EcoShopping - Energy efficient & Cost competitive retrofitting solutions for Shopping buildings

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Deliverable 3.1

Specification of selected types of insulation solutions based on the created database of the different conventional and most innovative insulation technologies and self-cleaning materials

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Lead contractor............................. CNR

Authors:

Adriana Bernardi........................... CNR-ISAC

Francesca Becherini .... CNR-ISAC

Arianna Vivarelli............................ CNR-ISAC

Paolo Bison .... CNR-ITC

Alessandro Bortolin....................... CNR-ITC

Gianluca Cadelano .... CNR-ITC

Giovanni Ferrarini .... CNR-ITC

Monica Favaro .... CNR-IENI

Alessandro Galenda .... CNR-IENI

Maria Garrido................................ ANCODARQ

Emil Lezak .... IZNAB

Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Deliverable administration

No & name	**D3.1 Specification of selected types of insulation solutions based on the created database of the different conventional and most innovative insulation technologies and self-cleaning materials**					
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Author(s)	Adriana Bernardi, Francesca Becherini, Arianna Vivarelli (CNR-ISAC); Paolo Bison, Alessandro Bortolin, Gianluca Cadelano, Giovanni Ferrarini (CNR-ITC); Monica Favaro, Alessandro Galenda (CNR-IENI); Maria Garrido (ANCODARQ)Emil Lezak (IZNAB)					
Description of the related task and the deliverable in the DoW	In Task 3.1 a database collecting the information on the conventional and innovativeinsulation products for walls, windows and roofs used in buildingconstruction has been created. The mostpromising oneshavebeenselected and the assessment of theoptimization in the applicability of insulation solutionshasbeenperformed. In addition, a research on efficient self-cleaning coatings to coverthe insulating panels has beencarried out, in order to add self-cleaning properties to the insulation solutions, improving at the same time IAQ. Finally, the main standards and codes associated to theinsulation, comfort and healthy targetshave been identified.					
Planned resources PM	CNR	IZNAB	ANC	RED	NTUST	Total
	6	2	5	0	0	13
Comments	RED and NTUST are participants of Task 3.1 in relation to the activities concerning the lighting. Results are reported in D3.2					

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1. Publishable executive summary

This Deliverable describes the results of the wide review activity carried out within WP3 “Envelope and Day lighting technologies” – Task 3.1 “Specification of insulation and day lighting requirements”. The present document is focused on insulating and self-cleaning materials, whereas lighting technologies are described in D3.2.

Several subtasks have beencreated to organize the different activities of Task 3.1 and theycan be grouped into four main areas described hereunder. D3.1 has been structured in compliance with Task 3.1:

- **Insulating products**, including a state of the artof materials for walls/roofs and windows (chapter 3 and 4); the selection of the most promising ones that will be characterized in laboratory and in field (chapter 5);the assessment of the optimization in their applicability (chapter 6);
- **Self-cleaning materials**, containing a short description of the background and the basic outlines of the research foreseen in Task 3.2 (chapter 7);
- An overview of the main **standards and codes**thatactually rule insulation, comfort, health and energy saving targets at national and European level(chapter 8);
- Description of the **databases**created for the organization of the collected information, their management and fruition (chapter 3.2, 4.2, 7.2 and 8.2).

The most importantoutcomes brought by this literary research are:

- Identification of the most suitable insulating solutions for energy retrofitting of buildings, in terms of high insulation performance, thin thickness to save inner space, cost of the materials;
- Identification of dopedtitania photocatalyst for indoor application to be improved by the modification of the band gap in order to extend the photocatalytic activity under visible radiation and to reduce the dependence on the presence of UV light;
- Creation of public databases, accessible by the consortium of the EcoShopping project both for consultation and implementation, and by anyoneoutside the project who is interested in finding information and being updatedon the currentinsulating solutions available in the market, including the most innovative ones.

2. Introduction

2.1 Purpose and target group

The purpose of this document is to summarize all the information collected, to explain how they have been categorized for an easy consultation, and which criteria have been followed to selectthe insulating and self-cleaning products to be respectively characterized and developed in laboratory in Task 3.2.

The work started with a review of the commercial insulating materialsfor walls, roofs and windows, including the innovative ones.The most promising ones have been selected mainly on the basis of the optimal costs/performance ratio, taking into account also the pros and cons of each product. A review on the past and on-going European projects has also been performed to identify the main research trends concerning insulating products.
The possibility to cover the insulating panels with self-cleaning coatings will be investigated to achieve both depolluting and self-cleaning effects in indoor environments. At this stage, a research on efficient self-cleaning products commercially available has been carried out in order to select the most proper ones to be used either as benchmark and as basis for the development of the new doped titanium photocatalyst.
Besides, the different standards and codes associated to insulation, comfort, health and energy saving targets have been identified.
Finally, four different structured databases for the collection and organization of the huge amount of information have been created and published on the project website.

The target groups of this deliverable are the consortium of the EcoShopping project and anyoneoutside the project who isinterested in finding information and being updated on the current insulating solutions available in the market, including the innovative ones.The present documenthas been created on the basis of the databases that are the most effective and specific dissemination tool to reach the target groups. The databases can be further implemented by EcoShopping partners throughout the progress of the project or they can consulted by the stakeholders, e.g. professionals involved in retrofitting/refurbishment of buildings, dealing with the building energy management and indoor air quality, working both in private companies and public administrations/entities.

2.2 Contributions of partners

The partners involved in Task 3.1 contributed to the delivery of the mentioned results as follows:

- CNR led the activities related to the creation of the different databases, the state of the art oninsulating materials, the selection of the most promising ones and the identification of standards and codes. In particular, IENI focused on the research concerning self-cleaning;
- ANCODARQperformed the assessment of the optimization in the applicability of insulating solutions;
- IZNAB gave its feedback about the structure and management of the databases and contributed to the filling of the tables of self-cleaning products as well as of standards.

Some inputs came from other project partners, not directly involved in Task 3.1, but asked for contributing to identify the different technologies actually in use in their own countries or abroad. In particular, contributions were received on:

- insulating solutions for windows by YaşarUniversity;
- self-cleaning products by BRE.

2.3 Baseline

The state of art of the different materials/technologies has been built by means of an extended literary research and web investigation, taking also into account the manufacturer websites and technical/safety data sheets of the products. Information from conference proceedings, webinar and European project disseminating materials have been also considered. The list of past or ongoing European projects that deals with the development and/or enhancement of insulating products/solutions/strategies for walls and/or windows is given in chapters 3.2 and 4.2 respectively. The section concerning the assessment of the optimization in the applicability of insulating solutions (chapter 6) has been completed on the basis of the expertise and experience of partner ANCODARQ, a construction company.

2.4 Relations to other activities

The analysis of building codes of the different European countries, performed in Task 2.1 “Buildings code, EPBD and standardization” (see Deliverable 2.1 “Assessment of national building codes, EPBD implementation and standards identified”), has been used as starting point for the identification of standards and codes related to the topics of energy efficiency and improvements of the building envelope.

The methodology for retrofitting windows and envelope, drawn up in Task 2.2 “Building characterization and Retrofitting Methodology Design” (see Deliverable 2.3 “Identification of European existing peri-urban commercial building stock and retrofitting methodology”), has been deepened through a detailed research on the specific materials and products currently used, among which the ones to be characterized in laboratory have been selected.

During the composition of the SToA, thepreliminary information collected on the main characteristics of insulating products, their strong and weak points and their potential energy savings have been included in Task 2.8 “Industrial viability of technologies and replication potential analysis” for the evaluation of their industrial viability (see Deliverable 2.9 “Viability and feasibility report of retrofitting technologies”).

The selected insulating materials and self-cleaning products will be characterized in laboratory in Task 3.2 “Effective insulation and self-cleaning solutions for walls and/or windows” in order to find the best solutions to be used for the installation in the case study.

3. Insulating materials for walls/roofs

3.1 Commercial materials

The most common materials for thermal insulation are:

- Mineral wool, a non-metallic inorganic product manufactured from glass (fiber glass) or rock (rock wool), which combines high thermal resistance with long-term stability, good fire resistance and acoustic properties;
- Expanded polystyrene (EPS) or extruded polystyrene (XPS), a polymer made from the monomer styrene, a liquid petrochemical. Polystyrene can be rigid or foamed;
- Polyurethane (PUR), where during an expansion process the air is exchanged with a lower thermal conductor gas, trapped in the closed pore system. It rises serious health concerns and hazards in case of fire, due to the release of hydrogen cyanide, which is very poisonous.

Their thermal conductivity is typically around 30-40 $mWm^{-1}K^{-1}$, decreasing to 20-30 $mW\ m^{-1}\ K^{-1}$only in PUR. These values vary with temperature, moisture content and mass density.

The more innovative thermal building insulation materials are called "super-insulator".Aerogel is a low-density solid-state material (0.2% of SiO_2-chains) in which the liquid component of the gel has been replaced with gas (99.8% of air filled pores on a micro and nano size scales). Its thermal conductivity is 13-14 $mWm^{-1}K^{-1}$, but it can be decreased to 4 $mW\ m^{-1}\ K^{-1}$ using carbon black to suppress the radiative transfer.

Vacuum insulated panels (VIP) consist of solid material with a high porosity level and a very small pore dimension on which a technical vacuum is produced and maintained by enveloping the solid core with a plastic and/or metallic sheets. The fine porosity of the matrix is very effective in decreasing the thermal conductivity and blocking the convective transfer, while making the core material of VIPs opaque (e.g. with a dispersion of carbon powder) reduces the radiative heat transfer. The application of VIP has important drawbacks: they cannot be cut for adjustment at the building site or perforated without losing a large part of their thermal insulation performance; moreover, the initial thermal conductivity increases from 3-4 $mW\ m^{-1}\ K^{-1}$ to typically 8 $mWm^{-1}\ K^{-1}$ after 25 years ageing, due to water vapor and air diffusion through the envelope and into the open pore structure of the core material.

Close to VIPs, in principle, is the technology of gas-filled panel (GFP), which replaces air with a gas having a lower thermal conductivity, usually noble gases such as argon, krypton or xenon. GFP is made of two types of polymer films. Metalized films are used in a tied assembly called baffle, arranged in a three-dimensional form of multiple layers of cavities that produce a cellular structure which suppress convection and radiation.Low diffusion gas barrier foils are very thin layers of aluminum or polymer barrier resins that are used in a hermetic barrier, keeping the panels gas-tight. Thermal conductivities for prototype GFPs are quite high, e.g. 40 $mW\ m^{-1}\ K^{-1}$, although much lower theoretical values have been calculated.

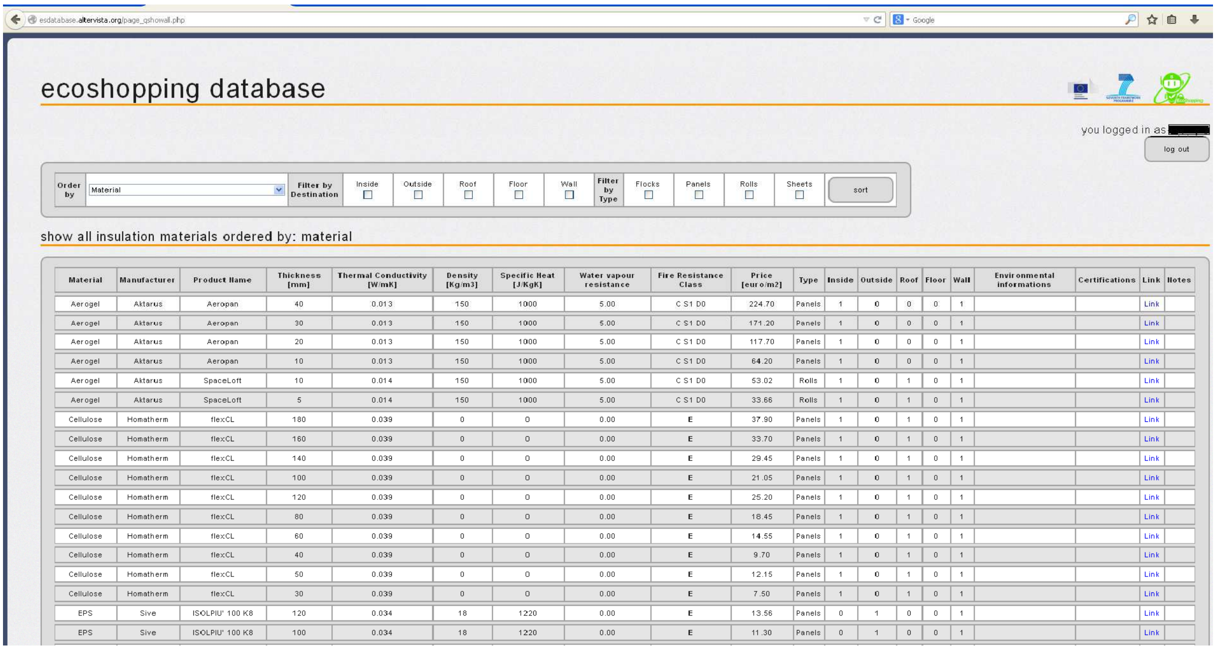
3.2 Specific Database

The aim is to create a database of the insulation materials currently available in the market, based on the data declared by the manufacturers or on literary data, in order to evaluate the best solutions from an energetic and economic standpoint. The main categories of insulation properties required to make a valid comparison are shown in Table 1, with an example record.

*Table 1.*Properties of a record of the walls/roof insulation database.

Categories	Fields	Example value	Field description
Product identification	Material	Wood fiber	Main component
	Manufacturer	Fiber Inc.	Name of the manufacturer
	Product name	Ultra Fiber Plus	Commercial name of the product
	Type	Panels	Format of the material: Flocks, Rolls, Panels or Sheets
	Inside	1	The value is 1 when the product could be applied for internal insulation, 0 if not
	Outside	1	The value is 1 when the product could be applied for external insulation, 0 if not
	Roof	1	The value is 1 when the product could be applied for roof or ceiling insulation, 0 if not
	Floor	1	The value is 1 when the product could be applied for floor insulation, 0 if not
	Wall	1	The value is 1 when the product could be applied for wall, facades or vertical surfaces insulation, 0 if not
	Link	www.insulation.com	Link to the product website or to the technical documentation
	Thickness [mm]	20	Measured in [mm]
Thermophysical properties	Thermal Conductivity [$W\ m^{-1}\ K^{-1}$]	0.035	Measured in [$W\ m^{-1}\ K^{-1}$]
	Density [$Kg\ m^{-3}$]	100	Measured in [$Kg\ m^{-3}$]
	Specific Heat [$J\ Kg^{-1}K^{-1}$]	1000	Measured in [$J\ Kg^{-1}\ K^{-1}$]
	Water vapour resistance	50	Dimensionless
	Fire Resistance Class	A	Class according to EN 13501-1:2009
Economic properties	Price [$Euro\ m^{-2}$]	10.05	Measured in [$Euro\ m^{-2}$]
Other properties	Environmental information		LCA value or Embodied Energy
	Certifications		Product certifications, if available
	Notes		Additional information on the product

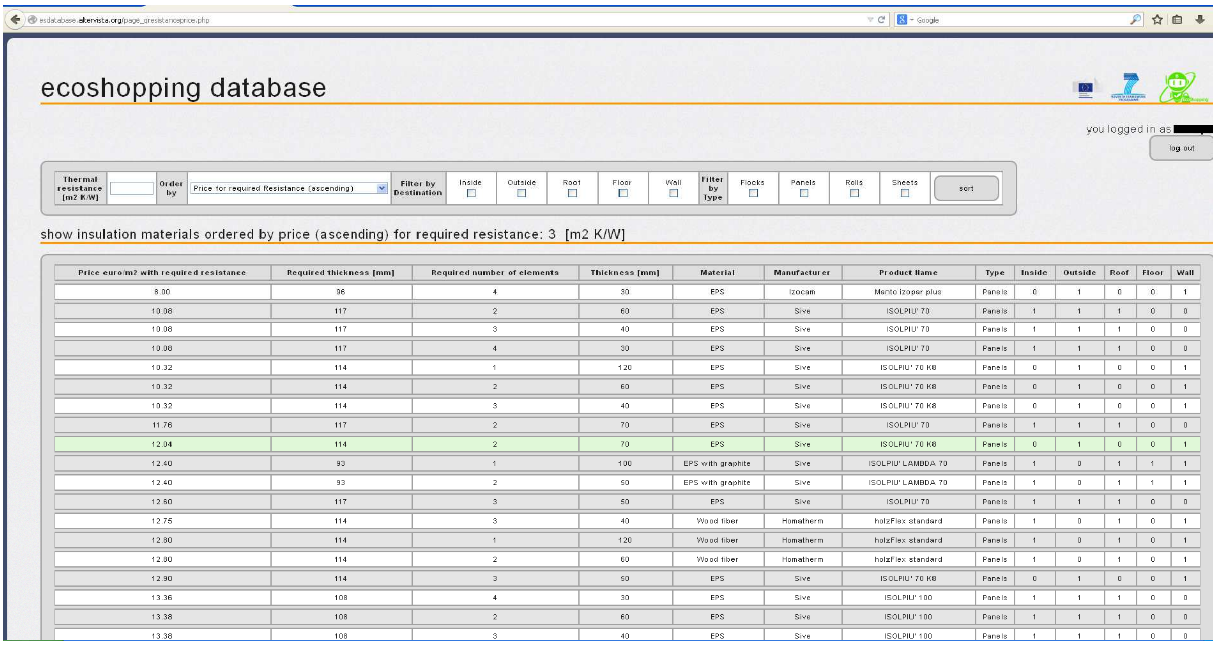
The data on insulation materials can be collected through a dedicated website, that is running athttp://esdatabase.altervista.org/.On this website every user can create an account, with different privileges, that allows him to complete a form with the required parameters for a material and create a new record in the database. A new record is hidden until an administrator verifies it and makes it public.It is possible to create custom queries to the database, for example to show all records, as in the page: http://esdatabase.altervista.org/page_qshowall.php(Figure1).



Material	Manufacturer	Product Name	Thickness [mm]	Thermal Conductivity [W/mK]	Density [Kg/m3]	Specific Heat [J/KgK]	Water vapour resistance	Fire Resistance Class	Price [euro/m2]	Type	Inside	Outside	Roof	Floor	Wall	Environmental informations	Certifications	Link	Notes
Aerogel	Aktarus	Aeropan	40	0.013	150	1000	5.00	C S1 D0	224.70	Panels	1	0	0	0	1			Link	
Aerogel	Aktarus	Aeropan	30	0.013	150	1000	5.00	C S1 D0	171.20	Panels	1	0	0	0	1			Link	
Aerogel	Aktarus	Aeropan	20	0.013	150	1000	5.00	C S1 D0	117.70	Panels	1	0	0	0	1			Link	
Aerogel	Aktarus	Aeropan	10	0.013	150	1000	5.00	C S1 D0	64.20	Panels	1	0	0	0	1			Link	
Aerogel	Aktarus	SpaceLoft	10	0.014	150	1000	5.00	C S1 D0	53.02	Rolls	1	0	1	0	1			Link	
Aerogel	Aktarus	SpaceLoft	5	0.014	150	1000	5.00	C S1 D0	33.66	Rolls	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	180	0.039	0	0	0.00	E	37.90	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	160	0.039	0	0	0.00	E	33.70	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	140	0.039	0	0	0.00	E	29.45	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	100	0.039	0	0	0.00	E	21.05	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	120	0.039	0	0	0.00	E	25.20	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	80	0.039	0	0	0.00	E	18.45	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	60	0.039	0	0	0.00	E	14.55	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	40	0.039	0	0	0.00	E	9.70	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	50	0.039	0	0	0.00	E	12.15	Panels	1	0	1	0	1			Link	
Cellulose	Homatherm	flexCL	30	0.039	0	0	0.00	E	7.50	Panels	1	0	1	0	1			Link	
EPS	Sive	ISOLPIU' 100 K8	120	0.034	18	1220	0.00	E	13.56	Panels	0	1	0	0	1			Link	
EPS	Sive	ISOLPIU' 100 K8	100	0.034	18	1220	0.00	E	11.30	Panels	0	1	0	0	1			Link	

Figure 1. Screenshot of the database of insulating materials for walls/roofs.

A more advanced query consists in finding the least expensive material after choosing a thermal resistance value of the insulation layer. In this case the software calculates the minimum thickness required for every record in the database and then orders the products from the least to the most expensive as shown in Figure 2 and at the following link: http://esdatabase.altervista.org/page_qresistanceprice.php.



Price euro/m2 with required resistance	Required thickness [mm]	Required number of elements	Thickness [mm]	Material	Manufacturer	Product Name	Type	Inside	Outside	Roof	Floor	Wall
8.00	96	4	30	EPS	Izocam	Manto izopar plus	Panels	0	1	0	0	1
10.08	117	2	60	EPS	Sive	ISOLPIU' 70	Panels	1	1	1	0	0
10.08	117	3	40	EPS	Sive	ISOLPIU' 70	Panels	1	1	1	0	0
10.08	117	4	30	EPS	Sive	ISOLPIU' 70	Panels	1	1	1	0	0
10.32	114	1	120	EPS	Sive	ISOLPIU' 70 K8	Panels	0	1	0	0	1
10.32	114	2	60	EPS	Sive	ISOLPIU' 70 K8	Panels	0	1	0	0	1
10.32	114	3	40	EPS	Sive	ISOLPIU' 70 K8	Panels	0	1	0	0	1
11.76	117	2	70	EPS	Sive	ISOLPIU' 70	Panels	1	1	1	0	0
12.04	114	2	70	EPS	Sive	ISOLPIU' 70 K8	Panels	0	1	0	0	1
12.40	93	1	100	EPS with graphite	Sive	ISOLPIU' LAMBDA 70	Panels	1	0	1	1	1
12.40	93	2	50	EPS with graphite	Sive	ISOLPIU' LAMBDA 70	Panels	1	0	1	1	1
12.60	117	3	50	EPS	Sive	ISOLPIU' 70	Panels	1	1	1	0	0
12.75	114	3	40	Wood fiber	Homatherm	holzFlex standard	Panels	1	0	1	0	1
12.80	114	1	120	Wood fiber	Homatherm	holzFlex standard	Panels	1	0	1	0	1
12.80	114	2	60	Wood fiber	Homatherm	holzFlex standard	Panels	1	0	1	0	1
12.90	114	3	50	EPS	Sive	ISOLPIU' 70 K8	Panels	0	1	0	0	1
13.36	108	4	30	EPS	Sive	ISOLPIU' 100	Panels	1	1	1	0	0
13.38	108	2	60	EPS	Sive	ISOLPIU' 100	Panels	1	1	1	0	0
13.38	108	3	40	EPS	Sive	ISOLPIU' 100	Panels	1	1	1	0	0

Figure 2. Screenshot of the database with the required thermal resistance query.

3.3 Further research on innovative materials

The innovative products described in chapter 3.1, e.g aerogel, VIPs and GFPs, are a broad research object of recent projects aimed at overcoming their drawbacks and limitations. Main objectives of the latter developments in the field of insulating materials are to: reduce their fragility, increase service life, enhance thermal and mechanical properties, cut the production costs, compliance with the criteria of eco-sustainability, etc.

More and more opportunities are guaranted by the use of nanomaterials and nanotechnology, biocomposites, wasted/recycled materials, etc.

Past and ongoing European projects dealing with the development of new solutions for the insulation of walls/roofs are summarized in Table 2. Common target is to evolve progressively towards eco-friendly products with low/zero volatile organic compounds (VOCs) emissions and more efficient and energy-saving heat insulation systems.

*Table 2.*European projects that contribute to the advancements in the state of the art of insulating products for walls/roofs

Year	Acronym	Title	Research Outlines
2010-2014	NanoInsulate	Development of nanotechnology-based high-performance opaque &transparent insulation systems for energy-efficient buildings	Durable, robust, cost-effective opaque and transparent vacuum insulation panels (VIPs) that incorporate new nanotechnology-based core materials, such as nanofoams and aerogel composites and high-barrier films to reduce their fragility and increase their service life.
2010-2013	NANOPCM	New advanced insulation phase change materials	Nanotechnology-based phase change materials (PCMs) integrated into smart insulation materials with enhanced thermal and mechanical properties. The main technical innovation are: • New low-cost form stable thermal storage component based on the anchorage at nanoscale of organic PCMs between the polymeric chains of selected polymer with improved conductivity incorporating nanoparticles; • New thermal insulation inorganic nanofoam with thermal storage capacity through impregnation with organic or organic PCMs; • Thermal behaviour improvement of the materials developed and PCM microcapsules with the incorporation of high thermal conductive nanomaterials.
2012-2014	NANOFOAM	New nanotechnology based high performance insulation foam system for energy efficiency in buildings	Innovative high performing nanostructured polymeric foam, employing a low Global Warming Potential (GWP) blowing agent such as CO_2. Main advancements compared to standard product are: lower thermal conductivity and superior properties (mechanical, fire resistance, moisture/fungi resistance), no toxic, recyclable, no production of ozone depletion potential (ODP) and indoor volatile organic compounds (VOCs),

			competitive price.
2011-2015	AEROCOINS	Aerogel based composite/hybrid nano-materials for cost-effective building super insulation systems	New super-insulating aerogel composite hybrid material to overcome the mechanical weakness of silica aerogels and its high cost through: i) the synthesis of reinforced aerogel-based thermally superinsulating material by coupling with cellulosic polymers and/or incorporation of cellulose-based nanomaterials; ii) the reduction of the production cost via ambient pressure drying and 'continuous' production technology.
2010-2013	COOL-Coverings	Development of a novel and cost-effective range of nanotech improved coating to substantially improve NIR (Near Infrared Reflective) properties of the building envelope	Innovative highly-reflective nano-based materials for the building envelope that significantly reduce heat transfer to indoor spaces improving the Near Infrared Reflecting (NIR) reflection capabilities while keeping traditional colors. Additional properties are algae resistance, waterproofness and mechanical resistance. The set of outdoor covering materials consists of: • External walls – NIR reflecting paints enabled by new nanocrystalline metal oxides; • Façades – ceramics using a new nano technological-based NIR reflecting inorganic coating; • Roof – an already existing 3D textile membrane incorporating a nanotechnology-based NIR.
2011-2014	HIPIN	High Performance Insulation Based on Nanostructured Encapsulation of Air	Sustainable, cost-effective route to nanostructured multi-functional (self-cleaning, sound insulation, fire retardant) aerogel-based coating that can be applied as thick paint layers, thicker coatings such as plaster, or as ventilated facade panel membranes, both indoors and outdoors.
2012-2016	EASEE	Envelope approach to improve sustainability and energy efficiency in existing multi-story multi-owner residential buildings	Toolkit for energy efficient envelope retrofitting of existing multi-story and multi-owner buildings. Main expected outcomes are: • Innovative pre-fabricated panels with built-in insulation, reproducing the original aesthetics of the façade; • A new range of insulating inorganic materials for the cavity wall based on natural and synthetic perlite; • Innovative insulating solutions for the internal walls based on a combination of technical textiles, coatings and high performance plasters.
2012-2015	LEEMA	Low Embodied Energy Advanced (Novel) Insulation Materials and Insulating Masonry	Range of new insulation products suitable for both new and retrofitted buildings to include loose filling insulationmaterials, innovative Fesco-, foam- and fibre- boards and innovative bricks with advanced insulation properties.

		Components for Energy Efficient Buildings	Production based on intelligent use of inert, “zero-embodied energy” wastes originating from industrial mineral exploitation (i.e. perlite, bentonite, amorphous silica and other volcanic minerals) and other industrial wastes.
2011-2015	BioBuild	High-performance, economical and sustainable biocomposite building materials	Low cost, lightweight, durable and sustainable biocomposite building systems, based on panels, profiles, frames and sandwich structures, capable of offering 40 years outdoor durability and improved reaction to fire by protecting the fibres using treatments and coatings. Cork and biobased foams used to improve the thermal andacoustic-insulating performance of thematerials, coupled with system design.
2013-2017	BRIMEE	Cost-effective and sustainable Bio-Renewable Indoor Materials with high potential for customisation and creative design in Energy Efficient buildings	Novel class of insulating materials, based on renewable organic porous materials: Nano-Cristalline Cellulose (NCC) based foam extracted from the waste streams of the pulp and paper industry, strengthened with natural derived resin with additional functionalities, such as fragrance release, water repellence or anti-bacteria.
2012-2015	SUS-CON	Sustainable, innovative and energy efficient concrete, based on the integration of all-waste materials	Develop novel technologies to reduce the embodied energy and CO_2 footprint of concrete through total replacement of current binders by novel ones (geo-polymers) made of waste or by-products in addition to producing thermally efficient and lightweight aggregates, composed completely of waste.
2008-2012	Clear-up	Clean buildings along with resource efficiency enhancement using appropriate materials and technology	Photocatalytic materials for air purification and microporous vacuum insulation in combination with phase change materials to passively control temperature.
2009-2013	MESSIB	Multi-source energy storage system integrated in buildings	Short thermal storage by means of PCMs with microencapsulation of salt hydrates and paraffin.
2011-2014	StorePET	Development of PCM-based innovative insulating solutions for the Light-weight building sector	Nonwoven insulation product that integrates PCMs for heat storage capacity, maintaining the levels of thermal and noise insulation by using fiber materials.
2012-2016	EFFESUS	Energy efficiency for EU historic districts sustainability	Development of new compatible conservation materials for envelope retrofitting: • new, cost effective, transparent IR reflective coating for outdoor applications, compatible with façade and roofing materials of historic buildings, to reduce the transfer of heat through the building envelope; • advanced aerogel insulation for blow-in application allowing to optimize the insulation’s performance both in terms of

			the space used and the reversibility of intervention; • new insulating mortar compatible with historic buildings façades as well as being able to reduce the transfer of heat through the envelope.
2010-2014	3ENCULT	Efficient energy for EU cultural heritage	High performance capillary active internal insulation.
2011-2015	BEEM-UP	Building energy efficiency for massive market uptake	Optimize advanced insulation and energy management solutions for cost-efficient application.
2011-2014	CETIEB	Cost-effective tools for better indoor environment in retrofitted energy-efficient buildings	Lightweight insulation mortar system with photo-catalytic plaster finish and enhanced thermal storage capacity.
2012-2016	HERB	Holistic energy efficient retrofit of buildings	Super-thin insulations, combining ventilation and lighting systems.
2013-2017	CommONEnergy	Re-conceptualize shopping malls from consumerism to energy conservation	Multi-functional coatings for opaque surfaces: IR reflective, self–cleaning and thermal insulating colored coatings.
2011-2015	Buildsmart	Buildsmart energy efficient solutions ready for market	Energy efficient building envelopes with high air tightness and low energy losses.

4. Insulating products/technologies for windows

4.1 Commercial products/technologies

The manufacturersof windows is developing products more and more effective from the point of view of energy saving. The window is usually composed by one or more glass panes attached to a frame that covers typically less than 15% of the total area. In order to improve the insulation of the windows several strategies can be followed:

- increasing the number of panes (triple-pane, quadruple-pane);
- inserting gases with low thermal conductivity in the cavities between the panes (argon, krypton);
- covering the internal surface of the panes with low-emissivity coatings in order to reduce the radiative heat transfer.

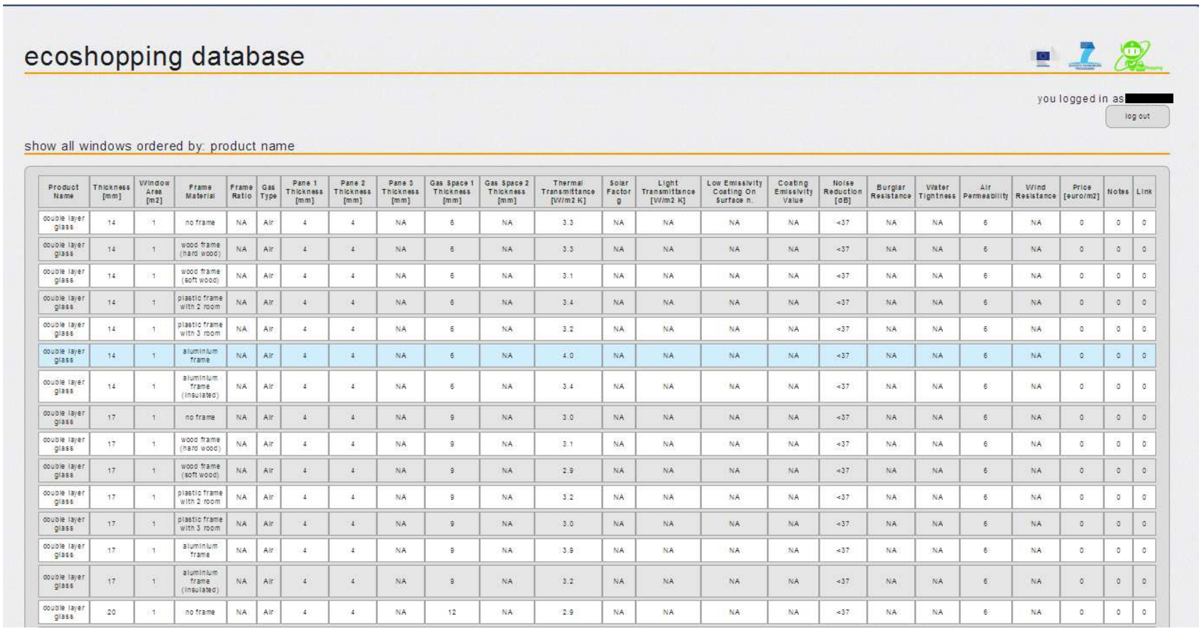
The frame is usually made of wood, aluminium or plastic materials (e.g. PVC) and could be designed with thermal break in order to lower the thermal transmittance.

In the current market, triple-pane windows with low-emissivity coatings and argon in the cavities between the panes are widespread, as required by several of the current standards. Their thermal transmittance can be lower than 1 W m^{-2} K^{-1}.

The most insulated product available in the current market is a quadruple-pane window with krypton in cavities between the panes, that guarantees a glass thermal transmittance equal to 0.3W m^{-2} K^{-1} and a globalthermal transmittance of the window equal to 0.6 W m^{-2} K^{-1}.

4.2 Specific Database

For the windows products, as for the insulating products for walls and roofs, a database is available at http://esdatabase.altervista.org/page_wshowall.php(Figure 3). Also in this case it is possible to view all the products and make queries. The information needed to create a new record are shown in Table 3.



ecoshopping database

you logged in as [redacted]

log out

show all windows ordered by: product name

Product Name	Thickness [mm]	Window Area [m2]	Frame Material	Frame Ratio	Gas Type	Pane 1 Thickness [mm]	Pane 2 Thickness [mm]	Pane 3 Thickness [mm]	Gas Space 1 Thickness [mm]	Gas Space 2 Thickness [mm]	Thermal Transmittance [W/m2 K]	Solar Factor g	Light Transmittance [W/m2 K]	Low Emissivity Coating On Surface n.	Coating Emissivity Value	Noise Reduction [dB]	Burglar Resistance	Water Tightness	Air Permeability	Wind Resistance	Price [euro/m2]	Notes	Link
double layer glass	14	1	no frame	NA	Air	4	4	NA	6	NA	3.3	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	14	1	wood frame (hard wood)	NA	Air	4	4	NA	6	NA	3.3	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	14	1	wood frame (soft wood)	NA	Air	4	4	NA	6	NA	3.1	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	14	1	plastic frame with 2 room	NA	Air	4	4	NA	6	NA	3.4	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	14	1	plastic frame with 3 room	NA	Air	4	4	NA	6	NA	3.2	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	14	1	aluminium frame	NA	Air	4	4	NA	6	NA	4.0	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	14	1	aluminium frame (insulated)	NA	Air	4	4	NA	6	NA	3.4	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	17	1	no frame	NA	Air	4	4	NA	9	NA	3.0	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	17	1	wood frame (hard wood)	NA	Air	4	4	NA	9	NA	3.1	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	17	1	wood frame (soft wood)	NA	Air	4	4	NA	9	NA	2.9	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	17	1	plastic frame with 2 room	NA	Air	4	4	NA	9	NA	3.2	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	17	1	plastic frame with 3 room	NA	Air	4	4	NA	9	NA	3.0	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	17	1	aluminium frame	NA	Air	4	4	NA	9	NA	3.9	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	17	1	aluminium frame (insulated)	NA	Air	4	4	NA	9	NA	3.2	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0
double layer glass	20	1	no frame	NA	Air	4	4	NA	12	NA	2.9	NA	NA	NA	NA	<37	NA	NA	6	NA	0	0	0

Figure 3. Screenshot of the database of insulating systems for windows

Table 3. Properties of a record of the window insulation database.

Fields	Example value	Field description
Manufacturer	Glass Co.	Name of the manufacturer
Product name	Ultra Glass	Commercial name of the product
Total thickness [mm]	44	Total thickness of the glazing system, measured in [mm]
Total window area	0.85	Area occupied by the window, measured in [m^2]
Frame material	PVC	Material by the frame of the window is made
Frame ratio	15%	Ratio between the area of the frame and the total window area, in %
Number of panes	3	Number of the panes by which the window is made
Gas type	Argon	Type of gas which fills the space between the panes
Pane 1 thickness [mm]	4	Thickness of the first pane from outside, measured in [mm]
Pane 2 thickness [mm]	4	Thickness of the second pane from outside, measured in [mm]
Pane 3 thickness [mm]	4	Thickness of the third pane from outside, measured in [mm]
Gas space 1 thickness [mm]	16	Thickness of the first gas space from outside, measured in [mm]
Gas space 2 thickness [mm]	16	Thickness of the second gas space from outside, measured in [mm]
Thermal transmittance [$W\ m^{-2}\ K^{-1}$]	0.9	Thermal transmittance of the total window, included the frame, measured in [$W\ m^{-2}\ K^{-1}$]
Solar factor (g)	0.6	Percentage of the total solar radiant heat energy entering the room through the glass, as in standard EN 410
Light transmittance	0.72	Relative amount of light transmitted through the glazing, as in standard EN 410.
Low-emissivity coating on surface n°	4	Indicate on which surface a low-emissivity coating is applied, if present, according to the scheme of Figure 4
Coating emissivity value	0.04	Emissivity value of the coating eventually applied on the surface of the window
Noise reduction (EN 20140) [dB]	44	Value of the acoustic insulation of the window, according to standard EN 20140, measured in [dB]
Burglar resistance (ENV 1627)	4	Class of the burglar resistance according to standard ENV 1627
Water tightness (EN 12208)	9A	Class of the water tightness according to standard EN 12208
Air permeability (EN 12207)	4	Class of the air permeability according to standard EN 12207
Wind resistance (EN 12210)	C5	Class of the wind resistance according to standard EN 12210
Price [Euro]	841	Measured in [Euro]

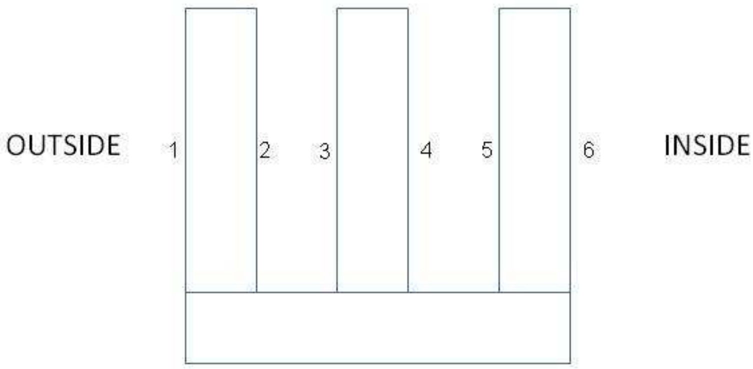


Figure 4. Schematic image of a window

4.3 Further research on innovative products/technologies

Research and development on the different types of glazing have created a new generation of materials that offers improved window efficiency and performance for consumers. The research and development of even more efficient technologies is on-going.

Glazing technologies or advanced window systems should provide both improved lighting and thermal controls. Indeed, advanced techniques for integration, control, and distribution of daylight should significantly reduce the need for electric lighting in buildings, whereas more durable high-reflectance coatings and insulated windows should allow better control of solar heat on building surfaces for the reduction of energy consumption related to HVAC (heating, ventilation and air conditioning) systems.

Among the most recent developments, "smart glasses" have the ability to control the amount of light and heat passing through changing from transparent to completely opaque. Unlike blinds, smart windows are capable of partially blocking light while maintaining a clear view of what lies behind the window. "Smart glasses" include:

- electrochromic windows, which change their colored translucent state -usually blue- to a transparent state, thanks to exchange of ions when voltage is applied;
- photochromic windows, which change their transparency in response to light intensity;
- thermochromic windows, which change color due to a change in temperature;
- gasochromic windows, which have an electrochromic selective layer sensitive to the hydrogen content contained in the gas: the product reacts to the luminosity variations, since the kinetics of tinting is couple with the speed of the gas circulation within the double glazing;
- suspended particles device (SPD) windows, which consist of a transparent electronic conductive coating and particles scattered in a polymeric matrix: the suspended particles align themselves in a rectilinear way under the effect of an electric field and allow light to cross the glazing;
- liquid crystal device windows, which turn from translucent milky white state to slightly hazy clear when electric current is applied.

The main systems toimprove the insulation properties of a glazingare:

- Vacuum Glazing;
- Insulation-filled Glazingswith aerogel, honeycombs, and capillary tubes. Aerogel is currently available in a variety of glazing systems: fiber reinforced daylight system, policarbonate glazing system, u-channel glass.

The combination of technologies for solar control and convective/ conductive heat loss results in "superwindows": multiple layers of clear, tinted, or reflective glazings with multiple low-emissivitycoatings and gas fills.

As advance glazing with improved thermal properties are introduced, a parallel development of the frame and edge seal is required, in order to reap the full benefit of new glazing technologies. New high performance frames and edge sealsare:

- High-tech composites;
- Factory-trimmed windows, i.e. aluminium-clad windows with all the exterior trim - including casings, mouldings, sill, and flashing - built right in.

Recent European projects dealing with the development of new systems for windows are summarized in Table 4.

Table 4. European projects that contribute to the advancements in the state of the art of insulating products/technologies for windows

Year	Acronym	Title	Research Outlines
2012-2016	Winsmart	Smart, lightweight, cost-effective and energy efficient windows based on novel material combinations	New Vacuum Insulation Glazing (VIG) solution combined with newly developed switchable glazing systems for a "smart active" solar control that prevents overheating, mounted in a durable, energy efficient, highly insulating and bio-based sash and frame.
2012-2016	MEM4WIN	Ultra-thin glass membranes for advanced, adjustable and affordable quadruple glazing windows for zero-energy buildings	Novel insulated glass unit for quadruple glazing containing ultra-thin glass membranes for frameless openable windows with direct installation in facades.
2012-2015	HarWin	Harvesting solar energy with multifunctional glass-polymer windows	Multi-purpose windows based on laminated composites made from new materials not yet utilized for glazing. New laminated composites are light-weight structures made from thin glass panes which will be joined together with newly developed light transparent polymer-composite sheets containing glass particles, which provide visual, thermal and sound functionality as well as mechanical reinforcement.
2008-2012	clear-up	Clean buildings along with resource efficiency enhancement using appropriate materials and technology	Advancement in the practical use of shutters and electrochromic windows for reducing the building's cooling load.
2010-2014	3ENCULT	Efficient energy for EU cultural heritage	Windows Integration of shading systems within window/glazing system, aesthetically compatible with the historic buildings.
2012-2016	EFFESUS	Energy efficiency for EU historic districts sustainability	Improvement of moisture and thermal properties of original windows with non-destructive low energy double/triple glazing systems with minimal visual impact

5. Selection of insulating materials

The choice of an insulation material can be made considering different parameters such as:

- Thermal resistance (or conductivity);
- Cost;
- Thickness.

A higher thermal resistance can reduce the energy demand of the building, that is usually prescribed by standards. As construction have also strict budget limitations, the cost is a fundamental parameter. A reduced wall thickness may increase the value in the real estate, overcome legal or practical restrictions in the retrofitting of existing buildings, allow a reduction of transport costs.

Exploiting the insulation database explained in 3.2, some insulation materials have been selected fixing a thermal resistance value. Table 5 contains the insulation materials that guarantee the lowest cost while Table 6 the ones that guarantee the lowest thickness for a thermal resistance value equal to 3 $m^2K\ W^{-1}$.This value has been chosen as it represents a realistic target value for a refurbishment.

Table 5. Insulation material with the lowest cost for a thermal resistance value equal to 3 $m^2K\ W^{-1}$.

Material	Thermal Conductivity [W / m K]	Minimum Thickness [mm]	Cost [Euro/m^2]
EPS	0.038	114	10.32
Wood fiber	0.038	114	12.80
Rock Wool	0.035	105	17.38

Table 6. Insulation material with the lowest thickness for a thermal resistance value equal to 3 m^2KW^{-1}.

Material	Thermal Conductivity [$W\ m^{-1}\ K^{-1}$]	Minimum Thickness [mm]	Cost [Euro m^{-2}]
Aerogel	0.013	39	224.70
Thermoset	0.020	60	21.70
Expanded Polyurethane	0.023	69	28.37

Figure 5 combines the previous data in a diagram where the x axis represents the insulation thickness and the y axis the cost of the material.

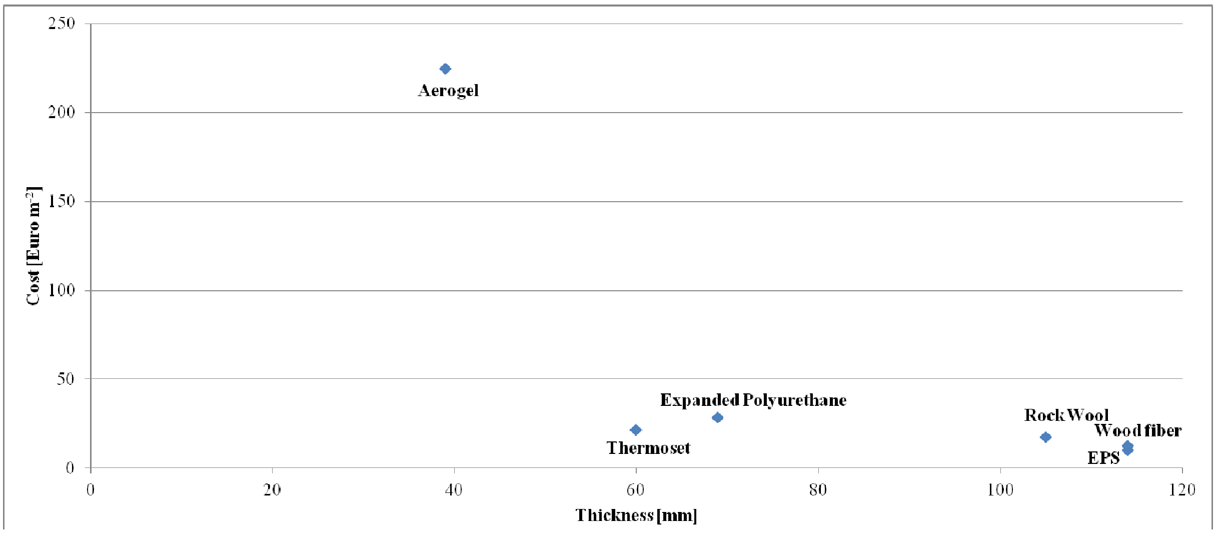


*Figure 5.*Cost versus thickness for insulation materials with a thermal resistance value equal to 3 $m^2K\ W^{-1}$.

At the current stage of the database, the three materials that could be selected are the cheapest one, the thinnest one and a compromise between the two parameters. Expanded Polystyrene (EPS), Aerogel and Thermoset are the materials that respectively fulfill these targets.

6. Assessment of applicability optimization

In this section the insulation application and procedure optimization are described. The implementation of insulation solutions is divided into 3 different systems (external, internal and mixture), though each one is also subdivided in different categories.

Moreover, each subcategory takes into account several aspects that are explained below.

6.1 External

6.1.1 External thermally insulating cladding systems (ETICS)

The ETICScomposition and scheme (Figure 6) are shown below:

1. Base coat (adhesive mortar);
2. Insulation material;
3. Facade plug anchors;
4. Reinforcing mesh embedded in the base coat ;
5. Masonry primer;
6. Top coat (mineral or, at customer's request, but vapour permeability should be checked).

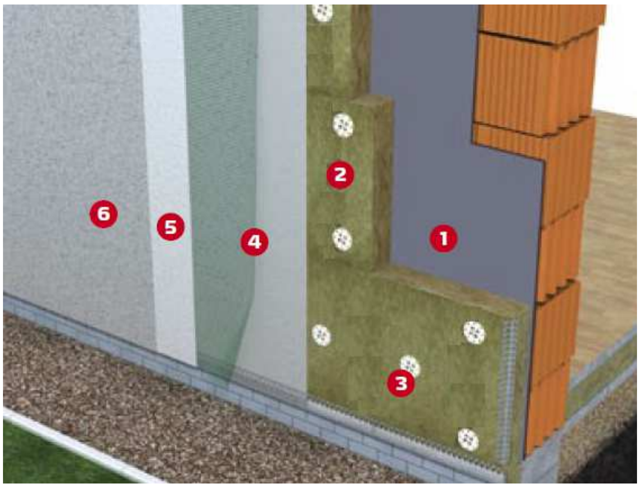


Figure 6. ETICS composition

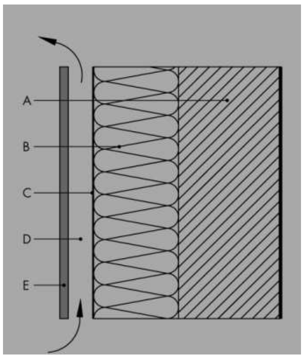
The ETICS solution is applied following the next steps in order to overcome thermal bridges and avoid internal wall condensation and damp:

- The skirt board should be fixed level and at least 40 cm above the ground. It must be attached horizontally around the entire building;
- The insulation slabs are applied to the wall with the adhesive applied in line along the edge of the slab using the dab fixing method;
- Fixing the insulation slabs. The insulation panels are bonded to each other by being pressed against the slabs already attached;
- The insulation panels are fixed with plug anchors;
- The external reinforced layer is applied;
- After the adhesive has dried out, a finishing layer of mineral or silicate mortar,eventually painted in selected colour, is applied.

6.1.2 Ventilated façade

The implementation of a ventilated façade provides several constructive, technical and economic advantages, such as ease of installing with low maintenance, elimination of moisture condensation, reduction of outside noise, excellent thermal insulation and adaptability to replace tiles without any construction work.

A common scheme of a solid wall with a ventilated façade(Figure 7) is shown below:



A. Load bearing wall (p.e. concrete)
B. Thermal insulation
C. Weather barrier (vapor permeable)
D. Ventilation cavity and subframe
E. Light outer leaf(p.e. ceramic tile)

Figure 7. Scheme of a ventilated façade

Its main elements from the construction point of view are:

- The **light outer leaf**, which is independent of the rest of the facing;
- The **air chamber**, which guarantees the air tightness of the system whilst enabling air circulation in its interior;
- The **auxiliary substructure**, which is employed to support the light outer leaf, incorporates the insulation and maintains the air chamber's dimensions;
- The **insulation**, which is fitted to the outer face of the inner leaf, guarantees continuity throughout the façade and avoids the appearance of the thermal bridges.

6.2 Internal

6.2.1 Floor insulation

6.2.1.1 Insulating timber ground floors

This solution is used when the boards can be lifted without unacceptable levels of damage. If boards are to be lifted for any other reason it would normally be appropriate to take the opportunity to install insulation at the same time. Suitable materials are semi-rigid batts, boards or loose fill cellulose. If this solution causes damage, the most suitable way to insulate the floor is to access it from under the floor as explained in chapter 6.3.2.

As shown in Figure8, the insulation is supported between the floor joists and an air and vapour control layer is laid over the insulation below the floorboards. This should be fully supported and therefore used in conjunction with rigid insulation. The insulation can be supported by netting, a breather membrane or proprietary fixings depending on the type of insulation material being used.

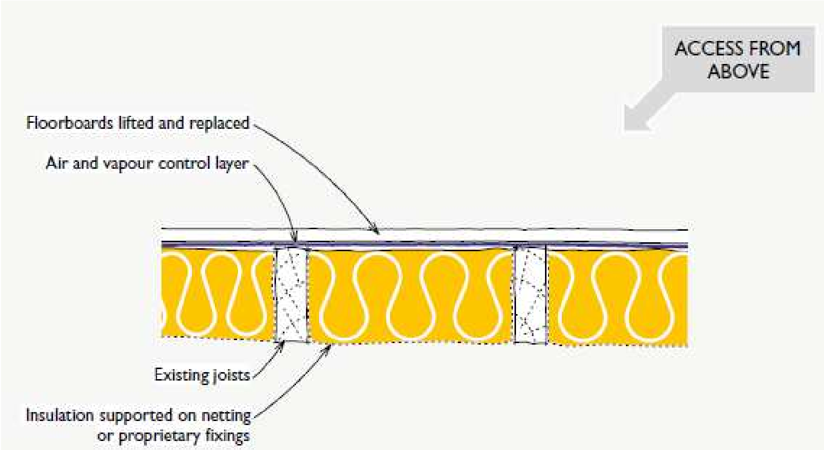


Figure8. Fixing insulation from above floor

6.2.1.2 Insulating solid ground floors

In many cases the energy saving resulting from insulating solid ground floors can havenegligible benefits, since the cost and disruption to the building fabric have to be considered. There are several risks involved with insulating solid ground floors.

6.2.2 Wall insulation

The internal wall insulation can be added in two different ways: as a composite thermal board or as a built up system using insulation behind timber battens fixed behind conventional plasterboard.

For both systems the surface of the wall must be carefully prepared and all cracked or damaged plaster must be either repaired or removed. Bare brickwork or blockwork should be pointed with mortar to eliminate air paths to the exterior.

As consideration for both systems, it must be taken into account that it is very important to ensure that moisture cannot penetrate behind the plasterboard as condensation and dampness will result. Besides, additional insulation will be required around the sills and reveals of openings and adjacent to where internal masonry partitions meet external walls in order to prevent thermal bridging.

Below both systems are explained.

6.2.2.1 Thermal boards

Made of plasterboard bonded to an insulating material (e.g. polystyrene, polyurethane or mineral wool), which usually have a thickness between 25 and 50mm.This system incorporates a vapour control layer to prevent water vapour passing through the board and condensing on the cold masonry behind.

This system should be fixed to the wall using a continuous ribbon of plaster or adhesive, and not individual 'dabs' of plaster, unless the wall is particularly uneven.

6.2.2.2 Built up systems

Conventional insulation (in most cases mineral wool) is placed between vertical timber battens fixed to the wall. It is recommended to put a polythene sheet over the insulation and battens beneath the plasterboards, since it acts as the vapour control layer.

If polythene sheet is used, joint edges and services (electrical cables and wiring, which penetrate the polythene sheet) must be thoroughly sealed using tape to exclude water vapour and subsequent condensation formation behind the lining.

6.3 Mixture (External and/or Internal)

6.3.1 Cavity wall insulation

To ensure that cavity wall insulation is only installed where it is appropriate, a procedure for assessing whether the wall is suitable for the incorporation of cavity wall insulation is described below. This procedure involves:

- Determining whether the wall is in fact a masonry wall with unfilled cavities;
- Inspecting the general condition of the external wall;
- Identifying any constructional defects that first need to be remedied;
- Checking on the inside of external walls to see if there are any existing dampness problems that need to be remedied;
- Checking any penetrations of the external wall, e.g. for flues and air ventilators;
- Finding out if the cavity of a directly adjacent house has already been filled, e.g. in a terraced or semi-detached house;
- If necessary for the insulation system, checking the exposure of the wall.

It is very important a deep inspection of the walls. All defects and dampness penetration problems must be addressed before starting the work. Walls with cavities less than 50mm wide are not suitable for insulation and any PVC covered electrical cables should have been removed.

The three most common types of cavity wall insulation used are: 1) Blown mineral fiber, 2) Polystyrene beads or granules, and 3) Urea formaldehyde foam.

The installation procedure starts drilling small holes into the mortar between the brick courses of the outer leaf at approximately one meter intervals. The insulating material is blown or injected into the cavity through these holes which are subsequently filled to leave no sign of the work that has been carried out.

If re-plastering of the internal walls is planned then it may be preferable to inject the insulation material through holes drilled in the internal walls, which are then covered when the wall is plastered.

6.3.2 Flat roofs / Ceiling insulation / Pitches insulation

In this section it is described the implementation of insulation material in ceiling, roofs or pitches, though it is not specified each case. The different typologies of insulation solution have been divided into 3 categories: 1) Insulation within the zone of structure, 2) Insulation above the existing structure, and 3) Insulation beneath the existing structure.

Within each case, it is explained several requirements (e.g. if the system can be added from indoor or outdoor side).

6.3.2.1 Insulation within the zone of structure

The most common location to add insulation within an existing flat roof is to install it within the existing structure zone, generally between the existing joists. This has the advantage of causing the least alteration to the existing roof by retaining the structure, its overall thickness, and the upper and lower surface finishes.It can be installed with or without ventilation (Figure 9).

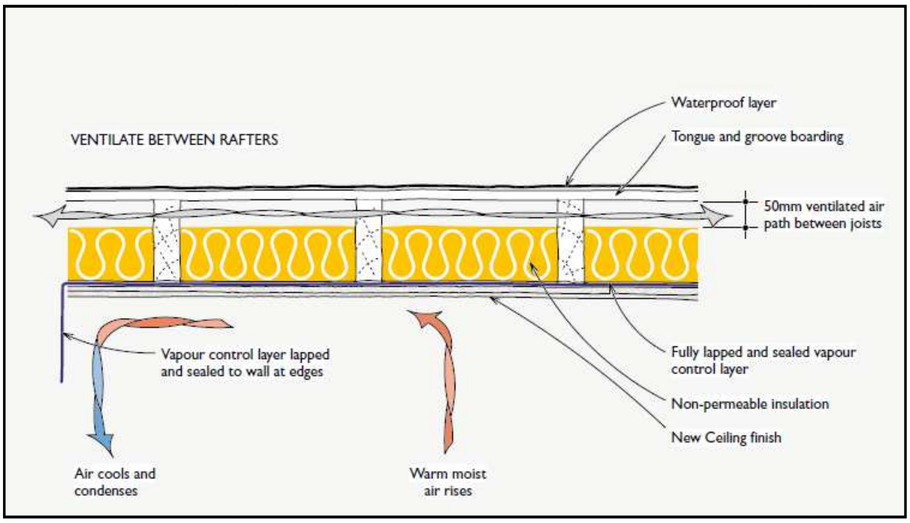


Figure9.Ventilated cold deck using vapour permeable insulation

For the installation of insulation within the existing structural zone, the ceiling is usually removed for accessing the roof internally. Insulation is added to part of the depth of the roof joists to maintain an air-path above. A vapour control layer is shown to prevent moist air entering the roof-space and condensing.

If the implementation of insulation material is done without ventilation, it is possible to install it between joists to their full depth without allowing for ventilation. This will allow the maximum possible amount of insulation to be added without altering the appearance or thickness of the roof, but certain risks will inevitably result. Control of condensation build-up in the structure will rely entirely on the efficiency of a vapour check layer below the insulation, with all the consequent drawbacks. This layer is best installed below the joists to ensure both its durability, and to protect the structural timber, although replacement of the ceiling will therefore be necessary. Under no circumstances should unventilated insulation be used below a lead or zinc roof.

6.3.2.2 Insulation above the existing structure

Where it is feasible to raise the level of the roof covering without compromising the character of the building, new insulation can be installed above the decking. There are two systems named 1) Warm deck system, and 2) Inverted system (Figure 10).

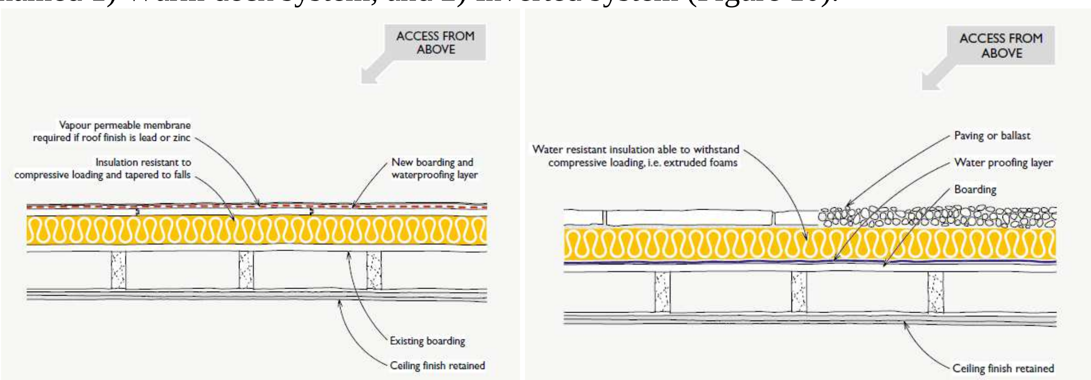


Figure10.Warm deck system and Inverted system

Where the existing flat roof covering is being replaced or repaired it can provide the opportunity to add insulation above the existing roof deck tapered to provide a fall. The existing roof covering could also be retained providing a partial vapour check. As there is no ventilation between the insulation and the underside of the roof covering then this detail would be most suited to finishes such as asphalt, stainless steel and copper.

This will require either the use of insulation boards which can resist a compressive load, or the addition of deep firrings or in order to carry a raised deck above the existing one. If rigid insulation is used, a new roof covering can be directly installed with a corrosion-resistant metal such as stainless steel or copper, or a continuous covering such as asphalt can be used.

The inverted roof is a modified version of a warm deck roof where insulation is applied above a continuous waterproofing layer. Rainwater is allowed to percolate through the joints in the insulation and drain away via the waterproof layer below. In this case, the insulation is placed above the waterproof layer and is protected and held down by paving or ballast. The insulation needs to be able to withstand compressive loading. This detail is particularly suited to asphalted roofs. The roof space is unventilated.

6.3.2.3 Insulation beneath the existing structure

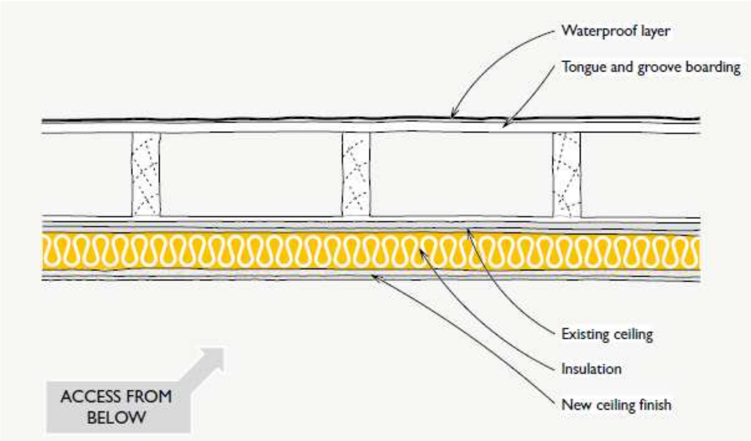


Figure11. Insulation added below roof structure

As shown in the Figure 11 the existing lime plaster ceiling is retained and insulation is added below with a new ceiling under. A new ceiling can easily be added below an existing ceiling using shallow joists.

7. Self-cleaning products

7.1 Background

Environmental issues become more and more relevant year by year, and topics related to pollutants removal from air and wastewaters generate thousands of works involving a large number of research groups worldwide. Literature evidences, indeed, that more than 3000 records are indexed by "Web of Knowledge" in 2013 and more than 3700 in 2012 when "environmental pollution" string is used as topic research keyword. Photocatalytic methods are known to be widespread applicable in advanced oxidation processes (AOPs). Thanks to the high reactivity of the in situ generated active species, the selectivity of the photocatalyst is very low, leading therefore to the complete mineralisation of a wide number of organic pollutants (producing CO_2 and H_2O as final degradation products). Inorganic pollutants such as NO_x and sulphureted compounds are converted into nitrates and sulphates respectively, while ozone is converted into O_2 [1]. Photocatalytic processes are also active in removing microorganism: cellular membranes are degraded thus leading to the bacteria death [2, 3]. A large number of papers well resumes the main characteristics of a photocatalytic process [4-6]. Briefly, the irradiation of a semiconductor by photons with adequate energy creates a couple of photo-electrons (e-) and photo-holes (h+) which can react with acceptors (O_2 as an example) and donors molecules, and initiate the oxidation process. Four main parameters affect the oxidation process: the catalyst mass, the photons wavelength, the concentration of the reactants and the radiation flux. Titanium dioxide is considered one of the most suitable photocatalysts because of its chemical stability, non-toxicity toward environmental and living species, low cost and wide availability [7]. The diffusion of self-cleaning materials is growing and the sales volumes increase year by year; self-cleaning materials currently available include glass, concrete, ceramic tiles and paint [8]. Photocatalytic paints can be conveniently applied in a wide variety of cases. Their use in hospitals, as an example, can help in preventing the diffusion of infections caused by antibiotic-resistant pathogens. Taking into account daily life, photocatalytic paints can be widespread employed in private homes, public buildings and shop centres both in indoor and outdoor in order to reduce atmospheric pollutant and thus improving air quality, but also in reducing the cost for the maintenance of the buildings [3].

7.2 Specific Database

The database for market available self-cleaning paints was built by means of an extended web investigation, taking into account the manufacture websites. The research was performed by using common internet search engines and by means of common keywords (as "self-cleaning paint" or "photocatalytic paint" as examples), in order to achieve the same information that common people or users (i.e. without specific training) can obtain from web.

The research was extended to the companies which have headquarter or branches in EU.

The database was filled with information obtained directly by producer website and technical and/or safety sheets. As can be seen from the database, information regarding both outdoor and indoor paints are reported for sake of completeness, although, taking into account the EcoShopping target, only the indoor products have been subsequently deeply evaluated.

For the self-cleaning materials, as for the insulating products, the database is downloadable at http://esdatabase.altervista.org/page_home.php (Figure 12). The information contained in the records are shown in Table 7.

product name	company producer (name, address, country, website)	cost per unit (specify unit)	available form (powder, liquid suspension, ready to use paint...)	particle size	active material (rutile, anatase)	application methodology (fill in if technical sheet not available)	main employment (indoor/outdoor)	type of light required to be activated	type of action (pollutants degradation, antibacterial...)	indication for the best utilization (from supplier)	availability of technical sheet (Y/N). If Yes, please provide the docs or the link to them	availability of safety sheet (Y/N).If Yes, please provide the docs or the link to them	site where products where applied (please provide any docs/link related to the treatments)	bibliography	additional notes
TX Active	Italcementi, Via Camozzi 124, Bergamo, Italy	2-60€/m2 120-150€/m3					outdoor		self-cleaning, pollutants degradation		Y http://www.pavital.it/pdf/TX_A_approfondimento.pdf		Dives in Misericordia Church, Tor Tre Teste, Rome, Italy	http://www.richardmeier.com/www/#/projects/architecture/location/europe-a-m/italy/1/132/0/	is the mentioned cost the effective cost or the exceeding cost with respect to tradizional cements? (http://www.italcementigroup.com/NR/rdonlyres/BF206691-F2EF-43B0-A5F4-05A6CD29CBF6/0/TXactiveapprofondimentoottobre2009_ITA.pdf)
Activ	Pilkington, http://www.pilkington.com/					pyrolysis	outdoor	UV	self-cleaning, pollutants degradation		N (I didn't find something interesting about it)				
CIMAX Ecosystem PAINT	Calci Idrate Marcellina. http://www.cimax.it/index.htm	NA from the website	dry powder to be diluted up to 60% with water. Sold in 10 kg bucket	"ultrafine"		with paint-brush or paint roller	indoor/outdoor	UV	self-cleaning, pollutants degradation and antibaterial (thanks to organic compound mineralization)						the active material is the TX-Active by Italcementi
Catalysis pittura-interior	colorificio MP http://www.colorificiomp.it/prod/item/66-0130-catalysis-pittura-interno.html	NA from the website	paint			paint--brush or paint-roller	indoor/outdoor		mineralization of organic matter and atmospheric pollutants decomposition		available see attached file	on request to the company			
Capasan	Caparol http://www.caparol.com/		paint 5 or 12 litres tanks (to be diluted up to 5% with water)	< 100 µm		paint--brush or paint-roller or air or airless application	indoor		mineralization of organic matter and atmospheric pollutants decomposition		available see attached file				
Smog-eating Ecopittura	Global Engineering http://www.globalengineering.info/index.php?lang=ing	by the website: the costs are as for high quality common paints	paint 14 litres tanks	nanometric	anatase	paint--brush or paint-roller or spray	indoor/outdoor	UV	mineralization of organic matter and atmospheric pollutants decomposition		available see attached file				"Ecopittura" is available with silicone and siloxane binders suitable for exterior surfaces, with vinyl binders or as an enamel paint for any indoor surface.
KEIM EcoSil-ME	KEIM FARBEN http://www.keimfarben.de/en/		paint 5 or 15 litres tanks	"fine"	TiO2	paint--brush or paint-roller or air or airless application	indoor		mineralization of organic matter and atmospheric pollutants decomposition		available see attached file	available see attached file			
SigmaCare CleanAir	Sigma Coatings http://www.sigmacoatings.it/ - http://www.sigmacoatings.com/ - http://www.ppg.com/en/Pages/home.aspx		paint (to be diluted up to 5-10% with water)	nanometric	TiO2	paint--brush or paint-roller or air or airless application	indoor	solar or artificial light	mineralization of organic matter and atmospheric pollutants decomposition		available in Italian see attached file	available in Italina see attached file			acrylic base

Figure 12. Screenshot of the database of self-cleaning products

Table 7. Properties of a record of the self-cleaning products database.

Fields	Example value	Field description
Product name	SigmaCare CleanAir	The commercial name of the product is here mentioned
Company producer (name, address, country, website)	Sigma Coatings http://www.sigmacoatings.it/ - http://www.sigmacoatings.com/ - http://www.ppg.com/en/Pages/home.aspx	The field shows the manufacture company and several information about it. The name, the address, country and website are showed if available
Cost per unit (specify unit)	2-60€/m^2 120-150€/m^3	The field shows the cost of the material as showed from the company website
Available form (powder, liquid suspension, ready to use paint…)	Nanometric	The dimension of the active material in self-cleaning is here showed
Active material (rutile, anatase)	TiO_2	The chemical nature of the active self-cleaning material id showed
Application methodology (fill in if technical sheet not available)	Paint-brush or paint-roller or air or airless application	The field shows the company guideline for the application of the self-cleaning paint
Main employment (indoor/outdoor)	Indoor	The field shows if the product is for an indoor or outdoor application
Type of light required to be activated	Solar or artificial light	The field shows type of radiation required by the self-cleaning paint to be active in photocatalysis
Type of action (pollutants degradation, antibacterial…)	Mineralization of organic matter and atmospheric pollutants decomposition	The filed describes the action of the self-cleaning material for the pollutant removal from air
Indication for the best utilization (from supplier)	Masonry	The field indicates if the producer company gives additional information for the best use of the product
Availability of technical sheet (Y/N). If Yes, provide docs/weblink	Available an Italian version	The availability of additional information about technical sheets is here showed
Availability of safety sheet (Y/N). If Yes, provide docs or weblink	Available an Italianversion	The availability of additional information about safety sheets is here showed
Site where products where applied (provide docs/weblink)	Dives in Misericordia Church, Tor Tre Teste,Rome, Italy	The field describes available examples obtained by using the product
Bibliography	http://www.richardmeier.com/www/#/projects/architecture/location/europe-a-m/italy/1/132/0/	The field shows the available bibliography
Additional notes	Acrylic base	Any additional information is showed in this field.

7.3 Further research on innovative products

The most recent researches are addressed to overcome the big lack related to indoor applications, studying the modification of band gap in order to allow the use of natural visible light or conventional indoor illumination systems for the activation of the photocatalysts, as it will be performed in EcoShopping.

Moreover, studies on the characterization of mortars covered by a surface layer of TiO_2, added as suspension and as powder, show adhesion problems. Hence, further researches are needed also to solve this issue and enhance layer durability.

Recent European projects dealing with the optimization of self-cleaning products are summarized in Table 8.

Table 8. European projects that contribute to the advancements in the state of the art of self-cleaning products

Year	Acronym	Title	Research Outlines
2008-2012	Clear-up	Clean buildings along with resource efficiency enhacement using appropriate materials and technology	Optimization of photocatalytic materials (paints) for air purification.
2011-2014	CETIEB	Cost-effective tools for better indoor environment in retrofitted energy-efficient buildings	Development of lightweight insulation mortar systemwith photocatalytic plaster finish.
2013-2017	CommONEnergy	Re-conceptualize shopping malls from consumerism to energy conservation	Development of multi-functional colored coatings for opaque surfaces with IR reflective, self–cleaning and thermal insulating properties.
2012-2016	RETROKIT	RetroKit - Toolboxes for systemic retrofitting	Development of long endurance coatings for healthier environment.
2011-2014	HIPIN	High performance insulation based on nanostructured encapsulation of air	Development of innovative multi-functional (self-cleaning, fire retardant) aerogel incorporated into paint, plaster and panels forbuilding applications.
2011-2015	HEROMAT	Protection of Cultural Heritage Objects with Multifunctional Advanced Materials	Development of self-cleaning coatings, anti-microbial coatings and consolidants with or without hydrophobic properties effective for inorganic mineral substrates of Cultural Heritage objects (stone, brick, mortar, render and colour finishing layers).
2009-2012	NANOCLEAN	Optimisation and upscaling of self-cleaning surfaces for automotive sector by combining tailored nanostructured machined injection tools and functional thermoplastic nanocompounds	Mass production of permanent superhydrophobic and self-cleaning plastic components via the upscalingof a nano-engineered highly-versatile integrated one-step injection moulding technique for the automotive sector.
2004-2007	SELF-CLEANING GLASS	Nano-structured self-cleaning coated glasses: Modeling and laboratory tests for fundamental knowledge on thin film coatings, EC	Study and characterization of self-cleaning glasses to acquire a thorough understanding of the real soiling mechanisms and to define standard test methods.

		normalisationand customer benefits	
2003-2007	NR2C	New Road Construction Concepts	Study of photocatalytic materials and different application methods in combination with cement for use in road pavement blocks.
2002-2005	PICADA	Photocatalytic Innovative Coverings Applications for De-pollution Assessment	Development of a range of materials with enhanced catalytic properties (plaster, mortar, concrete, coating, paint), easily applicable on facades, with both self-cleaning and de-polluting properties. Two binders were considered : cement-based materials and organic-based coatings.

7.4 Selection of self-cleaning products

7.4.1 Criteria

EcoShopping project aims to supply smart solutions for an innovative and eco-sustainable indoor building management. Taking into account this target, the main guideline for the selection of the commercial available self-cleaning paints was the illumination requirements for an adequate photocatalytic performance. Briefly, active components in photocatalytic paints are semiconductors which need radiation with adequate wavelengths to execute an effective photocatalytic action. Since most of the active component of commercial paints derives from titanium dioxide (which requires UV-light for photocatalytic action), they need an UV emitting light source. Because of this reason, in the present research, only the products from manufactures that clearly declare the indoor UV-free use for their paints have been taken into account.

Among the companies reported in the database, only the following have been selected for further investigations(Table 9).

Table 9. Selected manufactures of self-cleaning products

#	Company	Product(s)	Website
1	STO	STO Color Climasan	www.sto.com
2	Sigma Coatings	SigmaCare Cleanair	www.sigmacoatings.com
3	Nanoprotect	P&T 230 - P&T 230Ag - P&T	http://www.nanoprotect.co.uk/photocatalyst.html
4	KEIM FARBEN	KEIM Ecosil	www.keimfarben.de/en
5	Caparol	Capasan	www.caparol.com
6	Colorificio MP	Catalysis interior	www.colorificiomp.it

Companies reported in Table 8 have been contacted by conventional means (e-mails and "contact us" form on company websites).

The company STO, Sigma Coatings and KEIM FARBEN agree to supply their products for the subsequent task 3.2.

7.4.2 Benchmark and Improvements

The selected photocatalytic paints listed above will be investigated by means of appropriate analytical techniques and tested with respect to their photocatalytic performances as described in WP3 task 3.2. Moreover, as they are required to reduce indoor pollutants in indoor environment, performance test will be carried out with different lighting sources selected accordingly to requirements defined in WP3 task 3.1.

Commercial products will be tested together with Degussa P25, used as benchmark. P25, indeed, is a common TiO_2 nano-powder from Degussa (Germany). It is commercially available and widely employed as photocatalytic pigment mainly under UV light. P25 is a well note material made of a mixture of anatase-TiO_2 and rutile-TiO_2 (in proportion from 70% - 30% to 85% - 15% anatase – rutile) with a specific surface area of about 50 m^2/g and crystallites about 20-30 nm wide.

P25 is here chosen as benchmark because dedicated scientific literature often cites it as milestone when dealing with photocatalytic materials, both under UV and visible light.

Despite the commercial availability of indoor UV-free photocatalytic paints, new TiO_2-based products will be developed and tested in order to identify the photocatalytic activity in the visible range. The new material will be characterized and tested as for the commercial products and P25 benchmark.

8. Standards and codes

8.1 SToA

8.1.1 Insulation

The standards from EN 13162 to EN 13171 [9-18] describe product characteristics and includes procedures for testing, evaluation of conformity, marking and labelling regarding a wide amount of commercial insulation materials (EPS, XPS, mineral wool, polyurethane, wood fiber, etc). Standard ISO 10456 [19] specifies methods for the determination of declared and design thermal values for thermally homogeneous building materials and products. Standard EN 13172 [20] is related to factory-made products for buildings and to external thermal insulation composite systems.

8.1.2 Comfort

The main standards regarding comfort and inside environmental conditions of the buildings are ISO 7730[21] and EN ISO 15251 [22].

ISO 7730 presents methods for predicting the general thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments. It enables the analytical determination and interpretation of thermal comfort using calculation of PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) and local thermal comfort, giving the environmental conditions considered acceptable for general thermal comfort as well as those representing local discomfort.

The standard EN ISO 15251 specifies the indoor environmental parameters which have an impact on the energy performance of buildings and how to evaluate, monitor and display them. It is applicable mainly in non-industrial buildings. It could be integrated with national regulations or individual project specifications and it does not include criteria for local discomfort factors.

8.1.3 Health

The European Standard EN 15804:2012 [23] provides the coreProduct Category Rules (PCRs) forType III Environmental Product Declarations (EPD) for anyconstruction product and service.For the EPD of construction services the same rules and requirements apply as for the EPD of construction products.

The core PCRs:

- define the parameters to be declared and the way in which they are collated and reported;
- describe which stages of a product’s life cycle are considered in the EPD and which processes are to be included in the life cycle stages;
- define the rules for the development of scenarios;
- include the rules for calculating the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) underlying the EPD, including the specification of the data quality to be applied;
- include the rules for reporting predetermined, environmental and health information, that is not covered by LCA for a product, construction process and construction service where necessary;
- define the conditions under which construction products can be compared based on the information provided by EPD.

8.1.4 Energy saving

The current legislative framework is based on the European Directive 2002/91/CE [24] regarding the energy efficiency of buildings: in particular this regulation, when applied at a national level, establishes maximum values of the heating energy demand (expressed in kWh/m^2) and of the thermal transmittance of the various building elements for new buildings or important retrofits of buildings.

This directive has been updated by the European Directive 2010/31/EU [25]in which the concept of nearly-zero energy building has been introduced and a deadline for its implementation has been set.

The European Directive 2009/28/EU [26] regards renewable energy sources. When applied at national level it establishes that, in the cases of new buildings or important retrofits of buildings, use of renewable energy must cover a quote of the consumption of hot water and electricity.

8.2 Specific Database

For the standards and codes, as for the other products, a database is downloadable at http://esdatabase.altervista.org/page_home.php. The standards have been divided into five categories: insulation, comfort, health and energy saving. For each one of these categories a record could be created inserting the following values: document name, publication year of current version, document type (regulation, standard or guideline), European or National level, content, compliance target and specified requirements, comments, references.

9. Conclusions

9.1 Summary of achievements

The installation of thermal insulation materials is part of the holistic approach conceived in EcoShopping project to find the best retrofitting solution to reduce primary energy down to less than 80 kWh/m^2 per year in commercial buildings. In particular, the optimization of the envelope is expected to further reduce the thermal losses and lower the energy consumption up to 10% compared to the current conditions of the demo building located in Sopron (Hungary). Moreover, new efficient self-cleaning coatings will be used to coverthe insulating panels, in order to add self-cleaning properties to insulation solutions and at the same time improve IAQ.

The choice of the insulating materials has been performed considering as major parameters thermal resistance (or conductivity), cost and thickness. Finally, threematerials (Expanded Polystyrene (EPS), Aerogel and Thermoset)have been selected for the characterization of their physical properties in laboratory.

Commercial self-cleaning products for indoor application have been selected. Degussa P25 will be used as benchmark; next to the other selected products, it will be analyzed in laboratory to evaluate the performance of the new developed titania photocatalyst.3 companies have been identified for supplying the products for the laboratory tests.

Finally, public databases have been created. They are accessible by the consortium of the EcoShopping project both for consultation and implementation, and by anyone outside the project who is interested in finding information and being updated on the current insulating solutions available in the market, including the most innovative ones.

9.2 Relation to continued developments

The selected insulating materials and self-cleaning products will be characterized in laboratory in Task 3.2 in order to find the best solutions to be used for the installation in the demo building (Task 7.2) that will be later evaluated in terms of performance, energy efficiency, comfort and IAQ improvement, durability, costs (Task 3.4) and LCA (Task 2.7).

The main research trends resulting from the review of recent European projects can give food for thoughts on still existing gaps, encouraging continuous future researcheson materials and technological development even beyond EcoShopping project.

10. Acronyms and terms

EPBD........................... Energy Performance Building Directive
SToA .... State of the art
EPS .... Expanded polystyrene
XPS .... Extruded Polystyrene
PUR .... Polyurethane
VIP .... Vacuum insulated panels
GFP .... Gas-filled panel
LCA .... Life Cycle Analysis
VOCs .... Volatile Organic Compounds
PCMs .... Phase Change Materials
GWP .... Global Warming Potential
ODP .... Ozone Depletion Potential
NIR .... Near Infrared Reflecting
NCC .... Nano-Cristalline Cellulose
HVAC.......................... Heating, Ventilation and Air Conditioning systems
SPD .... suspended particles device
VIG .... Vacuum Insulation Glazing
ETICS .... External thermally insulating cladding systems
AOPs .... Advanced Oxidation Processes
PMV .... Predicted Mean Vote
PPD .... Predicted Percentage of Dissatisfied
PCRs............................ Product Category Rules
EPD .... Environmental Product Declarations
LCI .... Life Cycle Inventory
LCIA............................ Life Cycle Impact Assessment
IAQ.............................. Indoor Air Quality

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[11] EN 13164:2012 - Thermal insulation products for buildings - Factory made extruded polystyrene foam (XPS) products - Specification

[12] EN 13165:2012 - Thermal insulation products for buildings - Factory made rigid polyurethane foam (PU) products - Specification

[13] EN 13166:2012 - Thermal insulation products for buildings - Factory made phenolic foam (PF) products - Specification

[14] EN 13167:2012 - Thermal insulation products for buildings - Factory made cellular glass (CG) products - Specification

[15] EN 13168:2012 - Thermal insulation products for buildings - Factory made wood wool (WW) products - Specification

[16] EN 13169:2012 - Thermal insulation products for buildings - Factory made expanded perlite board (EPB) products – Specification

[17] EN 13170:2012 - Thermal insulation products for buildings - Factory made products of expanded cork (ICB) – Specification

[18] EN 13171:2012 - Thermal insulation products for buildings - Factory made wood fibre (WF) products - Specification

[19] ISO 10456:2007 - Building materials and products - Hygrothermal properties - Tabulated design values and procedures for determining declared and design thermal values

[20] EN 13172:2012 - Thermal insulation products - Evaluation of conformity

[21] ISO 7730:2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

[22] EN ISO 15251:2006Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

[23] EN 15804:2012 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products

[24] 2002/91/CEDirective of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings

[25] 2010/31/EU Directive of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

[26] 2009/28/EUDirective of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance).