THERMAL PERFORMANCE OF COOL FACADES. EVALUATION BY INFRARED THERMOGRAPHY

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Abstract *High reflective paints (cool paints) are used on flat roofs to reduce heat gains from the incidence of solar radiation and thus improve the thermal comfort and energy efficiency of buildings, especially in summer periods.*

Given the application potential of these paints on vertical surfaces, a research study has been developed to evaluate the thermal performance of reflective paints on walls under real exposure conditions. Accordingly, different reflective paints have been applied as the final coating of an ETICS type solution, on the facades of a full scale experimental cell built at LNEC campus. For being applied in an ETICS system a paint has to fulfill several requirements, whether aesthetic or functional (such as the adhesion between the coating layers or the durability of the insulation), essential for its efficient performance. Since this construction coating system is subject to a prolonged sun exposure, various problems may arise, such as paint degradation or deterioration of the thermal insulation properties, particularly when dark colors are applied.

To evaluate the thermal performance of the chosen paints, the method of non-destructive analysis by Infrared Thermography was used. Thermography allows knowing the temperature distribution of facades by measuring the radiation emitted by their surfaces. To complement the thermographic diagnosis, thermocouples were placed between the insulation and the paint system of the experimental cell. Additional laboratory tests allowed the characterization of the optical properties (reflectance and emittance) of the different reflective paints used in this study.

The comparative analysis of the thermal performance of reflective and conventional paints revealed that the reflective paint allows a reduction of the facade surface temperature, reducing the risk of loss of insulating properties of the ETICS system and thus ensuring its longevity and functionality. The color of the paint used affects, naturally, the reflective ability of the surface and may have an important role in energy balance of the building. This paper also showed the potential of infrared thermography in the evaluation of the thermal performance of reflective paints.

1. INTRODUCTION

The main characteristic of reflective (or cool) paints is its high ability to reflect solar radiation. These paints absorb only a small fraction of incident solar radiation, while maintaining the surface temperature lower than corresponding conventional paints, thus reducing the heat flow to the inside of buildings.

The large-scale application of surfaces with higher solar reflectance may affect the urban micro-climate, by allowing air temperature to decrease, due to a smaller heat transfer from the surface to ambient air, thereby reducing the heat island effect [1]. In this context arises the need to use materials or coatings which allow an economic and environmentally friendly way to improve thermal comfort and energy efficiency in buildings. The solution presented in this study makes use of cool materials, such as reflective paints. These paints have high solar reflectance and emittance, thus contributing for the reduction of convective and radiative heat gains in urban environment and to mitigate the heat island effect. Currently, this kind of paint are already widely used in flat roofs, in order to reduce heat gains from the incidence of solar radiation and thus improving the thermal comfort and energy efficiency in buildings, especially in summer periods. Due to the potential application of these paints on walls, it was developed in LNEC a research study to evaluate the thermal performance of reflective paints applied on walls under real exposure conditions, within the Master's Dissertation of the first author [2]. Accordingly, different paints have been applied, mainly characterized by a high reflection, as the final coating of an ETICS type solution, on the facades of a full scale experimental cell built at LNEC campus. To evaluate the thermal performance of the used paints, the method of non-destructive analysis by Infrared Thermography was used. The Infrared thermography can be defined as the thermal mapping of surface temperature patterns of the object under observation. These maps are produced by equipments such as an thermographic camera and are designated by thermographies or thermograms [3]. Infrared camera measures and reproduces in visible thermal images (thermograms), the infrared radiation emitted by objects. Non-destructive analyses methods such as infrared thermography are based on the principle, that the presence of certain kind of anomalies alters the heat flow through the material, allowing its identification in the thermogram [4]. But the thermographic analysis cannot be reduced to the identification of anomalies. The influence of the different radiative properties of materials and local environmental conditions have a significant weight in what you "see" in thermogram, and its characterization, is an important factor in decoding the thermal pattern, which is often not easy to interpret. Therefore thermography allows knowing the temperature distribution of facades by measuring the radiation emitted by their surfaces. The knowledge of the surface temperatures pattern enables the exploration of another important aspect, such as the detection of temperature variations harmful to the durability of materials and that could lead to their degradation. Additional laboratory tests allowed the characterization of the optical properties (reflectance and emittance) of the different reflective paints used in this study. This paper presents the results obtained in the study, including the comparative analysis of the thermal performance between panels painted with reflective and conventional paints (in real conditions of exposure) and the assessment of the risk of loss of insulating properties of the ETICS system.

2. METHODOLOGY OF STUDY

2.1. Experimental cell

To evaluate the thermal performance of reflective paints on walls in real exposure conditions, an experimental full-scale cell was used (Figure 1). This cell is part of a set of three cells built within a doctoral study, to evaluate the thermal performance of innovative roofing solutions [5]. The experimental cell has dimensions 4.80 m x 4.80 m x 3.74 m and the constructive solution consists of highly thermally insulated walls (Rt = 3.75 m^2.°C / W), consisting of hollow blocks of permanent formwork in EPS (expanded molded polystyrene) filled in situ with steel rods and concrete. The total wall thickness is 0.28 m. An ETICS coating system was applied on top of the EPS wall blocks. The cover consists of pre-slabs of reinforced concrete, under a layer of concrete topping, including additional armor. Reflective paints were applied on each one of the cell facades, in vertical panels in three colors: white, black and tile, the latter so named because it is similar to current ceramic tiles (Figure 1).

Figure 1. Full-scale experimental cell painted with three reflective paints.

2.2. Experimental campaign

For the evaluation of the thermal performance of the different colors, thermocouples were placed between the insulation and the reflective painted coating, one for each panel, of the west and south facades of the experimental cell (Figure 2).

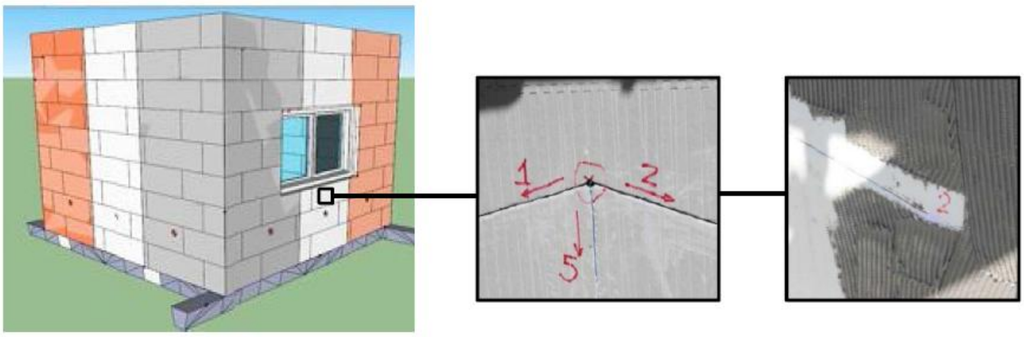

Figure 2. Location of thermocouples in the South and West wall of the experimental cell (applied between the insulation and coating).

The temperature measurements obtained with the thermocouples (recorded every 10 minutes) allowed tracking the evolution of the surface temperature of the different paints applied, continuously for long periods during the various seasons. Beyond the reflective paint on each panel, the West wall facade also includes areas painted with a conventional paint of the same color, highlighted in yellow in figure 3. Each one of these areas was situated approximately halfway up the wall and had a section of 0.20 m x 0.20 m.

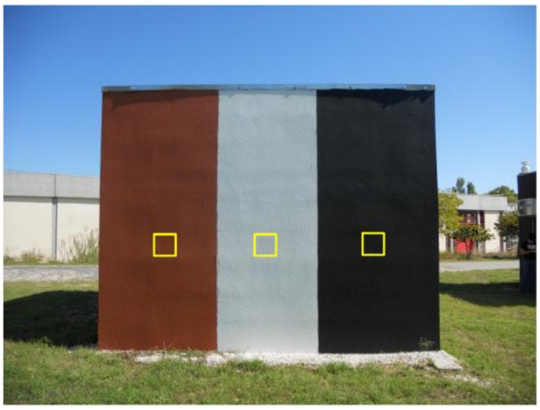

Figure 3. Location of the three areas painted with conventional paints with the same color as the reflective paints.

The evaluation of the thermal performance of reflective paints was performed for several days in the summer period (August 2013), in the West and South facades of the experimental cell. The thermal analysis that will be presented is based on the results obtained by the thermograms performed over a day (clear sky), as well as in the temperatures obtained by the thermocouples.

3. RESULTS

3.1. Validation of the thermographic method

As already mentioned, this experimental development was intended to analyze the performance of three reflective paints applied on walls´ facade, in a real application context, inquiring the applicability of thermographic method and the quality of the results. During a day of observation, several thermograms (T1 to T6) were recorded, at different times of the day, namely, at 11h, 13h, 16h, 18h30, 19h30 and 20h30. Based on the temperature recorded by the thermocouples, it was possible to ascertain the accuracy / reliability of the results obtained by thermography. Figure 4 presents the surface temperatures measured by the thermocouples and by the thermographic method, in the South facade, on the panels coated with white reflective paint (BrT) and with black reflective paint (PrT). The estimated emittance for the different surfaces of ε = 0,89 (reflective paints), and ε = 0,90 (conventional paints) for setting the thermographic camera resulted from previous characterization tests conducted in the laboratory. The remaining configuration parameters of the equipment that depend on atmospheric conditions and methodology were determined at the time of testing.

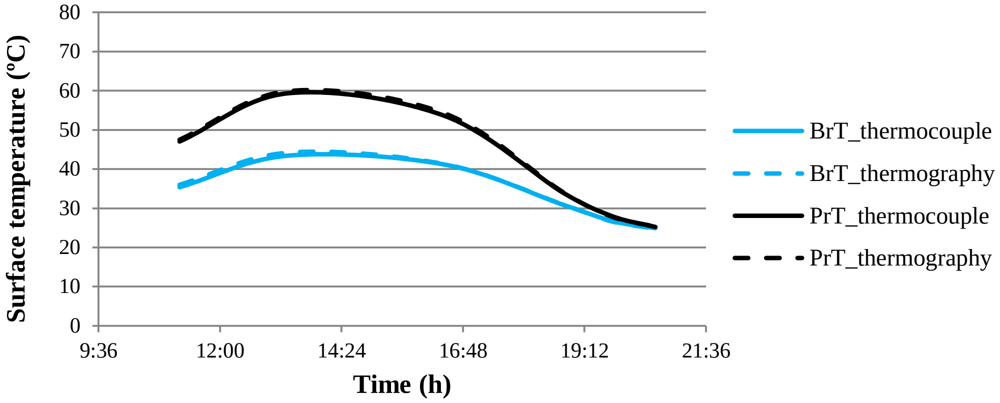

Figure 4. Evolution of the temperature, measured by the thermocouples and thermography, on areas coated with two reflective paints (white, BrT, and black, PrT) over a day.

From the analysis of Figure 4 and the results shown in Table 1 it was found that the difference between the surface temperature measured by the thermocouples and thermography (ΔT_{surf}) on the South wall, for the two colors (BrT and PrT) was at most of 2%.

Thermogram	**Surface temperature (South wall), T_{surf} (°C)**				**Surface temperature difference, ΔT_{surf} (%)**	
	Thermography		**Thermocouples**		**(Thermocouples/Thermography)**	
	BrT	PrT	BrT	PrT	BrT	PrT
T1	36,0	47,5	35,4	47,0	1,8	1,0
T2	44,2	59,9	43,4	59,4	1,7	0,9
T3	41,3	54,3	41,2	53,7	0,2	1,1
T4	31,0	34,2	30,9	34,1	0,2	0,4
T5	26,6	27,8	26,7	28,0	0,5	0,6
T6	24,8	25,3	24,9	25,2	0,4	0,3

Table 1. Temperature difference between measurements (thermocouples and thermography) for white (BrT) and black (PrT) reflective paints.

Observing Table 1, it can be concluded that the maximum value of ΔT_{surf} is not significant because the average temperature difference between measurements equates to about 0.3 °C for both colors (PrT and BrT). The results obtained show that, although conditioned by course in real exposure conditions, with the thermographic method a good approximation to the real situation is achieved, allowing estimate with relative safety the surface temperature of the element.

3.2. Thermal performance of reflective paints

During the measuring day, several thermograms (T1 to T6), each corresponding to a different time of day, were obtained. The meteorological conditions observed on that day were characterized by clear sky, light wind and temperatures typical of summer (Table 2). These weather conditions prove to be ideal for the performance of reflective paints, as well as for the application of the thermographic method.

Thermogram	Time (h)	External conditions	
		Incident solar radiation, I_{global} (W/m^2)	Surface temperature, T_{amb} (ºC)
T1	11:04	719	21,2
T2	13:11	905	27,0
T3	16:18	722	31,3
T4	18:39	309	32,0
T5	19:37	109	28,6
T6	20:30	1	26,7

Table 2. External conditions (incident solar radiation and ambient temperature) for the thermographic inspection

As mentioned, the evaluation of the performance of different types of paints (reflective and conventional) was only possible in the West facade. For that facade the overall thermogram and corresponding real image at 16h is presented in Figure 5.

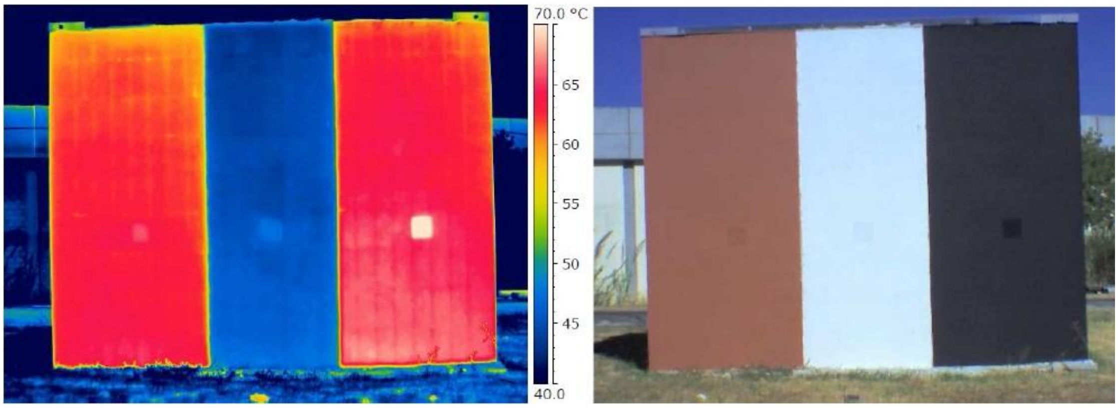

Figura 5. Overall Thermogram of the West facade and corresponding real image at 16h.

The overall thermogram shown in Figure 5 allowed observing the performance of the two different types of paint with each of the three colors in the wall.

It is possible to verify that the vertical areas of black reflective paint (PrT) and tile reflective paint (TeT) appeared in the thermography with very similar colors, indicating that surfaces were at a similar temperature. The inverse happened to the white BrT color area, appearing in the thermogram in a totally different color, in this case, indicative of a lower surface temperature. It is possible to distinct the squares painted with conventional tile (TeN), conventional white (BrN) and conventional black (PrN) paints, always warmer than the corresponding reflective paints (BrT, TeT and PrT). Figures 6, 7 and 8 show the thermograms obtained on the thermographic inspection; when incident solar radiation was more intense, by 13h (T2), immediately before the cessation of sunlight, at 18h30 (T4) and at the end of the day, by 20h30 (T6). In each thermogram, the measurement area 1 (Ar1), is located on the square painted with conventional paint and the measurement area 2 (Ar 2) on the surface corresponding to reflective paint. Only the thermograms of the white and black panels are presented because the surface temperature of the color tile area is similar to the black color.

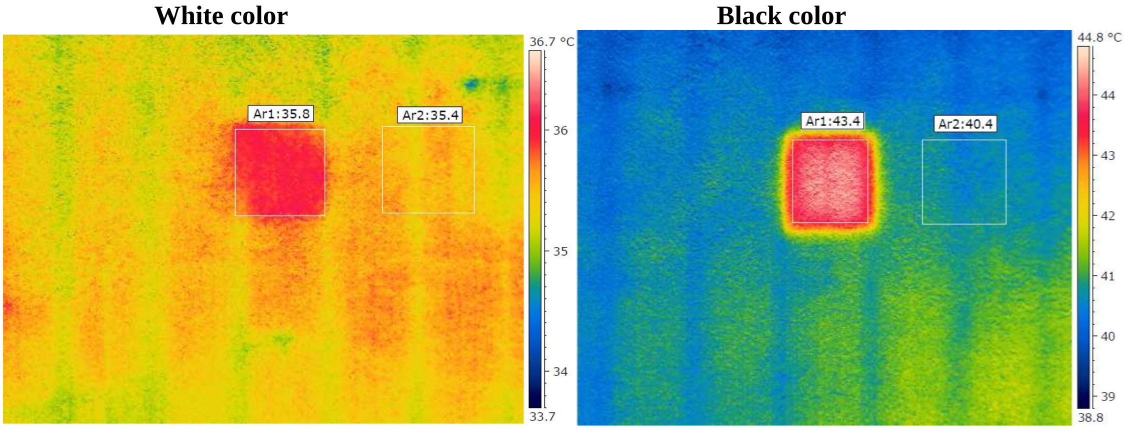

Figure 6. Thermograms (T2) of the white and black panels, on the west wall, at **13h.**

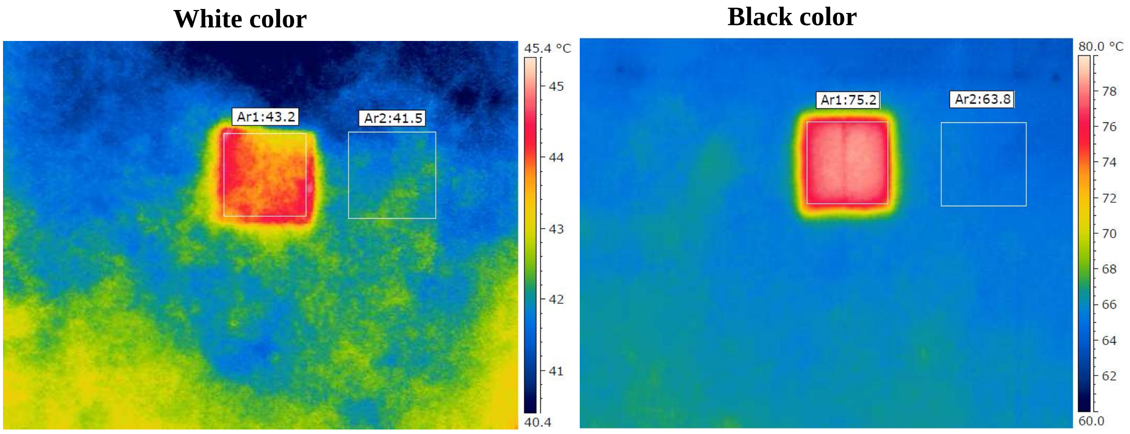

Figure 7. Thermograms (T4) of the white and black panels, on the west wall, at **18h30.**

By analyzing Figures 6 and 7, it is observed that the surface temperatures are distinctly different in the areas painted with reflective and conventional paints. The temperature difference observed between the type and color of paints is due to a greater or lesser heating of the surface by solar radiation and a direct result of intrinsic paint properties (reflective or conventional) and color (black or white). When thermograms (T2 and T4) were obtained, the analyzed surfaces were insolated. Knowing that the reflective paints (BrT and PrT) have a higher solar reflectance that the corresponding conventional paints, especially in the near infrared radiation (NIR), it was found that the surfaces on which reflective paints were applied reached lower surface temperatures (the result of less absorption of radiation).

In Figure 8, it is noticeable that stopped the "heating" by solar irradiation, the emitted energy was only depending of the emittance and the thermal properties of materials, and no more influenced by the capacity of the surface to reflect solar radiation.

When the wall started to cool, the major or minor emission of thermal energy from the various elements of the wall was captured by the thermal camera, that translated into thermographic images the surface areas with different temperatures, showing the wall constitution. In this case, the reinforcement steel inside the wall was visible in the thermogram.

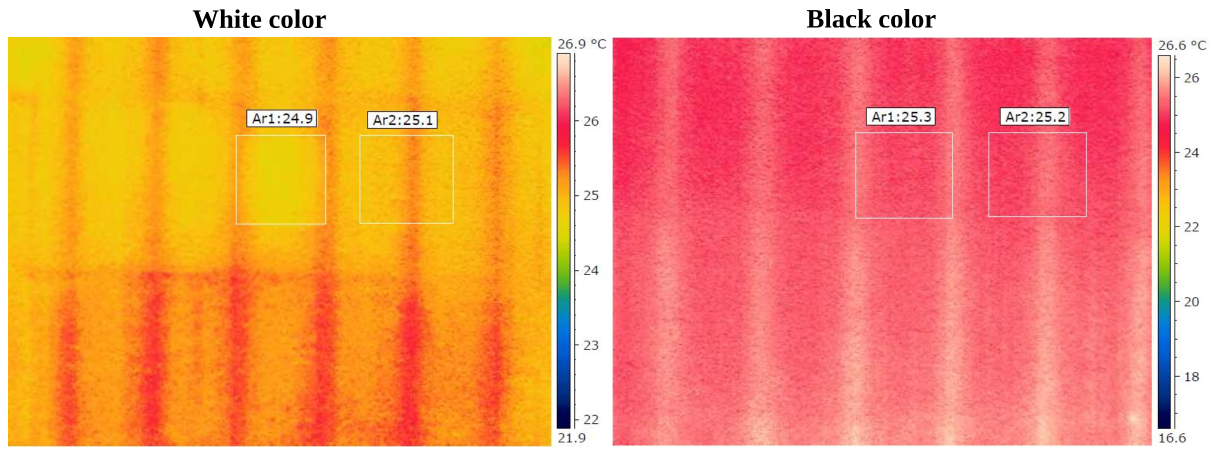

Figure 8. Thermograms (T6) of the white and black panels, on the west wall, at **20h30.**

Below, Figure 9 shows the evolution of the surface temperature on the West wall, in panels with white and black paint, reflective and conventional, respectively BrT, BrN, PrT, and PrN, throughout the analyzed day. By analyzing Figure 9 it can be seen a maximum temperature difference between the conventional (PrN) and reflective (PrT) black paints of 11.4 °C and for the white, only of 1.8 °C. In addition, Table 3 shows the temperature difference (ΔT), for the three colors, between the conventional and reflective paints on West wall, analyzed throughout the day. Table 4 presents the differences in surface temperature in the West wall, between panels with reflective paint of the three colors (BrT, PrT and TeT).

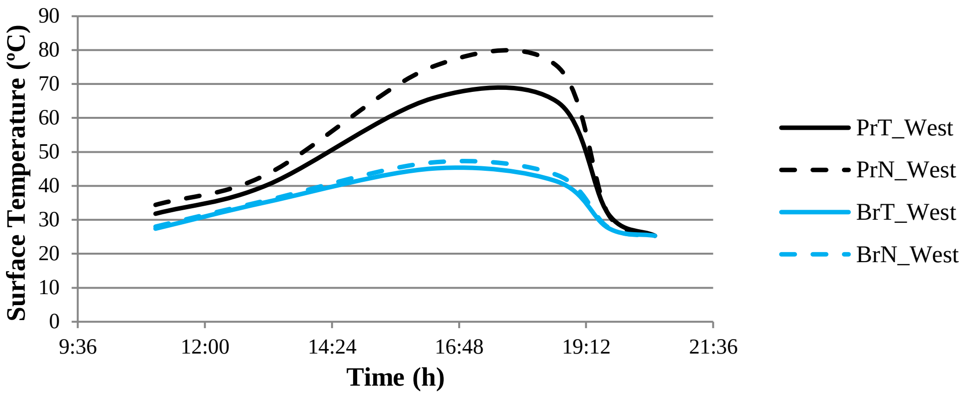

Figure 9. Evolution of the surface temperature on the West wall, in the white and black panels, reflective or conventional.

In Table 3, it can be seen that ΔT_{surf} between reflective and conventional paints decreased for the late periods of the day. It was concluded that the reduction of the difference resulted from the lower intensity of sunlight during these periods and the fact that both types of paint presented very similar emittance. It is found that the temperature differences between reflective paints are higher among dark and light colors, as expected, and that the surface temperature of the PrT and TeT differed at most in 3ºC. The choice of a specific color follows several aesthetic or functional requirements (for example, the durability of the insulation), and it is considered that, for the latter, this study may provide some help. In the case study, the thermal insulation of the experimental cell consists of an ETICS system. This solution consists, briefly, in the application of thermal insulation on the outer face of the wall, covered by a thin coating system.

Thermogram	**Period (h)**	**Surface temperature difference, ΔT_{surf} (°C)**		
		BrN-BrT	PrN-PrT	TeN-TeT
T1	11:00	0,6	2,6	1,0
T2	13:00	0,4	3,0	0,5
T3	16:00	1,8	9,3	1,5
T4	18:30	1,7	11,4	1,4
T5	19:30	0,2	0,6	0,4
T6	20:30	-0,2	0,1	-0,2

Table 3. Temperature differences between the conventional N and reflective T paints, for the three colors white Br, black Pr and tile Te, in the West wall.

Thermogram	**Period (h)**	**Surface temperature difference, ΔT_{surf} (°C)**		
		PrT-BrT	PrT-TeT	TeT-BrT
T1	11:00	4,4	2,7	1,7
T2	13:00	5,0	1,4	3,6
T3	16:00	20,7	2,3	18,4
T4	18:30	22,3	2,4	21,1
T5	19:30	4,2	2,7	1,5
T6	20:30	0,1	0,2	-0,2

Table 4. Temperature differences between the three reflective paints black Pr, white Br and tile Te in the West wall.

When the insulation system is subjected to extended sun exposure, several problems can occur, from the degradation of paint to loss of insulating properties. In this context, a decisive factor in maintaining the functionality of the system is the thermal insulation, in this case, molded expanded polystyrene (EPS). The range of temperatures for which the EPS can be used safely, without its properties being affected, has as limit value of operating temperature, around 100 °C for short-term actions, and 80-85 °C for long-term actions [6]. It is noted that the reflective paints can significantly lower the surface temperature, reducing the risk of loss of insulating properties of the ETICS systems, thereby ensuring its functionality and longevity.

4. CONCLUSIONS

The study allowed establishing that the application of reflective paints on walls can constitute a valid solution in reducing the surface temperature, enabling a reduction of heat gains through the building envelope, a desirable situation in the cooling period (summer). This kind of solution (passive) reveals to be easy to use and with relatively low application cost. It can be assumed that there are inherent advantages to using reflective paints, not only in terms of energy and financial savings, resulting from reduced energy consumption for cooling, but mostly in terms of durability of ETICS coating solutions. Prolonged exposure to high thermal loads, associated with atmospheric factors (UV rays, wind, precipitation), causes wear of the surface and consequent degradation. This wear can be reduced by applying reflective paints, as these can significantly reduce the surface temperature, contributing to the reduction of the thermal load, especially in periods where there is a greater solar intensity. The results also showed that, as expected, paints that have lighter color present lower temperatures then dark colors, when exposed to solar radiation. In summary, the results show that there are inherent advantages to use reflective paints on facades, when inserted into a bioclimatic strategy whose planning improves the comfort conditions inside buildings. Regarding the thermographic method it was found that, taken the necessary precautions, Thermography reveals to be an effective and relatively accurate method for determining wall surface temperatures in real exposure conditions, allowing the evaluation of the thermal performance of such solutions.

ACKNOWLEDGEMENTS

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