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Analysis on existent thermal insulating plasters towards innovative applications: Evaluation methodology for a real cost-performance comparison

Silvia Barbero ^a, Marco Dutto ^b, Cinzia Ferrua ^b, Amina Pereno ^a

^a Politecnico di Torino, Department of Architecture and Design, 39 viale Mattioli, 10125 Torino (TO), Italy

^b Vimark S.r.l., 2 Strada Spartafino, Peveragno (CN), Italy

abstract

Thermal insulating plasters are an important means to face the energy efficiency issues in building field, above all in renovation processes. New solutions, such as nanotechnology or aerogel based plasters, could make a significant contribution to this field, reaching higher level of thermal performance and reducing needed thickness. But, in order to be really suitable for the market, new plaster solutions have to answer to specific economical and technical needs. This research provides an overall analysis of thermal insulating plasters in European market, comparing existing products according to technical specifications and economical features. The main goal of this survey is to drive researches in thermal plasters fields towards innovative application, creating new plasters able to meet real market and end-users demands. Technical cross assessment considers three main factors, defined according to European standards: volume mass powder, dry bulk density of hardened mortar and thermal conductivity. Benchmarking analysis compares prices per unit, in order to relate material quantity to the achieving of common R_x value. Cross assessments results allow to define thermal, technical and economical requirements that new thermal insulating plasters have to meet to be suitable for European volume market.

1. Introduction

The entry of thermal insulating plaster in building sector aimed to face the problem of energy consumption and thermal insulation in construction wrapping. The thermal insulating plaster represents one of the possible solution to face energy problem in buildings, with the consistent advantage to be a common and traditional product used in building sites [1]. Plasters, used since thousands of years, are still used as constructive elements in many architectures. The versatility of these materials allows both indoor and outdoor applications, with different substrates, constructions and compositions. The plasters are used not only as finishing or protecting the walls, but they are developed to satisfy higher and higher technical requirements. According to recent reviews, inorganic fibrous materials and organic foamy materials have 87% of the European market [2]. However, the desire for improved thermal performance has resulted in these types of insulation materials becoming ever thicker. The remaining 13% is made up from a wide range of natural products, examples being sheep-wool, coconut fibers and wood-wool. Higher technology solutions, such as vacuum insulated panels and nanotechnology based options are present on market but still at a low level [3]. Due to a constant market push towards more durable, more sustainable and more cheap products, products for the construction industry are opt for continuous research and development. One of the most recent technological developments to apply in this R&D is nanotechnology [4]. Improving the performance of the construction sector will increase the quality of life and contribute to reduce the challenges related to the environment and climate [5]. To achieve high levels of insulation in buildings, external walls are getting thicker, resulting in a lower number of homes that can be built on the site. This factor implies issues in terms of space saving aspects, especially in large urban centers where the need to accommodate a large number of people becomes crucial. For retrofit, the application of thick insulation (required to achieve improved performance) to the inside of walls is often unwelcome because it impacts on the internal floor area [6]. There is therefore a need for new materials to supply the future required levels of insulation, without the insulation system being so thick that it meets with significant market resistance [7]. Additionally, successful approaches will have the ability to be used on both new build and retrofit, using techniques that are familiar to today's construction industry. Usually, thermal insulating plasters are used on existing support, as bricks, mixed wall (bricks and stones) or wall that has already been plastered. The workability of thermal plasters is very similar to the traditional ones, it can be used on non-aligned, out of square, or, even, curved support. So that, thermal insulating plaster are flexible and can be suitable for any architectural and design solutions. These plasters are usually pre-mixed and ready to use, they are reformulated with light aggregates, like cork, clay, perlite, silica, pearls of expanded polystyrene, expanded glass, etc. [8]. They can be applied to high thickness and have a high water vapour diffusion coefficient, i.e. the material is very transpiring. This research aims to understand the current scenario of thermal insulating plaster in European market, in order to define the requirements that innovative thermal insulating plasters should meet, in order to be suitable for European volume market. This research merges the performances of the material with the cost on the market, so that it is possible to define a target for a new thermal insulating plaster [9] in terms of technical aspects and economical value. At the moment, nano-materials, and consequently the final products made with them, are more expensive than their non-nano materials alternatives. The price can decrease with the increased volume.

2. Methods for analysis

This research concerned thermal insulating plasters available on the European market: the use of the plasters is typical of European construction techniques, furthermore the Western European Countries have mainly a moderated climate, which led to an increasing use of thermal insulation plasters, above all in the colder part of Europe, according to energy saving and environmental sustainable logic [10,11].

In order to better compare different typologies of plasters, all considered products were divided into three main families, according to the binders they are based on:

1. Thermal insulation plasters based on cementitious and/or artificial binders (14 products).
2. Thermal insulation plasters based on cementitious and expanded mineral aggregates (8 products).
3. Thermal insulation plasters based on natural hydraulic lime NHL (9 products).

The first family includes products based on virgin polystyrene beads or silica and diatomic dust; the second one includes plasters based on cementitious and expanded mineral aggregates like perlite; and the last one products based on natural hydraulic lime. In that way the products of the same family are comparable for their thermal performance.

The assessment of all considered products was based on common parameters, defined according to European technical standards. In particular we considered:

- EN 998-1:2010 Specification for mortar for masonry—Rendering and plastering mortar [12].
- EN 1015-10:2006 Methods of test for mortar for masonry—Part 10: Determination of dry bulk density of hardened mortar [13].

- EN 1015-19:2006 Methods of test for mortar for masonry—Part 19: Determination of water vapour permeability of hardened rendering and plastering mortar [14].
- EN 1745:2002 Masonry and masonry products—Methods for determining design thermal values [15].


The study started from the procurement of technical, chemical and physical data, and application features of each thermal insulation plaster; all characteristics were obtained through direct contact with manufacturers and a careful review of data sheets [16]. The data collection is done with official technical data sheet given by each producer and when the information was not public, the specific request was asked with e-mails and phone calls. Especially, for the price range of each thermal insulating plaster, each producer states its 2012 price list (just 14 companies on 31 give us the cost of their products).

- For each was drawn up a summary (Fig.1) that report in detail:
- Producer/distributor's record (Country and contacts for further communications);
- General information (main information about the product and specific characteristics);
- Certifications (tests or standards that certificate the products);
- Applications (supports on which the plaster could be used and way applications);
- Indicative amount required (surfaces covered by 1 unit of product);
- Technical solutions (pre and post treatment operations);
- Commercialization (Countries in which the company operates and/or the product is sold);
- Price range (price per liter and per unit, expressed in euro);
- Technical specification (product values in reference to European standards, like color, packaging, indicative amount required thermal conductivity, volume mass of powder, dry bulk density of hardened mortar, application temperature, volume mass of mixture, average compressive strength after 28 days, water absorption, water vapour permeability).

For a fair and honest survey, we cannot public the name of the manufacturers and of the considered commercial products, because the goal of this research is not to detect the best or the worst product, but the right collocation on the market of innovative thermal insulating plaster. Among the technical specifications we asked for, some values have been chosen as the most important to effectively compare the performances of all different thermal insulation plasters (Table 1): we considered the volume mass powder, the dry bulk density of hardened material, and the thermal conductivity. Consider that the thermal conductivity and bulk density values are interrelated (EN 1745:2002, appendix A.12) [14]. Finally, it is important to define not only the technical requirements but also the economic ones; new products must meet the physical, thermal and application requests, but to be suitable for the market it is necessary to evaluate the price range. So the last part of this research concerned a benchmarking analysis to compare prices of all analyzed products: we considered the price per unit and we related it with the quantity of material needed to achieve a common R_s value.

3. Results

All plasters were compared to each other according to three main parameters (volume mass of powder, dry bulk density of hardened mortar and thermal conductivity) and then the water vapour



Thermal plaster 1
produced by: Company 1

address: Xxxxxxxxx 11
123456 City
Country

website: www.website1.com

phone: +11 [0]1234/56789
fax: +11 [0]1234/10112

e-mail: mail@website1.com

General information

It is a insulating plaster for facades and inner walls. It can be used on all common bottoms.

Certification

-

Applications

The plaster is suitable for all conventional surfaces such as clay bricks, concrete blocks, sand-lime and rough concrete surface. It is not specific for wainscoting.

Indicative amount required

1 bag (50 lt) covers 1 sqm with 40 mm thickness.

Technical solution

After preparing the support for plastering (closure of cracks, leaks and missing parts) must be provided a suitable pre-treatment in relation to the characteristics of the medium itself. The weakly absorbing media or the non-uniform absorbent media are treated by applying the mortar on the entire surface.

In the case of concrete substrates should be used an adhesion bridge and, in the case of

sensitive substrates [old buildings], also a plaster support.
Before the plastering on all edges are applied galvanized corner beads.

Commercialization

The company is present in Austria, Italy, Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Serbia, Slovenia, Switzerland.

Price range

0.296 €/lt | 14.80 €/bag.

Technical specification

| Properties | Standard | Comments | Values |
|-------------------------------------|--------------|--------------|--------------------------|
| Color | | | n.d. |
| Packaging | | Paper bag | 50 lt |
| Indicative amount required | | Thickness | 20 mm (minimum) |
| Thermal conductivity | EN 1745:2002 | | 0.074 W/m ² K |
| Volume mass of powder | EN 12190 | | 250 kg/m ³ |
| Application temperature | | | > +5°C |
| Volume mass of mixture | EN 1015-6 | Fresh mortar | 500 kg/m ³ |
| Dry bulk density of hardened mortar | EN 1015-10 | | 250 kg/m ³ |
| Average compressive strength | EN 1015-11 | | 0.5 N/mm ² |
| Average flexural strength | | | 1 N/mm ² |
| Water absorption | EN 998-1 | | W1 |
| Water vapour permeability | EN 1015-19 | | μ 8 |

Fig. 1. Example of a complete analysis record for each plaster.

Table 1
Summary of the properties evaluated for each plaster material present in current scenario.

| Properties | Symbol | Unit | Standard | Notes |
|---------------------------------------|-----------|-------------------|------------|---|
| Volume mass powder | ρ | kg/m ³ | - | The indicated value is declared by the manufacturer, then we are not able to provide any information about it. For completeness, it appoints the EN 196 [17] and EN 1015-2 [18], normally used for the determination of bulk density. |
| Dry bulk density of hardened material | ρ | kg/m ³ | EN 1015-10 | [18] |
| Thermal conductivity | λ | W/mK | EN 1745 | [15] |
| Water vapour permeability coefficient | μ | - | EN 1015-19 | [14] |

permeability was considered to calculate the real performance of the plaster.

3.1. Technical result

The basic values of thermal conductivity (λ) of mortars, as required by EN 1745:2002 [14], may be determined in two different ways: table λ values or measured λ values. The determination of the table λ values is uniquely based on the mass density. These values are valid for materials under the control of production of the density and not directly to the measurement of λ values. Values are reported as fractals of 50% and 90% (P) of the existing range of λ values of a given material for a given density. Instead, measured λ values are based on the relationship of λ mass density and the initial type test of λ , according to the measurement scheme described in ISO 8302 [19] or EN 12664 [20]. As we can see from Fig. 2, the performance of the thermal conductivity of the plaster mortars increases with the increase of the density of the hardened mortar, whose values change significantly from a density of hardened mortar of 1500 kg/m³. The realization of the graph allows us to obtain, by the difference of variables integrals (P = 90–50%), a known area in which we can place all the plaster materials, that declare their values of density of hardened mortar, following the scheme of European standard EN 1745:2002 [15]. Sometimes, however, the data offered by the plaster manufacturers lack this value that is fundamental to a direct relationship with the normative data. Instead, the apparent density of the powder is provided, but it is not in direct relation with the tabular thermal conductivity data. In this way, it is difficult to obtain a correct and clearly reportable comparison between all types of materials on the market.

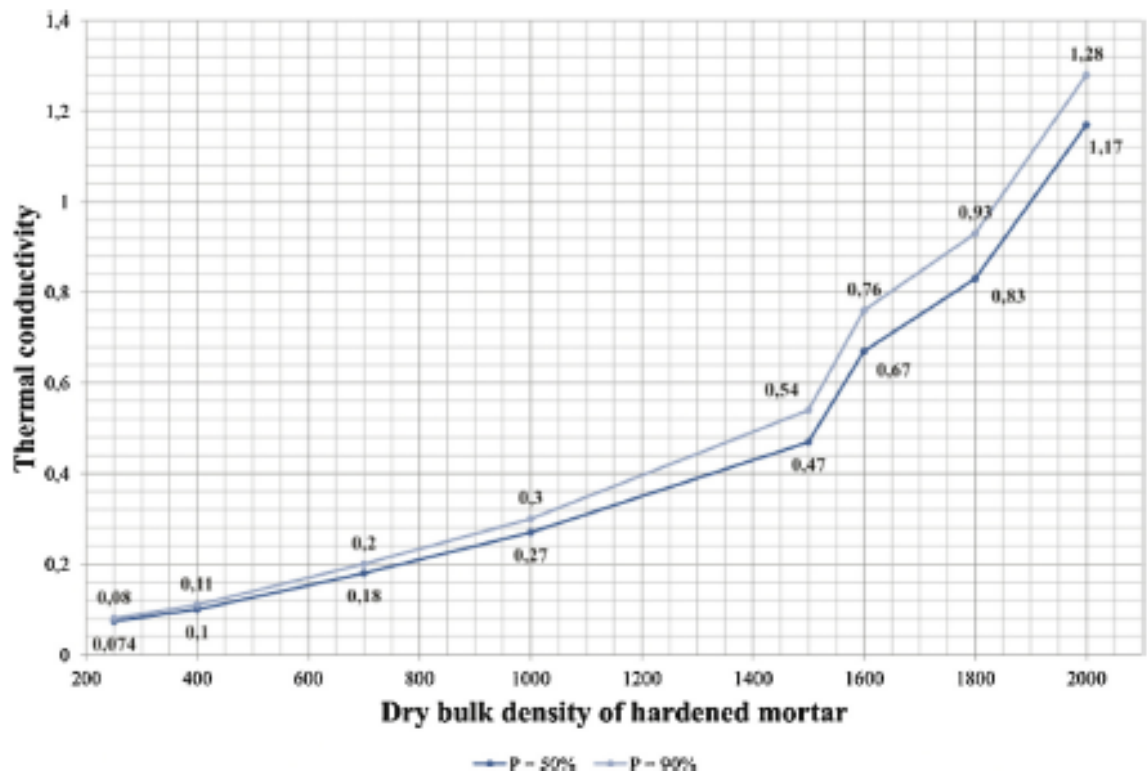


Fig. 2. Relationship between the thermal conductivity of the plaster $\lambda_{10, \text{DRY}}$ and the mass density of the material.

This market analysis provides a first useful observation from our research: not all values reported in the technical material sheet of plaster for thermal insulation of buildings are directly related to the reference standard. Another interesting aspect is the comparison between the values of the standard and the thermal conductivity data reported by producers. In the charts below are shown, in relation to the values of EN 1745:2002 [15], the declared data of the products we know the density of hardened mortar (Figs. 3–5). It is evident that all added data are below the threshold determined by the reference standard. Some of these values were measured in laboratory according to the scheme described in ISO 8302 [19] or EN 12664 [20]. The values declared by producers are better than the trend line given by the European standard. The study could also follow the development of a real correlation between the thermal conductivity of materials and their hardened mass in relation to the reference path. Considering

this analysis, we can say that to obtain an innovative high-performance insulation product, we should seek for a new formulation whose density of hardened mortar has a value between 250 and 350 kg/m³.

3.2. Benchmarking results

The analysis of plaster products for thermal insulation of buildings goes forward with the cost comparison of different materials.

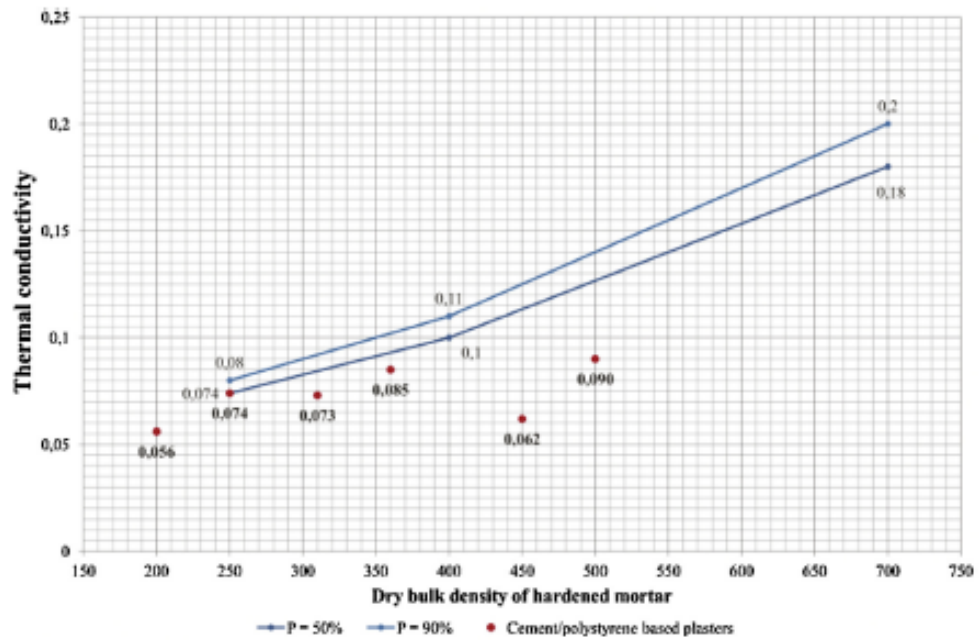


Fig. 3. Comparison between standard values and the one declared by producers in Family 1 (thermal plaster based on cementitious or artificial binders).

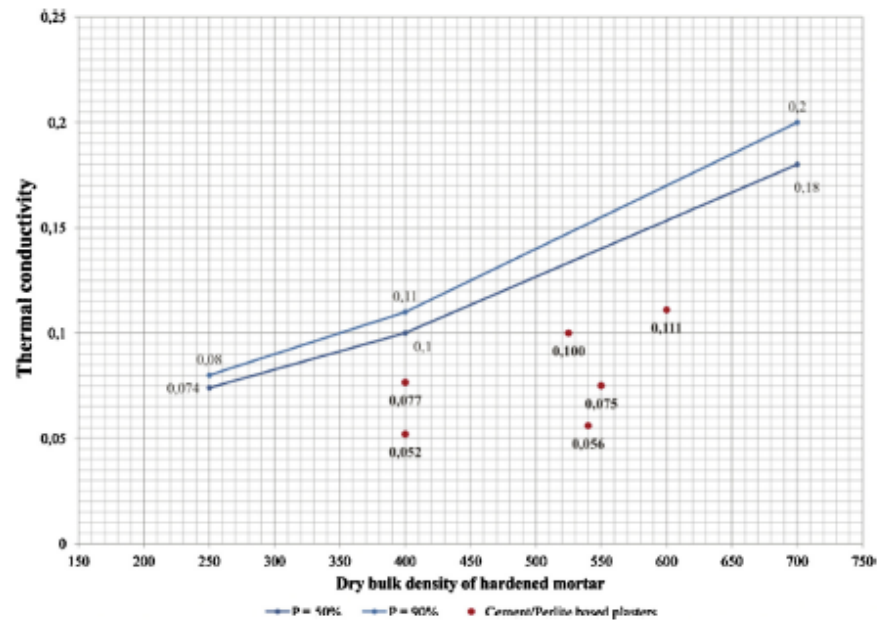


Fig. 4. Comparison between standard values and the one declared by producers in Family 2 (thermal plaster based on cementitious and expanded mineral aggregates).

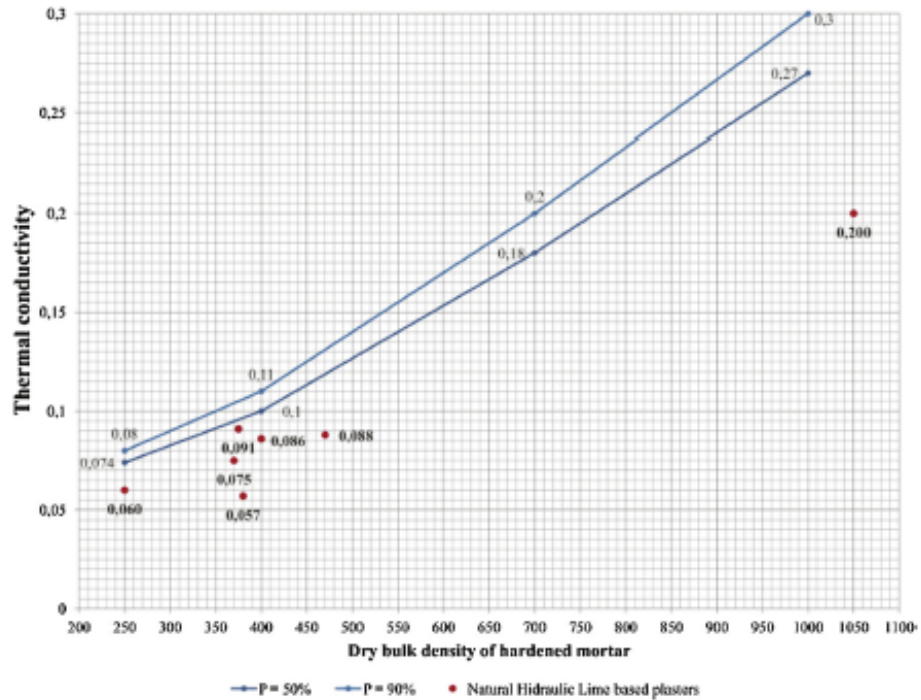


Fig. 5. Comparison between standard values and the one declared by producers in Family 3 (thermal plaster based on natural binders - natural hydraulic lime NH).

In the market and technical analysis, 31 products are analyzed, but just 14 ones have public official price lists. The data are organized in two sets of products according to the type of binder used: the cement-based plaster (the first two Families of the previous part of analysis were merged in just one category) and natural hydraulic lime-based plaster (Family 3). Then, the prices, all converted in Euros, are reported in table and related to the following main parameters:

- indicative amount of product required to make 10 mm of thickness (kg);
- thermal conductivity values;
- thickness to have a pre-determined R value (R_x).

The relationship among these three parameters allows to have the incidence of the cost per square meter for each single product, at

Table 2
Pricing table for cement-based insulating plaster.

| Product | Price [D/unit] | 10 mm of thickness/sqm [unit] | Thermal conductivity [W/m K] | Thickness R_x [mm/sqm] | Price [D/sqm R_x] |
|-----------|----------------|-------------------------------|------------------------------|--------------------------|----------------------|
| Product 1 | 1.197 | 3.00 | 0.055 | 55 | 19.75 |
| Product 2 | 0.435 | 12.50 | 0.090 | 90 | 48.94 |
| Product 3 | 0.296 | 12.50 | 0.074 | 74 | 27.38 |
| Product 4 | 0.440 | 10.00 | 0.056 | 56 | 24.64 |
| Product 5 | 0.416 | 12.50 | 0.090 | 90 | 46.80 |
| Product 6 | 0.352 | 10.00 | 0.062 | 62 | 21.82 |
| Product 7 | 0.834 | 5.50 | 0.075 | 75 | 34.40 |
| Product 8 | 1.084 | 10.00 | 0.111 | 111 | 120.32 |
| Average | | | | | 31.96 |

Table 3
Pricing table for natural hydraulic lime-based plaster.

| Product | Price [D/unit] | 10 mm of thickness/sqm [unit] | Thermal conductivity [W/m K] | Thickness R_x [mm/sqm] | Price [D/sqm R_x] |
|------------|----------------|-------------------------------|------------------------------|--------------------------|----------------------|
| Product 9 | 1.150 | 10.00 | 0.200 | 200 | 230.00 |
| Product 10 | 1.900 | 4.50 | 0.075 | 75 | 64.13 |
| Product 11 | 0.400 | 12.00 | 0.060 | 60 | 28.80 |
| Product 12 | 1.460 | 4.00 | 0.091 | 91 | 53.14 |
| Product 13 | 2.770 | 4.00 | 0.066 | 66 | 73.13 |
| Product 14 | 1.340 | 4.00 | 0.088 | 88 | 47.17 |
| Average | | | | | 53.27 |

the same final thermal resistance (conventionally pre-determined value of $R_x = 1.0$ m K/W). Furthermore, the average cost of a potential new product has been determined, with the sole exclusion of the higher parameters in each system analyzed (Tables 2 and 3). In this regard, two graphs show the results of the benchmarking analysis (Figs. 6 and 7).

To reach the value of thermal resistance pre-determined in this research we take in consideration each product evaluating the different needed thickness [21]. In that way, we realize that two products are under-performing in terms of thermal conductivity in comparison with the other, one for the category of cement-based plaster, and another for the natural hydraulic lime-based plaster. Those products are the number 8 in Table 2, and number 9 in Table 3, that are not presented in Figs. 6 and 7. This exclusion is not due to the package price, and neither to the unit of measurement for the product (kg or liter), but it is due to the high amount

required of material per square meter used to achieve the insulation values set in this analysis (R_x). At this point, it is possible to conclude that the average cost of the cement-based products, with the same thermal performance, is equal to D 32.00/sqm; while the average cost of the natural hydraulic lime-based plaster is D 53.00/sqm.

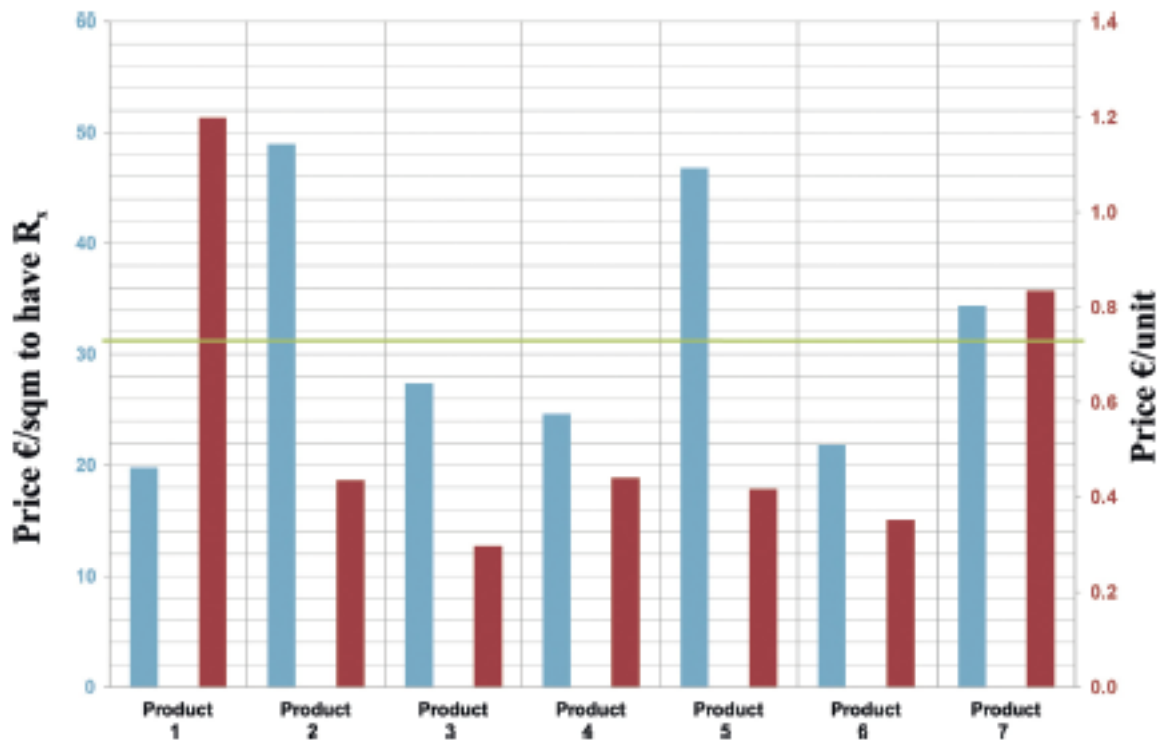


Fig. 6. Graph for cement-based insulating plaster. The average line is green.

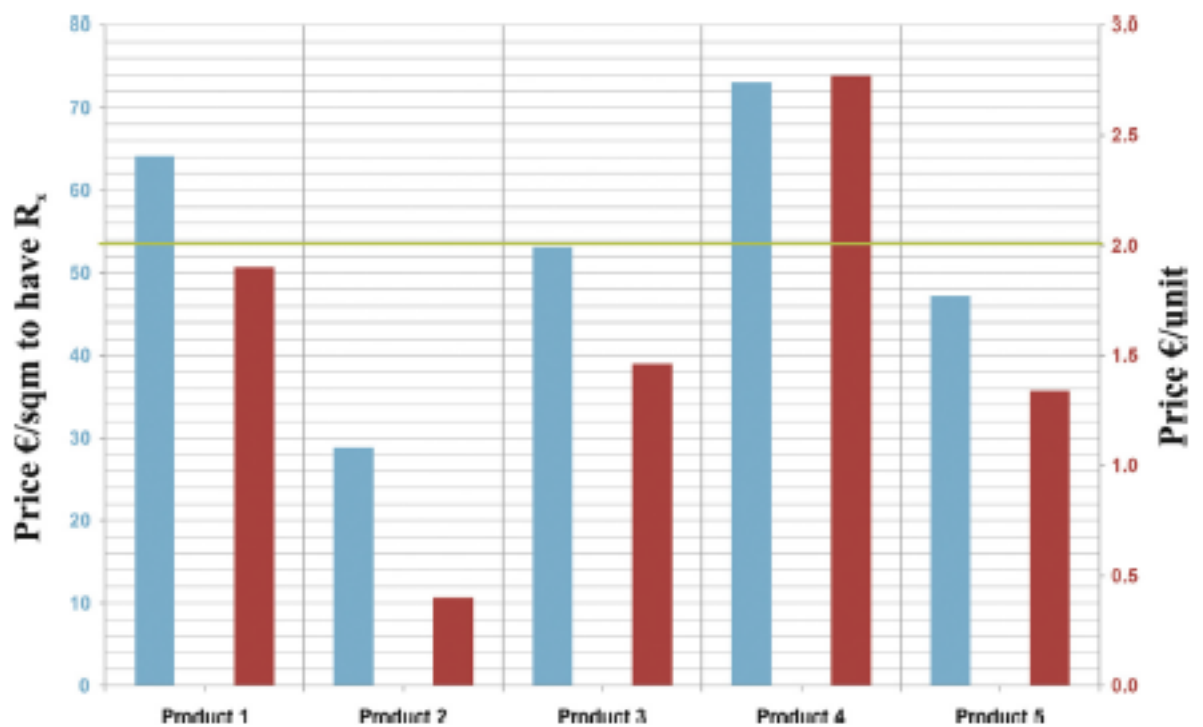


Fig. 7. Graph for natural hydraulic lime-based insulating plaster. The average line is green.

Table 4
Table of target value for a new thermal insulating plaster for the European market.

| Parameter | Current specification | Must to have |
|---|-----------------------|------------------------|
| Cost of thermal insulating plaster at the same conductivity (Value related to $R_x = 1 \text{ m K/W}$) | N.A. | 45–60 €/sqm |
| Density of hardened mortar | N.A. | <250 kg/m ³ |

4. Conclusions

The performed analysis highlights interesting results both from the technical-functional point of view, and from the economic one (Table 4).

At a technical level, the main parameter to be achieved, in terms of innovation, concerns the desirable value of density of hardened mortar less than 250 kg/m³; furthermore, it requires very low water absorption and high water vapour permeability (transpiration). Even the application features are essential to meet market and users demands:

- low thickness of application with equal thermal insulation;
- fast installation and application by machine;
- application in different fields: new or old buildings, civil or industrial constructions, different supports (e.g. brick, concrete, mixed masonry bricks/stones, etc.);
- versatility of use in both indoor and outdoor.

Finally, it would be important to provide a product suitable for achieving energy certification of buildings. The present analysis allowed also determining a price range, which constitutes the optimum for the product positioning on the market: a new thermal insulating plaster should have a cost around 45 and 60 €/sqm, with the same thermal performance with R_x values (Table 4).

Furthermore, this study wants to define a clear methodology to compare the thermal insulating plasters with different information (thermal conductivity, indicative amount required, packaging, . . .). This methodology allows to make in comparison data otherwise not comparable.

Indeed, there are many factors that influence the presence on the market of a product: more expensive thermal insulating plasters could also grow in the market, focusing on different features. Mainly in renovations, super insulating products may offer low thickness, with the same thermal insulation: this is a key element in choosing a thermal insulating plaster, because of the possibility to insulate building walls, maximizing the inner spaces [6].

Although considering the growing demand for SIP, even with higher price range, the aim of this benchmarking is to determine the best price range for a thermal insulating plaster in order to create a best practice not only from a technical point of view but also from the economic one, representing a market disruptive innovation [22].

The achievement of this ambitious goal is an open and present challenge and it is necessary to find the right balance between innovation, high-performance products and the tradition of the building history, such as mineral plaster.

In a sense, innovative solutions for thermal insulating plasters based on material with pore size in nanometer range, such as aerogel [22,3], are very interesting: the development and large-scale production of aerogel-based plasters can improve the spread of new plaster acting sensibly on final costs of the product and of the production system. Currently there is only one aerogel-based plaster in European market: Fixit 222, by EMPA, is a high performance insulating plaster that reached excellent values both in density of hardened mortar (220 kg/m³) and in thermal conductivity ($\lambda = 0.028 \text{ W/m K}$). [9] [23].

New researches are addressing the creation of new aerogel-based plasters, starting from aerogel's characteristics: the HIPIN Project (from European Union's Seventh Framework Programme) aims to test new formulations of aerogel in order to improve its mechanical strength, other features being equal. This would allow to test the realization of thermal insulating plasters, paints and panels based on new aerogel formulations, suitable for building application. Indeed aerogel have high insulation performance, with thermal conductivities in the range 0.01–0.04 W/m K, which compare very favorably to conventional construction materials such as concrete, with thermal conductivities in the range 0.2–1.0 W/m K [24]. The basic reason for this excellent performance is that materials with pore size in nanometer range have a high porosity (often greater than 90%). Until very recently, aerogel have been considered to be too expensive and mechanically fragile, to make their widespread use in the construction sector possible [25]. Many technical changes recently enabled aerogel having much higher mechanical integrity to be manufactured at lower cost [26,9]. The physical and mechanical features of these new materials ensure not only the technical performance of the system, but also the fully integration with the building, opening a new interesting way to face the problem of energy saving in buildings. Answering the stated technical and economical values, the choice of an innovative thermal insulating plaster like these can satisfy a wide public from the construction market, facilitating various design choices, improving the overall thermal performance of buildings. These new products should allow to enhance part of the cultural and historical heritage countries of Europe without changing the nature and structure of the buildings.

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