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Evolution of Degradation and Decay in Performance of ETICS

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ABSTRACT

This paper provides initial results from experimental work on laboratory accelerated ageing of external thermal insulation composite systems with rendering (ETICS) undertaken at the Building Environment Science and Technology department of the Polytechnic of Milan. The work forms part of a broader experimental programme seeking to develop knowledge on the relationship between critical properties affecting long-term performance and test parameters that reveal the process of degradation.

The performance evaluation of ETICS specimens consisted of several different types of tests conducted on non-aged specimens and specimens subjected to accelerated environmental ageing. The ageing procedure consisted of exposing specimens to different environmental macro-cycles comprised of ageing under ultraviolet radiation and warm and cold temperature cycling that replicated temperature cycling occurring in winter or summer in Italy. Non-destructive tests were carried out that included obtaining photos to characterise the evolution of surface degradation of specimens and conducting absorption tests to determine the degree of moisture uptake in the specimens. Other tests were used for assessing hygrothermal performances including dynamic thermal response, thermal inertia, thermal resistance and dynamic response to variations in moisture content of base and finish coat. In this paper the tests methods are described and initial results analysed following two ageing macro-cycles used to discern the process of degradation of the specimen, in terms of monitoring changes in capillary water absorption, thermal resistance and rendering degradation (photo survey). The long-term aim of this study is to develop a method to evaluate the Serviceability Limit State of building components based on understanding relationships between performance attributes and physical properties of building components.

KEYWORDS

ETICS, End of service life, Limit state, Performance decay, Degradation evolution

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1 INTRODUCTION

The aim of this paper is to portray the initial results of an experimental programme to evaluate the thermal performance of ETICS, introduced by Daniotti & Paolini [2008]. The specimen being evaluated has a vinyl resin-based base coat and an acrylic resin-based finish coat. Performances have been surveyed on the non-aged specimens and every ageing macrocycle (i.e. 5 x (25 UV cycles + 10 winter cycles + 25 summer cycles) with non-destructive tests: i.e., photos of the evolution in surface degradation, capillary absorption tests and cycles suited for assessing hygrothermal performances (dynamic thermal response, thermal inertia, thermal resistance and dynamic response to variation in moisture content of base and finish coat). In this paper the tests methods are described and initial results analysed following two ageing macrocycles used to discern the process of degradation in the specimen, in terms of monitoring changes in capillary water absorption and thermal resistance. The long-term aim of this study is to search for a relationship between single performances and properties in order to develop a method to evaluate the Serviceability Limit State of building components.

2 PERFORMANCE LOSS IN THERMAL RESISTANCE

2.1 Preliminary Analysis of System Performance

As an initial step, the thermal performance of the building component being studied was evaluated in accordance with different reference standards, namely: EN 12524 for specimen type A.1; steady state properties calculated according to EN 6946; and, dynamic properties calculated according to EN 13786. These values are provided in Table 1.

Table 1. Physical and related hygrothermal properties of specimens

n°	*Layer*	*s* *[m]*	ρ *[kg/m^3]*	λ_d *[W/mK]*	$c_{p\,d}$ *[kJ/Kkg]*	*R* *[m^{2}K/W]*	μ *[adim]*	*M** *[kg/m^2]*
1	Gypsum	0.005	900	0.300	1	0.017	10	4.500
2	Cement Lime Plaster	0.015	1600	0.902	1	0.017	10	24.000
3	Masonry wall	0.12	650	0.385	0.84	0.312	7	78.000
4	Cement Lime Plaster	0.015	1600	0.902	1	0.017	10	24.000
5	Adhesive	0.003	1800	1.001	0.84	0.003	15	5.400
6	EPS insulator	0.06	25	0.034	1.25	1.765	35	1.500
7	Base coat	0.005	1800	1.001	0.84	0.005	15	9.000
8	Finishing coat	0.0015	1100	1.000	0.84	0.001	7	1.650

Total thickness	s	0.2245	[m]
External surface coefficient of heat transfer	h_e	25	[W/(m^{2}K)]
Internal surface coefficient of heat transfer	h_i	7.7	[W/(m^{2}K)]
Conductive thermal resistance nodes 12	$R_{cd\,12}$	0.362	[m^{2}K/W]
Conductive thermal resistance nodes 23	$R_{cd\,23}$	1.774	[m^{2}K/W]
Total conductive thermal resistance	$R_{cd\,TOT}$	2.136	[m^{2}K/W]
Thermal conductance	Λ	0.468	[W/(m^{2}K)]
Total thermal resistance	R_{TOT}	2.306	[m^{2}K/W]
Thermal transmittance	U	0.434	[W/(m^{2}K)]
Thermal capacity nodes 12	C_{12}	118.02	[kJ / (m^{2}K)]
Thermal capacity nodes 23	C_{23}	15.36	[kJ / (m^{2}K)]
Total thermal capacity	C_{TOT}	133.38	[kJ / (m^{2}K)]
Decrement factor	f	0.3219	[-]
Shift (on internal side)	ϕ	6h 46’	[h]

2.2 Test Description

Before being exposed to ageing cycles and after every ageing macrocycle, the thermal insulation performance was evaluated with a steady state test (referred to as CON, i.e. thermal conductance measurement). Data provided in this paper relate to: (i) initial conditions determined according to EN 12524, (ii) non-aged specimens (ageing time, T0), (iii) aged specimens, following two macrocycles (i.e. ageing time T1, T2 and T2+); and, (iv) data (ageing time T2+) concerns loss in thermal performance after a rain cycle (last part of RHst cycle), while the other measuring cycles have been performed after three cycles suited for evaluating thermal dynamic properties in summer conditions (SINa, SINb and TI cycles). This was to ensure that the loss in thermal performance was not influenced by an excessive amount of water gained during the ageing cycles that included rain.

The CON measurement cycle consisted of exposure of the specimen for 96 hours to the following conditions:

Climatic chamber	T [°C] = – 20 constant; RH [%] = 0 constant
Laboratory	ΔT_{MAX} [°C] = 2; RH [%] = 40 ÷ 60 [acceptance intervals during test]
Recording	180 [s] between readings

Laboratory conditions are not fixed, however tests are considered valid because:
- temperature and relative humidity oscillations are not large;
- tests having high T [°C] or RH [%] oscillations (beyond acceptance intervals) were rejected;
- dynamic calculation to filter the contribution due to small oscillations in environmental conditions was adopted.

In order to observe the loss in thermal insulation, only the conductive portion of the thermal resistance of the wall assembly was determined (total values – thermal transmittance and total thermal resistance – are reported only with the aim towards completeness and for comparison purposes), because of the fact that surface heat transfer coefficients:
- are different in laboratory and outdoor and are different for a one square meter specimen;
- show great variations due to different conditions during the same test and different tests and are strongly influenced by radiative boundary conditions;
- are not obviously influenced by degradation.

The calculation of conductive thermal resistance of the substrate, of the ETICS and of the entire specimen has been performed according to ISO 9869, using the average and storage effect methods. The data that was analyzed was that of the main section profile, whereas the loss in thermal performance coincidence with thermal bridges located at joints between insulation panels and bed mortar joints were evaluated with IR thermography that permitted assessing the changes in thermal gradient across the face of the specimens.

An analysis using the average method (av in figures) provides a value of thermal resistance assessed over a period of 24 hours, when steady state thermal conditions are reached and as well, conditions specified in the standard are met. On the other hand, using the storage effect method, a correction to the mean heat flow rate was introduced that takes into account dynamic effects (using a resistance-capacity method). In this study, the correction to heat flow due to storage effects was performed by considering both the thermal capacity of the dry layer and the total thermal capacity of the layer, including the contribution of water present in the pores. EPS has been divided into six layers of 1 cm (referring to the outer section as EPS 6) and the thermal resistance of each layer and respective water contents were obtained from a numerical solution starting from an estimate of the moisture distribution and thermal gradient in the building component from the interior side of the assembly. It is important to highlight that the aim of this test was not to obtain a deterministic measurement of the physical properties of the specimen, but to evaluate the loss in thermal performance.

2.3 Discussion of İnitial Results of Loss in Performance of Thermal İnsulation

The initial results are useful to highlight the difference between the values for thermal resistance calculated with the standard reference and those measured that show an evident loss in insulation performance. At the same ageing conditions, and after a rain cycle, a significant loss in thermal resistance was observed.

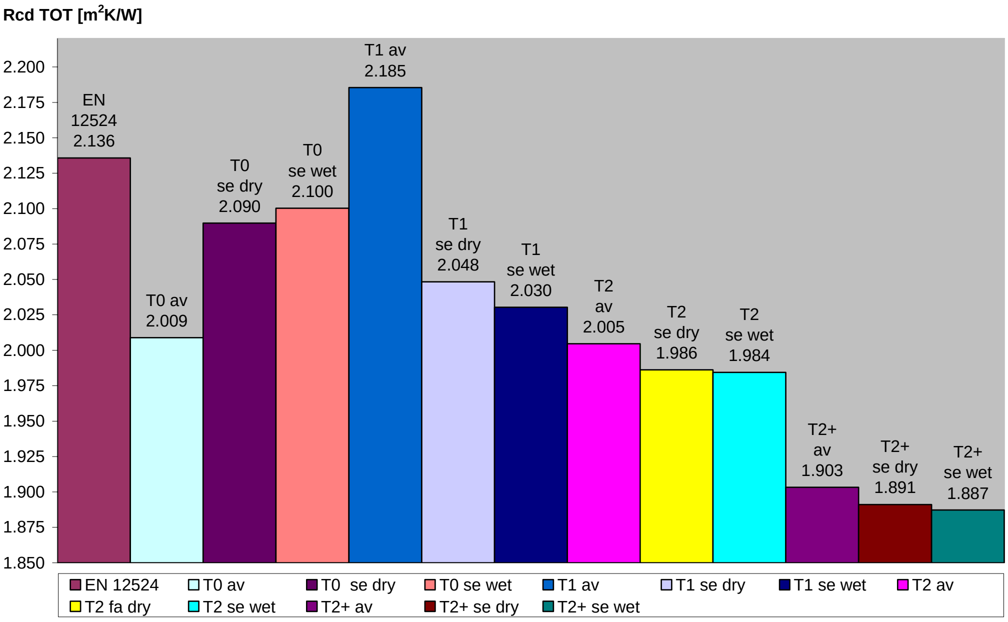


Figure 1. Loss in total conductive thermal resistance.

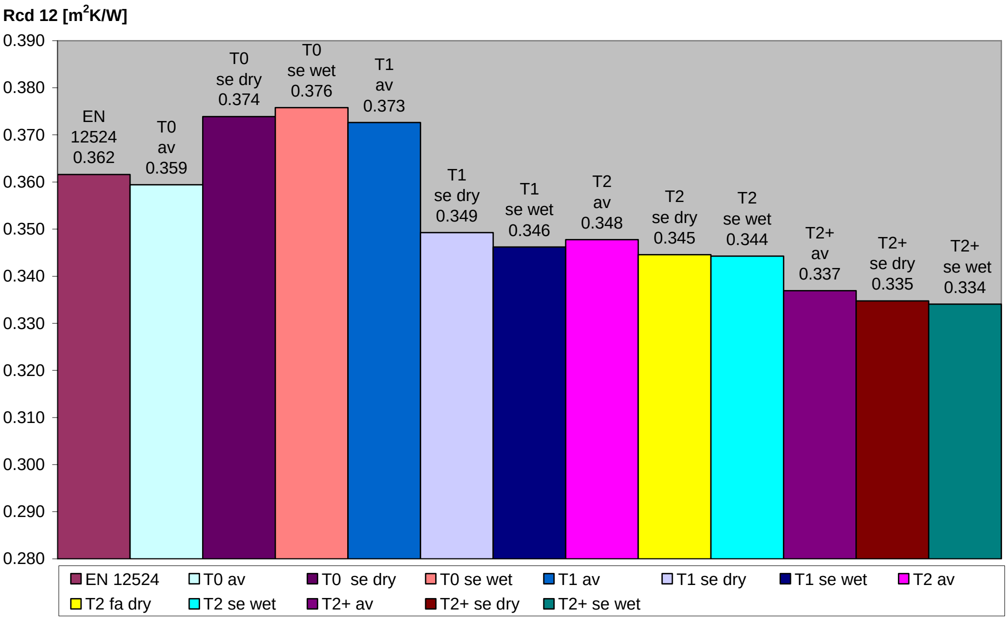


Figure 2. Loss in thermal resistance of masonry wall and plaster substrate.

In Figure 2 a limited reduction in thermal resistance of the substrate is noticed, that is due to an increase in moisture content; this increase in moisture was brought about by water that permeated the ETICS. It is estimated that construction water would be taken up prior to initiating tests (6 months later than fabrication of the substrate). On the other hand (see Figure 3), the thermal resistance of the ETICS suffers a pronounced loss, that could be explained by the increase in moisture content in the outer layers of the EPS where water is in the solid phase at most exterior portion of EPS, and in a physical transition phase in the middle section of the EPS. Even if the thermal resistance of the base and finish coat are set to zero, the loss in thermal could not be reached.

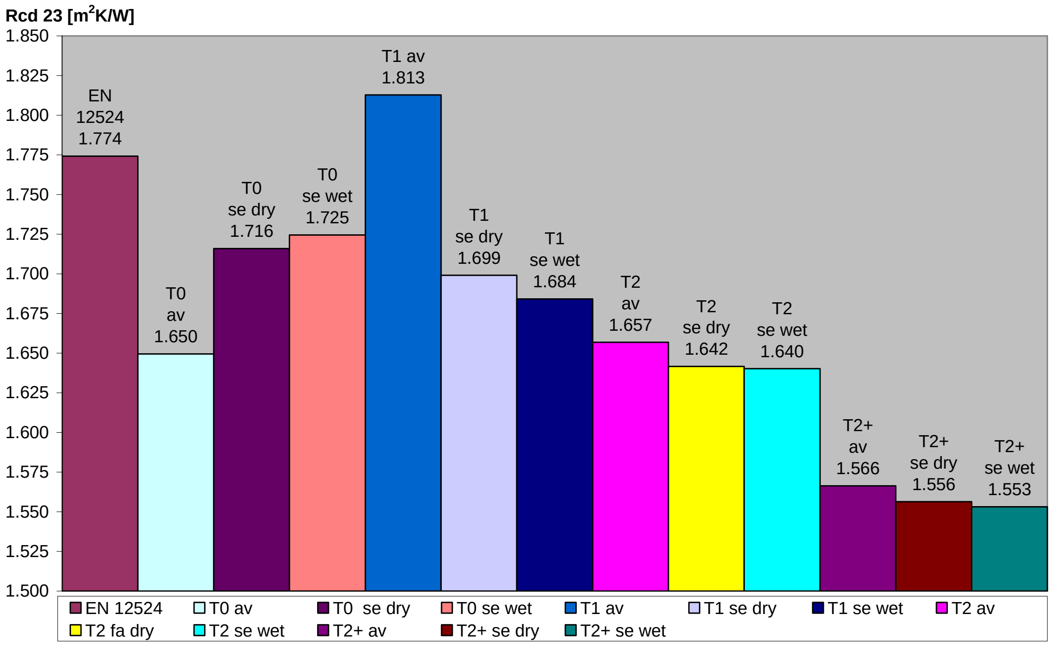


Figure 3. Loss in thermal resistance of ETICS (EPS, base and finishing coat).

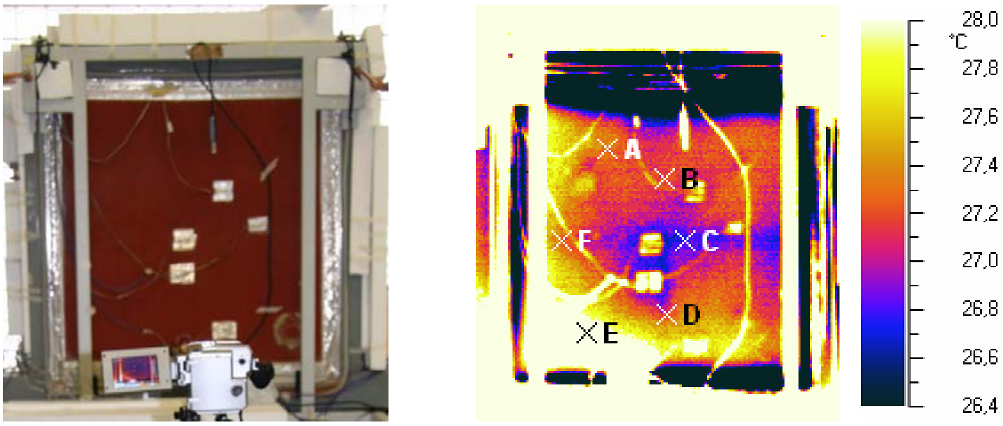
Table 2. Values from standard and values measured at T0 and after two ageing macro-cycles.

Thermal property		*EN 12524*	*T0 dry*	*T0 wet*	*T1 dry*	*T1 wet*	*T2 dry*	*T2 wet*	*T2+ dry*	*T2+ wet*	*u.m.*
Substrate resistance	$R_{cd\ 12}$	0.362	0.374	0.376	0.349	0.346	0.345	0.344	0.335	0.334	$\left[\frac{m^2K}{W}\right]$
ETICS resistance	$R_{cd\ 23}$	1.774	1.716	1.725	1.699	1.684	1.642	1.640	1.556	1.553	$\left[\frac{m^2K}{W}\right]$
Tot conductive resistance	$R_{cd\ TOT}$	2.136	2.090	2.100	2.048	2.030	1.986	1.984	1.891	1.887	$\left[\frac{m^2K}{W}\right]$
Conductance	Λ	0.468	0.479	0.476	0.488	0.493	0.503	0.504	0.529	0.530	$\left[\frac{W}{m^2K}\right]$
Tot resistance	R_{TOT}	2.306	2.260	2.270	2.218	2.200	2.156	2.154	2.061	2.057	$\left[\frac{m^2K}{W}\right]$
Transmittance	U	0.434	0.443	0.440	0.451	0.455	0.464	0.464	0.485	0.486	$\left[\frac{W}{m^2K}\right]$
Substrate capacity	C_{12}	145.0	145.0	162.9	145.0	165.4	145.0	168.0	145.0	177.5	$\left[\frac{kJ}{m^2K}\right]$
ETICS capacity	C_{23}	15.7	15.7	18.7	15.7	19.0	15.7	19.9	15.7	21.3	$\left[\frac{kJ}{m^2K}\right]$
Tot capacity	C_{TOT}	160.6	160.6	181.6	160.6	184.5	160.6	187.8	160.6	198.8	$\left[\frac{kJ}{m^2K}\right]$

Performing a test with ice water or water in a transition phase does not introduce a useless complication in the analysis of data, but allows determining a more evident loss in thermal performance. Without the use of ice presence, it would be difficult to separate the loss in thermal resistance from measurement errors and other experimental uncertainties.

2.4 Infrared Thermography

The development of a thermal bridge coincidence with joints between insulation panels, in particular horizontal joints, is noticed from analysing the data provided by the infrared thermography performed at ageing time T2+. At the vertical joints the accumulation of water tends to spread at the base of the joint and not remain close to the joint line.



Point	T[°C]
A	27.2
B	27.3
C	26.8
D	27.1
E	28.4
F	27.2

Figure 4. Infrared thermography at ageing time T2+; Laboratory air temperature $T_{A.LAB}$ = 29.0 °C. Surface emissivity ε = 0.92. IR-camera distance from specimen: 4 [m].

3 CAPILLARY WATER ABSORPTION

In order to survey the water absorption evolution at different ageing times, the test on the same specimen was repeated a specified times using Karsten's method that is given in NORMaL 44-93. This method is a non-destructive test for water absorption using low water pressure. During the test, the volume of water [mL] absorbed by the exterior surface of the complete specimen was recorded at different times. The degree of water absorption [L/m^2] is expressed as a function of the square root of time [s$^{1/2}$].

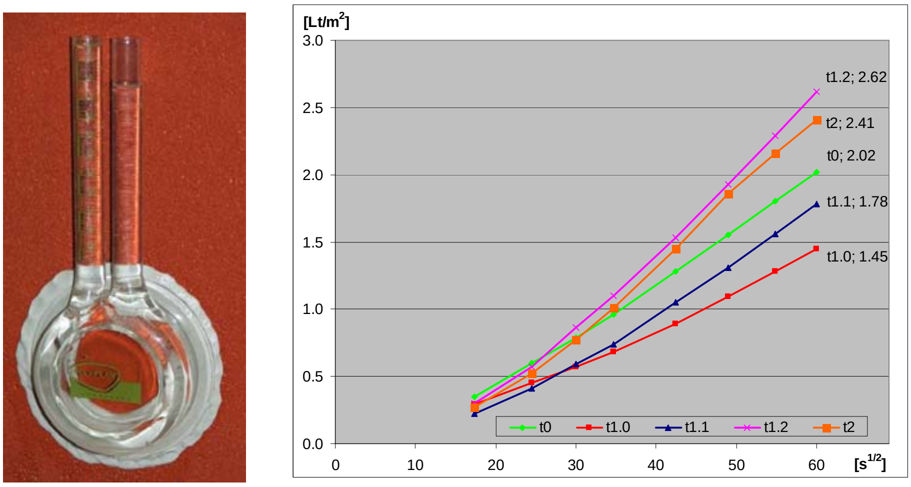


Figure 5. Measurement apparatus and initial results showing water absorption as a function of absorption time.

At ageing time T1.0 a relevant loss in absorption was noticed, that could have two possible causes: water saturation conditions and increase in cross-linking of polymeric binder of finish coat and curing of cement matrix of base coat. At ageing times T1.2 and T2 an increase in water absorption was measured. It is important to stress that this kind of test is useful because it is non-destructive; however, a significant standard deviation of results is obtained in this test. As such, it would require validation with other tests, in particular, tests such as the capillary absorption test, which is a disruptive test.

4 PHOTO-SURVEY OF SURFACE DEGRADATION

A photographic survey of the degradation of the surfaces of ETICS has shown that the most significant evolution in degradation at ageing time T1 is evident by the development of blisters on the surface of the finishing coat. As well, at all ageing times it has been observed that there is an increase in the dimension of pores of the finish coat.

Figure 6. (Left side) Photograph of ETICS finish coat at ageing time T1; blisters (larger ones: 10 cm diameter circa) are evident on the surface of the sample; (Right-side) dimension of pores and surface appearance are changed (aggregate dimension 0/1 mm); Localized fading due to rain-wash is shown.

5 CONCLUSIONS

5.1 Initial Results

Following on the analysis that was implemented and initial hypothesis for causes of degradation , decay in thermal performance is mainly due to an increase in water content of the EPS; hence an apparent rise in thermal conductivity of the EPS layer is evident. A first hypothesis for the evolution of ageing could be the following:

- UV cycles: UV degradation (i.e. progressive chain scission), of the polymeric binder of the finishing coat brings about an increase in cracking of capillary size and likewise an increase in the depth of penetration of UV rays;
- Winter cycles: the base coat and finishing coat are both subject to tensile forces that result in increases in the width of capillary cracks that in turn during rain events allow water penetration; such penetration also causes rain-wash. As well, wet rendering, having a reduced tensile strength, is susceptible to freeze-thaw cycling; this deteriorative effect contributes to the degradation of the cementitious matrix;
- Summer thermal shock cycles: base coat and finish coat are subjected to compression and adhesion stresses resulting in deformation of the finish coat that can lead to the formation of voids between layers that potentially can fill with moisture and cause blistering as water vapour intrudes the voids during a heating phase.

The cycle of degradation can be summarized as:

- Increase in capillary crack width; followed by,
- Water absorption; thereafter,
- Reduction in tensile strength; from which ensues,
- Reduction in thermal resistance; thereby bringing about an,

- Additional increase in capillary crack width
- Continued cycling of the degradation phenomena

5.2 Future Development of Research Programme

Future activities of this research programme that focuses on ETICS will be the evaluation of dynamic tests, performing destructive tests and exposure of specimens to exterior conditions to establish re-scaling factors useful for relating results derived from accelerated and long-term exposure tests. On the other hand the Performance Limit Method developed by the BEST will be used to experimentally assess ETICS such that the basic functional properties of ETICS and their respective performances can be linked to one another. This will permit moving towards an initial draft of a generic Serviceability Limit State Method suitable for assessing building components.

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