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Low-E paints enhanced building components: Performance, limits and research perspectives

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Abstract

In the latest years, different solutions have been developed in order to increase the energy performance of opaque building envelopes as far as the heat losses are concerned. Most of them are mainly focused on the bulk properties of materials and are aimed at reaching very low values of thermal conductivity, i.e., super insulating materials. Contemporarily research has been carried out aimed at exploiting the low emissivity in order to reduce the radiative heat transfer between surfaces separated by cavities and, if applied as an internal coating, in order to increase the indoor thermal comfort. In this paper, several solutions that have been experimentally investigated in the latest two years by the authors are presented.

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Keywords: emissivity paint, reflective insulation, radiation, hollow brick, radiator, roof insulation;

1. Introduction

In the last few years advanced insulation techniques for building applications attracting increasing interest, since they can noticeably improve the thermal performance of building components without increasing their thickness, with consequent important advantages, especially in term of space savings when applied on the internal side of the wall. These advantages are particularly significant when they are adopted as energy retrofit solution of existing buildings since space savings represent a relevant issue according to the technical and economic feasibility of the intervention.

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In this context the technologies based on Super Insulating Materials (SIMs) show promising opportunities, nevertheless their cost and the lack of a shared methodology to determine their effective thermal performance when they are applied to buildings remain the main drawbacks for a significant market diffusion [1],[2].

A promising solution (even if less performant than SIMs) is represented by thermal reflective insulation systems. This technology is based on placing a low-emittance aluminum foil, facing one or more enclosed air spaces, to reduce the radiation heat exchange between two opposite surfaces. This solution is becoming quite popular since if correctly applied can represent a cost effective solution to reduce the building heating/cooling energy consumption. Nevertheless, this solution is not always applicable, for both technological and architectural compatibility issues. The aim of this paper is to investigate a series of solutions based on the use of low emissivity paints showing higher potentials due to low cost and easy installation. The presented research activities are aimed on the one hand to experimentally investigate the thermal performance of building components enhanced using low emissivity paint, and on the other hand to explore new fields of application for this technology and their related drawbacks.

1.1. Low emissivity coatings in opaque envelope components

Several studies in literature report that the main field of application for reflective insulation is related to the use in roof and wall components. The studies of [3],[4],[5] and [6] investigates the effect of reflective insulation in roof and (attic space) demonstrating that a summer cooling energy reduction between 25% and 70% are achievable and up to 100% in roof mounting multi-reflective radiant barriers.

[7] and [8] investigates the performance of wall mounting reflective insulation through numerical analysis and hot box experiments showing an increase of the thermal resistance of the air cavities depending on their thickness.

[9] ,[10], and [11] studied the effect of the application of reflective insulation in walls behind radiators. In particular [11] highlighted that around 48% of the heat losses in the uninsulated wall behind radiators should be avoided by using a reflective metallic plate. Nevertheless [9] and [10] also highlights that if a reduction of the heat flow across the wall is achievable, on the other, a reduction of the radiator heat output occurs.

Despite the growing interest, only few studies are focused on the performance of low emissivity paints. Jelle at al. [12] reports a comprehensive review on reflective insulation. The study include a series of commercial paints characterised by low emissivity properties due to the presence of aluminum flakes dispersed in the epoxy-based coating, showing that most of the commercial Low-E paints has an emissivity between 0.15 and 0.49 depending on their composition and on the surface in which they are applied. Nevertheless, only few studies are focused on the application of low emissivity paints. [13], [14], and [15] analysed the improvement of the performance achievable by coating the cavities surfaces of hollow bricks. In particular [13] highlights an increase of the thermal resistance of about 20% if compared to uncoated bricks. Moreover, an investigation by means of simulations were carried out in [16]and [17]. In [17] the analysis was focused on the potential benefits achievable by using internal and external reflective coatings. Results demonstrate that for the interior coatings a contribute to the net heating savings is achievable, while in summer, not significant improvements were evidenced, as far as the cooling energy demand is concerned. On the other hand for external reflective coating, the main benefits are related to the reduction of the cooling loads, while a penalisation was observed in winter due to the decrease of the solar heat gains.

2. Methods

The thermal performance of building components coated with low emissivity paints was investigated in three different cases studies. Table 1 summarises for each case study the adopted solution and the respective experimental analyses that were carried out.

Table 1. Resume of the analysed Low-E treated building components

Case study	Low-E paints integration	Application	Experimental test
I	Hollow brick cavity surfaces	Paint sponge device	Guarded heat flow meter test (GHFM)
II	Below roof tiles	Paint brush	In-field experimental campaign
III	Wall behind radiator	Paint brush	Small scale prototype in double climatic test room (BET-cell)

2.1. Hollow bricks coated with low-emissivity paint (Case Study I)

A hollow clay brick currently used for internal partition wall (dimension 480 x 380 mm), 80 mm thick was chosen for the analyses. This brick type has been selected since able to guarantee a sufficient surface of measurement without coupling more bricks together, with the advantage of avoiding the presence of potential thermal bridges generated by the mortar joints.

Two specimens were prepared, the uncoated brick used as reference sample (brick A) and the Low-E coated brick (brick B), in which the internal cavities surfaces were coated with a commercial Low –E aluminum paint (Figure 1).

Fig. 1. (a) Rough brick used as reference case (brick A); (b) Coating phase (c) Brik with Low-E coating (brick B).

2.1.1. In-lab experimental campaign

Laboratory measurements were performed to assess the equivalent thermal conductivity of the two different specimens, by means of a guarded heat flow meter apparatus (GHFM) according to the international standard UNI - EN 12664:2002 [18]. The device consists of a single sample heat flow meter with guarded ring “LASERCOMP FOX600” (Figure 2a) equipped with two plates containing heat flow meters sensors (measurement area of 254x254 mm) placed above and below the measurement specimen.

To seal the brick voids and to thermal short circuits between the two measuring plates (lateral heat losses), the specimens were surrounded by an insulating ring made of polyester fibre (λ = 0,039 W/mK) (Figure 2b). Moreover to prevent damage at the measurement device and to reduce the effects of contact resistance the specimens were sandwiched between two rubber sheets of 3 mm of thickness each and a thermal conductivity λ of 0.135 W/mK).

Moreover, to assure that test were performed at the same conditions, before each measurement, the specimens were dried up to constant mass in a ventilated oven for unless 48 h at 60°C.

To minimize the temperature difference measurement errors, the tests were carried out with a mean temperature of 20°C with a temperature difference between the plates of 20 °C.

The measurement principle is based on forcing a constant temperature difference between the upper plate and lower plate, and to measure the specific heat flow and surface temperatures when the steady state conditions are reached. The equivalent thermal conductivity was then calculated using equation (1).

$$\lambda_{eq} = \frac{s \cdot |q|}{|T_{up} - T_{low}|} \tag{1}$$

Where:

λ_{eq} is the equivalent thermal conductivity, s is the sample thickness, q is the specific heat flow, T_{up} *and* T_{low} are respectively the upper plate and the lower plate temperatures.

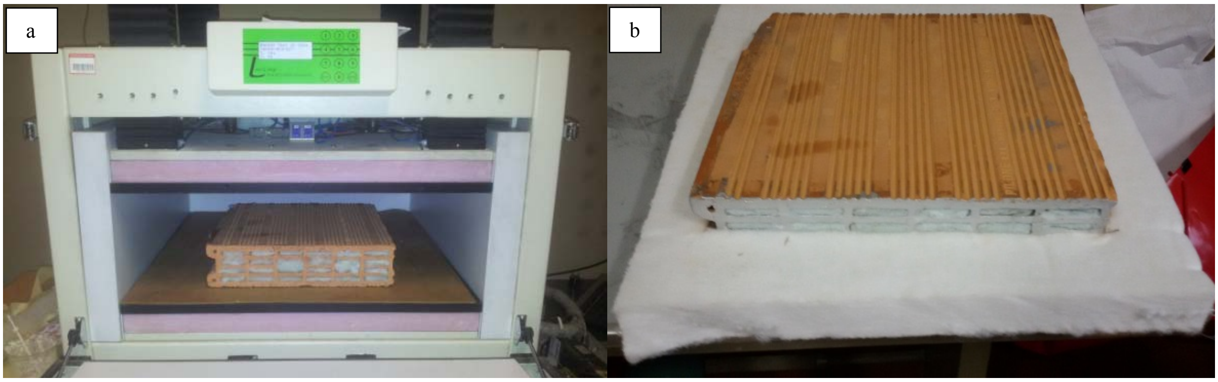

Fig. 2. (a) Brick placed in GHFM apparatus. (b) Insulation ring surrounding the brick specimen;

2.2. Low-E paint coating below roof tiles (Case Study II)

The aim of this study was to evaluate the performance and relative benefits in term of summer heat load reduction achievable by painting the bottom side of roof clay tiles with a Low-E paint.
The case study is represented by an attic space of a residential building under refurbishment in Turin – Italy. The monitored pitched roof has a timber-frame structure, covered by clay roof tiles. The roof surface was divided into different portion (Figure 3a), and one of these surfaces (raw tiles roof) was used as a reference (config. A), while the other one was coated with the Low-E paint (config. B) (Figure 3b). Each configuration was then finished with other layers from the inside: 1) 10 mm gypsum board, 2) 50 mm extruded polystyrene XPS, 3) 100 mm slightly ventilated air layer and 4) 30 mm clay roof tiles.

Fig. 3. (a) on the left (config B), on the right (config. A); (b) Low-E treatment by paint brush coating

2.3. In-field experimental campaign

For the experimental campaign, a series of sensors were installed on the roof components (Figure 4a). The global incident solar irradiation was measured by means of a second class pyranometer LP02 (calibration uncertainty ≤ 1.8%). Indoor and outdoor temperatures and layers temperatures were measured by means of type-T thermocouples (nominal accuracy ± 0.25 K), while the convective heat fluxes were measured by means of HFP01 heat flux sensors (measurement uncertainty ± 5%) placed on the indoor side of the roof section (Figure 4b). The measurements were acquired every 15 min by a data logger DT600.

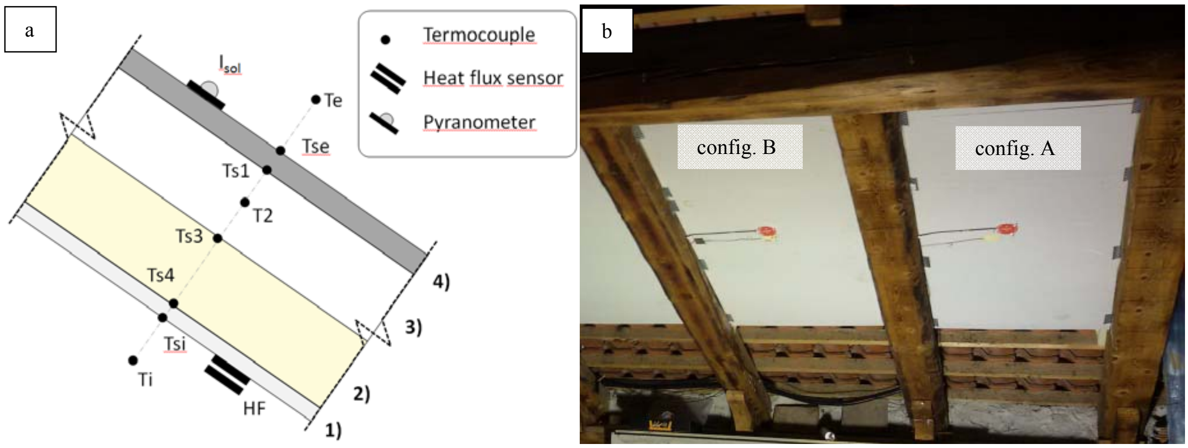

Fig. 4. (a) Roof section with indication of the installed sensors; (b) Heat flux sensors placed in the indoor side of config. A and B.

2.4. Low-E paint on the walls behind radiators (Case Study III)

The case study III is represented by the application of low-E paints in walls behind radiators. This solution is aimed at reducing the radiation heat exchange between the radiator and the behind wall, with a consequent reduction of the winter heat losses. Two configurations were tested, one with the bulk surface (config. A, Fig. 5a) and one coated with the low-E paint (config. B, Fig.5b), both constituted by the same layers. From the side facing the radiator, the assembly is constituted by a 6 mm MDF (Medium Density Fiber Board) panel and a 20mm XPS (Extruded Polystyrene) panel. The radiator is separated from the adjacent wall by an air layer of 50 mm. Figure 5 show the low-E paint specimen facing the radiator.

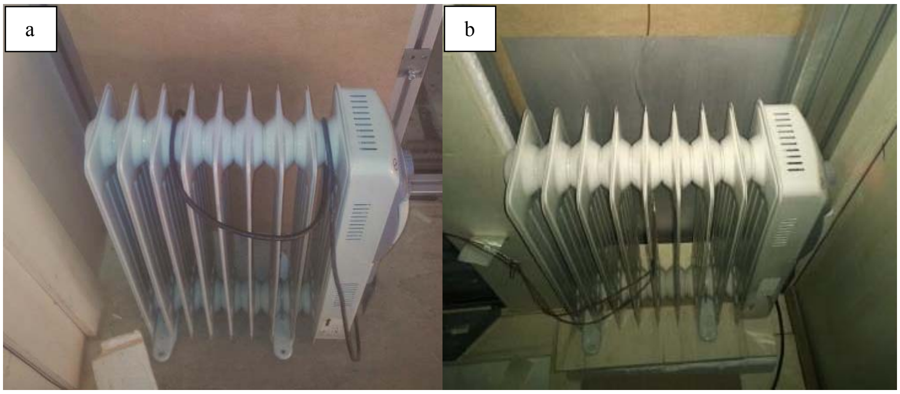

Fig. 5. (a) Configuration A (bulk wall); (b) Configuration B (wall coated with low-E paint)

2.4.1. In-lab and in-field experimental campaigns

The experimental campaign was carried out by in the climatic chamber “BETcell” (Building Envelope Test cell) (Figure 6a) [19]. The apparatus consists in a dual climatic chamber in which the separation between the two environments is constituted by a movable wall that allows to host building envelope specimens. The apparatus allows to perform experiments on the thermal performance of building envelope components and systems in both steady-state and dynamic boundary conditions, in a controllable laboratory environment.

During tests, the two environments separated by the specimen (thermal resistance R=0.69±0.02 m^2K/W previously measured by means of the GHFM apparatus) were maintained at 30±0.15°C and 14±0.3°C with a temperature difference of ~16°C. For the experiments, six T-Type thermocouples (nominal accuracy ± 0.25 K) connected to a data logger dt85 were placed following the scheme presented in Figure 6b, while the heat losses were measured by two heat flow meter sensors (sensitivity 0.028 [mV/(W/m^2)]) (Figure 6c). The tests were performed until the equilibrium of temperature and heat flows were maintained constant for non-less than 24h. For the calculation of the average temperature and heat fluxes, only the last six hours of measurement were considered.

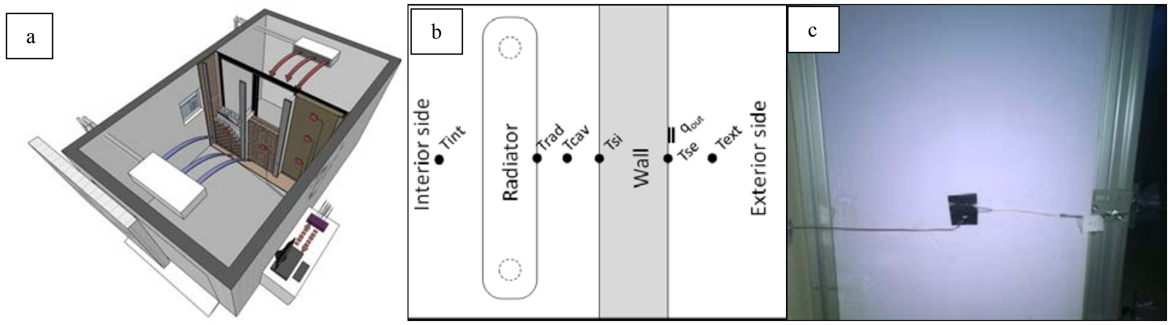

Fig. 6. (a) Scheme of the BETcell apparatus; (b) Experimental layout and sensors; (c) Sensors on the external (cold) surface.

3. Results and discussion

3.1. Hollow bricks coated with low-E paint

The results of the equivalent thermal conductivity λ_{eq} measurements by means of the guarded heat flow meter apparatus are reported in Table 2. It is interesting to observe that a reduction of ~18% of the λ_{eq} (from ~0.192 to ~0.158 W/mK) was measured in the brick with low-E paint (brick B). These results are in line with those reported in the literature, stating that with a low emissivity coating it is possible to have a 20% reduction in the λ_{eq} [13].

Table 2. Results of the equivalent thermal conductivity measurements.

Specimen	T_{up} (°C)	T_{low} (°C)	λ_{eq} (W/mK)
Brick A (reference)	35.02	15.02	0.192 ± 0.006
Brick B (low-E coated)	35.02	15.01	0.158 ± 0.005

3.2. Low-E paint below roof tiles

Figure 7a show the heat flow crossing the roof components, config. A (grey solid line) and config. B (black solid line). For the sake of brevity and to avoid overpopulation of results, only a representative sunny day was selected. Results highlight that for the chosen day a reduction of the daily heat loads from the component are achievable by applying a Low-E paint, with a maximum peak reduction during the afternoon of around 14%.

In Figure 7b the results of the percentage daily heat loads reduction *Pc* achievable by the Low-E treatment (Equation 2) [5] are shown for all the monitoring period (12th August – 23rd September).

$$Pc = \frac{\int_{test,period} q_{in,(A)} dt - \int_{test,period} q_{in,(B)} dt}{\int_{test,period} q_{in,(A)} dt} \cdot 100 \qquad (2)$$

Where: $q_{in\ (A)}$ and $q_{in\ (B)}$ represents respectively the ongoing heat flow through the roof components with and without the reflective treatment.

The daily performance indicator *Pc* show a variation between ~6% and ~24% with a consequent maximum daily reduction in the indoor surface temperature between 0.6 and 1.4°C. (depending on the outdoor weather conditions).

Nevertheless, the value calculated by integrating the ongoing heat flows for all the monitoring period is ~ 19%.

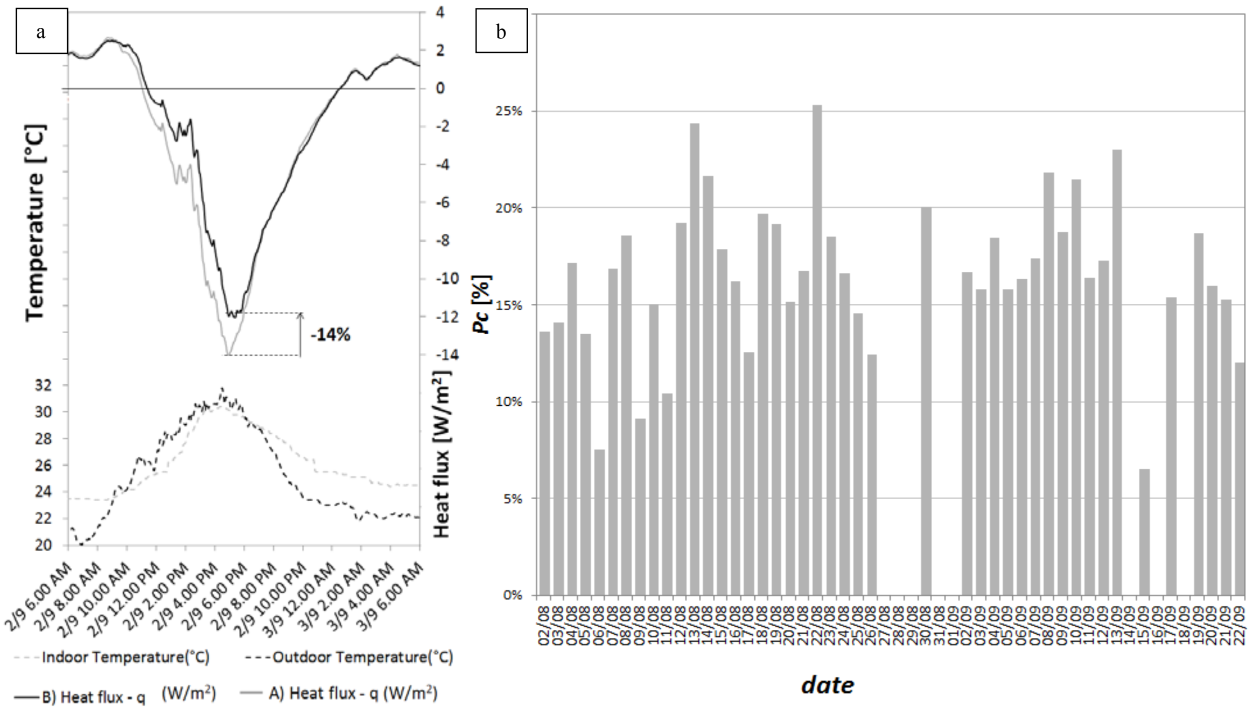

Fig. 7. (a) Indoor/outdoor temperatures and heat fluxes measured at the indoor surface; (b) Daily heat loads reduction by means of Low-E paint.

3.3. Low-E paint on the wall behind a radiator

Results of the temperature trend measured on the wall component coated with Low-E paint (dashed grey line) and the uncoated reference component (solid black line) are shown in Figure 7. It is worthy highlight that the presence of the low-E paints allows a reduction in the indoor surface wall temperature *Tsi* (wall facing the radiator) of ~6°C, and of ~1°C in the outdoor surface temperature (*Tse*), with a consequent reduction in the heat losses of ~25% from 39.8 W/m^2 to 30.0 W/m^2.

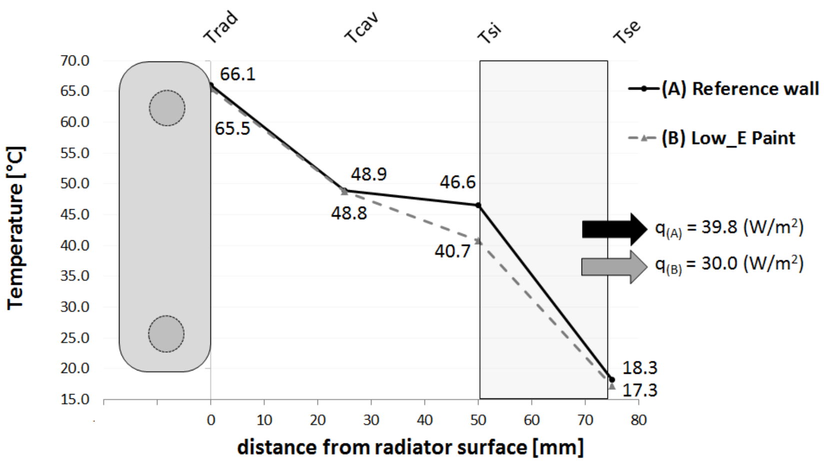

Fig. 8. Temperature trend and heat fluxes measured in BETcell apparatus, config. A (black solid line), config. B (grey dashed line).

4. Conclusions and outlooks

The study presents an overview of three case studies in which low emissivity paint was applied. Experimental results demonstrate that with this technology an improvement of the envelope performance is achievable.

In particular:

I) a reduction of ~18% of the equivalent conductivity was measured in hollow bricks;

II) a reduction of the summer heat loads across a roof component of ~19% was measured;

III) a reduction of ~25% in the heat losses from the wall behind radiators was measured.

Despite the fact that all the studied applications show advantages in term of thermal performance improvement, some drawbacks have to be pointed out. The application process of low-E coatings in bricks is not yet developed, and the performance improvement is strictly dependent on the geometry of the cavities. For the application in roof components and behind radiators the reported advantages are lower if compared to the application of reflective insulation constitute by aluminum foils. Moreover, as well as for all the low emissivity materials the long term performance should be verified and there is no study related to the evolution of the emissivity values over time.

The authors suggest that the possible benefits achievable by the use of low-E paints, such as the application of interior paints to improve the indoor comfort condition or as outdoor paints to reduce the heat losses through sky radiation should be further investigated, as well as studies focused on the improvement of the emissivity values.

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