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D4.4 – Report on performance evaluation of prototypes of inner insulation kits

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

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Introduction

This document reports on the performance evaluation activities that took place about retrofitting solutions for the inner envelope.
Figure below provides the articulation of the proposed indoor retrofit kits.

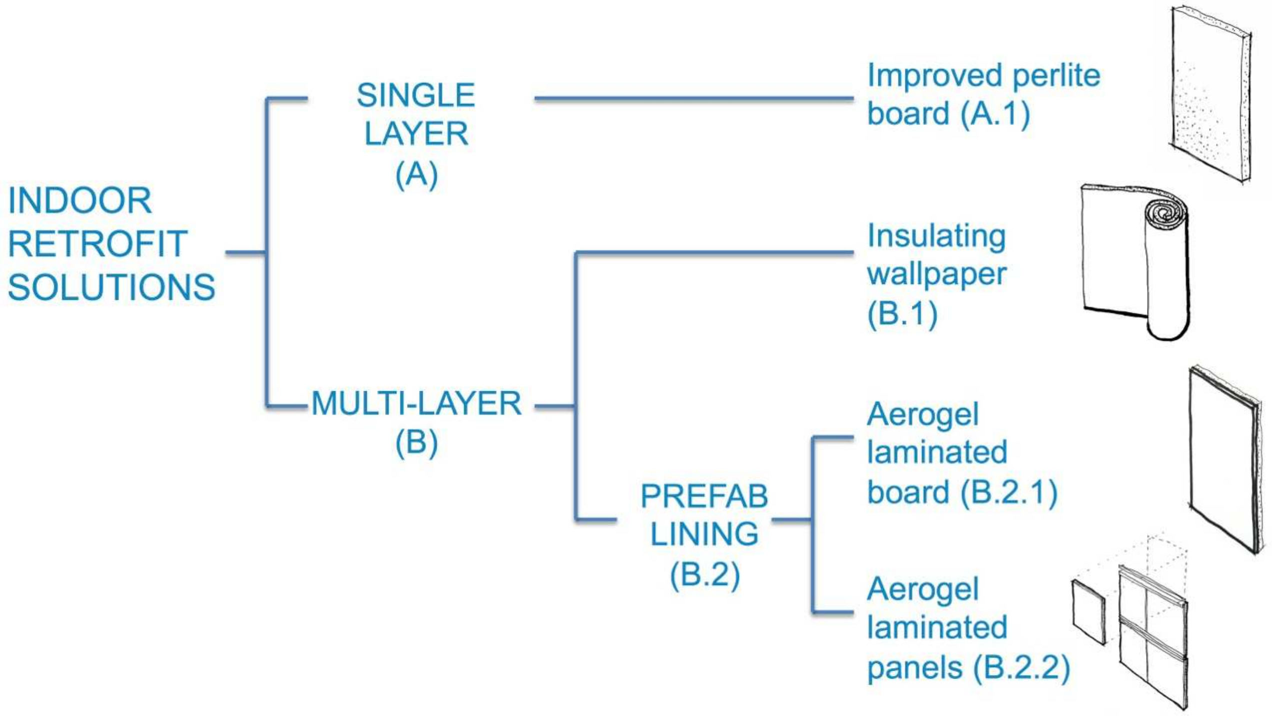

Fig. 1: Scheme of the internal insulating solutions proposed within the EASEE project in WP4.

On the one hand, the research partners carried on the design work about the development of the retrofitting kits that were identified in previous Tasks. These solutions needed further refinement as the performance evaluation proceeded and more tests were carried out by partners. Once the basic characteristics of the different kits were defined, specific materials and jointing solutions were defined and tested.
On the other hand, the indoor retrofitting kits were tested at laboratory scale and through software simulations in order to test some of their performances. In particular, activities concentrated on:

- The most important hygrothermal properties for solutions that are in contact with the internal environment, i.e. thermal conductivity, water vapour permeability and water absorption;
- The assessment of cold bridges and condensation risk in a variety of typical joints of residential construction – a very important aspect, since with indoor retrofitting it is impossible to guarantee the continuity of the insulating layers and it is imperative to avoid condensation and the build up of mould;
- The Life Cycle Assessment (LCA) comparing the proposed kits with other, standard insulating solutions and comparing different jointing solutions to support the choice of the materials with a smaller impact on the environment.

The kits will be further refined through the installation of prototypes on a test wall at Politecnico di Milano.

1 Development of the internal retrofit kits

1.1 Introduction to the kits

In order to satisfy the requirements of the EASEE project as well as the installation procedures of the internal energy retrofitting system, three different design hypotheses have been developed. Each of the investigated solutions has specific characteristics as in Fig. 2.
In general terms, the wills expressed by the project could be summarized through this sentence: *"The proposed solutions for the interiors are applied according to the owner's decision, and however will have fast installation minimizing discomforts for the occupants"*. More specifically, set objectives can be summed up through the following points:

- Easy installation in a minimally intrusive way;
- Optimise the worksite in general;
- Reducing installation time by 20% or more;
- Do It Yourself [DIY];
- Compatibility with existing building functions and aesthetics;
- Reduce the waste production by at least 30%;
- Lightweight;
- Low environmental impact using Life Cycle Assessment (LCA);
- Economic sustainability.

These solutions have been generated within WP4 of the EASEE research project. The investigated design solutions are:

1- **Prefab (improved advanced perlite boards in Fig. 1):** Insulation panel glued on an expanded glass granulate panel.
2- **Deployable wall (aerogel/laminated boards in Fig. 1):** Insulation material glued on expanded glass granulate panel (L 1.2 m X H 0.33 m), connected together by flexible elements, which allows packaging.
3- **Enhanced Wallpaper (permeable insulating wallpaper in Fig. 1):** Rollable insulation layer with textile finishing.

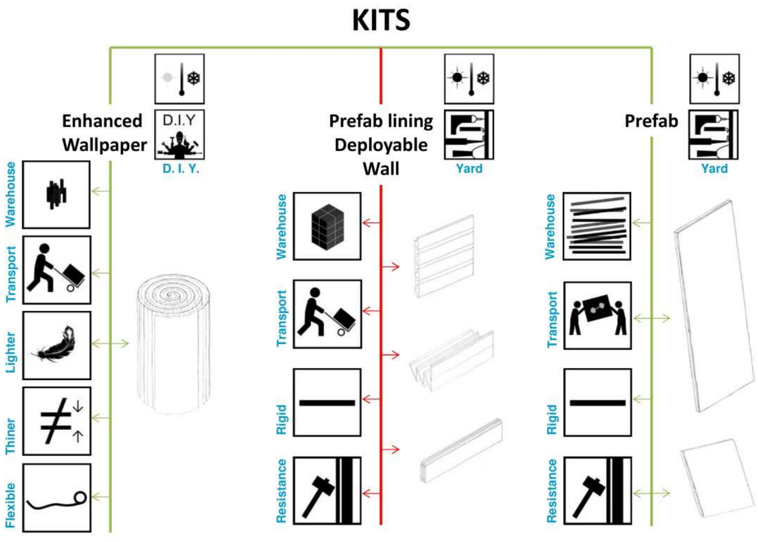

Fig. 2: Characteristics of the different investigated design solutions.

Each of these investigated solutions has specific characteristics, briefly summed up in Fig. 3.

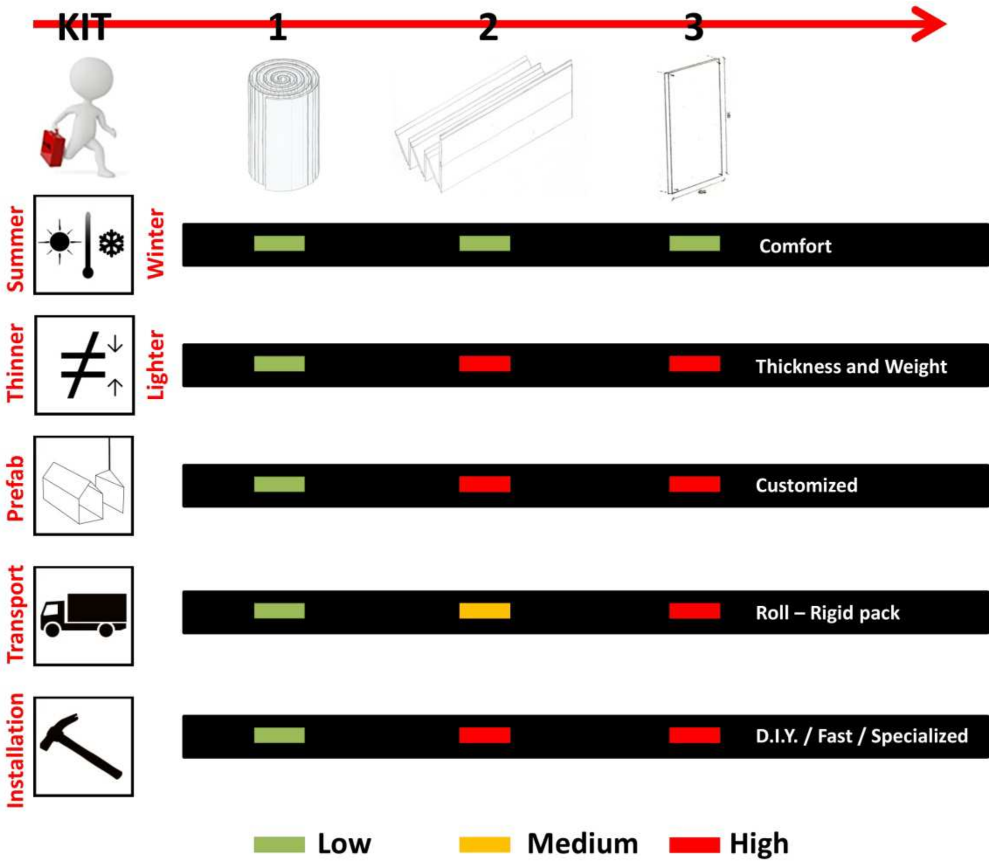

Fig. 3: Kits characteristics.

1.2 Kit A.1: Advanced perlite board

1.2.1 Concept of the board

This configuration represents a hydrophilic perlite board which allows gluing and reinforcing rendering with a continuous hydrophobic zone in a defined depth of the board to avoid liquid moisture transfer to the room side but to allow water vapour diffusion i.e. drying into both directions. Fig. 4 shows a schematic representation with the hydrophobic layer in a depth of 25 mm of a totally 60 mm thick panel.

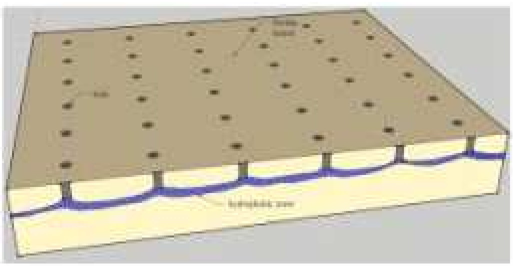

Fig. 4: Schematic representation of the advanced perlite board.

In order to guarantee the installation of the above described solution, SCHWENK developed two special products:

- The glue for gluing the perlite boards on the wall.

- The mineral cement filler as panel finishing

Fig. 5 shows samples of the glue used for walls and the filler used for finishing.

Fig. 5: Perlite board glue and filler.

The glue was based on a mineral binder. The product is free of pollutants (the components are REACH conform).The components are cement, grains, perlite and some harmless additives. The application occurs in buttering floating procedure. The next coating can be applied upstairs 20-24 hours. The table below reports some technical data.

Table 1: Cement glue technical data.

Water demand (%)	31%
Wet density (kg/dm³)	1432
Air pores (%)	12
Thermal conductivity λ	0,169 W/m²k
water vapour transmission µ	9,8
Flexural strength 7d	1,05 N/mm²
compressive strength 7d	2,75 N/mm²
Flexural strength 28d	3,3 N/mm²
Compressive strength 28d	7,5 N/mm²
Randament	ca. 940 lt/m³
Shrinkage	0,5 - 0,6 mm/m
Thickness for application as glue	4-8 mm buttering floating
Density 28 d (kg/m³)	1178

Dry density 28 d (kg/m³)	1121

The filler, whose function is to safeguard the insulation panel, has a good thermal conductivity and vapour transmission besides a very good impact resistant. For secure to get cracks or pin holes a reinforcement fabric in the filler has been made. It´s possible to apply the filler with hand or with machine. After 24 hours the final layer can be applied. The table below reports some technical data.

Table 2: Cement filler technical data.

Water demand (%)	88%
Wet density (kg/dm³)	712
Air pores (%)	31
Thermal conductivity λ	0,093 W/m²k
water vapour transmission µ	6,6
Flexural strength 7d	0,15 N/mm²
compressive strength 7d	0,25 N/mm²
Flexural strength 28d	0,78 N/mm²
Compressive strength 28d	1,76 N/mm²
Randament	ca. 1950 lt/m³
Shrinkage	0,5 - 0,6 mm/m
Thickness for application as filler	4-6 mm
Density 28 d (kg/m³)	563
Dry density 28 d (kg/m³)	532

1.3 Kit B.1: Permeable insulating wallpaper

1.3.1 The concept of the wallpaper

The idea behind the permeable insulating wallpaper design is to have an insulation system, which can be rollable, compact, lightweight, easily portable and handy, maneuverable even by one single person. Connections and fixing systems have been designed following the will to create a finished product (insulation + finishing) that could be easily adaptable to the specific apartment needs according to the surface shape of the wall, not always regular especially in old buildings. Everything has to happen in a simple, intuitive, fast way, and most of all, Do It Yourself (DIY).

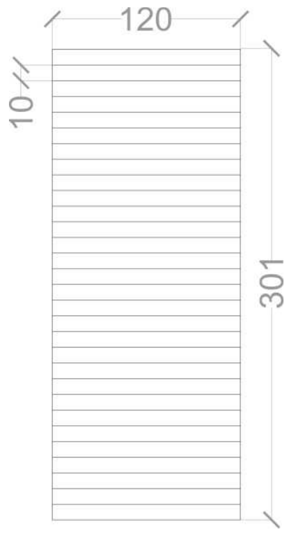

Fig. 6: Elevation of insulation layer (wallpaper solution).

This concept has been developed following two distinct routes:

1) In order to meet the rollability needs of material, a slats' insulation layer has been designed (each slat is 120 cm X 10 cm, making a total of thirty slats, as showed in Fig. 6), coated on both sides by a textile layer of polyester (PES). Polyester fabric linked to the wall is a single piece, whereas fabric, which covers the insulation layer facing the inside, is divided in small pieces with the same dimensions as slats and glued on them (Fig. 7). In this way, a rollable insulation system has been achieved, easily transportable and storable.
2) In order to achieve the desired lightness, it was decided to work on the finishing using a textile finishing instead of the usual plasterboard panels. In this way, a thin and light insulation kit (insulation + finishing) has been developed. Making a comparison between the wallpaper solution and the previous ones and considering just finishing weights (recycled glass and fabric) it's possible to obtain, in wallpaper solution, a weight reduction of 26.7 Kg; indeed, the mean weight of the fabric is 1.5 Kg (referred just to the textile finishing for a module of L 120 cm X H 300 cm), while the mean weight of the recycled glass is 28.2 Kg.

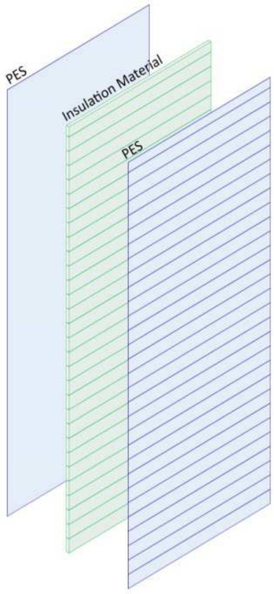

Fig. 7: Layers composing the slats' insulation roll.

The panel textile finishing design, however, has to face and solve other issues such as:

- Guaranteeing the correct finishing cleanliness and its easy replacement over time. For these reasons the finishing has been conceived in order to ensure an easy removal system of the wall itself.
- Guaranteeing optimal values of vapor permeability. By appropriately choosing the textile finishing, it's possible to obtain an insulation system that could be breathable or non-breathable, making its application suitable to whatever climatic context.

Fig. 8: a) Rollable system's prototype, b) Insulation fixing to the wall, c) Prototype detail of a tensioning textile system for internal spaces currently on the market.

Besides these aspects, from the study of internal walls' textile solutions already available on the market and developed through textile tensioning, a problem due to the use of fibrous textile (for instance a cotton fabric) emerged. In Fig 10.c it is possible to observe this problem through the photo of a prototype made with one of those systems. From this photo it's evident how a fibrous fabric could compromise the correct tensioning of the textile. Therefore, an installation system has been defined, in order to solve this problem enabling the future client to be totally free in the choice of textile finishing, feasible both with fibrous and coated materials.
In order to meet all the requirements outlined above, several prototypes have been developed; some of these have already been presented in the previous project documents. Here are the last designed solutions, which let to develop the best final one.

Table 3: Stratigraphy and weights of the insulation mat.

LAYER	THICKNESS [cm]	MATERIALS	WEIGHT [Kg/m^2]
Polyester	/	Polyester	/
Glue	/	Polyethylene	/
Insulation Materials	3 – 6	Polyester + Silica Aerogel	/
Glue	/	Polyethylene	/
Polyester	/	Polyester	/
Nails	8	Steel	9 X 0.002 = 0.018
Tot.			/

In the following paragraphs, the design path of the optimization process regarding installation solution of the textile finishing is described. The three proposed solutions have in common the installation procedures of the insulation, but differ for the installation system of the textile finishing.

1.3.1.1 Sol 1 - Wallpaper. Upper and lower aluminum profiles

KIT:	TOOLS:
Insulation material	Meter
Upper Profile (Fig. 12a)	Screws
Lower Profile (Fig. 12b)	Nails
Keder (Fig. 12c)	Cutter
Finishing Textile	Scissors
	Saw
	Hammer

Fig. 9: Kit and tools.

Fig. 10: a) Upper profile, b) Detail of textile slot for Keder, c) Lower profile.

This solution is composed by an upper profile and a lower profile (Fig. 10). These profiles are fixed to the wall with some screws (3 screws per ml, making a total of 6 screws). In the upper part, finishing textile has to be realized including a textile slot in which a Keder cord (PVC) can be inserted (Fig. 10). Profiles (usually 2 – 3 ml dimensions are sold) need to be cut on-site with a saw for iron, according to the length needed. Once prepared, it's possible to proceed assembling the solution (Fig. 11).

Fig. 11: Sequence of assembling: 1- Inserting fabric with Keder in the upper profile, 2- Fixing the upper profile, 3- Fixing the lower profile, 4- Fabric tensioning, 5- Fabric fixing.

Fig. 12: Detail of the upper and lower profile.

Table 4: Stratigraphy and weights of the wallpaper system: Upper and Lower Profiles.

LAYER	MATERIALS	WEIGHT [Kg/1.2 m]
Upper Profile	Aluminium	0.22
Keder	PVC	0.05
Lower Profile	Aluminium + PVC	0.23
Finishing textile	/	1.5 (indicative value)
Tot.		2

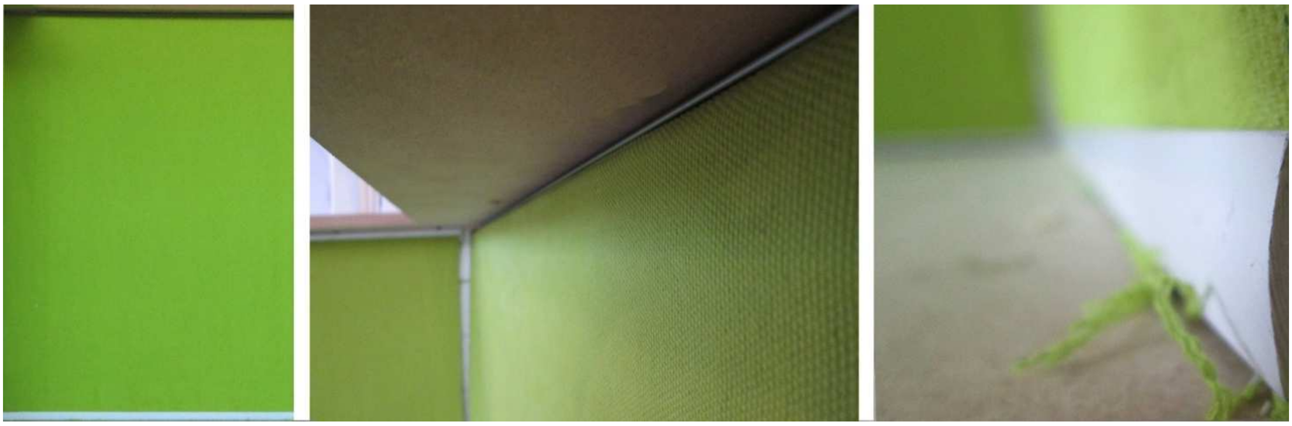

Fig. 13: Detail of the finished solution. On the left: Elevation; in the middle: upper profile; on the right: lower profile.

Different solutions have been studied to provide a fastening system for the finishing layer that are quick and reversible. This part of the research is currently under intellectual rights protection in view of future patents

1.3.2 Choice of the textile layers for backing and finishing

On behalf of the project meeting agreements, investigation on finishing textiles for the inner insulation panels/wallpaper in the EASEE project was performed. The general given requirements of the textile materials were: insulation properties, good breathability, aesthetics, and the fact that the material should not exhibit lining.

Therefore key elements - composition, material properties, product price and market availability were taken into account. Modified polyester (PES) - based textiles were chosen as the most appropriate, conforming to the requirements. Modification of the textile surface that contributes to its characteristics is performed by the following processes: coating and lamination. Therefore textiles can be coated with an additional polymer (that is a cheaper solution) or laminated with a membrane which generally is more expensive), but laminated materials exhibit far better performance. Polymers widely used in the textile industry for these applications are: , polyurethane (PU) (most cost effective), , (PES) – of moderate price range - and polytetrafluoroethylene (PTFE) – most expensive but of best performance, designed especially for sport clothing. For the purpose of the EASEE project a moderate cost-effective solution for polyester (PES) based laminates was used.

Textile laminates with breathable membranes are used extensively in waterproof clothing items such as jackets, footwear and gloves. The polymer membranes act as a barrier to liquid water and soil entry from the environment, but they are sufficiently permeable to water vapour to allow significant amounts of sweat or moisture to evaporate through the clothing system and greatly affect the comfort of the wearer.
The waterproof, windproof and breathable membrane are created of great deal of microscopic pores per square centimetre. To construct the fabric, a membrane is connected to the upper material and lining with special glue and then laminated under pressure.

The microscopic pores in the membrane are 20,000 times smaller than a drop of water, which means that a drop of water cannot pass through them. The membrane has billions of tiny pores per square inch, allowing the water In clothing products, to increase water resistance, zippers are covered by laminate and sealing seams is practised, which reduces the risk of seepage through the holes created during sewing. Textiles may be covered with a durable water repellent polymer used for the outer layer to avoid soaking drops in it. Water resistance is therefore measured in millimetres of water per m^2, which acting on the material does not break down its water resistance. The higher the number, the more the material is waterproof, and that is another parameter taken into account in the appraisal of the material.

The other key element that was taken into account is good breathability. Breathability of these materials is measured in g/m^2 per 24 hours, which defines how much water vapour is able to pass a material, having a surface area of 1 m^2 / per day (MVT – Moisture Vapour Transfer) expressed as $g/m^2/24hrs$ – moisture vapour transmission - the more the better. Another parameter, accepted as an industry standard is Ret - resistance to the water vapour transmission, expressed as $Pa{\cdot}m^2/W$. In this case, the lower the value, the better. For moderate effort there should be waterproof clothing over 20,000 mm/m^2 and breathability more than 15,000 and less than 10 g/m^2 Ret. In sport clothing, that require high activity like running, climbing or walking in difficult terrain, breathable clothing to a standard of at least 20,000 $g/m^2/24h$.

Table 5: Breathability values expressed in Ret units according to the ISO 11092:1993 - Textiles -- Physiological effects -- Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test).

Breathability	Usage
Ret 2-4 (30000-25000 g/m^2/24h)	Best breathability - dedicated to increased physical effort
Ret 5-7 (25000-20000 g/m^2/24h)	Excellent breathability – dedicated to increased physical effort
Ret 8-13 (20000-15000 g/m^2/24h)	Very good breathability – dedicated to average physical effort
Ret 14-20 (15000-10000 g/m^2/24h)	Acceptable breathability – dedicated to minimal physical effort
Ret 21-30 (10000-5000 g/m^2/24h)	Barely breathable, are not suitable for increased activity
Ret more than 30 (5000-0 g/m^2/24h)	Practically unbreathable

1.3.3 Composition of the fabrics that were selected for the project purpose

The following fabrics have been investigated in order to assess the best one to be further analysed and used for the project aims.

1.3.3.1 Coated and 2-Layer Laminates (bi-laminates) textiles

The fabric has been developed due to demand of soft and lighter fabrics. This fabric not only guarantees comfort, it can also be chosen depending on activity and individual needs. Textiles manufactured by polish textile manufacturer Optex S.A. were chosen, due to the market availability and price, all in white colour for aesthetics. The product is soft, lightweight, multi-purpose. 2-layer construction is light and simple. The membrane is permanently connected to the outer fabric, and as the softest and lightest product it is the most universally used.

TEXTILE 1
Brand name: TO-OPT-131
MASS 100 +- 5 g/m^2
COATED – WHITE
COMPOSITION: 100% POLYESTER
WATERPROOF – VAPOUR PERMEABLE

TEXTILE 2
Brand name: TO-OPT-072
MASS 146 +- 6 g/m^2
BI-LAMINATE - WHITE-
COMPOSITION: 100% POLYESTER + 100% PTFE membrane
LAMINATED-WATERPROOF-VAPOUR-PERMEABLE

TEXTILE 3
Brand name: TO-OPT-076
BI-LAMINATE - WHITE
MASS 160 +- 6 g/m^2
COMPOSITION: 100% POLYESTER + 100% Polyurethane membrane
LAMINATED-WATERPROOF-VAPOUR-PERMEABLE

1.3.3.2 3-Layer Fabrics (tri-laminates)

At present, the fabric is used for the production of many types of clothing and insulation layers that can be used in various situations. Due to the design of the membrane placed in a permanent way between the outer layer and the lining, we get a very strong and durable connection. Advantages: Made of the most durable material, perfect for the poor environmental conditions with respect to the weight. Textiles manufactured by polish textile manufacturer Optex S.A. were chosen, due to the market availability and price, all in white colour for aesthetics.

TEXTILE 4

BRAND NAME TO-OPT-099/TYPHOON 56
TRI-LAMINATE – WHITE
MASS 195 +- 15 g/m^2
COMPOSITION: 3X POLYESTER
LAMINATED-WATERPROOF-VAPOUR-PERMEABLE

TEXTILE 5
BRAND NAME TO-OPT-098/TWISTER-30
BI-LAMINATE – WHITE
MASS 145 +- 6 g/m^2
COMPOSITION: 2 X 100% POLYESTER
LAMINATED-WATERPROOF-VAPOUR-PERMEABLE

1.3.4 Production of sample aerogel impregnated panels, coupling of aerogel layers and coupling of aerogel layer with backing / finishing.

A non-woven polyester textile has been pored over with a sol (liquid) until it was completely covered. The sol gelated in a next step and was dried afterwards. By doing so the air volume in the textile was replaced by aerogel reducing the thermal conductivity of the textile. As the production plant belongs to a producer outside the present consortium, no additional information regarding the production procedure can be delivered. The final mat has a thickness of about 5-6 mm.

The glue for fixing the wallpaper to the wall is provided by Schwenk.

It has been left open whether a tri-laminated PES textile (Ridan) will be glued by ironing to the internal surface of the insulating wallpaper (see Fig. 14), previous to covering it with a final textile clamped at the top and bottom of the wall.

Fig. 14: Example of Aerogel containing non-woven PES mat coupled with a white tri-laminate Polyester-finishing textile.

1.4 Kit B.2: Flat laminated panel

1.4.1 Considerations about the finishing layers

1.4.1.1 Prefab system

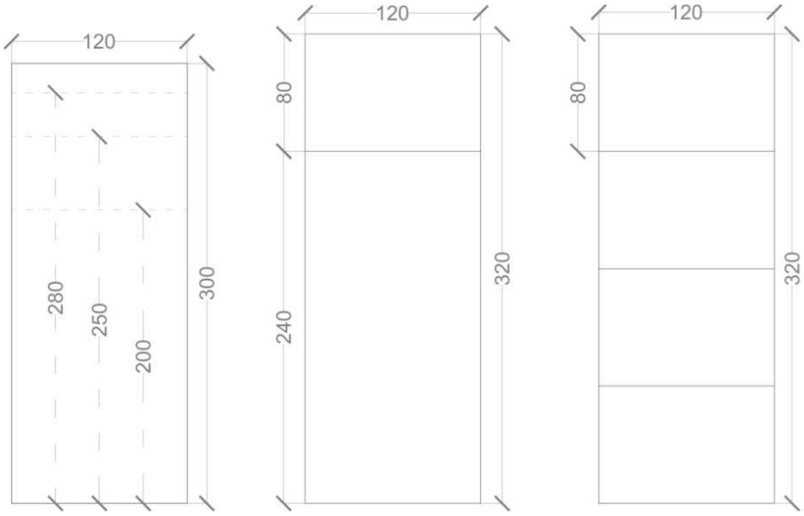

Fig. 15: Elevation of the prefab design solution 1) Insulation coupled to a traditional plasterboard panel 2 – 3) Insulation coupled to an expanded glass granulate panel.

The prefab system solution developed in WP4 is similar to prefab insulation panels already available on the market; these panels requires on-site adjustments. The panel could be attached to the existing wall or fixed to a substructure.

The will is to market a system that is well known, broadly tested and already largely accepted by future users. The system is composed by an expanded glass granulate panel coupled to thermal insulation (Non-woven textile, 100% PES impregnated with silica Aerogel) developed within WP4. The panel has to cover a height of 3 m. So, panel dimensions are: L 120 cm and H 300 cm. However, the height of the panel can be reached both by a single panel 300 cm high (panels with different heights are available on the market: 200 cm, 250 cm, 280 cm…) and shorter panels (Fig. 15). Panels can be cut with a cutter and adapted to the wall.

Table 6: Layers and weights of the prefab system

LAYER	THICKNESS [cm]	MATERIALS	WEIGHT [Kg] L 1,2 m X H 3 m
Insulation Materials	3 – 6	/	/
Glue	/	/	/
Expanded glass granulate	1.25	Recycled glass	26.64
Paint	0.0003	Made of acrylic resins in emulsion	1.08
Fixing plug	8	Polypropylene with nylon nail reinforced with fiberglass PA6 GF30	0.035 X 12 = 0.42
Tot.			28.14

Concerning weight, taking into account the dimensions of H 300 cm X L 120 cm and the stratigraphy of Table 10, the panel weighs 28.14 Kg (plus the weight of insulation). Added to the dimensions of the panel itself, weight makes difficult both handling and transport of the panel by a single person.

1.4.1.2 Prefab lining, deployable wall

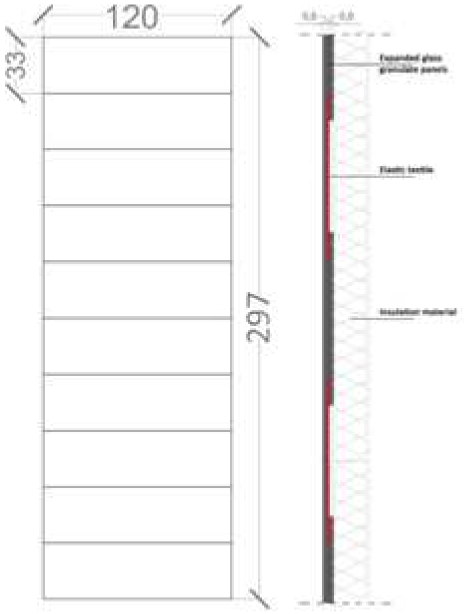

Fig. 16: Elevation and section of the deployable wall solution.

The deployable wall system is composed by rigid elements small in size (33 cm X 120 cm), realized with plasterboard panels (pre-coupled with aerogel insulation developed in WP4). This system has been conceived in order to simplify transport and storage. The individual elements are linked together through flexible elements (elastic fabric bands) which allow to pack the element during the phases of storage and transportation, unpacking it during installation (Fig. 18). Packed system's dimensions (L 120 cm X H 80 cm) have been thought in order to facilitate stacking on pallets (standard pallet dimensions: 120 cm X 80 cm), as in Fig. 35. Besides packed system's dimensions, the total weight of the system has been reduced, making its portability and manageability easier. Solution's weight is 25.6 Kg (plus the weight of insulation), 2.54 Kg less than the previous solution. The smaller weight is due to the T section of the elements (Fig. 16).
The installation of this system is made through two fixing plugs for each slat, making a total of 18 fixing plugs per linear meter (for H 3 m). Dimensional adaptability of the panel to the wall could be obtained cutting the elements with a cutter, as for the previous solution.

Table 7: Stratigraphy and weights of the deployable wall system.

LAYER	THICKNESS [Cm]	MATERIALS	WEIGHT [Kg] L 1,2 m X H 3 m
Insulation Materials	3 – 6	/	/
Glue	/	/	/
Expanded glass granulate	1.25	2 - Plasterboard	24.17
Elastic Textile	/	/	0.028
Paint	0.0003	Made of acrylic resins in emulsion	0.8
Fixing plug	8	Polypropylene with nylon nail reinforced with fiberglass PA6 GF30	0.035 X 18 = 0.63
Tot.			25.6

During installation, utmost attention must be given to the juxtaposition between slats, avoiding possible discontinuities. This aspect is really important insofar as discontinuity between slats could generate a thermal bridge with all the related consequent problems (Fig. 36, Fig. 37a).

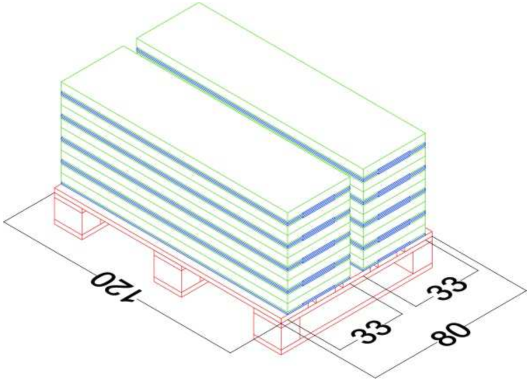

Fig. 17: Stacking on pallets of the system.

Installation feasibility has been evaluated through realization and assembling of some prototypes in 1:1 scale, applied on a surface of $1m^2$. From this study, as reported in deliverable D4.3, the need to use an elastic textile band emerged. Instead, a series of considerations came up from the system installation. For its assembly, two persons are needed; for wall fixing, two fixing plugs per slat are necessary because, otherwise, slats without fixing plugs would not be in compliance with the existing wall (Fig. 18).

Fig. 18: Sequence of assembly.

Fig. 19: a) Back view of the assembled system, b) Fixing details of the textile finishing.

In order to facilitate dismissing procedures of the deployable wall, a textile finishing has been chosen; in fact, gaps should be refined in order to be hidden, so textile could be used in order to hide gaps and to have the possibility of removing fixing plugs and then dismissing everything. This finishing system is fixed to the plasterboard panel on the upper part and to the skirting board on the bottom part (Fig. 19).

1.4.2 Coupling of aerogel layer with recycled glass board

The developed laminated panel consists of three aerogel-containing mats (5-6 mm) stick together by discontinuous layers of polyethylene and a covering panel (8 mm) of expanded recycled glass (commercially available). The aerogel mats have been produced using the same procedure as the wallpaper explained above.
The glue for fixing the 3 mats to the expanded recycled glass panel has been put together at Empa consists of a water glass based (potassium silicate) with other additives

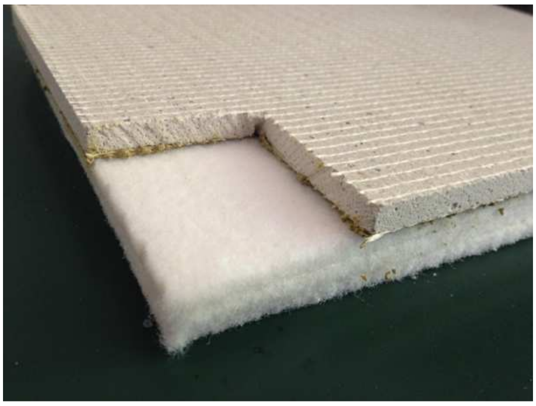

Fig. 20: Three layers of aerogel containing PES mats and an expanded recycled glass board-

The glue for fixing the whole sandwich to the wall will be provided by Schwenk.

2 Tests about Hygrothermal properties

Lab tests for determining the main hygrothermal properties of the materials composing the three solution kits have been carried out at EMPA. The testing procedures are in compliance with the relevant European standards, as listed below:

1) EN ISO 12571:2000, Hygrothermal performance of building materials and products-Determination of hygroscopic sorption properties;
2) EN ISO 12572:2001, Hygrothermal performance of building materials and products-Determination of water vapour transmission properties;
3) ISO 15148:2002 Hygrothermal performance of building materials and products-Determination of water absorption coefficient by partial immersion;
4) EN 12087: 2013 Thermal insulating products for building applications -Determination of long term water absorption by immersion;
5) EN 12667:2001, Thermal performance of building materials and products – determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Products of high and medium thermal resistance.

2.1 Materials properties for Kit A.1: Advanced perlite board

The samples for testing have been cut from boards 500x500mm in the required size and conditioned (see Fig. 21). All the properties already are summarized below:

Table 8: Main hygrothermal properties of perlite boards.

PERLITE BOARD	Test condition description	Value	Unit	Standard
Bulk density	Determination of volume and weighing of sample after conditioning:		$kg\ m^{-3}$	EN 1602:1999
ρ_{dry}	Dried at 65°C until constant mass	**190**		
$\rho_{50\%}$	At 23 ± 0.5°C and 50 ± 3 %RH	**200**		
Thermal conductivity	Both heat flow meter and guarded hot plate (hot plate 30°C – cold plate 10°C):		$mW\ m^{-1}K^{-1}$	EN 12667:2001
λ_{dry}	After drying at 65°C until constant mass	*		
$\lambda_{50\%}$	Conditioned at 23 ± 0.5°C, 50 ± 3% RH	**60±5**		
λ_{wet}	After total immersion in water	*		
Water vapour resistance	Dry and wet cup method inside conditioning chamber at 23 ± 0.5°C and 50 ± 3% RH:		-	EN ISO 12572:2001
μ_{dry} hydrophilic board	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	5-6		
μ_{dry} hydrophobized board		*		
μ_{wet} hydrophilic board	By means of $NH_4H_2PO_4$ aqueous solution for 93% RH inside the cup	6-7		
μ_{wet} hydrophobized board		*		
Water absorption coefficient	Partial immersion (5mm thick) of squared samples after sealing 4 sides:		$kg\ m^{-2}\ h^{-0.5}$	ISO 15148:2002
A_{w24} - hydrophilic board	Both side not hydrophobized	*		
A_{w24} - hydrophobized board	Hydrophobized side into the water	*		
Hygroscopic sorption (at isotherm condition)	After drying at 65°C, conditioning at 23 ± 0.5 °C and RH consecutive steps until the equilibrium (constant mass) is reached:		$kg\ kg^{-1}$ (%)	EN ISO 12571:2000
$u_{at\ 30\%}$	RH 30% - inside the conditioning room	1.10		
$u_{at\ 50\%}$	RH 50% - inside the conditioning room	1.83		
$u_{at\ 80\%}$	RH 80% - inside the conditioning room	4.54		
$u_{at\ 95\%}$	RH 95% - inside the climatic chamber	*		
Free water saturation	Total immersion into the water for 1 month (28 days) minimum		$kg\ kg^{-1}$ (%)	EN 12087: 2013
$u_{at\ 100\%}$	Moisture content after surface drying	*		

* Value not yet available

Fig. 21: Perlite specimens, with and without hydrophobic agent, ready for testing.

2.2 Materials properties for Kit B.1: Permeable insulating wallpaper

2.2.1 Aerogel containing non-woven PES

All the properties of the aerogel based mat, non-woven PES fibres after aerogel impregnation are summarized in the table below:

Table 9: Main hygrothermal properties of aerogel containing non-woven PES.

PES plus AEROGEL	Test condition description	Value	Unit	Standard
Bulk density	Determination of volume and weighing of sample after conditioning:		kg m^{-3}	EN 1602:1999
$\rho_{50\%}$	At 23 ± 0.5°C and 50 ± 3 %RH	**160**		
Thermal conductivity	Both heat flow meter and guarded hot plate (hot plate 30°C – cold plate 10°C):		mW $m^{-1}K^{-1}$	EN 12667:2001
$\lambda_{50\%}$	Conditioned at 23 ± 0.5°C, 50 ± 3% RH	**24**±2		
$\lambda_{80\text{-}95\%}$	Conditioned at 23 ± 0.5°C, 80-95% RH	**24**±2		
λ_{wet}	After total immersion in water	**28**±2		
Water vapour resistance	Dry and wet cup method inside conditioning chamber at 23 ± 0.5°C and 50 ± 3% RH:		-	EN ISO 12572:2001
μ_{dry}	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**4 - 6**		
μ_{wet}	By means of $NH_4H_2PO_4$ aqueous solution for 93% RH inside the cup	**2 - 4**		
Water absorption coefficient	Partial immersion (5mm thick) of squared samples after sealing 4 sides:		kg m^{-2} $h^{-0.5}$	ISO 15148:2002
A_{w24}	Difficult to determine due to very low value	*		
Hygroscopic sorption (at isotherm condition)	After drying at 65°C, conditioning at 23 ± 0.5 °C and RH consecutive steps until the equilibrium (constant mass) is reached:		` (%)	EN ISO 12571:2000
$u_{at\ 30\%}$	RH 30% - inside the conditioning room	**0.31**		
$u_{at\ 50\%}$	RH 50% - inside the conditioning room	**0.44**		
$u_{at\ 80\%}$	RH 80% - inside the conditioning room	**0.61**		
$u_{at\ 95\%}$	RH 95% - inside the climatic chamber	**0.73**		
Free water saturation	Total immersion into the water for 1 month (28 days) minimum		kg kg^{-1} (%)	EN 12087: 2013
$u_{at\ 100\%}$	Moisture content after surface drying	**6.83**		

2.2.2 Effect of PE layer on properties

Adding a PE layer (discontinuous) does not affect the permeability of the aerogel containing PES mat. The water vapour resistance increasing at wet state (50/93 %RH) is determined by non-hygroscopic behaviour of PE and boundary effects. The thermal conductivity value increases by 2-3 mW mK^{-1} with respect to the original aerogel-PES mat.

Table 10: Main hygrothermal properties of aerogel containing non-woven PES plus melted PE.

PES – AEROGEL plus PE	**Test condition description**	**Value**	**Unit**	**Standard**
Thermal conductivity	Both heat flow meter and guarded hot plate (hot plate 30°C – cold plate 10°C):		mW $m^{-1}K^{-1}$	EN 12667:2001
$\lambda_{50\%}$	Conditioned at 23 ± 0.5°C, 50 ± 3% RH	**26**±2		
Water vapour resistance	Dry and wet cup method inside conditioning chamber at 23 ± 0.5°C and 50 ± 3% RH:		-	EN ISO 12572:2001
μ_{dry}	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**4 - 6**		
μ_{wet}	By means of $NH_4H_2PO_4$ aqueous solution for 93% RH inside the cup	**2 - 8**[a)]		
[a)] Variability of results depends on the irregular PE layer and boundary effects				

2.2.3 Aerogel containing mat coupled with finishing textile

Several finishing woven textiles (provided by RIDAN) have been considered and tested (see Fig. 22)., The total water vapour resistance factor has been measured (see Fig. 23), as well as the thermal conductivity. The last one mentioned has been measured for the best solution in terms of permeability and adhesion (textile T.4, tri-laminate PES mass 195 +- 15 gm^{-2}).

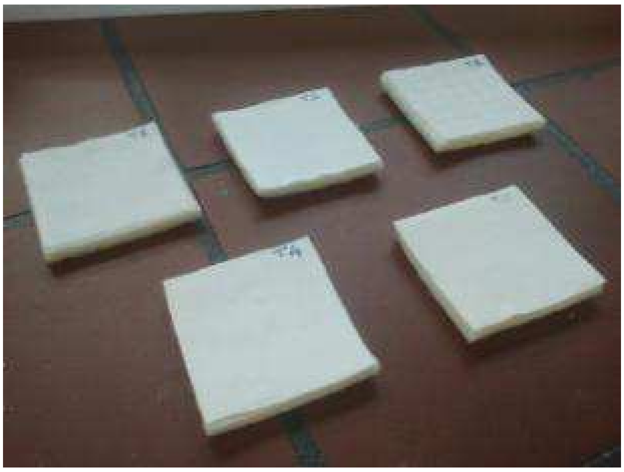

Fig. 22: Textile from 1 to 5 glued on aerogel-PES.

Fig. 23: Sample of aerogel-PES coupled with melted PE and finishing textile for the permeability test.

Table 11: Main properties of aerogel containing non-woven PES coupled with different textiles.

PES – AEROGEL plus TEXTILE	Test condition description	Value	Unit	Standard
Thermal conductivity	Both heat flow meter and guarded hot plate (hot plate 30°C – cold plate 10°C):		$mW\ m^{-1}K^{-1}$	EN 12667:2001
$\lambda_{50\%}$ with Textile T.4	Conditioned at 23 ± 0.5°C, 50 ± 3% RH	**29**±2		
Water vapour resistance	Dry and wet cup method inside conditioning chamber at 23 ± 0.5°C and 50 ± 3% RH:		-	EN ISO 12572:2001
μ_{dry} with Textile T.1	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**27**		
μ_{dry} with Textile T.2	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**16**		
μ_{dry} with Textile T.3	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**16**		
μ_{dry} with Textile T.4*	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**12**		
μ_{dry} with Textile T.5	By means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**11**		
* T.4 represents the chosen textile				

The PES-aerogel mat coupled with textile Table 16 shows a doubling of the water vapour resistance value but still guaranteeing a very good permeability for the wallpaper solution.

2.3 Materials properties for Kit B.2: Flat laminated panel

All the layers composing the B.2 solution have been tested.

Fig. 24: Pictures from the testing program.

2.3.1 Three layers Aerogel containing non-woven PES

The PES- aerogel mat for the sandwich panel is composed of three layers stick together. The water vapour resistance factor and the thermal conductivity have been measured (see Table 12). For all the other properties see Table 16.

Table 12: Main properties of three layers of Aerogel containing non-woven PES.

3 3 layer PES – AEROGEL plus PE	Test condition description	Value	Unit	Standard
Thermal conductivity	Both heat flow meter and guarded hot plate (hot plate 30°C – cold plate 10°C):		mW $m^{-1}K^{-1}$	EN 12667:2001
$\lambda_{50\%}$	conditioned at 23 ± 0.5°C, 50 ± 3% RH	**27±2**		
Water vapour resistance	Dry and wet cup method inside conditioning chamber at 23 ± 0.5°C and 50 ± 3% RH:		-	EN ISO 12572:2001
μ_{dry}	by means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**4 - 6**		
μ_{wet}	by means of $NH_4H_2PO_4$ aqueous solution for 93% RH inside the cup	**-** a)		

3.1.1 Expanded recycled glass board

The expanded recycled glass board (8 mm thickness), commercially available, has been tested to have a complete data set (see Table 13).

Table 13: Main hygrothermal properties of the expanded recycled glass board.

RECYCLED GLASS BOARD	Test condition description	Value	Unit	Standard
Bulk density	Determination of volume and weighing of sample after conditioning:		kg m^{-3}	EN 1602:1999
$\rho_{50\%}$	at 23 ± 0.5°C and 50 ± 3 %RH	**550**		
Thermal conductivity	Both heat flow meter and guarded hot plate (hot plate 30°C – cold plate 10°C):		mW $m^{-1}K^{-1}$	EN 12667:2001
$\lambda_{50\%}$	conditioned at 23 ± 0.5°C, 50 ± 3% RH	**130**		
$\lambda_{80\text{-}95\%}$	conditioned at 23 ± 0.5°C, 80-95% RH	*		
λ_{wet}	after total immersion in water	*		
Water vapour resistance	Dry and wet cup method inside conditioning chamber at 23 ± 0.5°C and 50 ± 3% RH:		-	EN ISO 12572:2001
μ_{dry}	by means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**22**		
μ_{wet}	by means of $NH_4H_2PO_4$ aqueous solution for 93% RH inside the cup	**21**		
Water absorption coefficient	Partial immersion (5mm thick) of squared samples after sealing 4 sides:		kg m^{-2} $h^{-0.5}$	ISO 15148:2002
A_{w24}	Samples 100x100mm	*		
Hygroscopic sorption (at isotherm condition)	After drying at 65°C, conditioning at 23 ± 0.5 °C and RH consecutive steps until the equilibrium (constant mass) is reached:		kg kg^{-1} (%)	EN ISO 12571:2000
$u_{at\ 30\%}$	RH 30% - inside the conditioning room	**0.12**		
$u_{at\ 50\%}$	RH 50% - inside the conditioning room	**0.21**		
$u_{at\ 80\%}$	RH 80% - inside the conditioning room	**0.52**		
$u_{at\ 95\%}$	RH 95% - inside the climatic chamber	**1.48**		
Free water saturation	Total immersion into the water for 1 month (28 days) minimum		kg kg^{-1} (%)	EN 12087: 2013
$u_{at\ 100\%}$	Moisture content after surface drying, after 21 days	**82.14**		
* Value not yet available				

3.1.2 Gluing mat between aerogel and recycled glass board

For characterizing the chosen gluing material (Fig. 25), the test program is still on-going due to the slow response of the material to the changes of environmental boundary conditions. Some value are already measured and collected (see Table 19).

Fig. 25: Sample of sandwich panel after gluing aerogel mat to the Recycled glass board.

Table 14: Main hygrothermal properties of the waterglass based glue.

WATERGLASS BASED GLUE	**Test condition description**	**Value**	**Unit**	**Standard**
Bulk density	Determination of volume and weighing of sample after conditioning:		kg m^{-3}	EN 1602:1999
$\rho_{50\%}$	at 23 ± 0.5°C and 50 ± 3 %RH	**1250**		
Thermal conductivity	Both heat flow meter and guarded hot plate (hot plate 30°C – cold plate 10°C):		mW $m^{-1}K^{-1}$	EN 12667:2001
$\lambda_{50\%}$	conditioned at 23 ± 0.5°C, 50 ± 3% RH	**180**		
Water vapour resistance	Dry and wet cup method inside conditioning chamber at 23 ± 0.5°C and 50 ± 3% RH:		-	EN ISO 12572:2001
μ_{dry}	by means of $Mg(ClO_4)_2$ desiccant for 0% RH inside the cup	**38-40**		
μ_{wet}	by means of $NH_4H_2PO_4$ aqueous solution for 93% RH inside the cup	*		
Water absorption coefficient	Partial immersion (5mm thick) of squared samples after sealing 4 sides:		kg m^{-2} $h^{-0.5}$	ISO 15148:2002
A_{w24}	Not possible to determine	**		
Hygroscopic sorption (at isotherm condition)	After drying at 65°C, conditioning at 23 ± 0.5 °C and RH consecutive steps until the equilibrium (constant mass) is reached:		kg kg^{-1} (%)	EN ISO 12571:2000
$u_{at\ 30\%}$	RH 30% - inside the conditioning room	**2.13**		
$u_{at\ 50\%}$	RH 50% - inside the conditioning room	*		
$u_{at\ 80\%}$	RH 80% - inside the conditioning room	*		
$u_{at\ 95\%}$	RH 95% - inside the climatic chamber	*		
Free water saturation	Total immersion into the water for 1 month (28 days) minimum		kg kg^{-1} (%)	EN 12087: 2013
$u_{at\ 100\%}$	Not possible to determine	**		
* Value not yet available ** Value not possible to measure due to the dissolving process in water				

4 Thermal bridges and assessment of condensation risk

This activity features the Thermal Bridges analyses for a large number of cases, which represents the critical points in a multi-storey building. The aim of this study is to understand the needs of adaptation to different climates, the impact of the added insulation on the inside surface temperatures in the worst case scenario, as well as the risk of condensation.
In particular, it is widely known that one of the biggest problems with internal insulation is the impossibility to guarantee the continuity of the insulation layer because of the interfaces with existing elements such as floor slabs and partition walls. The interruption of insulation leads to increased heat flows in the areas with lower thermal resistance. With lower surface temperatures, these areas are prone to condensation of indoor moisture and, if this water cannot evaporate back into the air, the formation of mould – which is unsightly and unhealthy.
Moreover, when thermal insulation (i.e., the temperature drop in the wall) is close to the inner surface of the wall, it is always recommended to perform an assessment of the risk of condensation to prevent the formation of liquid water in the insulating layer.

The main goals of the analysis, using DARTWIN Mold Simulator, are to:

- Assess the heat flow through the designed connections;
- Evaluate the minimum inner surface temperatures;
- Highlight the risk of condensation and mold growth;
- Suggest alternative options if problems appear to happen.

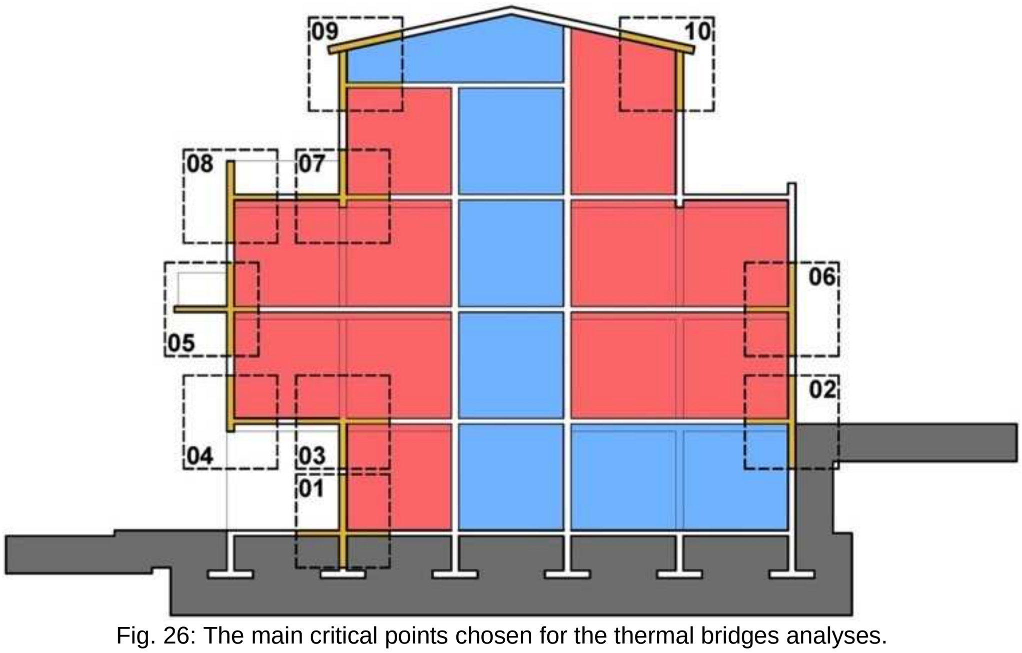

Fig. 26: The main critical points chosen for the thermal bridges analyses.

DARTWIN Mold Simulator software offers thermal bridges and condensation risk analysis in building components. The software performs the following calculations:

- <u>Thermal bridges analysis:</u>
  The software calculates the linear transmittance (Psi) value of thermal bridges. It evaluates the heat loss due to thermal bridges in walls, roofs, pillars, slabs, windows openings and other building structures. Analysis is performed according to ISO 10211:2008.
- <u>Mold and condensation risk analysis:</u>
  The software evaluates the risk of mold growth on building surfaces. It also finds any area that can be affected by surface or interstitial condensation. Analysis is performed according to ISO 13788:2013.
- <u>Dynamic heat transfer analysis:</u>
  The software evaluates dynamic thermal characteristics of homogeneous and non-homogeneous components under variable boundary condition. It can compute the thermal lag for composite structures such as walls, floors and roofs. Analysis are performed according to ISO 13786.

4.1 Climate

The chosen connections have been simulated in three climates, according to Köppen climate classification, representing the following cities (Fig. 27):

- **Agrigento, Italy:** a warm temperate climate with dry and hot summers, abbreviated as ‘Csa’.
- **Milan, Italy:** a warm temperate climate, fully humid with warm summers; abbreviated as ‘Cfb’.
- **Stockholm, Sweden:** a snowy climate, fully humid with warm summers; abbreviated as ‘Dfb’.

Fig. 27: The three climates chosen are represented in the cities of Stockholm (Sweden), Milan (Italy) and Agrigento (Italy).

4.2 Boundary conditions

4.2.1 Building walls and slabs description

One base building envelope is used according to the case presented in the EASEE Description Of Work (DOW). The insulation used internally is the Permeable Insulating Wallpaper, while externally is a normal ETICS system with EPS and a cementitious-finishing layer.
A summary of the building envelope components is found in Table 20 and Table 21.

Table 15: Base envelope - sensible properties (U = 1.16 W/m^{2}K).

Element	Element	ρ Kg/m^3	Cp kJ/KgK	λ W/mK	≠ Cm
Basic Envelope (Cavity Wall)	Int. Plaster	1800	1	0.711	2
	H. bricks	1500	1	0.919	8
	Air gap	1	1.004	0.238	10
	H. Bricks	1500	1	0.919	12
	Ext. Plaster	1800	1	0.761	2
Basic Slab	Int. Plaster	1800	1	0.711	2
	Perforated Bricks	1200	0.93	0.4	14.5
	RC Slab	2000	0.9	1.35	5
	RC Beam	2000	0.9	1.35	19
	Mortar Screed	2000	0.9	1.4	12
	Flooring Tiles	2000	0.9	1	1

Table 16: Insulation materials used.

Code	≠ (each layer) m	λ mW/mK	ρ Kg/m^3	Cp kJ/KgK
INS.1 Aerogel + Textile	0.01	15	120	0.9

The base slab changes depending on its position in the building (attached to the ground, balcony, roof… etc).
The base envelope is a masonry cavity wall with a U-value of 1.16 W/m^{2}K. Insulation layers are added in order to reduce the U-value to reach the level indicated in the various EU national regulations for refurbished buildings. However, the simulations made aimed to target less U-values than the currently required ones. This is because the EASEE project wishes for the end product to be valid for future applications as well. For that aim, the targeted U-value differed from one climate to another.
The decided U-values for the external walls in the simulations are as follows:

- Gdansk / Stockholm: U = 0.2 W/m^{2}K
  Corresponds to 6 layers of Aerogel + LOFTEX (in the case each layer = 1 cm), or 20 cm of Mixed Perlite.
- Milan: U = 0.3 W/m^{2}K
  Corresponds to 4 cm of Aerogel + LOFTEX (in the case each layer = 1 cm), or 12.5 cm of Mixed Perlite.
- Agrigento / Palermo: U = 0.4 W/m^{2}K
  Corresponds to 3 layers of Aerogel + LOFTEX (in the case each layer = 1 cm), or 10 cm of Mixed Perlite.

The difference in these U-values and the corresponding difference in the layers thicknesses are shown in Table 17.

Table 17: Table showing the needed insulation layers of each chosen material in order to fulfil the expected U-value for each of the decided climates.

Insulation Type	Layer(s) Thickness	U-VALUE (W/m^2K) Number of Insulation Layers Total Thickness								
Aerogel + LOFTEX	1 cm	1 1 cm	2 2 cm	3 3 cm	4 4 cm	5 5 cm	6 6 cm	7 7 cm		
Without a finishing Layer		0.654	0.455	0.349	0.283	0.238	0.206	0.181		
+ 1*1.25 cm Plasterboard	+ 1.25 cm	0.627	0.442	0.342	0.278	0.235	0.203	0.179		
+ 2*1.25 cm Plasterboard	+ 2.50 cm	0.605	0.431	0.335	0.274	0.231	0.201	0.177		
+ 1*0.8 cm Recycled Glass	+ 0.8 cm	0.618	0.438	0.339	0.276	0.233	0.202	0.178		
+ 2*0.8 cm Recycled Glass	+ 1.6 cm	0.586	0.421	0.329	0.270	0.229	0.198	0.175		
Mixed Perlite	2.5 cm	1 2.5 cm	2 5.0 cm	3 7.5 cm	4 10.0 cm	5 12.5 cm	6 15.0 cm	7 17.5 cm	8 20.0 cm	9 22.5 cm
Without a finishing Layer		0.740	0.543	0.429	0.355	0.302	0.263	0.233	0.209	0.190

Gdansk
Milan
Palermo

4.2.2 Position of the insulation materials

The main aim of this task is to check whether there will be thermal bridging, condensation and mould growth when adding internal insulation. However, it seemed necessary to compare it to cases where no insulation exists and in some of the cases, where external insulation is placed instead. In a climate like Milano, the Aerogel-based insulation used of 4 cm (in order to reach a U-value of 0.3 W/m2K) was substituted in the external insulation case with an 11 cm EPS layer, which results in the same U-value.

In addition, it is generally inferred that internal insulation allows heat to flow through the protruded elements, such as slabs or internal walls... etc. Therefore, a number of cases were simulated with insulation placed on the horizontal ceiling and/or the floor in different dimensions.

Windows and shutter boxes are critical components in the retrofitting process. Therefore, the following variables in the window cases have been simulated:

- In term of glazing:
  - Single-glazed
  - Double-glazed
- In term of the frame material:
  - Aluminium
  - PVC
  - Wood

In summary, throughout all the cases, the following connections insulation positions have been simulated

- No insulation.
- External full-length vertical insulation (on walls).
- External full-length horizontal insulation (on slabs).
- Internal full-length vertical insulation.
- Internal 50cm horizontal insulation.
- Internal 100cm horizontal insulation.
- Internal full-length horizontal insulation.
- Shutter box insulation.

The following Fig. 28 shows the full number of cases simulated in Milano, which adds up to 51 cases.

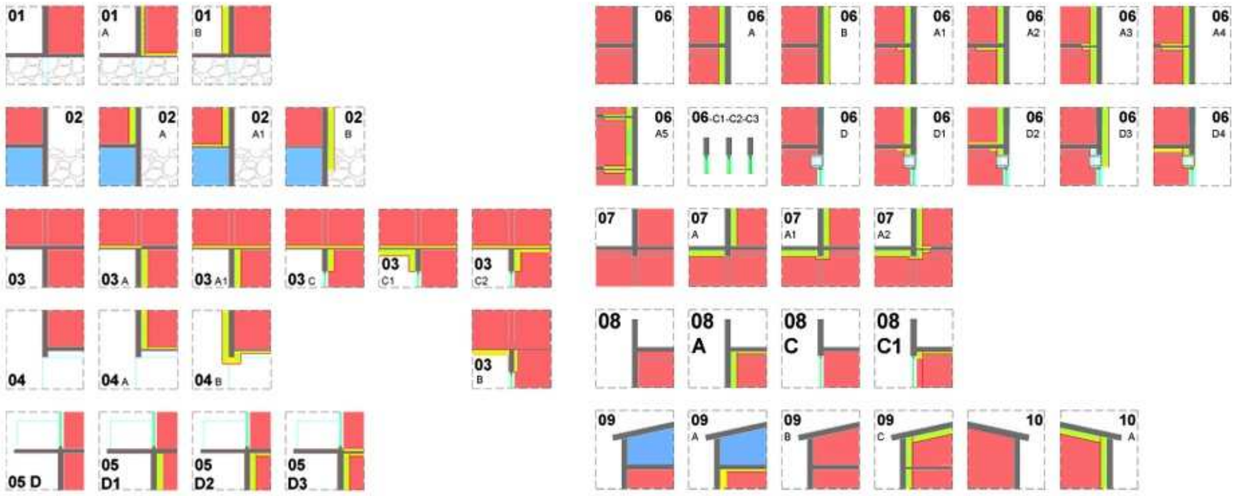

Fig. 28: Full number of cases simulated (51 cases) in Milano.

The RED highlighted zones in Fig. 28 represent the conditioned zones.
The BLUE highlighted zones represent the non-conditioned zones (e.g. Attic).
The YELLOW represents the insulation materials.
The GREY represents the walls and slabs.
The HATCH represents the ground.
The TURQUOISE represents the windows.

4.2.3 External and Internal Environments

The zones used for the simulations are as follows:

- External Zone: The external environment, simulated in the 3 previously specified climates.
- Internal Zone: The conditioned inside zones of the building, simulate with a fixed 20 °C.
- Attic: The non-conditioned inside zones of the building, simulated with a fixed 10 °C.
- Ground: The ground temperature is simulated according to a method developed in the simulation program.

4.3 Simulation results

This section aims to:

- Describe the information presented in the Annex and clarifies how to read them and compare the results.
- Summarize the work done on the critical points in terms of details and thermal bridge analyses, through the presentation of a number of the cases simulated.

The full simulation results are listed in the attached Annex 1.
In the beginning of the Annex, a general scheme is presented, showing the 51 main cases simulated in the city of Milano, as in Fig. 28.
The following pages are organized in pairs, as shown in the below example:

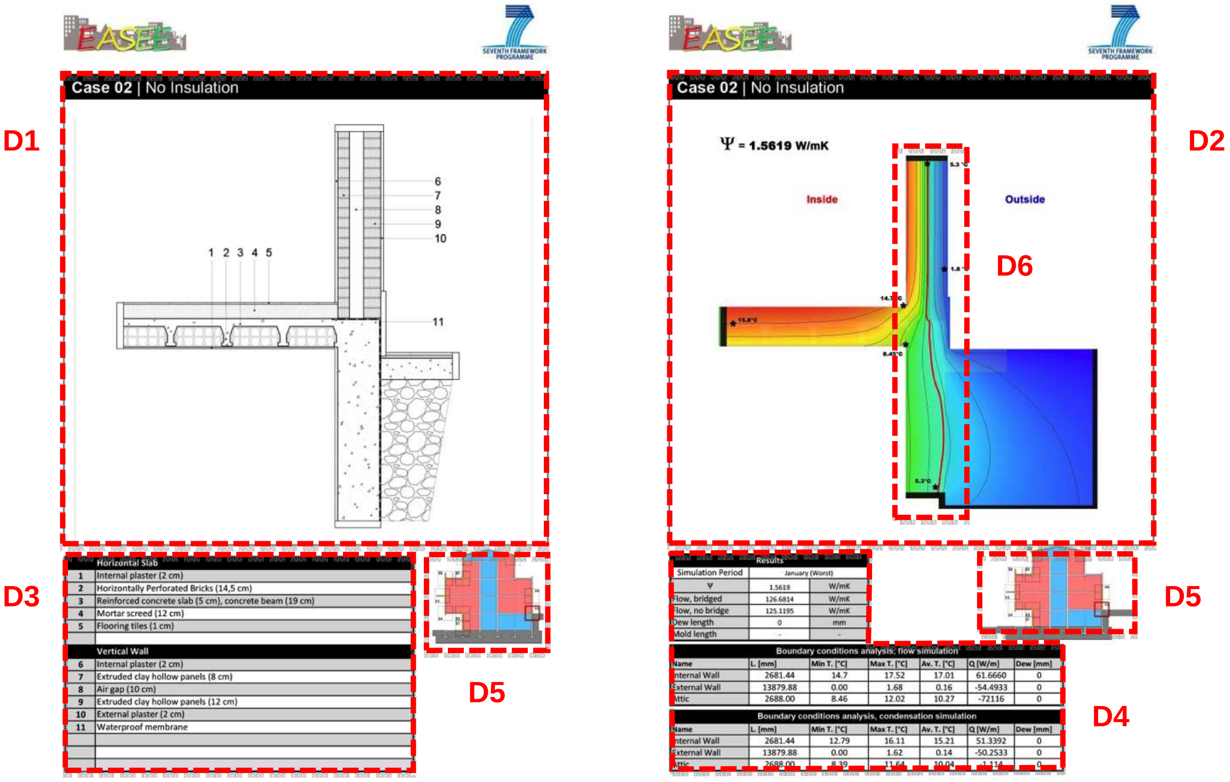

Fig. 29 Example of the pages organization in Annex 1.

Where
D1: The technological Detail.
D2: The simulation graphical result.
D3: The layers composing the vertical and horizontal layers.
D4: The simulation results and related data.
D5: The key drawing, which clarifies where the detail is taken.
D6: The red line in the simulation represents the condensation line.

4.3.1 Example – Case 06

For the sake of clarification, a few scenarios of connection no. 06 will be presented. Case 06 from Annex 1 hosts in total the following scenarios:

- Case 06: Wall connection without insulation

- Case 06-A: Wall connection with internal wall insulation
- Case 06-A1: Wall connection with internal wall + 50 cm ceiling insulation
- Case 06-A2: Wall connection with internal wall + 100 cm ceiling insulation
- Case 06-A3: Wall connection with internal wall + 50cm ceiling & floor insulation
- Case 06-A4: Wall connection with internal wall + 100cm ceiling & floor insulation
- Case 06-A5: Wall connection with complete internal insulation on walls, ceiling and floor

- Case 06-B: Wall connection with external insulation

- Case 06-C1: Wall connection without insulation and a single glazed window
- Case 06-C2: Wall connection with internal insulation and a single glazed window
- Case 06-C3: Wall connection with internal insulation and a double glazed window

- Case 06-D: Wall connection without insulation and a non-insulated shutter box
- Case 06-D1: Wall connection with internal, and 50 cm ceiling insulation

- Case 06-D2: Wall connection with internal, 50 cm ceiling and full-length floor insulation
- Case 06-D3: Wall connection with external insulation and a non-insulated shutter box
- Case 06-D4: Wall connection with internal, 50 cm ceiling, full-length floor insulation and an insulated shutter box

4.3.1.1 Comparison between internal and external insulation

The first example is a comparison between the detail in Case 06 without internal insulation, with internal insulation and with external insulation (Fig. 30, Fig. 31 and Fig. 32).

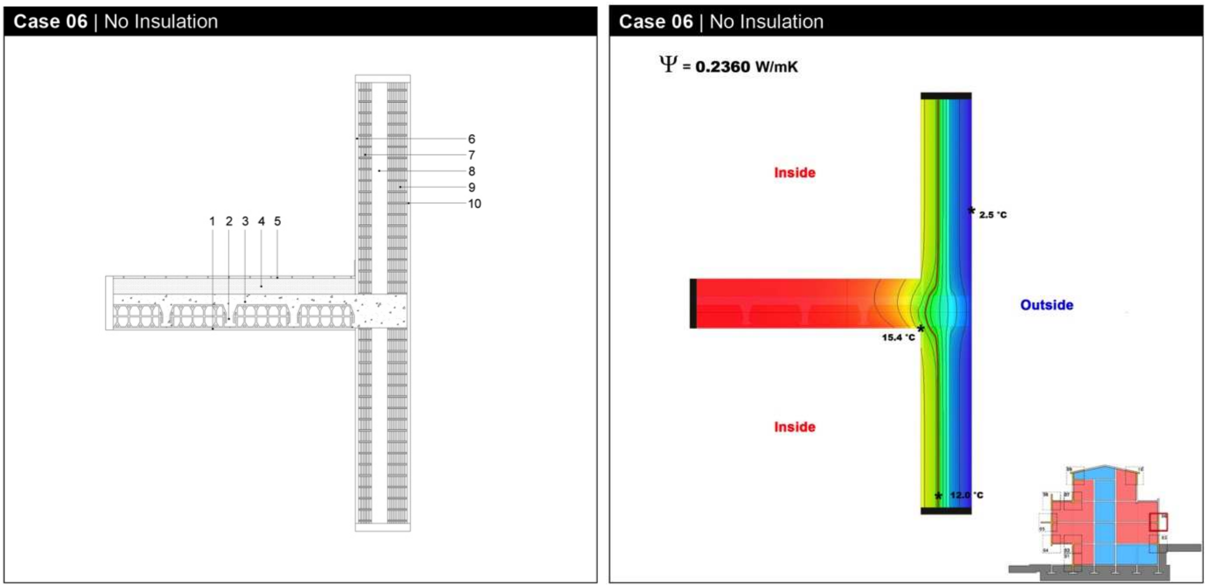

Fig. 30: Technological detail and thermal bridge simulation of Case 06 (without insulation).

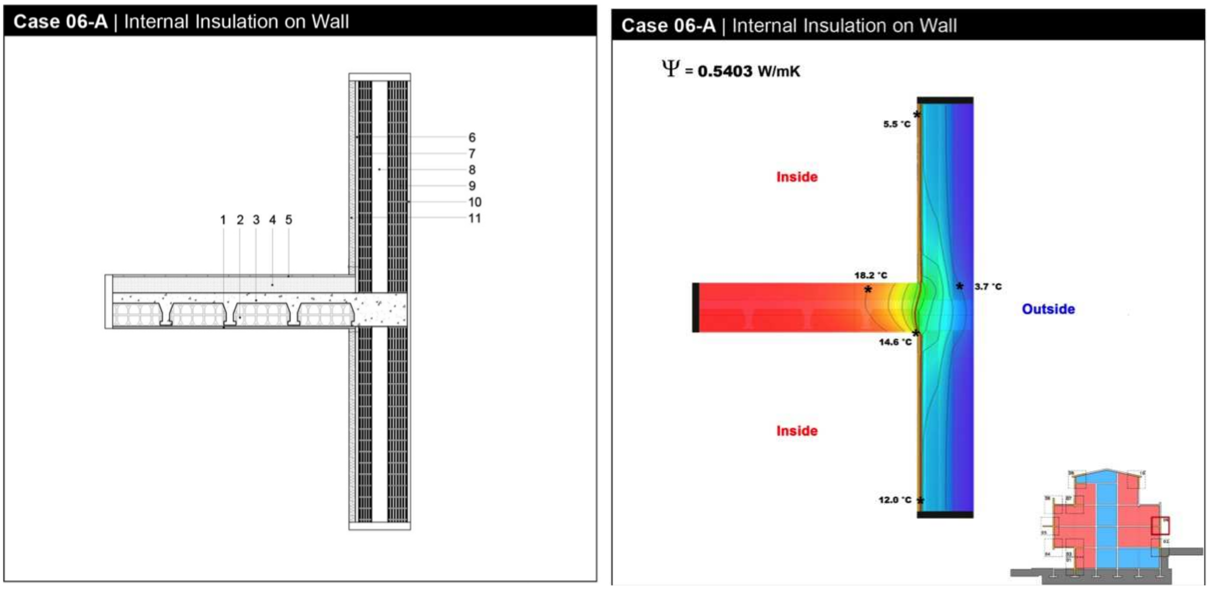

Fig. 31: Technological detail and thermal bridge simulation of Case 06-A (with internal insulation).

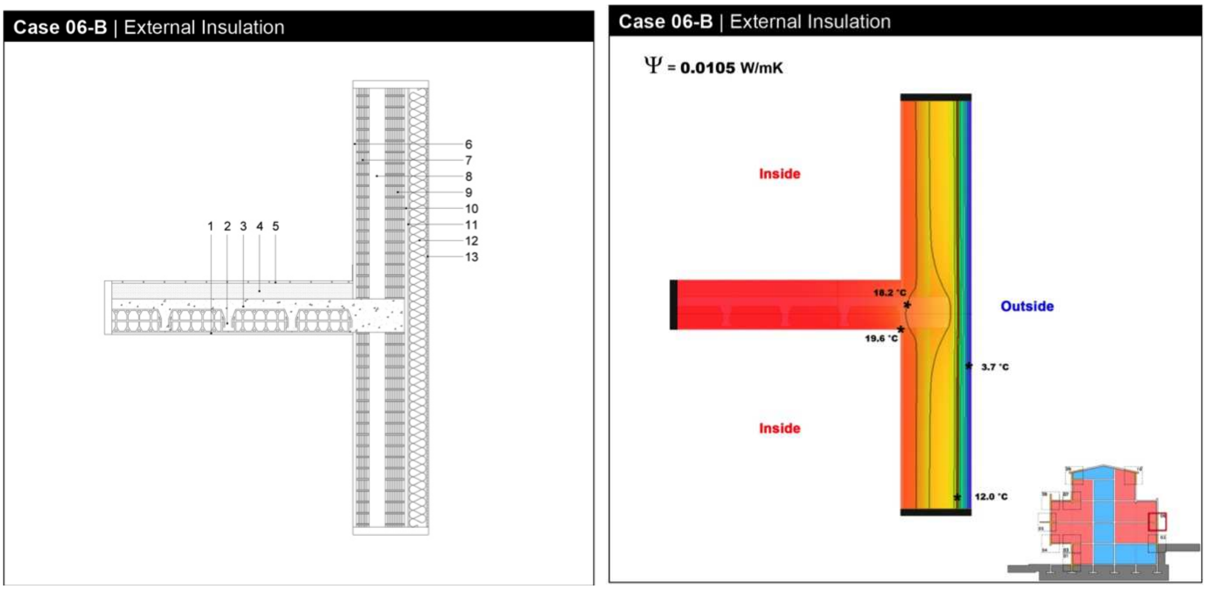

Fig. 32: Technological detail and thermal bridge simulation of Case 06-B (with external insulation).

Generally speaking, the externally insulated case shows a better performance than the internally insulated one, from both the linear thermal transmittance point of view **ψ** (Psi) as well as the minimum internal surface temperature (Tsi min), taken in the worst-case scenario along the year.
In terms of condensation risk, in this specific case, both types of insulation show no risk of condensation in the climate of Milano. The condensation line, as shows in the previous figures, is located in the area where the insulation and existing wall meets, and extends in the direction if the heat flow when it is closer to the connection cross.

When the same connection is simulated in a colder climate (Stockholm), the same conclusion in terms of linear thermal transmittance and internal surface temperatures can be deduced (refer to Annex 1). However, in the case of internal insulation, the condensation line in this case tends to move closer to the internal surface, which indicates a higher risk of condensation.
Although no dew or mold resulted from the simulations in this case, the risk of condensation depends on the existing wall type, layers and U-value in the various cases.

Below there is a summary of the comparison between the previously mentioned cases, in terms of the Psi values and minimum internal surface temperatures in the worst-case scenario along a year's time:

Table 18: Comparison between internally and externally insulated connections of Case 06.

Value	No insulation	Internal insulation	External insulation
ψ (Psi) (W/mK)	0.24	0.54	0.01
Tsi min (°C)	15.4	14.6	19.6

4.3.1.2 Comparison between floor and ceiling insulation extensions

The second example is a comparison between the detail in Case 06 with internal insulation on the vertical wall with a 50 cm ceiling insulation, with a 100 cm ceiling insulation, and a 50 cm ceiling and floor insulation (Fig. 33, Fig. 34 and Fig. 35).

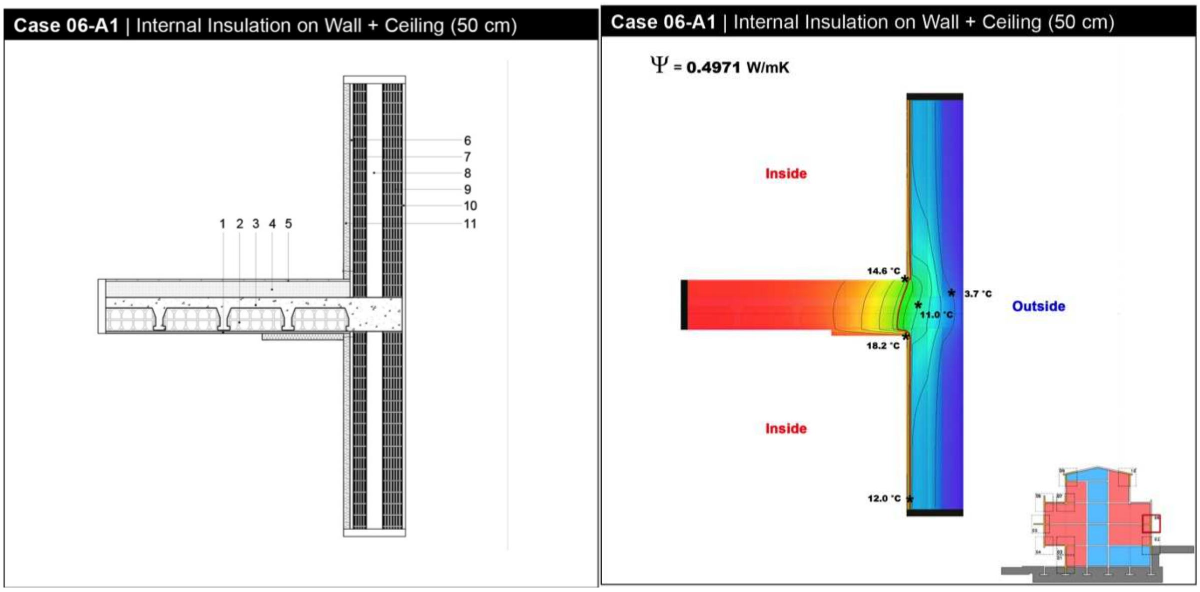

Fig. 33: Technological detail and thermal bridge simulation of Case 06-A1 (Internal insulation and 50cm length on the ceiling of the horizontal slab).

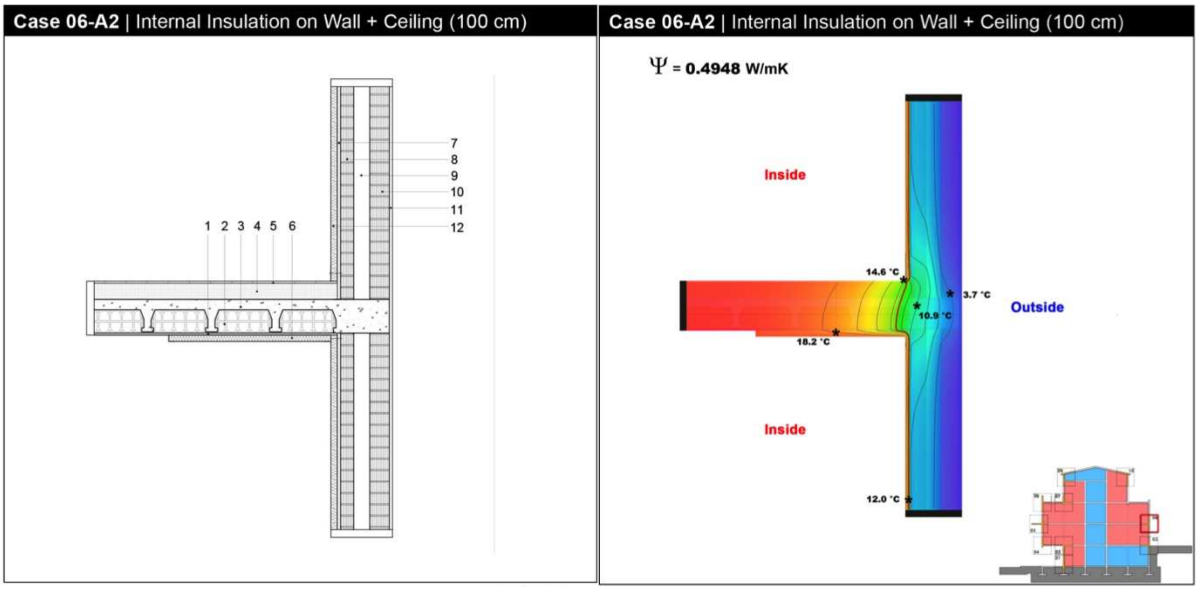

Fig. 34: Technological detail and thermal bridge simulation of Case 06-A1 (Internal insulation and 100cm length on the ceiling of the horizontal slab).

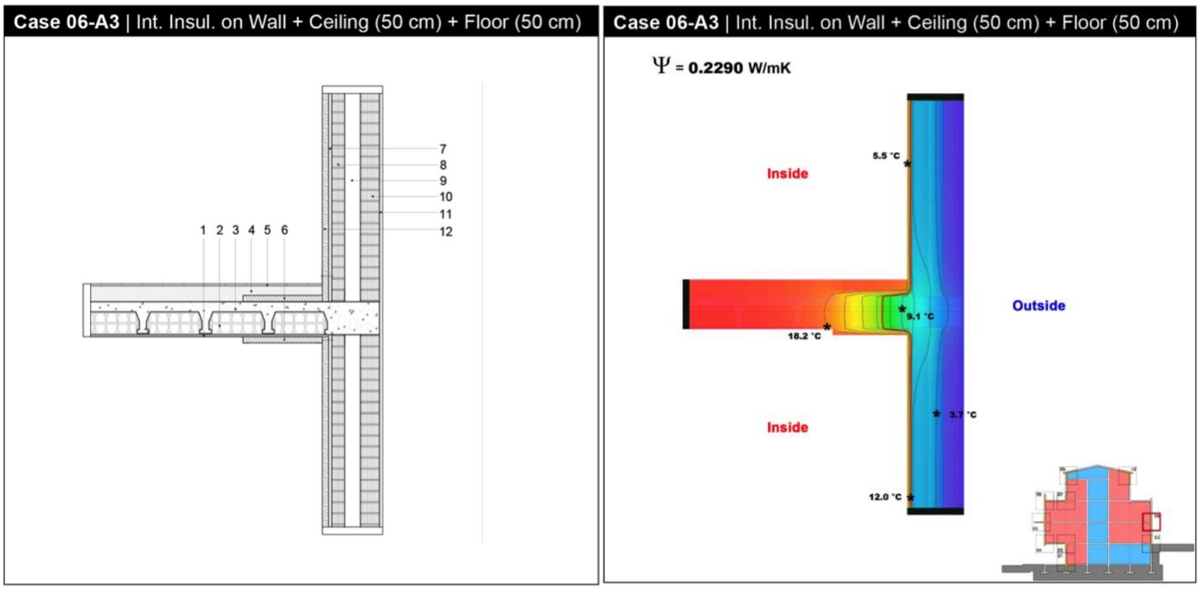

Fig. 35: Technological detail and thermal bridge simulation of Case 06-A1 (Internal insulation and 50cm length on the ceiling and floor of the horizontal slab).

Generally speaking, all three cases exhibit similar results in terms of the minimum internal surface temperature (Tsi min).

In terms of the **ψ** (Psi) value, the 50 cm and 100 cm ceiling insulation show negligible difference, therefore it is more reasonable, in terms of cost saving, to use the smaller length in the refurbishment process, in order to reduce the overall cost. The best result of the linear thermal transmittance is present in the case with the ceiling and floor insulation.

In terms of the risk of condensation, none of the three cases in this climate exhibits dew or mold risk. However, it seems that in both the 50 cm and 100 cm ceiling cases, the condensation line tends to move closer to the floor connection with the vertical wall, rendering a higher condensation risk, especially in colder climates, as the simulations show in Stockholm (refer to Annex 1).

Below is a summary of the comparison between the previously mentioned cases, in terms of the Psi values and minimum internal surface temperatures in the worst-case scenario along a year's time:

Table 19: Comparison between ceiling and floor insulated connections of Case 06.

Value	50 cm ceiling ins.	100 cm ceiling ins.	50 cm ceiling + floor
ψ (Psi) (W/mK)	0.50	0.50	0.23
Tsi min (°C)	14.6	14.6	14.6

4.4 Conclusions and Recommendations

The following main recommendations has been identified as follows:

- In general, external insulation is better in attenuating thermal bridges than internal insulation, due to the protruded planes, which obstruct the continuation of the insulating material (e.g. slabs and internal walls). Therefore, in some cases, insulating part of the protruded surfaces might be necessary.
- The lower the U-value of the surfaces, the better, but also the higher is the importance of insulating the connections in order to reduce the cold bridges and condensation risk (higher heat flow in the cold bridge areas).
- When insulating from the inside:
    - The thermal linear transmittance **ψ** (Psi) is often high, when we only insulate the vertical wall. Its value depends on the materials used in the protruded surface (slabs, internal walls… etc.), and it's dimension.
    - Solutions with vertical internal insulation only do not seem particularly critical, but if one wants to add some horizontal insulation, a "sandwich" 50 cm deep is enough to reduce cold bridging effects. However, in the case of insulating only one part of the horizontal surface (e.g. slabs), the condensation line tends to come closer to the non-insulated corner, which results in a higher condensation risk. From the simulations conducted, insulating both parts of the horizontal surface (e.g. ceiling and floor) gives the best results, however, it might require a more complex intervention on the floor part (partial removal of flooring etc.).
- When insulating from the inside in different climates:
    - <u>In the climate of Agrigento:</u> The simulations showed no risk of condensation whatsoever, therefore we could assume that there's minimal or no risk of condensation when internally insulating in this climate.
    - <u>In the climate of Milan:</u> Dew happens in a relatively limited number of cases, and no mold seems to form, which means that moisture can evaporate quickly, and/or condensation happens on non-porous surfaces (e.g. window frame);
    - <u>In the Climate of Stockholm:</u> Dew happens in a relatively higher number of cases, therefore, more detailed analyses are highly recommended, in order to figure out whether an extra vapor barrier layer might be needed or not. Insulating the horizontal slabs as well is recommended, in order to avoid low surface temperatures at the corners.
- When insulating from the inside with the existence of windows or doors:
    - Single-glazed windows:
        - In all the simulated cases, condensation was inevitable in temperate and cold climates. Condensation also occurred, when the frame wasn't thermally broken, which showed in the high U-value metal frame; while no condensation resulted when using thermally broken ones (e.g. PVC or Wooden).
    - Double glazed windows:
        - The simulations didn't show condensation on the glazed surface in this case. However, the frame needs to be thermally broken as well, otherwise, condensation will form on its surface and corners.
    - Generally speaking, when refurbishing the building envelope, it is highly recommended to buy new and more efficient windows as well, especially if the existing windows are single-glazed.
- When insulating from the inside or the outside with the existence of a shutter box:
    - Whether insulating form the inside or outside, there's a high condensation risk when having a shutter box as long as it is not insulated, especially in colder climates. This is due to the small thickness and high U-value of the shutter box. Therefore, in order to eliminate the risk of condensation and make sure to reduce cold bridges to the minimum, insulating the inside of the shutter box is a must.

5 Life Cycle Assessment (LCA)

5.1 Comparative LCA between the three designed kits

In accordance with ISO 14040 Environmental management, the LCA framework was selected for this analysis, its structure consists of four phases: **a.** goal and scope definition, **b.** life cycle inventory analysis, **c.** life cycle impact assessment and results interpretation. The SimaPro 7.3.2 database served as the primary source for obtaining the life cycle inventory data of all manufacturing process voices related with the building materials involved in the comparisons.
Regarding the aerogel based insulation material, at the actual development stage of the research it is difficult to build the life cycle inventory of the specific insulation panel in development into this WP of the EASEE project, because the production processes are at the lab scale and probably different from these of the industrial chain production. Consequently for its LCA, the primary source for obtaining the life cycle inventory data of all manufacturing process voices of the aerogel based insulation component (PET matt soaked with aerogel) has been the Environmental Product Declaration of a building product actually present on the market (Environmental Product Declaration according to ISO 14025 and EN 15804 SPACELOFT® AEROGEL INSULATION, October 2013). The inventoried processes have been assessed by CML 2 Baseline 2000 (V2.05) and EPD 2008. The EPD of the insulation matt has been assessed by CML, allowing the comparison of results and supporting the homogeneity of the data.
The considered indicators are: Abiotic depletion; Acidification; Eutrophication; Global warming (GWP100); Ozone layer depletion (ODP); Human toxicity; Fresh water aquatic ecotoxicity; Marine aquatic ecotoxicity; Terrestrial ecotoxicity; Photochemical oxidation; Non renewable fossil (Embodied Energy).

5.1.1 Goal and scope

The main goal of this LCA application is to investigate the environmental impact of three different solution of internal retrofitting installation. The LCA application is conducted at the design stage, in order to confirm or help the design of the kits' components, thinking environmentally efficient solutions. Its application between three different internal retrofitting systems aims especially:

- To help the improvement of the design of the fixing systems, which have to be minimal in dimension and weight and easy to be set up;
- To understand the ratio between the environmental impacts of the fixing tools of each system and these of the insulating and cladding layers.

5.1.2 System boundaries

Their definition into ISO 14040 is "*set of criteria specifying which unit processes are part of a product system*" and the unit process is the "*smallest element considered in the life cycle inventory analysis for which input and output data are quantified*" (ISO 14040, 2006). The processes examined in this LCA are during the pre-use phase: raw material extraction of materials, material processing, manufacturing of components. The operating phase is omitted because it is considered a constant: it means that the retrofitting of the existing façade follows up the transmittance of the wall from the U-value 1 W/m^2K to 0.30 W/m^2K, satisfying the local building energy performance requirements of Milan.
The thickness of the aerogel based insulating layer is the same into all the three compared internal retrofitting kits and it has the main role of retrofitting; considering the final design of the kits, the thermal contribution of the compared finishing layers can be neglected, but environmental impacts have to be checked, as follows.

5.1.3 Functional unit

It is defined as "*quantified performance of a product system for use as a reference unit*" (ISO 14040, 2006). The components of the Prefab kit, the Foldable one and the Wallpaper have

different sizes and, probably, different life spans. In order to design and compare the three designed kits, the functional unit for the LCA study was determined to be the dimension of 3 m^2 (1m long x 3 m high), the same one will be built up for the test facade.
The material masses of each internal retrofitting kit (the flow chart) were calculated based on the designed details.
The total material input of each kit for the functional unit was calculated by multiplying the individual mass of each component with required number to build a 3 m^2 internal retrofitting system.

5.1.4 The compared kits

The description of the compared kits is in the previous paragraph. The kits are three:

1) Prefab kit
2) Deployable wall
3) Enhanced Wallpaper kit

Regarding the third kit there are three different proposal (as), which are taken into account in the LCA comparison: solution 3.1, solution 3.2, solution 3.3. So totally 5 kits have been compared by LCA.
Each kit solution, as shown in the previous paragraphs, consists of:

A. an insulation layer
B. a finishing/cladding layer
C. fixing profiles and tools

The environmental impact assessment has been carried out at the material scale and then at the building system scale.
At the material stage the impacts of different types of insulation materials firstly, secondarily these of the cladding layers and thirdly these of different profiles for fixing have been compared. This step helped to understand which is the advantage/disadvantage to use super-insulating materials and which kind of material or profile had to be chosen.
At the building system stage the LCA compares the environmental impacts of the kit 1, 2, 3.1, 3.2, 3.3, in order to find out the weight, in terms of environmental loads, of each component of each kit and to underline the potentials and limits of each one.

5.1.5 The material scale: LCA comparison of different insulation materials

The environmental impacts of six different insulation materials, actually in the market, have been carried out (Table 25).
Only in this case a wall of 1 m^2 with a U-value of 0,30 W/m^2K has been considered as functional unit. Starting from the U-value of an existing wall (U= 1 W/m^2K) the needed thickness for each type of insulation material has been computed, in order to reach the U = 0,30 W/m^2K and satisfy the EASEE thermal requirements in the climatic context of Milan.

Table 20: Thermal characteristics of some insulation materials and needed thicknesses for the thermal requirements.

Materials	≠ [m]	λ [W/mK]	ρ [Kg/m³]	ρ [Kg/m²]
Cork	0.086	0.037	114	9,8
Foam Glass	0.088	0.038	100	8,8
Glass Wool	0.072	0.031	50	3,6
Polystyrene (XPS)	0.079	0.034	35	2,76
Rock Wool	0.081	0.035	100	8,1
PET + Aerogel	0.035	0.015	150	5,25

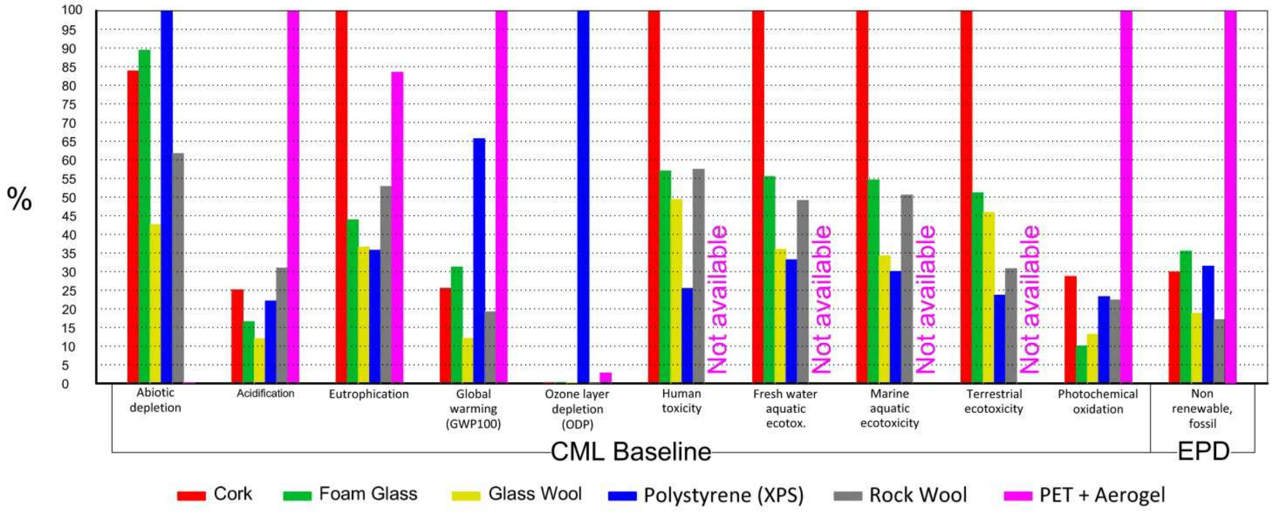

Fig. 36: LCA comparison of six types of insulation materials (in %).

Table 21: Environmental impacts of the six compared insulation materials.

IMPACT CATEGORY	CORK	FOAM GLASS	GLASS WOOL	XPS	ROCK WOOL	PET + AEROGEL
Abiotic depletion [kg Sb eq]	0.101	0.107	0.051	0.120	0.074	0.00017
Acidification [kg SO_2 eq]	0.052	0.034	0.025	0.046	0.064	0.209
Eutrophication [kg PO_4--- eq]	0.026	0.011	0.00974	0.009	0.014	0.022
Global warming (GWP100) [kg CO_2 eq]	11.346	13.883	5.379	29.204	8.539	44.45
Ozone layer depletion (ODP) [kg CFC_{-11} eq]	0.0000009	0.0000013	0.00000079	0.00045	0.00000036	0.0000127
Human toxicity [kg 1,4-DB eq]	9.804	5.590	4.839	2.500	5.634	N.A.
Fresh water aquatic ecotox [kg 1,4-DB eq]	4.198	2.330	1.512	1.393	2.062	N.A.
Marine aquatic ecotoxicity [kg 1,4-DB eq]	8893.563	4856.191	3044.442	2673.921	4498.206	N.A.
Non renewable, fossil [MJ eq]	244.458	310.904	164.687	275.639	149.965	875

5.1.6 The material scale: LCA comparison between different cladding layers

After the installation of the insulating layer on the existing wall, a "wallpaper"/finishing layer has been designed in order to protect the underneath layers and to guarantee an easy disassembly and substitution of a damaged or dirty finishing layer (instead of repainting in a traditional situation).

A wide range of wallpapers, textile or not, exist and the choice is it not simple.

The environmental impacts assessment of seven types of dry assembling finishing layers has been carried out (Fig. 55), considering, as explained in the par. 1.5.3, the needed material to cover an area of 3 m^2 as functional unit.

The types of finishing layer have been chosen in relation with the three kit solutions:
1. Prefab kit: a plasterboard (thickness 12mm) with a layer of paint have been considered
2. Deployable wall: two plasterboards (thickness 6 + 6mm), coupled to build a T shape with a layer of paint have been considered
3. Enhanced Wallpaper kit: in this case more different textiles for wallpaper have been compared.

Table 22: Characteristics of different finishing materials.

Materials	**≠ [m]**	**Surface mass [Kg/m²]**
Plasterboard	0.012	9.6
Plasterboard	0.006 X 2 (T Section)	9.6
Cotton Textile	/	0.360
Kenaf Textile	/	0.350
Polyester Textile 2 X 145 gr	/	0.145
Polyester Textile 3 X 195 gr	/	0.195
Vinyl Textile	0.00055	0.350

Fig. 37 shows clearly the relation between the choice of finishing textile and the impacts: as a consequence of a finishing textile instead of other, the environmental impact can change significantly compared with the impact of the plasterboard (which is the heaviest solution). This demonstrates the non-linear relation between weights of components and environmental impacts. Depending from the type of textile finishing layer, the Enhanced wallpaper kit could be less or more environmentally efficient than the Prefab or Deployable ones.

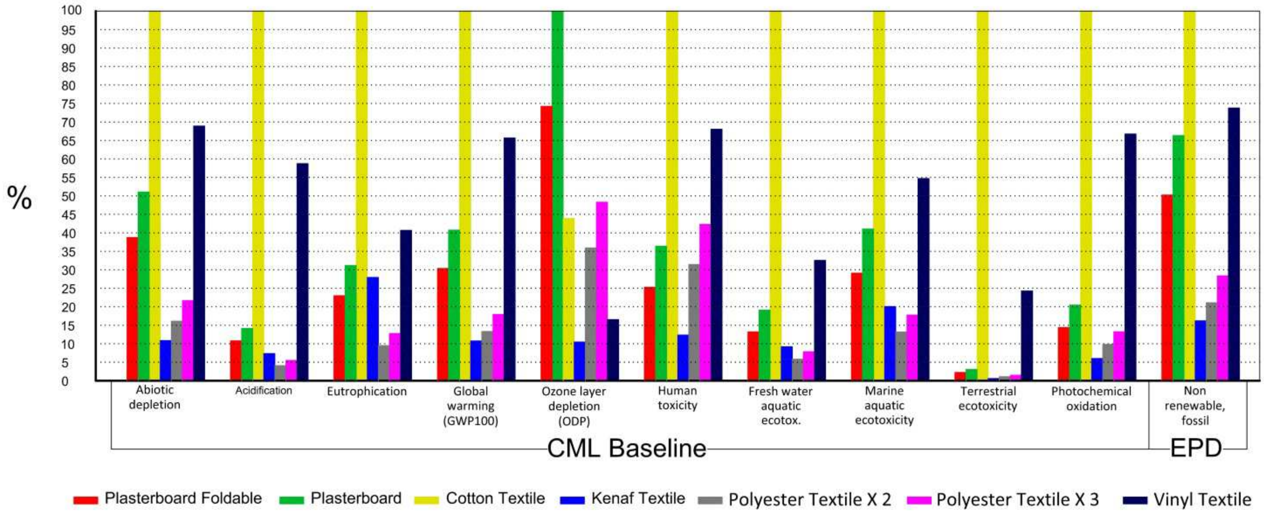

Fig. 37: LCA comparison between seven types of inner cladding layers (in %).

Table 23: Environmental impacts of the different finishing layers designed for the three kits.

	Plasterboard – Prefab and Foldable solutions		**Textile – WallPaper Solution**				
IMPACT CATEGORY	**Foldable solution**	**Prefab solution**	**Cotton 360 gr**	**Kenaf 350 gr**	**Polyester 2 X 145 gr**	**Polyester 3 X 195 gr**	**Vinyl 350 gr**
Abiotic depletion [kg Sb eq]	0.0223	0.029	0.057	0.0062	0.0092	0.0124	0.0397
Acidification [kg SO_2 eq]	0.0099	0.013	0.091	0.0067	0.0037	0.0050	0.0538
Eutrophication [Kg PO_4---eq]	0.0044	0.006	0.019	0.0054	0.0018	0.0024	0.0079
Global warming (GWP100) [kg CO_2 eq]	3.077	3.933	9.651	1.039	1.288	1.7332	6.3427
Ozone layer depletion (ODP) [kg CFC_{-11} eq]	0.00000034	0.00000047	0.0000002	0.00000005	0.00000017	0.0000002	0.00000008
Human toxicity [kg 1,4-DB eq]	0.964	1.390	3.817	0.473	1.2008	1.614	2.598
Fresh water aquatic ecotox [kg 1,4-DB eq]	0.654	0.937	4.905	0.452	0.286	0.385	1.597

Marine aquatic ecotoxicity [kg 1,4-DB eq]	1332.544	1880.982	4579.897	919.65	604.717	813.240	2506.096
Terrestrial ecotoxicity [kg 1,4-DB eq]	0.0083	0.011	0.369	0.00227	0.00411	0.0055	0.0898
Photochemical oxidation [kg C2H4 eq]	0.000451	0.00064	0.0031	0.00018	0.000308	0.000415	0.002090
Non renewable, fossil [MJ eq]	51.896	68.511	103.25	16.770	21.8020	29.320	76.204

5.1.7 The material scale: LCA comparison between different fixing systems' profiles for the kit 3 – Enhanced wallpaper

Designing the enhanced wallpaper different fixing systems, for the tensioning of the textile finishing, have been considered and compared from different points of view (lightness, costs, easy to be installed… etc.

The building system scale: LCA comparison between the three designed internal retrofitting kits

The environmental impact assessment of the three designed kits has been carried out. The results show the contribution of the insulation layer (PET + Aerogel, 35 mm – gray) and, separated, the contribution to the impact of the fixing system and the finishing layer (the other colours).

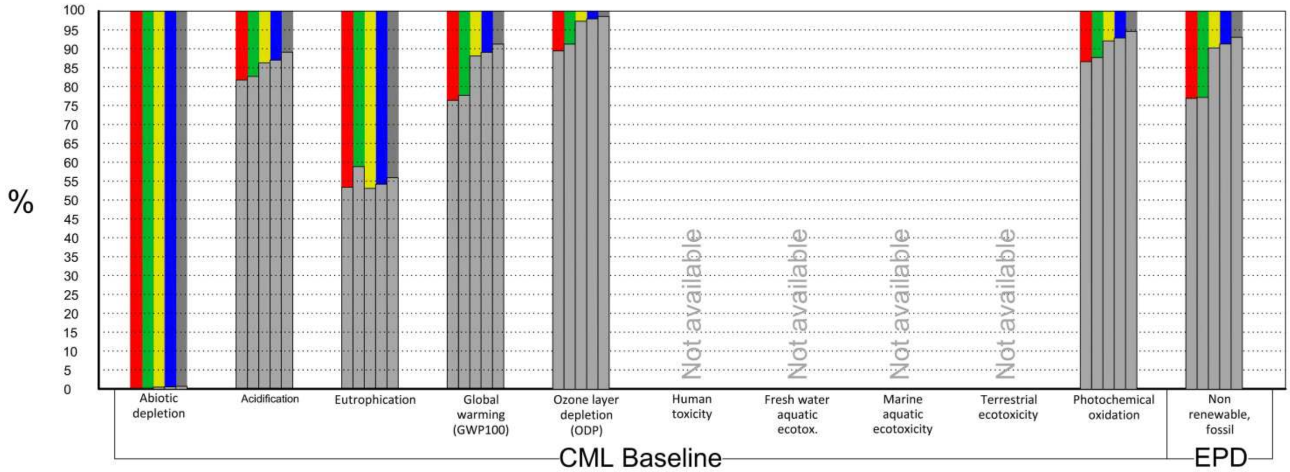

Fig. 38: Comparison between the environmental impacts of the designed kits (in %).

Table 24: Kits - Results of the LCA comparison.

IMPACT CATEGORY	Kit 1			Kit 2			Kit 3.1			Kit 3.2			Kit 3.3		
	Kit	Ins.	Tot.	Kit	Ins.	Tot.	Kit	Ins.	Tot.	Kit	Ins.	Tot.	Kit	Ins.	Tot.
Abiotic depletion [kg Sb eq]	0.11	0.0001	**0.11**	0.11	0.0001	**0.11**	0.03	0.0001	**0.03**	0.032	0.0001	**0.03**	0.02	0.0001	**0.02**
Acidification [kg SO2 eq]	0.04	0.20	**0.25**	0.04	0.20	**0.25**	0.03	0.20	**0.24**	0.03	0.20	**0.24**	0.02	0.20	**0.23**
Eutrophication [Kg PO4---eq]	0.01	0.02	**0.04**	0.01	0.02	**0.03**	0.01	0.02	**0.04**	0.01	0.02	**0.04**	0.01	0.02	**0.03**
Global warming (GWP100) [kg CO2 eq]	13.72	44.45	**58.17**	12.72	44.45	**57.17**	5.96	44.45	**50.41**	5.26	44.45	**49.71**	4.06	44.45	**48.51**
Ozone layer depletion (ODP) [kgCFC-11eq]	0.0000014	0.000012	**0.000014**	0.0000012	0.000012	**0.000013**	0.00000034	0.000012	**0.00013**	0.0000026	0.000012	**0.000012**	0.0000018	0.000012	**0.000012**
Human toxicity [kg1,4-DB eq]	4.45	N.A.	**N.A.**	3.40	N.A.	**N.A.**	6.02	N.A.	**N.A.**	4.17	N.A.	**N.A.**	2.46	N.A.	**N.A.**
Fresh water aquatic ecotox [kg1,4-DB eq]	2.91	N.A.	**N.A.**	2.14	N.A.	**N.A.**	2.28	N.A.	**N.A.**	1.98	N.A.	**N.A.**	1.66	N.A.	**N.A.**
Marine aquatic ecotoxicity [kg1,4-DB eq]	5893.15	N.A.	**N.A.**	4452.54	N.A.	**N.A.**	4185.00	N.A.	**N.A.**	3731.98	N.A.	**N.A.**	3224.01	N.A.	**N.A.**
Terrestrial ecotoxicity [kg1,4-DB eq]	0.03	N.A.	**N.A.**	0.02	N.A.	**N.A.**	0.02	N.A.	**N.A.**	0.02	N.A.	**N.A.**	0.01	N.A.	**N.A.**
Photochemical oxidation [kg C2H4 eq]	0.002	0.015	**0.017**	0.0021	0.015	**0.017**	0.0013	0.015	**0.016**	0.0011	0.015	**0.016**	0.0008	0.015	**0.016**
Non renewable, fossil **(EPD)** [MJ eq]	262.37	875.00	**1137.37**	259.02	875.00	**1134.0**	94.30	875.00	**969.30**	83.31	875.00	**958.31**	65.035	875.00	**940.03**

5.1.8 LCA conclusions

The three kits have been developed following an optimization process; the main goal aimed to facilitate both the implementation of the system, making it Do It Yourself, both the transportability. Together with these two aspects, the two other topics were, also, the optimization of the kits' weights and the environmental impact efficiency of the three proposed solutions.

The results of the comparison of the three designed building systems (**Error! Reference source not found.**) clearly show the optimization process. Starting from pre-coupled solutions (Kit 1 and Kit 2), both with similar environmental impacts, the impact is reduced, almost becoming the half, with the wallpaper solution

6 Conclusions

This document marks the conclusion of the activities of Work Package 4 about the internal retrofit solutions using advanced insulating materials.

The development of the indoor retrofit kits started with the identification of relevant requirements, which included lightness, ease of adaptation on site, limited annoyance for users, and limited thickness. This required special care in the choice of suitable insulating materials and a specific market and patent search to identify potential competitors and the improvement areas to focus on.

The adaptability to different European climates was an important asset in view of the diffusion of the kits on a wide market (which is an important added value of EU-funded research) and this was studied through dynamic energy analyses highlighting the potential for different layers with specific thermal capacity and resistance.

Iterative considerations led to the identification of three indoor retrofit kits:

- an improved perlite board with finishing mortar
- a breathable textile wallpaper with aerogel insulation
- a laminated panel consisting of aerogel insulation and a rigid finishing board.

Once the retrofit kits were defined, the different materials for the constituting layers were studied and finally specified, based on the expected requirements and the know-how of partners. It was then possible to test the hygrothermal properties of the various kits and, based on small prototypes, to test also finishing layers and assembly solutions.

Dynamic simulations were performed to assess the risk of condensation and the potential formation of mould at the critical connections, where internal insulation solutions can form cold bridging effects.

Finally, Life Cycle Assessment studies were carried out to support the choice of some materials and installation details.

Work Package 4 delivered three internal retrofitting kits that are now ready for prototyping and real-scale tests in Work Package 7 and finally for installation in some of the demonstration buildings envisaged in the project, within Work Package 8.