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Envelope systems with high solar reflectance by the inclusion of nanoparticles – an overview of the EnReflect Project

Nuno M. M. Ramos[1*], Joana Maia[1], Rita Carvalho Veloso[1, 2], Andrea Souza[1], Catarina Dias[2], and João Ventura[2]

[1] CONSTRUCT-LFC-Departamento de Engenharia Civil, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
[2] IFIMUP –Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre s/n, 4169–007 Porto, Portugal

*Corresponding author: nmmr@fe.up.pt

Abstract. High reflectance materials constitute an attractive idea to reduce cooling loads, which is crucial for attaining the Nearly Zero Energy Buildings goal, also presenting the benefit of broadening the range of colours applicable in building facades. The EnReflect project intended to re-design envelope systems by increasing their solar reflectance through nanotechnology. The main idea was to produce novel nanomaterial-based coatings with high near-infrared (NIR) reflectance by tuning their optical properties and testing their compatibility with typical insulation technologies such as ETICS. As such, this project focused on the synthesis of nanoparticles with improved NIR reflectance, the evaluation of the hygrothermal-mechanical behaviour of thermal insulation systems with the application of the improved coating solutions, the characterization of the more relevant material properties and the durability assessment. One of the main achievements was the development of a facile synthesis of a nanocomposite with improved performance in the NIR region that allowed the reflectance improvement of a dark-finishing coating. Also, the incorporation of such nanoparticles had a positive effect on keeping their optical properties after accelerated ageing cycles. The development of numerical simulations allowed the estimation of the maximum surface temperature in Mediterranean climates under different optical parameters. The study of the hygrothermal behaviour of thermal-enhanced façades led to the development of a new durability assessment methodology which contributed to closing a standardization gap.

1. Introduction

The use of thermal insulation materials is an effective way of reducing heat losses in buildings by increasing the thermal transmittance through the building envelope. In addition, new eco-efficient materials and technologies are being developed to mitigate building cooling needs. One of those technologies uses cool materials with high solar reflectance and infrared emittance. The use of such materials, including nanosized cool pigments [1], constitutes an attractive idea to achieve the reduction of cooling loads, a goal that is a condition for attaining the Nearly Zero Energy Buildings goal. Another benefit of this strategy is to broaden the range of colours, overtaking the current white-cool solutions.

The idea of the EnReflect project is outlined in Figure 1. The main idea was to fabricate novel nanomaterials with high near-infrared (NIR) reflectance by bandgap engineering to apply to typical envelope systems using a green synthesis approach. The improved performance in the field of Building

Physics was assessed through laboratory tests and advanced simulation. The durability aspects were evaluated through accelerated and natural ageing tests.

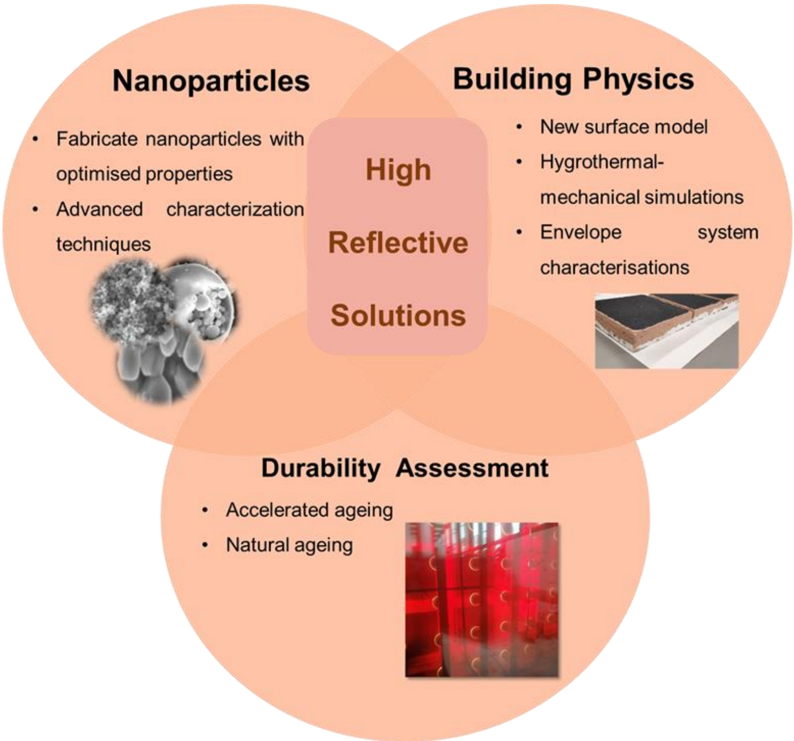


Figure 1. Outline of the EnReflect project.

2. Development and optimization of coatings doped with nanoparticles

This task aimed to develop and optimize the use of nanoparticles in black-coloured high-reflective coatings for envelope applications. Therefore, we fabricated and assessed the optical reflectivity of an extensive range of nanomaterials, including TiO_2 rutile and anatase (25, 40, 800 and 1000 nm), CuO (40 nm), ZnO, Al_2O_3 (13, 300, 1000 nm), black titania (self-doped Ti^{3+} titanium dioxide), black $MnFeO_4$, $Ca_3Mn_{2-x}Ti_xO_7$ and CuO@TiO_2 nanocomposites, for different concentrations (1 to 20%). The most promising results were achieved for the TiO_2 rutile and TiO_2/CuO samples. A typical spectral reflectance spectrum for the black colorant doped with 50 nm TiO_2 nanoparticles is shown in Figure 2. From the results, we observe that all the doped samples present a similar performance by partially absorbing visible light, as expected since we are dealing with black coatings. As for the near-infrared region, however, the samples present noteworthy differences. All the specimens show enhanced NIR reflectance when compared to the conventional colorant. The influence of the size and concentration of nanoparticles was also studied. Also, in Figure 2, the reflectance as a function of nanoparticle concentration is displayed, determined according to ASTM E903 [2].

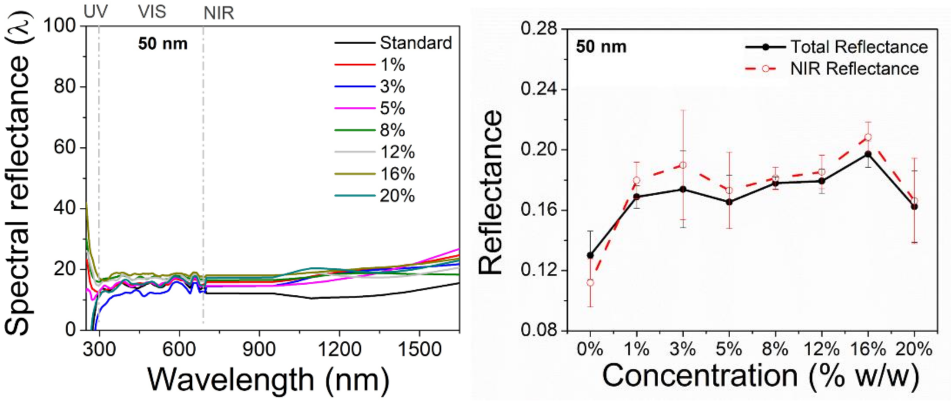


Figure 2. Spectral reflectance behavior for the TiO_2 doped black colorant with 50 nm and corresponding total average and NIR reflectance calculation using ASTM E903

3. Experimental assessment of high reflectance pigments effect

The project analyzed the influence of coatings using different types of high-reflectance pigments applied in ETICS. The experimental assessment of optical properties included: laboratory measurements with a modular spectrophotometer (FLAME-T and FLAME-NIR Ocean Optics) and *in-situ* measurements using a pyranometer (Figure 3). The two methods were compared, evidencing a good correlation, even in the specifically rough surface of ETICS (Figure 4).

Figure 3. Spectrophotometer and pyranometer measurements.

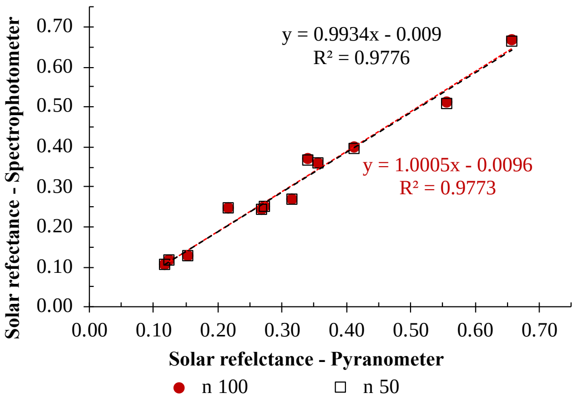
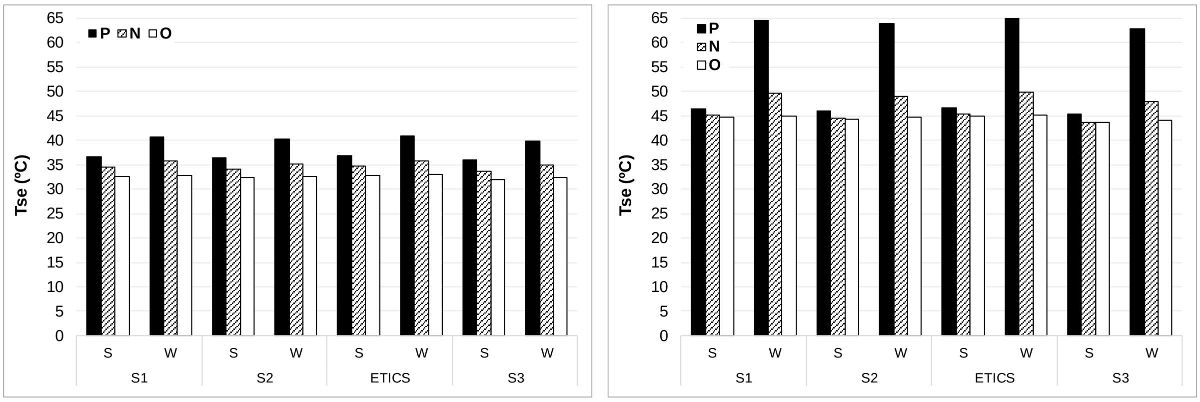


Figure 4. Correlation of the results of spectrophotometer and pyranometer methods.

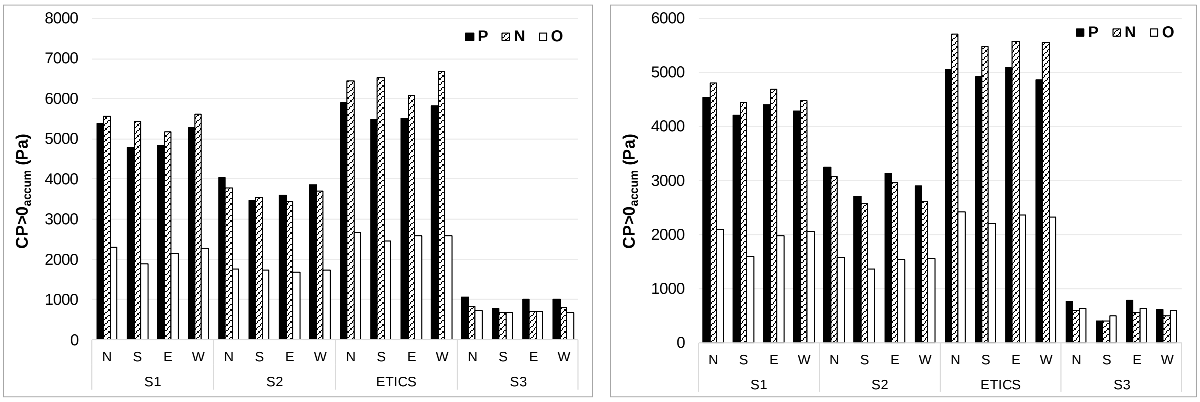
4. Numerical simulations

The numerical simulations conducted in the project were divided into two parts. First, there was an assessment of the potential benefits of solar reflectance enhancement with nanomaterials. In that sense, the finite-difference time-domain (FDTD) method was implemented using MEEP to obtain an oversight of the radiative properties of coatings pigmented with TiO_2 nanoparticles. The work [3] established limits for the reflectance dependence on particle size and particle volume fraction. In a second approach, the effect of different solar absorption levels on different wall compositions and climates was simulated using WUFI Pro software, which allowed assessing the impact on surface temperature, condensation potential, and average U-value [4]. Figure 5 and Figure 6 present the maximum exterior surface temperature and accumulate positive exterior condensation potential, respectively, considering different façade orientations (NSEW), two solar absorption coefficients (reflecting the dark and light colour effect) and three distinct climates (Porto – P, Nancy – N and Oslo – O) on the study of thermal rendering systems, using thermal renders (S1, S2 and S3), and external thermal insulation composite systems (ETICS).



a) b)

Figure 5. Maximum exterior surface temperature (Tse), considering south and west orientation and solar absorption of: a) 0.27 and b) 0.80.



a) b)

Figure 6. Accumulated positive condensation potential considering the 4 orientations (N, S, E, W) and solar absorption of: a) 0.27 and b) 0.80.

Beyond the properties of thermal insulation systems, the solar absorption coefficient significantly impacts hygrothermal behaviour because it contributes to reducing hygrothermal risk. However, it promotes an increase of thermal stresses, especially in warmer climates with high solar radiation, such as Porto. In contrast, for climates with low solar radiation, a high solar absorption coefficient constitutes a good way to increase hygrothermal performance.

5. Durability assessment

The durability assessment conducted in the project targeted different aspects of the performance of external insulation systems by applying coatings with high-reflectance pigments. The durability of coating formulations when applied in ETICS and thermal rendering systems was tested with laboratory and in-situ experiments. The tests highlighted the impact of incorporating NIR reflective pigments in finishing coatings [5], as they can contribute to the durability of their optical properties by reducing colour change and total reflectance loss (see Figure 7). It was also demonstrated how the peak surface temperatures were reduced, promoting an enhanced service life of the whole system.

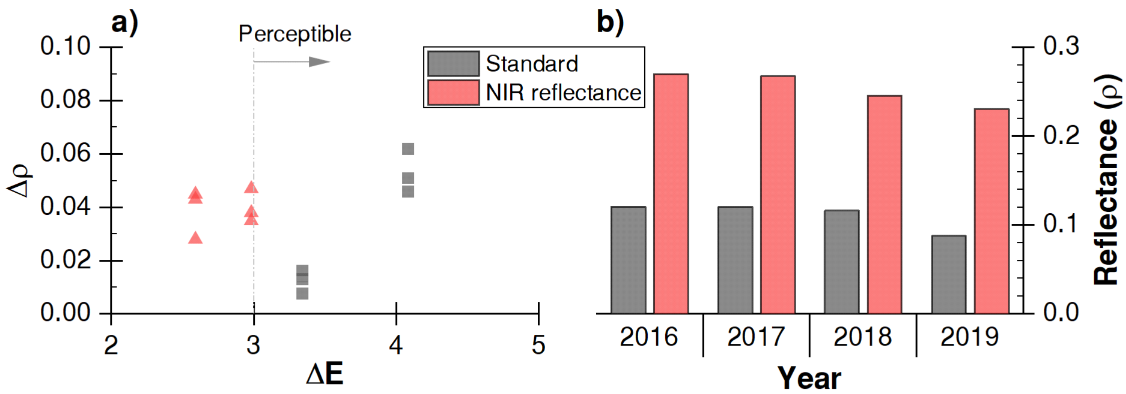


Figure 7. Influence of NIR reflectance pigments on a) colour difference (ΔE) and b) reflectance (ρ)

6. Conclusions

The EnReflect project produced new and relevant data about the fabrication and application of nanoparticles in finishing coatings for façades and their hygrothermal-mechanical behaviour and durability assessment. The work initiated in the project is ongoing as it inspired two PhD projects on the subject that will be completed by 2024.

Acknowledgements

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