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DURABILITY OF ETICS INCORPORATING HIGH REFLECTANCE PIGMENTS IN FINISHING COATINGS

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ABSTRACT

The increase of the durability of building materials and components presents great importance since it contributes to a more sustainable environment by increasing its service life. The development of new building materials and technologies with improved thermal characteristics, such as ETICS with high reflectance coatings, contributes to meet the thermal requirements defined by the European regulation. However, the importance of the durability assessment of new solutions cannot be understated as it plays a key role in the prevention of future early degradation.

This paper has the objective of assessing the durability of ETICS incorporating high reflectance pigments in organic coatings. The solar reflectance can be increased through optimized material formulations with the inclusion of nanoparticles in coatings. If the near-infrared (NIR) solar absorption is reduced, the referred benefits can be achieved even in darker colours. One of the main concerns is the durability of the entire system, but the stability of the darker colours must also be taken into account.

As such, relevant parameters – solar absorptance, surface temperature and colour – were measured in a long-term "in-situ" experimental campaign, in ETICS specimens with distinct coatings. The effect of the thermal insulation layer, in the referred parameters, was also evaluated, by measuring the effect of the same coatings in samples with traditional substrates. The solar absorptance was measured with a pyranometer with an adapted methodology based on the ASTM E1918 standard. The surface temperature of the samples was continuously monitored for an extended period enabling a comparison of the benefits under different climatic conditions. The colour was determined by the CIELAB colour space, by measuring the L*A*B parameters. The results showed that the incorporation of high reflectance pigments leads to a decrease in the solar absorptance and surface temperature even in darker colours. The pigments also influenced the lightness of the coating, by increasing the L parameter.

The potential benefits of these thermal enhanced systems combine an enhanced thermal performance, durability and a higher diversity of aesthetic features.

KEYWORDS: Durability, ETICS, High reflectance pigments, Solar absorptance, Dark colours.

1. INTRODUCTION

The European building stock is responsible for more than 40% of energy consumption and greenhouse gas emissions [1]. The increase of energy efficiency of buildings plays a decisive role in the transformation of the EU energy framework [2].

Thermal insulation materials could be an effective way to reduce heat losses in buildings by decreasing the thermal transmission of the building envelope. In addition, eco-innovative materials and technologies have been developed to reduce the need for air-conditioning of buildings [3 4]. One of these technologies corresponds to the application of high reflectance materials, which have high solar reflectance and high emission of infrared radiation. The use of reflective materials contributes to the reduction of cooling loads, which is required for achieving the Nearly Zero Energy Buildings as defined by the Building Energy Performance Directive 2010/31/EC [5]. Other benefits of these materials are the increase in the range of coating colours and the reduction of heat island effect [6]. Reflective coatings proved to have a significant impact on improving thermal comfort while reducing the energy consumption of buildings [7]. The colour change can contribute to energy efficiency by reducing the cooling load by almost 20% [8]. One of the main advantages of high reflectance pigments (HRP) is the high reflectance properties in the near-infrared (NIR) zone of the solar spectrum, maintaining the reflectance properties of materials with the same colour in the visible spectrum. Thus, it is possible to replace traditional dark-coloured pigments, which absorb the NIR radiation, by high reflectance pigments [9], maintaining their dark colour. According to Shen, et al. [10], the application high reflective façades contribute to a decrease of 6 to 20ºC in the surface temperature compared to traditional solutions.

Evaluating the actual performance of these innovative solutions is fundamental to optimize their application. In this work, the durability of ETICS incorporating high reflectance pigments in organic coatings was analysed. The solar reflectance can be increased through optimized material formulations with the inclusion of nanoparticles in finishing coatings, which contributes to the reduction of the surface temperature, non-compromising the aesthetic component.

2. MATERIALS AND METHODS

2.1. Materials

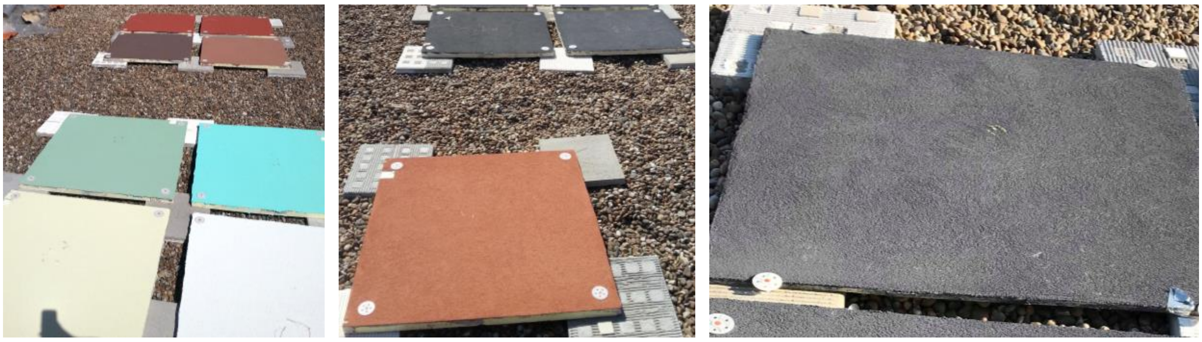
The proposed methodology was applied to a set of specimens constituted by three distinct layers:

- Finishing coating: organic coating composed by mineral fillers, resins in aqueous dispersion, pigments and specific additives (antifungals and others);
- Basecoat: cement, mineral fillers, resins, synthetic fibres and special additives;
- Insulation or concrete slab:
    - EPS slab: expanded polystyrene 20 kg/m^3;
    - Concrete slab: lightweight concrete (LC).

To evaluate the effect of high reflectance pigments (HRP), some specimens include these pigments in the finishing coating. The referred pigments are “Navapint D Solar Reflective", from "Chromaflo Technologies". These pigments result of a combination of the conventional pigments used in façades, which have a good solar reflection, with a black pigment reflective in the near-infrared zone, designated D803 [11].

The finishing coating consists of a thin layer of mortar of approximately 2 mm. The base coat is applied in two-layer of 1.5 mm with a glass fibre mesh between them. The insulation slab has a thickness of 4 cm, while the lightweight concrete has 12.5 mm. Taking into account the different variables, a total of 12 specimens, with 1x1 m^2, were placed horizontally on a roof of the Civil Engineering Department of the University of Porto, as shown in Figure 1. The ETICS specimens shown in Figure 1-a) were under one year of natural ageing (Year 0). The concrete slab specimen (Figure 1-b) was placed one year after

(Year 1) and was monitored simultaneously during the summer period. Table 1 presents the designation and constitution of each specimen.



a) b)

Figure 1: Analysed specimens: a) With insulation layer (EPS); b) Without insulation layer (concrete slab)

Table 1: Constitution of the specimens.

Designation/Colour	Substrate		Basecoat	Finishing coating	
	EPS	Concrete		Regular	With HRP
White	X		X	X	
Yellow	X		X	X	
Green	X		X	X	
Blue	X		X	X	
Orange	X		X	X	
Light Brown	X		X	X	
Dark Brown	X		X	X	
Red	X		X	X	
Red_HRP	X		X		X
Black	X		X	X	
Black _HRP	X		X		X
Black_without EPS		X	X		X

2.2. Methods

In this research, the performance of coating materials was evaluated by determining the solar absorptance, surface temperature and colour parameters.

The evaluation of solar absorptance was carried out using the E 1918A method, proposed by Akbari and Levinson [12]. This method consists of an adaptation of the ASTM E1918 Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-sloped Surfaces in the Field [13]. The E 1918A method uses a pyranometer in measuring the incident and reflected radiant solar energy in 1 m^2 surface. In this work, an SR05 Hukseflux Thermal Sensors pyranometer was used, which presents an estimated precision of 4.4%. The application of the method assumes a 3-step measurement, where the sample itself is evaluated, and the effect of a black mask and a white mask that allow eliminating the contribution of the contour to the reflection detected by the pyranometer. At the time of measurement, clear sky conditions and an angle of the sun with normal specimen surface area of less than 45° are required.

Surface temperature measurement was performed using T-type thermocouples using a standard metal combination (Copper Alloys and Constantan Alloys), and are attached to a Technetics datalogger designated by Mikromec Logger Multisens. The measuring accuracy is 0.2°C and at least two thermocouples were always applied in each sample. The exterior air temperature was recorded by the LFC-FEUP weather station. Temperatures were recorded every 10 minutes.

The colour was analysed using Konica Minolta's CR-10 Tristimulus portable Colorimeter. The equipment measures the L*a*b* and dE* in an area of 8 mm. All colour measurements are taken using conditions of the standard illuminant D65 and 10 degrees observer. This equipment operates between 0 to 40°C of temperature and 85% or less of relative humidity (at 35°C) with no condensation.

3. RESULTS AND DISCUSSION

3.1. Experimental results

Table 2 presents the obtained experimental results regarding the measured parameters: solar absorption coefficient (α), maximum surface temperature ($T_{surf,\ max}$) and colour parameters (CIE L*a*b colour space). The L* parameter refers to lightness, from black (0) to white (100), a* to green (-) to red (+) and b to blue (-) to yellow (+). The colour difference (ΔE) could be calculated using the L*a*b parameters as expressed in equation (1) [14 15].

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{1}$$

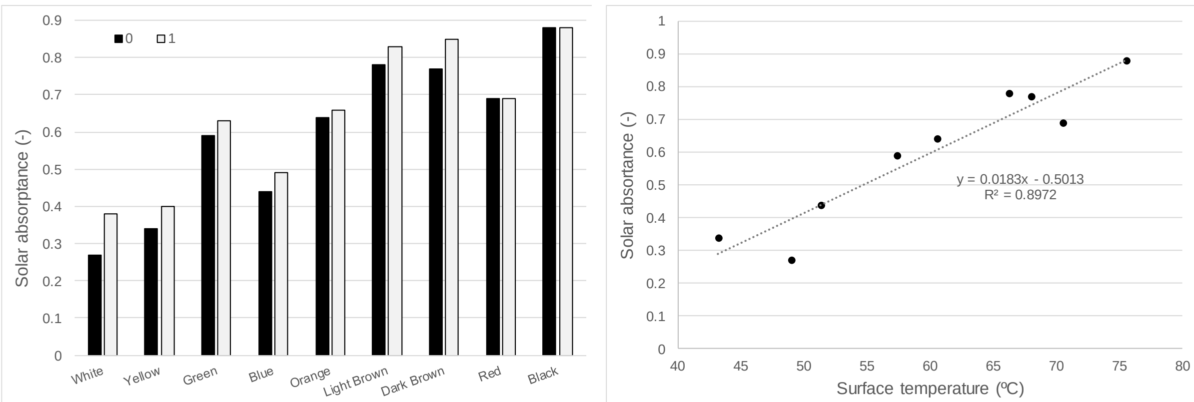
When ΔE is equal or lower than 1 the colour difference is not perceptible to the human eye. However, for values between 1-2, the difference is perceptible at a short distance and between 2-10 is perceptible to the human eye.

Table 2: Experimental results.

Parameter	α (-)		$T_{surf,\ max}$ (T_{ext}) (ºC)		L (-)		a (-)		b (-)		ΔE
Colour/ Year	0	1	0	1	0	1	0	1	0	1	(-)
White	0.27	0.38	49.0 (34.9)	47.9 (28.6)	88.5	79.7	1.0	1.0	3.1	7.4	9.8
Yellow	0.34	0.40	43.2 (28.8)	-	84.2	76.9	0.1	1.1	23.8	20.1	8.3
Green	0.59	0.63	57.4 (28.8)	-	63.2	62.1	-12.6	-9.6	9.3	10.0	3.3
Blue	0.44	0.49	51.3 (28.8)	-	73.1	69.5	-30.6	-23.2	-0.6	2.1	8.6
Orange	0.64	0.66	60.6 (29.1)	-	47.9	47.3	25.4	23.4	25.0	23.9	2.3
Light Brown	0.78	0.83	66.3 (29.1)	-	46.9	46.5	16.3	15.9	14.5	14.9	0.7
Dark Brown	0.77	0.85	68.0 (29.1)	-	35.9	36.2	6.6	7.1	6.1	7.1	1.2
Red	0.69	0.69	70.5 (34.9)	-	38.9	37.8	30.7	29.3	19.6	18.0	2.3
Red_HRP	0.66	0.66	66.5 (34.9)	-	38.7	38.8	28.4	26.4	17.8	17.1	2.2
Black	0.88	0.88	75.6 (34.9)	68.3 (28.6)	33.4	34.5	0.5	0.6	-1.4	0.4	2.1
Black _HRP	0.73	0.73	68.2 (34.9)	63.4 (28.6)	35.2	35.4	1.2	0.9	-2.3	-1.0	1.4
Black_HRP without EPS	-	0.75	-	56.8 (28.6)	-	34.4	-	0.6	-	-2.3	-

3.2. Effect of dark colours in the durability of ETICS

Different colours contribute to different thermal behaviour, regarding their thermal and optical properties. As such, 9 ETICS specimens, without HRP incorporation were analysed (see Figure 2).

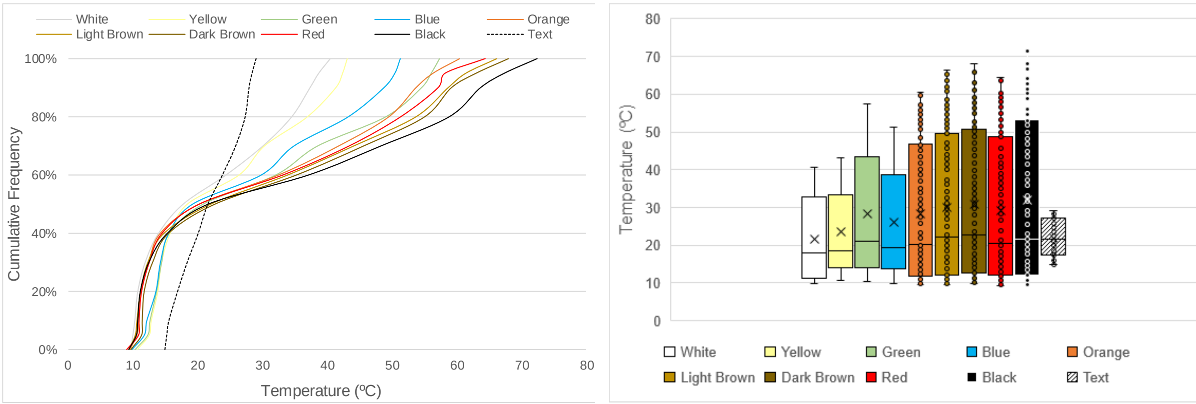


a) b)

Figure 2: a) Solar absorptance variation; b) Solar absorptance as a function of surface temperature (year 0).

As expected, darker colours, such as black, brown and red, present higher solar absorptance than lighter colours, such as white, yellow and blue. In addition, the solar absorption coefficient increases after one

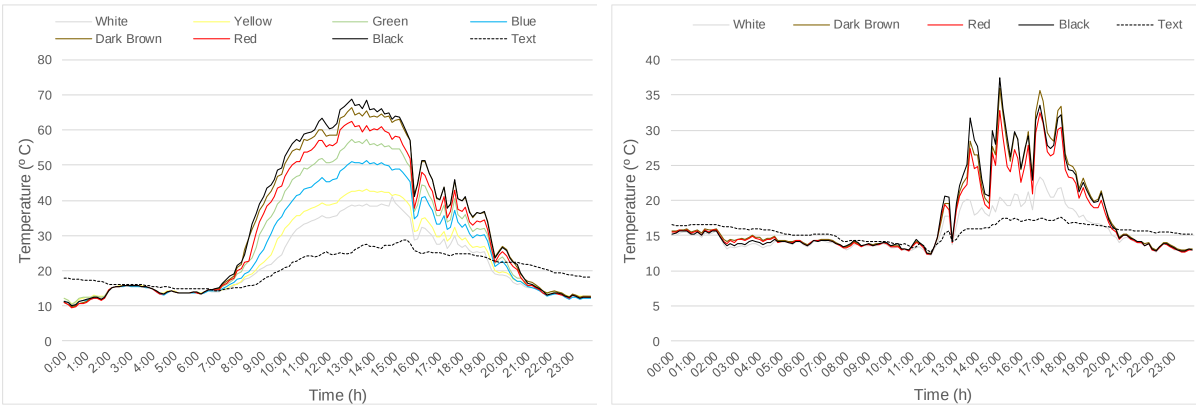
year of natural ageing. This fact corroborates with the decrease of the lightness and yellowing of the coatings (lower L* and higher b* parameters, respectively) (see Figure 2-a).
Another finding was the higher colour variation in lighter colours (α<0.5), which is perceptible to the human eye. This fact could be also related to the higher effect of dust deposition. Observing Figure 2-b, the higher the solar absorptance the higher the surface temperature.
Figure 3 presents the surface temperature variation, during the day of higher exterior temperature.



a) b)

Figure 3: Surface temperature (day of maximum air temperature): a) Cumulative frequencies; b) Box-plots.

As can be seen, until 15ºC the different colours present a similar behaviour (small amplitude). However, the higher the temperature the higher the differences between the different colours, presenting the darker ones higher temperature amplitude and peak values. Similar behaviour can be observed in different climatic conditions, such as cloudy and rainy conditions (see Figure 4).



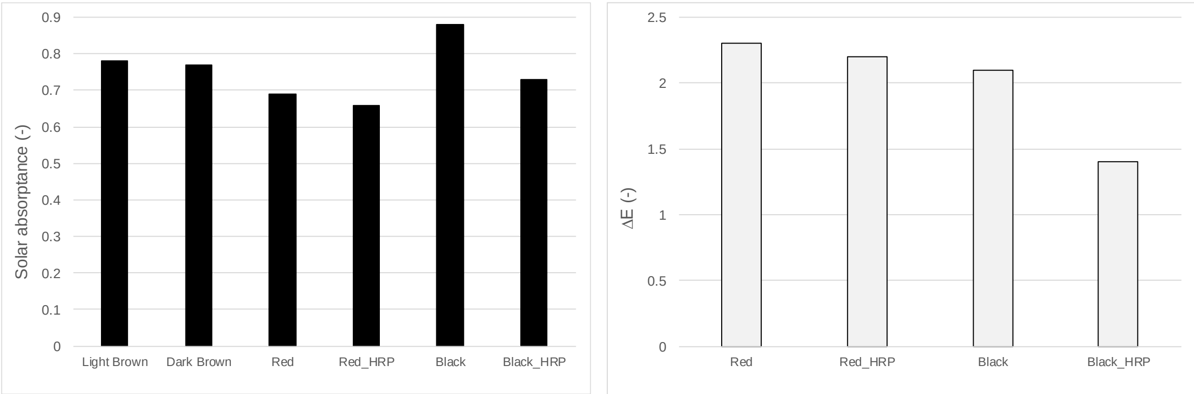
a) b)

Figure 4: Surface temperature variation: a) Cloudy day; b) Rainy day.

The non-direct solar radiation incidence, due to the presence of clouds during a day with high air temperature, results in lower maximum surface temperatures. In addition, higher temperature variation, evidenced by significant decreases and increases (that could be up to 20 ºC), could be observed. Regarding the influence of rain incidence in a façade, several peaks (more than observed during a cloudy day) can be observed. The higher the exterior temperature the higher the influence of the climatic conditions. This fact highlights the potential damages that higher temperature variation, especially an abrupt variation, could promote in façade systems.

3.3. Effect of the incorporation of high reflectance pigments in finishing coating of ETICS

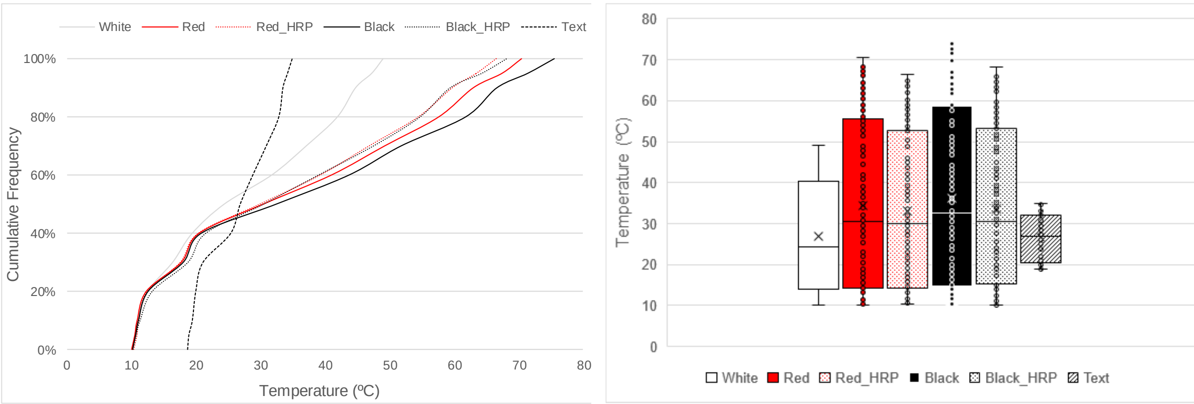
The effect of incorporating HRP in finishing coatings was analysed comparing two different colours – red and black – in 4 ETICS specimens (2 with HRP and 2 without) and also the white colour specimen (as reference). Observing Figure 5-a, the incorporation of HRP contributed to a significant decrease in the solar absorptance of dark colours. Comparing the black and brown colours, the incorporation of HRP in the black specimen resulted in lower solar absorptance despite the lower lightness (L*). In addition, HRP contributed to a lower colour variation after one year of natural ageing, especially in the black specimen, which variation is only visible for the human eye at a short distance (see Figure 5-b).



a) b)

Figure 5: a) Solar absorptance variation; b) Colour variation (ΔE).

As it can be seen in Figure 6, during a day with high exterior air temperature, the incorporation of HRP, in the finishing coating, promoted a significant decrease of the surface temperature in both red and black colours (≈ 5ºC considering peak values). As expected, the black coloured specimen presented higher surface temperatures compared to the other specimens. However, the incorporation of HRP resulted in similar values for both red and black specimens.



a) b)

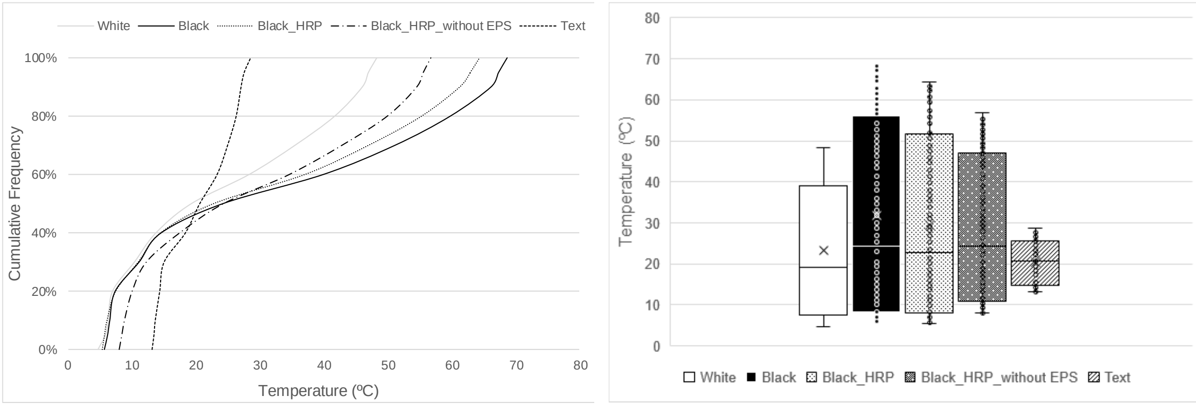
Figure 6: Surface temperature variation (day of maximum air temperature): a) Cumulative frequencies; b) Box-plots.

3.4. Effect of the thermal insulation layer in the performance of ETICS

The effect of the thermal insulation layer (EPS) in façade systems were analysed comparing the black specimens: ETICS with a regular coating (without HRP) and finishing coating incorporating HRP and a regular coating with a lightweight concrete substrate. The white colour specimen was monitored as a reference. The absence of thermal insulation did not influence the solar absorptance and colour parameters since very similar values were obtained for both specimens with HRP (see Table 2).
However, in terms of surface temperature, during a day with high exterior air temperature, the absence of thermal insulation layer promoted a decrease of the surface temperature even comparing with the ETICS specimen incorporating HRP (see Figure 7). Considering a warm period (when $T_{ext} > T_{int}$), the higher the thermal transmission (U) the lower the surface temperature (T_{surf}), as shown in Equation (2).

$$T_{surf} = T_{ext} - U \cdot R_{surf,ext}(T_{ext} - T_{int}) \tag{2}$$

Where $R_{surf,ext}$ is the exterior surface resistance.



a) b)

Figure 7: Surface temperature variation (day of maximum air temperature): a) Cumulative frequencies; b) Box-plots.

4. CONCLUSIONS

In façade systems, such as ETICS, the final layer properties present a very important role in the overall performance. The solar absorptance is particularly determinant for the thermal performance of these systems and contributes decisively to their durability. Taking into account that they are constituted of different materials/layers and, consequently, different thermo-mechanical properties, these systems are subjected to the development of cracking especially with a high-temperature variation. This fact contributes to compromising the stability and integrity of the different layers and the durability of the entire system.

The inclusion of high reflectance pigments contribute directly to a significant decrease of the solar absorptance and consequently to the decrease of surface temperature, even in darker colours: the higher the solar reflectance the lower the surface temperature. For example, a black specimen with high reflectance pigments resulted in a lower solar absorption coefficient than a current usual lighter colour (such as brown). Despite the demonstrated benefit of the incorporation of HRP, light colours, such as white, resulted in much lower surface temperatures.

The natural ageing did not promote degradation of the solar reflectance properties of the studied dark coatings while contributing to an increase of the solar absorptance of the white sample due to the yellowing and waste accumulation.

Therefore, the constitution of the finishing coating proved to be dominant in obtaining specific solar reflectance values.

In warm periods, the absence of thermal insulation contributes to the decrease of the maximum surface temperature and to the temperature amplitude when compared to a traditional system without insulation (substrate and cementitious render). As such, the temperature dissipation rate is different for each configuration.

In summary, façade systems incorporating high reflectance pigments in the finishing coating can contribute to a significant increase in the durability of façades, by lowering the thermal-induced stresses. However, the thermal system should be well analysed regarding the climatic conditions where it will be applied.

5. ACKNOWLEDGEMENTS

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