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

Contents lists available at ScienceDirect
Energy and Buildings

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

a b s t r a c t
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 appli-cation, creating new plasters able to meets 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 build-ing 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 di_erent 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 nat-ural products, examples being sheep–wool, coconut fibers and wood–wool. Higher technology solutions, such as vacuum insu-lated 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 prod-ucts, 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] . Improv-ing 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 accom-modate a large number of people becomes crucial. For retrofit, the application of thick insulation (required to achieve improved per-formance) 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 futurerequired levels of insulation, without the insulation system beingso thick that it meets with significant market resistance [7]. Addi-tionally, successful approaches will have the ability to be used onboth new build and retrofit, using techniques that are familiar totoday's construction industry.Usually, thermal insulating plasters are used on existing sup-port, as bricks, mixed wall (bricks and stones) or wall that hasalready been plastered. The workability of thermal plasters is verysimilar to the traditional ones, it can be used on non-aligned, out ofsquare, or, even, curved support. So that, thermal insulating plas-ter are flexible and can be suitable for any architectural and designsolutions.These plasters are usually pre-mixed and ready to use, they areformulated with light aggregates, like corck, clay, perlite, silica,pearls of expanded polystyrene, expanded glass, etc. [8]. They canbe applied to high thickness and have a high water vapour diffusioncoefficient, i.e. the material is very transpiring.This research aims to understand the current scenario of ther-mal insulating plaster in European market, in order to define therequirements that innovative thermal insulating plasters shouldmeet, in order to be suitable for European volume market.This research merges the performances of the material with thecost on the market, so that it is possible to define a target for anew thermal insulating plaster [9] in terms of technical aspectsand economical value. At the moment, nano-materials, and conse-quentially the final products made with them, are more expensivethan their non-nano materials alternatives. The price can decreasewith the increased volume.

2. Methods for analysis

This research concerned thermal insulating plasters availableon the European market: the use of the plasters is typical ofEuropean construction techniques, furthermore the Western Euro-pean Countries have mainly a moderated climate, which led to anincreasing use of thermal insulation plasters, above all in the colderpart of Europe, according to energy saving and environmental sus-tainable logic [10,11].
In order to better compare different typologies of plasters, allconsidered products were divided into three main families, accord-ing to the binders they are based on:
1. Thermal insulation plasters based on cementitious and/or artifi-cial binders (14 products).
2. Thermal insulation plasters based on cementitious andexpanded mineral aggregates (8 products).
3. Thermal insulation plasters based on natural hydraulic lime NHL(9 products).

The first family includes products based on virgin polystyrenebeads or silica and diatomic dust; the second one includes plastersbased on cementitious and expanded mineral aggregates like per-lite; and the last one products based on natural hydraulic lime. Inthat way the products of the same family are comparable for theirthermal performance.
The assessment of all considered products was based oncommon parameters, defined according to European technicalstandards. In particular we considered:
- EN 998-1:2010 Specification for mortar for masonry—Renderingand plastering mortar [12].
- EN 1015-10:2006 Methods of test for mortar for masonry—Part10: Determination of dry bulk density of hardened mortar [13].

- EN 1015-19:2006 Methods of test for mortar for masonry—Part19: Determination of water vapour permeability of hardened ren-dering and plastering mortar [14].
- EN 1745:2002 Masonry and masonry products—Methods fordetermining design thermal values [15].

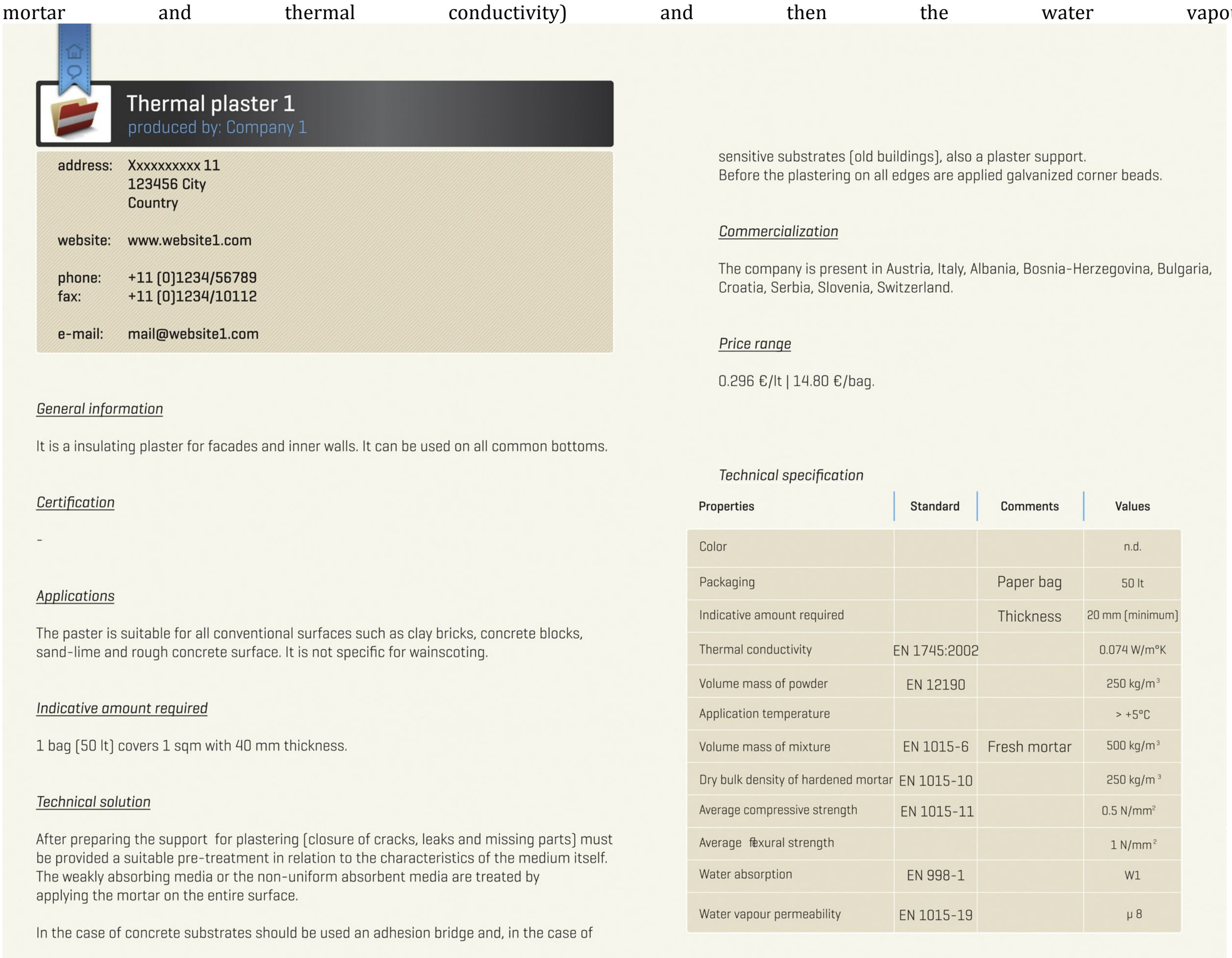
The study started from the procurement of technical, chem-ical and physical data, and application features of each thermalinsulation plaster; all characteristics were obtained through directcontact with manufacturers and a careful review of data sheets [16].The data collection is done with official technical data sheet givenby each producer and when the information was not public, the spe-cific request was asked with e-mails and phone calls. Especially, forthe price range of each thermal insulating plaster, each producerstates its 2012 price list (just 14 companies on 31 give us the costof their products).

- For each was drawn up a summary (Fig.1) that repost in detail:
- Producer/distributor's record (Country and contacts for further communications);
- General information (main information about the product and specific caracteristcs);
- 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, avarage compressive strength after 28 days, water absorpition, water vapour permeability).

For a fair and honest survey, we cannot public the name of themanufacturers and of the considered commercial products, becausethe goal of this research is not to detect the best or the worst prod-uct, but the right collocation on the market of innovative thermalinsulating plaster.Among the technical specifications we asked for, some valueshave been chosen as the most important to effectively compare theperformances of all different thermal insulation plasters (Table 1):we considered the volume mass powder, the dry bulk density ofhardened material, and the thermal conductivity. Consider that thethermal conductivity and bulk density values are interrelated (EN1745:2002, appendix A.12) [14].Finally, it is important to define not only the technical require-ments but also the economic ones; new products must meet thephysical, thermal and application requests, but to be suitable for themarket it is necessary to evaluate the price range. So the last part ofthis research concerned a benchmarking analysis to compare pricesof all analyzed products: we considered the price per unit and werelated it with the quantity of material needed to achieve a common$R_x$value.

3. Results

All plasters were compared to each other according to threemain parameters (volume mass of powder, dry bulk density of hard-ened mortar and thermal conductivity) and then the water vapour


Thermal plaster 1
produced by: Company 1

address: Xxxxxxxxxx 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 paster 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°K
Volume mass of powder	EN 12190		250 kg/m³
Application temperature			> +5°C
Volume mass of mixture	EN 1015-6	Fresh mortar	500 kg/m³
Dry bulk density of hardened mortar	EN 1015-10		250 kg/m³
Average compressive strength	EN 1015-11		0.5 N/mm²
Average flexural strength			1 N/mm²
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/m K	EN 1745	[15]
Water vapour permeability coefficient	μ	-	EN 1015-19	[14]

permeability was considered to calculate the real performance ofthe plaster.

3.1. Technical result

The basic values of thermal conductivity (_) of mortars, asrequired by EN 1745:2002 [14], may be determined in two differentways: table _ values or measured _ values.The determination of the table _ values is uniquely based on themass density. These values are valid for materials under the controlof production of the density and not directly to the measurementof _ values. Values are reported as fractals of 50% and 90% (P) of theexisting range of _ values of a given material for a given density.Instead, measured _ values are based on the relationship of _ massdensity and the initial type test of _, according to the measurementscheme described in ISO 8302 [19] or EN 12664 [20]. As we can see from Fig. 2, the performance of the thermal con-ductivity of the plaster mortars increases with the increase of thedensity of the hardened mortar, whose values change significantlyfrom a density of hardened mortar of 1500 kg/m3.The realization of the graph allows us to obtain, by the differenceof variables integrals (P = 90–50%), a known area in which we canplace all the plaster materials, that declare their values of density ofhardened mortar, following the scheme of European standard EN1745:2002 [15].Sometimes, however, the data offered by the plaster manufac-turers lack this value that is fundamental to a direct relationshipwith the normative data. Instead, the apparent density of the pow-der is provided, but it is not in direct relation with the tabularthermal conductivity data. In this way, it is difficult to obtain acorrect and clearly reportable comparison between all types ofmaterials on the market.

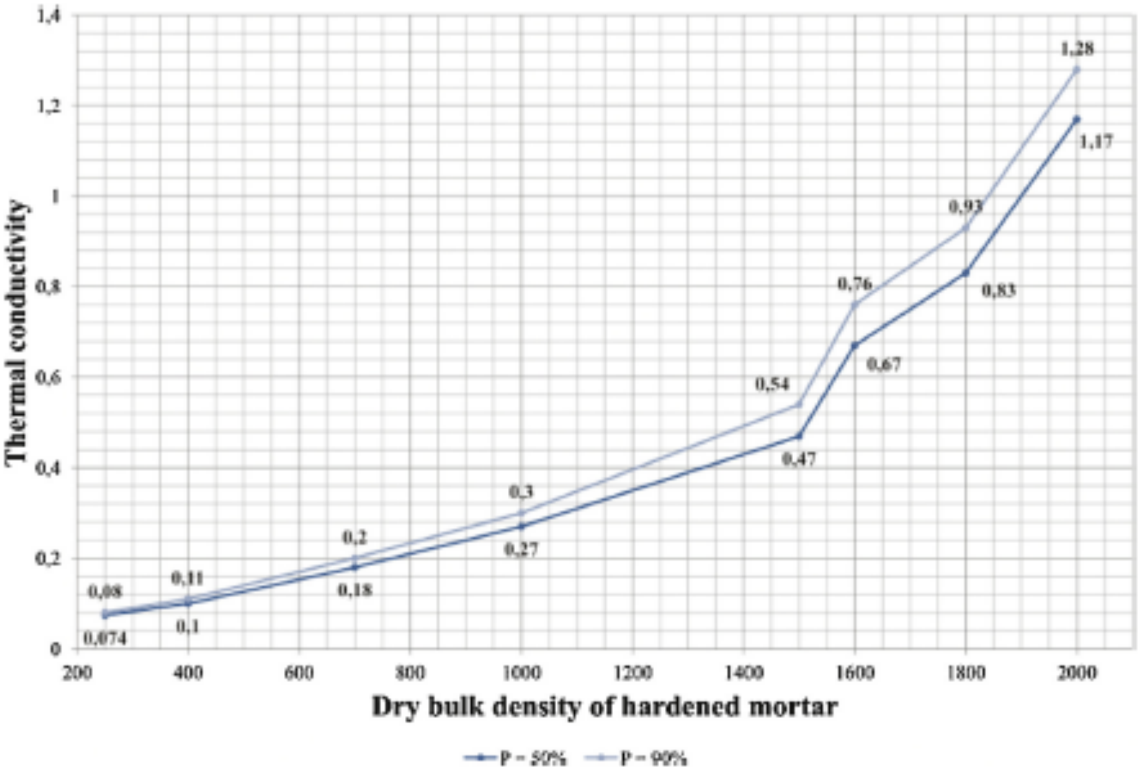


Fig. 2. Relationship between the thermal conductivity of the plaster $\lambda_{10,\,DRY}$ and the mass density of the material.

This market analysis provides a first useful observation from ourresearch: not all values reported in the technical material sheet ofplaster for thermal insulation of buildings are directly related to thereference standard.Another interesting aspect is the comparison between the val-ues of the standard and the thermal conductivity data reported byproducers. In the charts below are shown, in relation to the valuesof EN 1745:2002 [15], the declared data of the products we knowthe density of hardened mortar (Figs. 3–5).It is evident that all added data are below the thresholddetermined by the reference standard. Some of these valueswere measured in laboratory according to the scheme describedin ISO 8302 [19]or EN 12664 [20]. The values declared by producers are better than the trend line given by the Europeanstandard.The study could also follow the development of a real correlationbetween the thermal conductivity of materials and their hardenedmass in relation to the reference path. Considering this analysis, wecan say that to obtain an innovative high-performance insulationproduct, we should seek for a new formulation whose density ofhardened mortar has a value between 250 and 350 kg/m3.

3.2. Benchmarking results

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

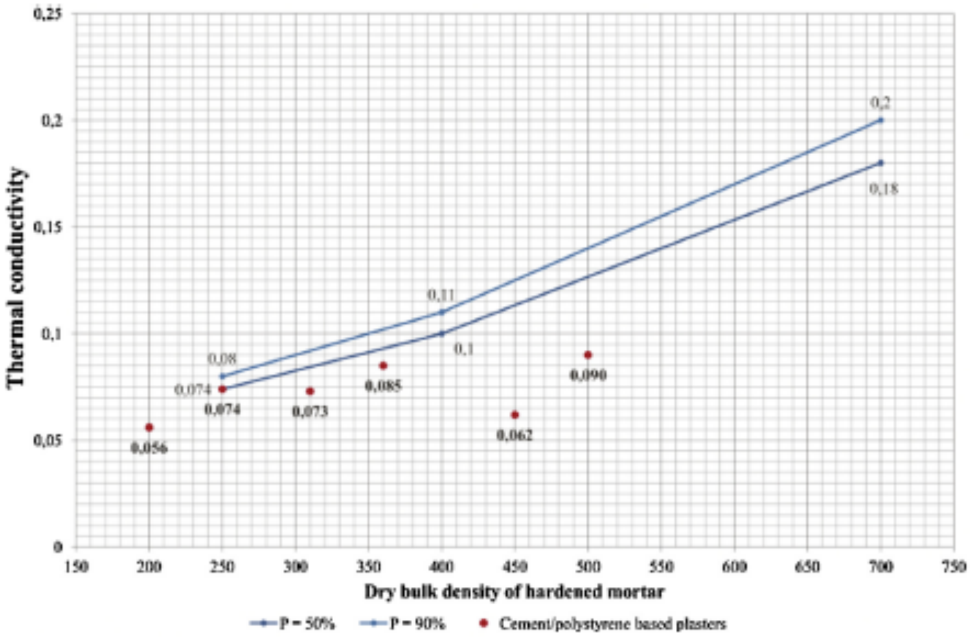


Fig. 3. Comparison between standard values and the one declared by producers in Family 1 (thermal plaster based on cementitious or artificial binders).

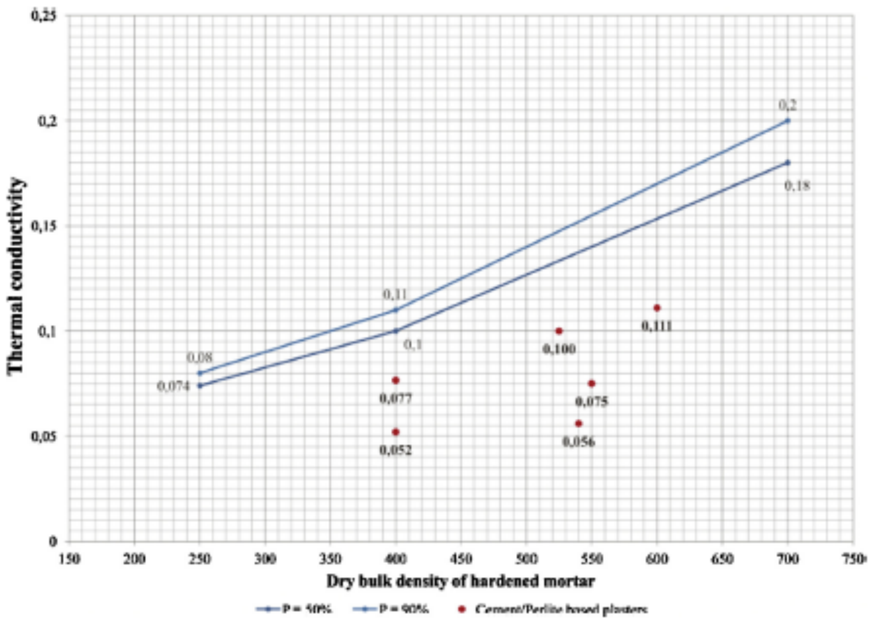


Fig. 4. Comparison between standard values and the one declared by producers in Family 2 (thermal plaster based on cementitious and expanded mineral aggregates).

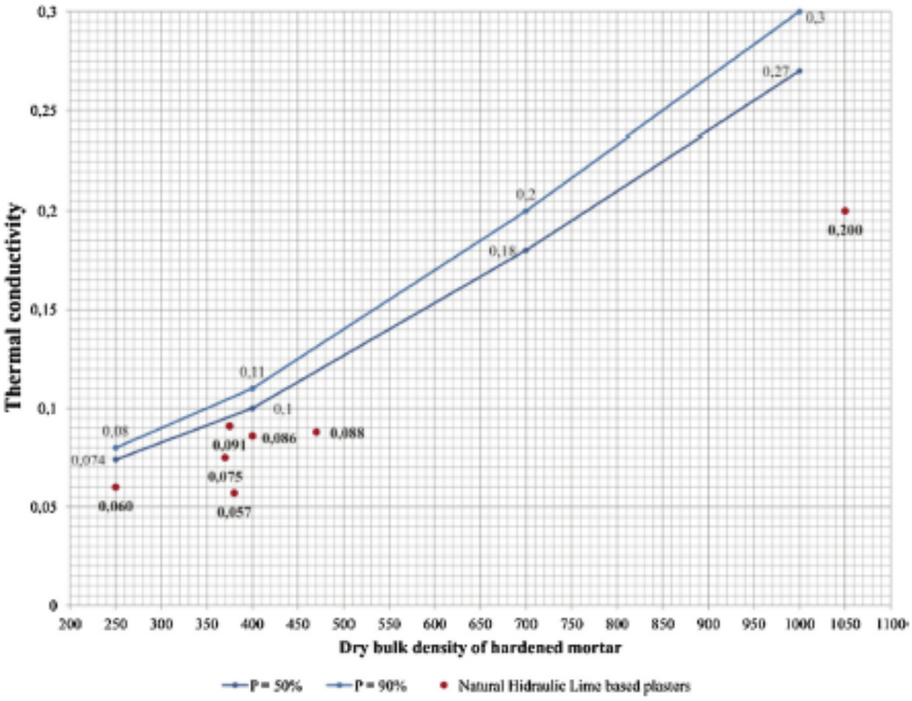


Fig. 5. Comparison between standard values and the one declared by producers in Family 3 (thermal plaster based on natural binders - natural hydraulic lime NH).

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 previouspart of analysis were merged in just one category) and naturalhydraulic lime-based plaster (Family 3). Then, the prices, all con-verted in Euros, are reported in table and related to the followingmain parameters:
- indicative amount of product required to make 10 mm of thick-ness (kg);
- thermal conductivity values;
- thickness to have a pre-determinated R value (R_x).

The relationship among these three parameters allows to havethe 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 poten-tial 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/smq; while the average cost of the natural hydraulic lime-based plaster is D 53.00/sqm.

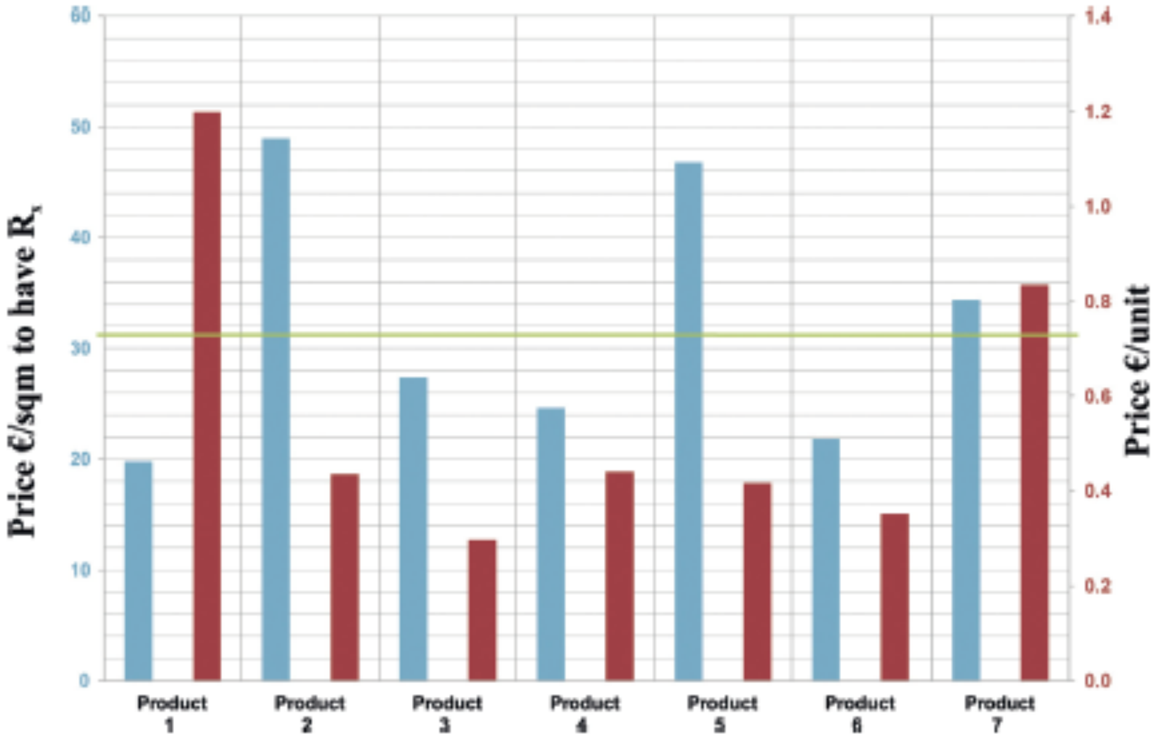


Fig. 6. Graph for cement-based insulating plaster. The average line is green.

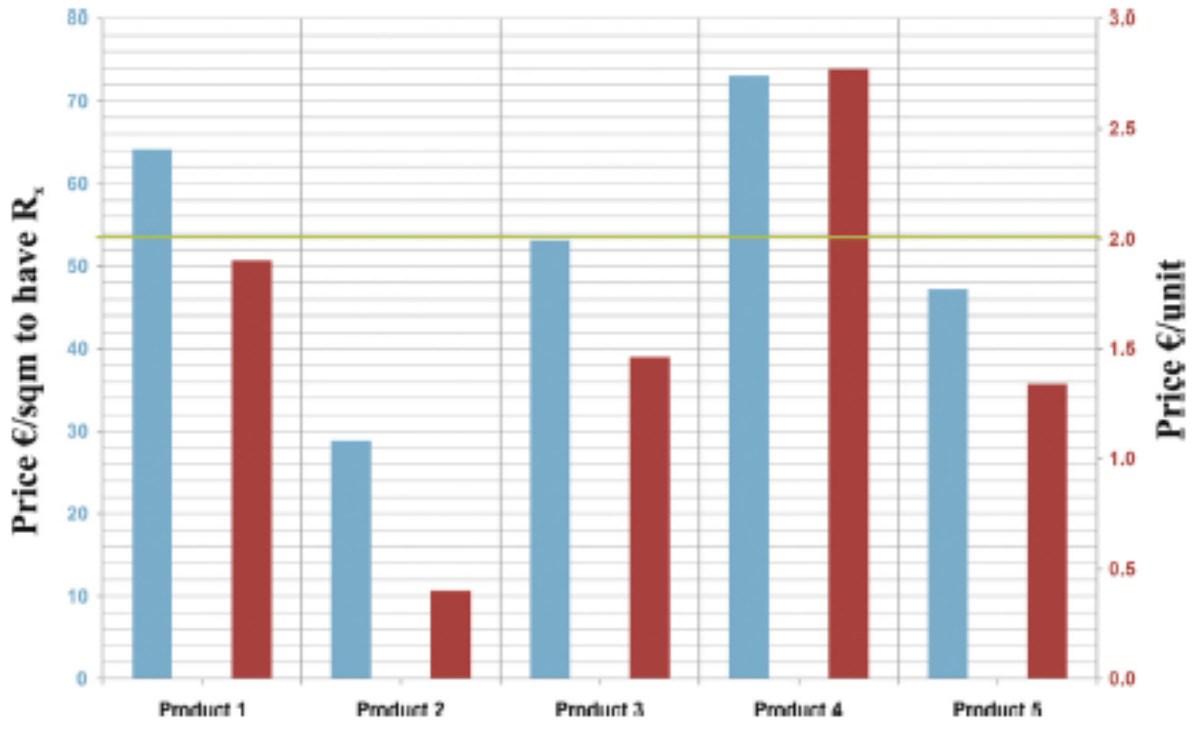


Fig. 7. Graph for natural hydraulic lime-based insulating plaster. The average line is green.

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 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 fromthe technical-functional point of view, and from the economic one(Table 4).

At a technical level, the main parameter to be achieved, in termsof innovation, concerns the desirable value of density of hardenedmortar less than 250 kg/m3; furthermore, it requires very low waterabsorption e high water vapour permeability (transpiration).Even the application features are essential to meet market andusers 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 indus-trial constructions, different supports (e.g. brick, concrete, mixedmasonry bricks/stones, etc.);
- versatility of use in both indoor and outdoor.

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

Furthermore, this study wants define a clear methodology tocompare the thermal insulating plasters with different information(thermal conductivity, indicative amount required, packaging, . . .).This methodology allows to make in comparison data otherwisenot comparable.

Indeed, there are many factors that influence the presenceon the market of a product: more expensive thermal insulating plasters could also grow in the market, focusing on differentfeatures. Mainly in renovations, super insulating products mayoffer low thickness, with the same thermal insulation: this is akey element in choosing a thermal insulating plaster, because ofthe possibility to insulate building walls, maximizing the innerspaces [6].

Although considering the growing demand for SIP, even withhigher price range, the aim of this benchmarking is to determinethe best price range for a thermal insulating plaster in order to cre-ate a best practice not only from a technical point of view but alsofrom the economic one, representing a market disruptive innova-tion [22].

The achievement of this ambitious goal is an open and presentchallenge and it is necessary to find the right balance between inno-vation, high-performance products and the tradition of the buildinghistory, such as mineral plaster.

In a sense, innovative solutions for thermal insulating plastersbased on material with pore size in nanometer range, such as aero-gel [22,3], are very interesting: the development and large-scaleproduction of aerogel-based plasters can improve the spread ofnew plaster acting sensibly on final costs of the product and ofthe production system. Currently there is only one aerogel-basedplaster in European market: Fixit 222, by EMPA, is an high per-formance insulating plaster that reached excellent values both indensity of hardened mortar (220 kg/m3) and in thermal conductiv-ity (_ = 0.028 W/m K). [9] [23].

New researches are addressing the creation of new aerogel-based plasters, starting from aerogel's characteristics: the HIPINProject (from European Union's Seventh Framework Programme)aims to test new formulations of aerogel in order to improve itsmechanical strength, other features being equal. This would allowto test the realization of thermal insulating plasters, paints andpanels based on new aerogel formulations, suitable for buildingapplication. Indeed aerogel have high insulation performance, withthermal conductivities in the range 0.01–0.04 W/m K, which com-pare very favorably to conventional construction materials such asconcrete, with thermal conductivities in the range 0.2–1.0 W/m K[24]. The basic reason for this excellent performance is that mate-rials with pore size in nanometer range have a high porosity (oftengreater than 90%). Until very recently, aerogel have been consid-ered to be too expensive and mechanically fragile, to make theirwidespread use in the construction sector possible [25]. Many technical changes recently enabled aerogel having much highermechanical integrity to be manufactured at lower cost [26,9].The physical and mechanical features of these new materialsensure not only the technical performance of the system, but alsothe fully integration with the building, opening a new interestingway to face the problem of energy saving in buildings.Answering the stated technical and economical values, thechoice of a innovative thermal insulating plaster like these cansatisfy a wide public from the construction market, facilitating var-ious design choices, improving the overall thermal performanceof buildings. These new products should allow to enhance part ofthe cultural and historical heritage countries of Europe withoutchanging the nature and structure of the buildings.

Reference

[1] F. Leopolder, The Global Drymix Mortar Industry, first ed., ZKG International, Munich, 2010.

[2] A.M. Papadopoulos, State of the art in thermal insulation materials and aims for future developments, Energy and Buildings 37 (2005) 77–86.

[3] R. Baetens, B.P. Jelle, A. Gustavsen, Aerogel insulation for building applications: a state-of-the-art review, Energy and Buildings 43 (2010) 761–769.

[4] F. Broekhuizen, P. Broekhuizen, Nano-products in the European construction industry—state of the art 2009. Produced in collaboration with FIEC, EFBWW and IVAM with EC support, Amsterdam, 2009.

[5] Ecorys, FWC Sector Competitiveness. Studies N(B1/ENTR/06/054–Sustainable Competitiveness of the Construction Sector, Final Reporto, London, 2008.

[6] R. Griffiths, S. Goodhew, Sustainability of solid brick wall with retrofitted external hemp-lime insulation, Structural Service 30 (2012) 312–332, http://dx.doi.org/10.1108/02630801211256661.

[7] K. Çomakli, B. Yüksel, Optimum insulation thickness of external walls for energy saving, Applied Thermal Engineering 23 (2003) 473–479.

[8] L.M. Silva, R.A. Ribeiro, J.A. Labrincha, V.M. Ferreira, Role of lightweight fillers on the properties of a mixed-binder mortar, Cement & Concrete Composites 32 (2010) 19–24, http://dx.doi.org/10.1016/j.cemconcomp.2009.07.003.

[9] T. Stahl, S. Brunner, M. Zimmermann, K. Ghazi Wakili, Thermo-hygric properties of a newly developed aerogel based insulation rendering for both exterior and interior applications, Energy and Buildings 44 (2012) 114–117, http://dx.doi.org/10.1016/j.enbuild.2011.09.041.

[10] L. Chesné, T. Duforestel, J. Roux, G. Rusaouën, Energy saving and environmental resources potentials: toward new methods of building design, Building and Environment 58 (2012) 199–207, http://dx.doi.org/10.1016/j.buildenv.2012.07.013.

[11] O.A. Kaynakli, Study on residential heating energy requirement and optimum insulation thickness, Renewable Energy 33 (2008) 1164–1172.

[12] The European Standard EN 998-1:2010, Specification for Mortar for Masonry–Rendering and Plastering Mortar, European Committee for Standardization, Bruxelles, 2011.

[13] The European Standard EN 1015-10:1999/A1:2006, Methods of Test for Mortar for Masonry–Part 10: Determination of dry bulk density of hardened mortar, European Committee for Standardization, Bruxelles, 2007.

[14] The European Standard EN 1015-19:1998/A1:2004, Methods of Test for Mortar for Masonry–Part 19: Determination of Water Vapour Permeability of Hardened Rendering and Plastering Mortar, European Committee for Standardization, Bruxelles, 2006.

[15] The European Standard EN 1745:2002, Methods for Determining Design Thermal Values, European Committee for Standardization, Bruxelles, 2002.

[16] T. Maile, V. Bazjanac, V. Fischer, A method to compare simulated and measured data to assess building energy performance, Building and Environment 56 (2012) 241–251, http://dx.doi.org/10.1016/j.buildenv.2012.03.012.

[17] The European Standard EN 196-1:2005, Method of Testing Cement–Part 1: Determination of Strength, European Committee for Standardization, Bruxelles, 2005.

[18] The European Standard EN 1015-2:1998/A1:2006, Methods of Test for Mortar for Masonry–Part 2: Bulk Sampling of Mortar and Preparation of Test Mortars, European Committee for Standardization, Bruxelles, 2007.

[19] ISO 8302:1991/2008, Thermal Insulation – Determination of Steady-state Thermal Resistance and Related Properties – Guarded Hot Plate Apparatus, International Organization for Standardization, Geneva, 2008.

[20] The European Standard EN 12664:2001, Thermal Performance of Building Materials and Products, Determination of Thermal Resistance by Means of Guarded Hot Plate and Heat Flow Meter Methods, Dry and Moist Products of Medium and Low Thermal Resistance, European Committee for Standardization, Bruxelles, 2003.

[21] M. Ozel, The influence of exterior surface solar absorptivity on thermal characteristics and optimum insulation thickness, Renewable Energy 39 (2012) 347–355, http://dx.doi.org/10.1016/j.renene.2011.08.039.
[22] M. Koebel, A. Rigacci, P. Achard, Aerogel-based thermal super insulation: an overview, Journal of Sol–gel Science and Technology 3 (3) (2012) 315–339, http://dx.doi.org/10.1007/s10971-012-2792-9.
[23] Fixit, Fixit 222 Aerogel Hochleistungsdämmputz. Retrieved March 18, 2014, from http://www.fixit.ch/Home/Produkte/Restaurierungs-und-Sanierungsprodukte/Aerogel-Hochleistungsdaemmputz/Fixit-222-Aerogel-Hochleistungsdaemmputz/(language)/ger-DE
[24] A. Berge, P. Johansson, Literature Review of High Performance Thermal Insulation, Chalmers Reproservice Publ., Gothenburg, 2012.
[25] R. Klose, A Good Insulation Plays Off, Empa News, Gothenburg, 2012, pp. 18–19, ISSN 1662-7768.
[26] A.G. Mainini, Le soluzioni di frontiera per l'isolamento termico, Ingegneri (1–2) (2009) 6.
[27] HIPIN, High Performance Insulation based on Nanostructure Encapsulation of Air, Retrieved March 18, 2014, from http://www.hipin.eu