Cool facades. Thermal performance assessment using infrared thermography

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Abstract. Considering the potential application of high reflective paints in facades (cool facades), to reduce solar heat gains and consequently improve thermal comfort and energy efficiency in buildings in summer period, a research study is being developed at LNEC. This study aims to assess the thermal performance under real weathering of reflective paints applied (over ETICS like solution) in facades of full-scale test cells built in LNEC's *campus*.

For this purpose, non-destructive infrared thermography method is being used. Infrared thermography allows knowing the temperature distribution on facades by measuring radiation emitted from its surfaces. Thermocouples placed on wall outside surfaces support thermographic diagnosis.

Additional laboratory tests allowed the characterization of optical properties (reflectance and emittance) of the different cool paints used in this research study.

This paper presents preliminary results of this research study, namely the comparative analysis of thermal performance between a white cool paint and a white conventional paint, and also shows the potential of infrared thermography in the assessment of thermal performance of cool paints.

Introduction

Recently, high reflective paints (*cool paints*) are being used on pitched and flat roofs and facades to reduce solar heat gains and consequently improve thermal comfort and energy efficiency in buildings in summer period.

Main characteristic of these paints is the high ability to reflect incident solar radiation. Cool paints absorb only a small fraction of incident solar radiation, maintaining surface temperatures lower than those of current coatings thus reducing the heat flow into the buildings.

Being an innovative solution the thermal performance information about cool paints performance under real weather conditions is limited.

Considering its potential application in facades (*cool facades*), a research study is being developed at LNEC to assess the thermal performance under real weathering of different reflective paints applied (over ETICS like solution) over the outside surface of three full-scale test cells built in LNEC's *campus*.

Non-destructive infrared thermography method is being used for the evaluation of cool paints' thermal performance. Infrared thermography allows knowing the temperature distribution on facades by measuring radiation emitted from its surfaces. Thermocouples placed on the outside surfaces of the wall support thermographic diagnosis.

Additional laboratory tests allowed the characterization of optical properties (reflectance and emittance) of the different cool paints used in this research study.

This paper presents preliminary results of this research study, namely the comparative analysis of thermal performance between a white reflective paint (**R_White**) and a white conventional paint (**C_White**), and also shows the potential of infrared thermography in the assessment of thermal performance of cool paints by the comparison of IRT and thermocouples data results.

Study methodology

Experimental cells

To evaluate the thermal performance of cool paints in real weathering conditions three full-scale test cell were used. These cells were built under a PhD study carried out to evaluate the thermal performance of innovative roofing solutions [1]. Each cell facade is painted with three colour cool paints; brown, white and black (Fig.1).

Figure 1: Full-scale test cells painted with three different reflective paints

The three experimental cells have identical dimensions (4,80 x 4,80 m x 3,74 m) and constructive solutions. Walls are highly insulated (Rt=3,75m^2/W.ºC) to improve the performance evaluation of roofing studied solutions, and are composed by permanent shuttering EPS (expanded molded polystyrene) hollow blocks filled in situ with pumped concrete with total thickness of 0,28 m. The structural roof is a precast reinforced concrete slab with 0,20 m of thickness. Several transducers (thermocouples, heat fluxmeters, temperature and humidity sensors) are installed inside and outside the experimental cells [1].

Outdoor climatic parameters, namely air temperature, air velocity and direction, relative humidity, precipitation and solar irradiation on vertical and horizontal plans, are also measured and recorded at LNEC’s meteorological station located close to the experimental cells [1].

For the assessment of the different cool paints temperatures thermocouples were placed between thermal insulation and painted finishing render (Fig. 2) in the three painted panels of West and South solar exposed facades.

These temperature measurements (recorded every 10 minutes) allow the analysis of the evolution of different cool paints temperature during extended periods (mainly in summer time) and also to support thermographic diagnosis.

This paper mainly focus on the validation of thermographic analysis with thermocouples data, but also analyses the performance of two white paints, one reflective (R_White) and the other a conventional (C_White) paint.

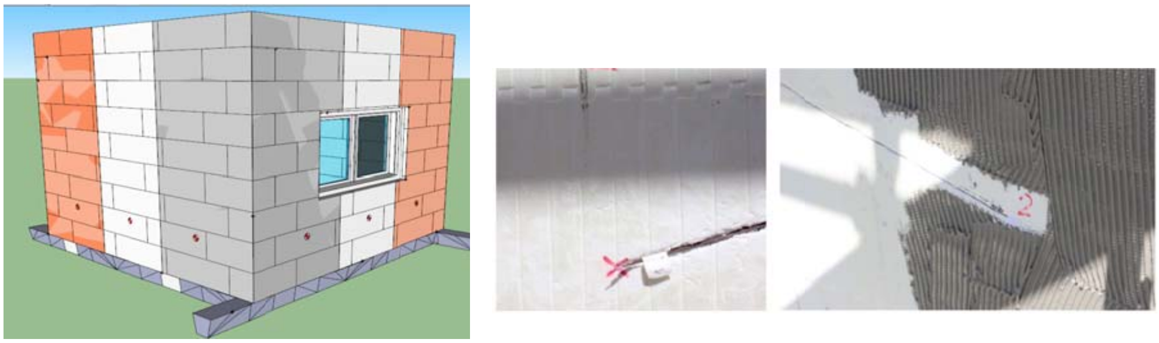


Figure 2: Location of thermocouples on test cell wall (on thermal insulation, under external rendering)

For this purpose, for a week exposed facades (South and West) of the three full-scale tests were painted with only two colors, white and black (Fig. 3). One white panel was painted with the reflective paint and the other with the original paint (conventional). After that period, panels painted with C_White were painted with a dark brick red reflective paint (Fig.1).

Figure 3: Test cell with Conventional White (C_White) and Reflective White (R_White) paints

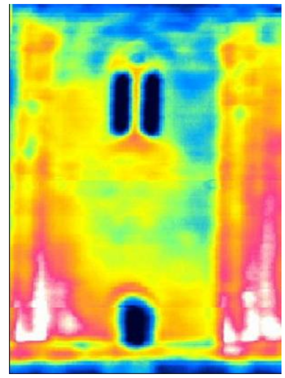
The analysis of the two white paints was performed during one day (8th February 2013) using thermocouples and thermographic data observed on the South facade of one test cell (vd. Results).

Infrared Thermography (IRT)

Infrared thermography (IRT) is a non-destructive testing method which allows the examination or inspection of part of material or system without impairing the future usefulness, and it is used to "see the unseen". As the name implies, thermography uses the distribution (suffix - graphy) of surface temperatures (prefix - thermo) to assess the structure or behaviour of what is under the surface of a body without any contact [2].

At any temperatures above absolute zero every object emits energy from its surface in the form of thermal radiation and the particular spectrum emitted by a surface depends upon its absolute temperature and its emissivity [3].

The invisible infrared radiation (thermal radiation) emitted by bodies is collected and converted by infrared thermography systems (Fig.4 a) into temperature and displayed as thermal image – thermogram (Fig.4 b). IRT can be defined as the science of acquisition and analysis of data from noncontact thermal imaging devices [4].



a) ***b)***

Figure 4: ***a)*** IRT equipment ***b)*** Thermogram of a building façade

Thermographic method has proved to be an effective and economic non-destructive method, very valuable in several branches of engineering, namely in civil engineering.

Nowadays, thermography may be applied to many facets of buildings, components and services performance. However, the main application of building thermography is to survey damage and energy-related conditions of the building envelope.

IRT has a large information potential and a wide field of application, because it’s a non-contact and a non-destructive testing technique that can be operated as an indicating method, giving either qualitative or quantitative data.

Results

The analysis of the two white paints (C_White and R_White) was performed during one day (8^{th} February 2013) using thermocouples and thermographic data observed on the South facade of one test cell.

During the observed day several thermograms (T1 to T12) were acquired to assess thermal performance of the two different white paints. The weather conditions for that day were characterized by a clear sky, ideal conditions for the proper cool white paint performance, and a typical temperature for winter season (Table 1).

Table 1: Outdoor conditions (temperature and radiation) during IRT diagnostic

Thermogram	Time	Outdoor conditions	
		Incident Solar Radiation, $\mathbf{I}_{gv}$ *[W/m²]*	Air Temperature, $\mathbf{T}_{out}$ *[ºC]*
T1	9:54	561	11,9
T2	9:59	580	12,1
T3	10:26	712	13,1
T4	11:03	742	13,7
T5	11:37	788	14,5
T6	12:21	855	15,1
T7	13:23	857	15,4
T8	14:36	796	14,7
T9	16:14	579	13,5
T10	17:08	298	12,3
T11	17:38	141	11,8
T12	17:41	86	11,7

Figure 5 shows three thermograms and related photos obtained in the day of testing; at the beginning (T2) and ending of solar radiation incidence on the South tested facade (T11) and a third, nearly solar noon (T7).

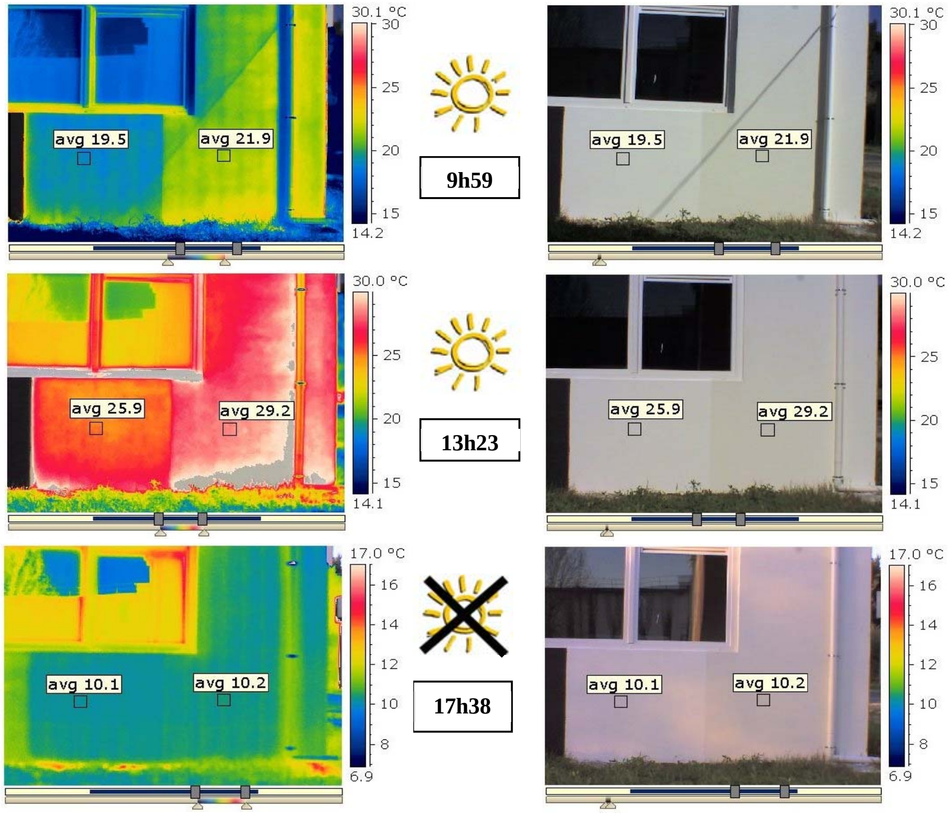


Figure 5: Thermograms and photos of test cell

The two first thermograms show different surface temperature between panels with R_White and C_White paints, displaying higher temperatures at C_White painted panel. When thermograms were obtained the analyzed facade was insolated so, knowing that R_White have a higher solar reflection (0,89 for R_White and 0,80 for C_White), as expected, panel with this paint absorbs less heat radiation and therefore reaches lower surface temperatures.

After solar irradiation ends on the viewed facade (at 17h38) surface temperatures converge to the same value on the two panels.

Like I said before during this day surface temperatures on the same facade were also measured with thermocouples located just under the render coating (Fig. 2). Figure 6 shows the evolution of daily temperatures on the two panels.

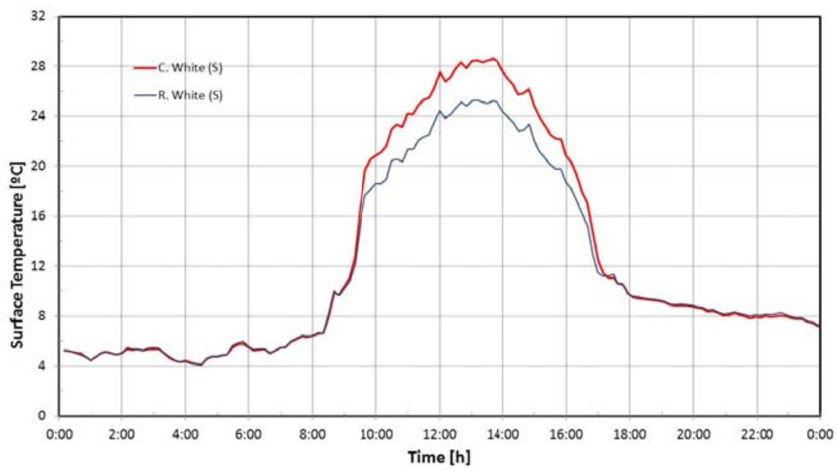


Figure 6: Temperatures of South facade of test cell (thermocouples)

Table 2 presents data values of measured temperature, at the same time (Table 1), with thermography and thermocouples on panels painted with R_White and CWhite paints. The emissivity[1] used (0,89 for R_White and 0,90 for C_White) to obtained infrared temperature was determined at LNEC laboratory. Tests performed in another laboratory[2] confirmed the used emissivity values.

Percent differences between data obtained with the two methods, for R_White and C_White paints, are also presented in Table 2.

Table 2: Surface temperature of South test cell facade obtained by IRT and Thermocouples

Thermogram	Surface Temperatures (South facade), T_{surf} *[ºC]*				Difference Surface Temperature, ΔT_{surf} *[%]*	
	Thermography		**Thermocouples**		**(Thermocouples/Thermography)**	
	C_White	R_White	C_White	R_White	C_White	R_White
T2	**21,9**	19,5	**20,9**	*18,6*	**5**	*5*
T3	**24,2**	21,1	**22,9**	*20,5*	**5**	*3*
T4	**24,6**	21,6	**24,2**	*21,4*	**2**	*1*
T5	**26,1**	22,7	**25,5**	*22,5*	**2**	*1*
T6	**28,5**	25,1	**27,1**	*24,1*	**5**	*4*
T7	**29,2**	25,9	**28,3**	*25,2*	**3**	*3*
T8	**27,0**	23,7	**25,9**	*22,9*	**4**	*3*
T9	**19,8**	17,6	**20,3**	*18,1*	**-3**	*-3*
T10	**11,3**	11,1	**11,4**	*11,2*	**-1**	*-0*
T11	**10,2**	10,1	**10,6**	*10,7*	**-4**	*-5*

As we can see the maximum difference temperature is 5%, a small deviation which demonstrates that IRT can estimate, with a good approximation (sufficient accuracy), temperature distribution of this kind of materials (*cool facades*). This fact validates ITR diagnostic as a good method for the assessment of cool facades thermal performance.

To assess thermal performance of the two different white paints, Table 3 shows differences between C_White and R_White, obtained by IRT and Thermocouples. Maximum differences (3ºC) were achieved close solar noon (13h30) with both test methods, expectedly when solar radiation is more intense.

Table 3: Surface temperature of South cell test facade obtained by IRT and Thermocouples

Thermogram	Time	Difference Surface Temperature, ΔT_{surf} *[ºC]*	
		(**C_White** / **R_White**)	
		Thermocouples	Thermography
T2	9:59	2,3	2,4
T3	10:26	2,5	3,1
T4	11:03	2,8	3,0
T5	11:37	3,0	3,4
T6	12:21	3,0	3,4
T7	13:23	3,2	3,3
T8	14:36	3,0	3,3
T9	16:14	2,2	2,2
T10	17:08	0,3	0,2
T11	17:38	0,0	0,1

It's interesting to note that soon at the morning (9:59), when the solar radiation is even weak (580 W/m^2; Table 1), difference between the two white paints is already significant (2,3 ºC). Observing data for Thermogram T10 (Table 3) we can also conclude that for radiation under 300 W/m^2 the improvement in the thermal performance of cool White (R_White) is negligible (Table 1) when compared with C_White.

[1] Parameter inserted in the IRT equipment control sofware
[2] Universidad Politécnica de Madrid

Additional data show that the two white paints had different thermal performance (for the specific studied day - 8th February) between about 9h30 and 17h30, corresponding to approximately insolated facade time.

Conclusions

Preliminary results of this study demonstrate that Infrared Thermography is an adequate method for the assessment of thermal performance of cool facades and that it can be very useful and practical in real applications since it's a non-contact and a non-destructive testing technique.

Small differences (5%) between IRT and thermocouples temperature data show the good accuracy of IRT method for setting temperature distribution of surface facades.

The assessment of cool paints thermal performance was initiated with the evaluation of two white paints, a conventional paint (C_White) and a cool paint with high reflective characteristic (R_White), applied on test cell facades. Thermal performance of other two cool paint colors (black and dark brick red) will be also evaluated in the future.

Thermograms obtained during a winter day (8th February) show different surface temperatures between panels with R_White and C_White paints (during insolated period), displaying higher temperatures on C_White painted panel. Maximum differences (3ºC) were achieved close to solar noon (13h30), expectedly when Solar Radiation is more intense.

Lower surface temperatures on cool white panel show that reflective paint, due to its high reflectance, absorbs less heat radiation and therefore reduce heat gains.

In winter heat gains are important for the achievement of indoor thermal comfort in buildings, so this solution seems check a worst thermal performance in that period. Nevertheless, considering the high thermal insulation of test cell walls, the reduction of heat gains arising from the use of *cool paints* is insignificant for indoor thermal conditions.

In summer time, due to more intense solar radiation, desirable reduction of heat gains is significantly more accentuated using *cool paints*. Recent summer measurements, already performed with the three reflective paints (Fig 1), show differences of about 11 ºC between (darker) conventional and reflective colors.

For this specific kind of wall solution (ETICS), lower temperatures achieved with cool paint, with dark colors, may be very important also for the protection of thermal insulation in summer period.

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References

[1] A. Costa, C. Pina dos Santos – *Avaliação de produtos de alta refletância na reabilitação de coberturas planas. Estudo experimental* in: "Congresso Luso-Brasileiro de Materiais de Construção Sustentáveis, CLB-MCS" proceedings. Guimarães (Portugal), March 2014.

[2] L. Matias – *Testing techniques for structures inspection. Thermography* in: DuratiNet Course book: Lisbon, LNEC, 29th to 30th May 2012.

[3] X. Maldague - *Theory and Practice of Infrared Technology for Nondestructive Testing*. ISBN 0-471-18190-0. John Wiley & Sons, 2001.

[4] L. Matias - *Evaluation of thermal performance of reflective protections applied on bent roofs*. ISBN 972-49-1937-4. Coleção Teses de Mestrado: Lisbon, LNEC (TM6), 2002.

[5] A. Costa, L. Matias; C. Pina dos Santos – *Soluções energeticamente eficientes de proteção térmica de coberturas inclinadas. Estudo experimental e modelação do desempenho*. Comunicação apresentada nas Jornadas de Investigação e Inovação – Cidades e desenvolvimento. Lisboa, LNEC: 18 a 20 de junho 2012.