key of this complex process: liquid water absorption and vapor permeability. Physically, they do not have mutual influence throughout the hygroscopic region of most building materials (Krus and Kiessl, 1998), but their values, as Kunzel proved by field test in Holzkirchen, must satisfy some specific limits so that the C_{RP} – constant driving rain protection coefficient – fulfils the performance criteria.

In order to ensure that organic coating products satisfy the above described hydrothermal specifications and other necessary characteristics (mechanical, fire protection or durability related); quality control standards have been implemented by occurrence in 2009 of Harmonized European standard EN 15824.

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