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	EASI ZERo **GA n°101091531**
Deliverable	**ENVELOPE MATERIAL SYSTEM WITH LOW IMPACT FOR ZERO ENERGY RENOVATION AND CONSTRUCTION**

Deliverable ID	**D2.5**
Deliverable name	**Final list of product requirements**
Deliverable description	The final list of product requirements is organized in two groups. Simple product requirements are those that do not depend on other requirements – examples are the requirements for new product to be fire resistant, lightweight, or applicable to various surfaces. On the other hand, complex product requirements are expected to fulfil their individual constraints and also to contribute to the achievement of other requirements. Product requirements through scenario analysis will deliver a comprehensive set of combinations of product illustrating that they can be obtained through different combinations of materials, such as targeted payback period that may be achieved with different combinations of material U-values and costs. Such scenario analysis will be performed using the Product Requirements Tool described in D2.4.

WP		**2**	**Specification and validation of products requirements**
Task		**2.3**	**Final list of product requirements**

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Glossary

EZ0 – EASI ZERo

KPI – Key Performance Indicator

LCS – Life Cycle Stage

GWP – Global Warning Potential

1. Objectives and development process

1.1 *Description of the deliverable content and objectives*

This deliverable contains the final product requirements that can be used to provide product designers with relevant feedback in the product development cycle.

The deliverable starts with defining product requirements, products they cover, the link between the project objectives and product performance targets, and the final list of product requirements with their geographic coverage. The second section explains the input data used to derive the product requirements, such as the results of tasks 2.2 and 2.3 and market data. The third section differentiates simple from complex product requirements and explains which requirements apply to which products and how the product requirements were obtained. The final sections contain the results (i.e., the final product requirements per product per target market) and conclusions.

1.2 *Project objectives and limitations of insulation products*

Project objectives are explained with 19 comprehensive key performance indicators, covering all the research activity of the project from renovation materials to building environmental performance. Not all KPIs can be used for defining product requirements. To track project objectives and consider physical limitations of insulation products, project KPIs were supplemented with additional product performance targets. These additional targets were based on marginal gains achieved at the building stock level when one unit of insulation is added to existing buildings. In addition, to properly reflect market realities in target countries, we have stated from the different economic conditions and building typology that the payback time (claimed in objective 8) could not be achieved in a very general way.

2. Product requirements

The purpose of product requirements is to guide design and development of EZ0 products and make sure that, once produced, EZ0 products achieve project objectives. There are 8 project objectives defined with 19 key performance indicators outlined at the beginning of the project.

Project objectives are:

1. Inclusive and versatile toolset towards efficient and easy renovation for buildings,
2. Durable performance gain for thermal insulation,
3. Low embodied energy and CO_2 of EASI ZERo bio-based components,
4. Easy, fast and reliable installation of panels, accessories and finishing materials,
5. Contribution to circular economy via recycling and material resources savings,
6. Sustainable material system demonstrated in zero energy buildings renovation,
7. Conformity to regulation and standards (fire, acoustics, pollutants, IAQ), and
8. Payback time through affordable material system and installation processes.

Each objective is described with one or more key performance indicators listed under 2.1.
Selected KPIs, together with additional targets on energy and CO_2 performance, make the final list of **product performance targets**. Finally, **product requirements** are defined as product properties necessary for reaching product performance targets and therefore project objectives.
Steps leading from project objectives to product requirements are visualised in Figure 1.
Each product requirement contains information on:

- Product property, such as thermal conductivity, λ,
- Unit, e.g., W/mK,
- Benchmark numerical value, such as 0.032.

Product requirement benchmark value is either the maximum or minimum value required to reach product performance target(s). For instance, thermal conductivity with benchmark value of 0.032 W/mK means that the thermal conductivity of the product should be equal or less 0.032 W/m.K.
Each product requirement is assigned to:

- A specific product, describing one of its characteristics, and
- Country where the product should be distributed, i.e., market covered.

Countries covered with product requirements are countries included in EZ0 project, i.e., Norway Poland, Denmark, Germany, Italy, France, and Spain. When provided for one country, a product requirement describes a characteristic the product should have when **distributed and used, not necessarily produced**, in the country.

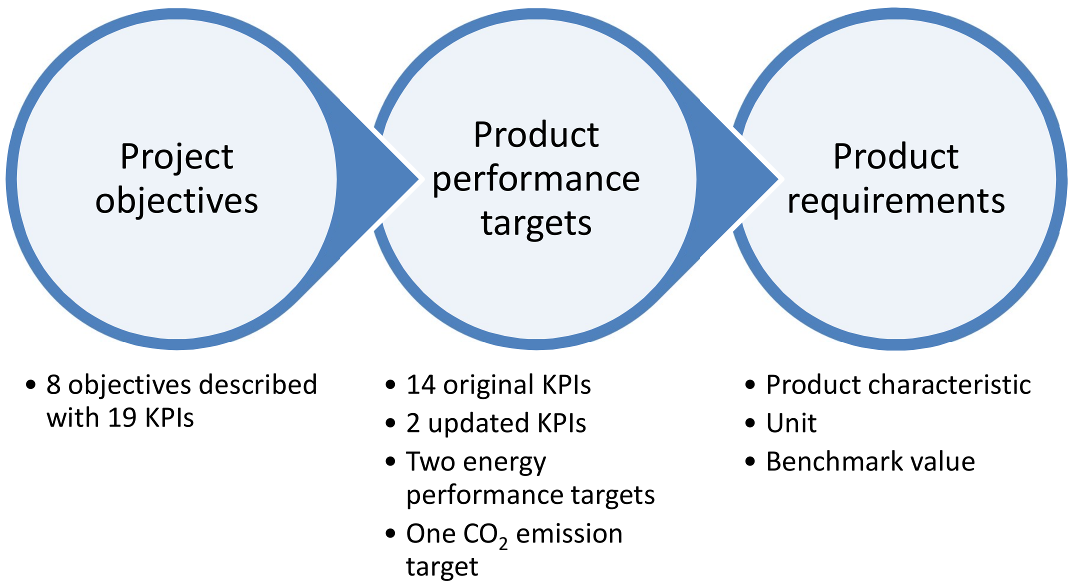

Figure 1: From project objectives to product requirements

The achievement of each objectives of the project uses a verification mean based on specific measurements conditions and protocols. In the present approach, we evaluate for each materials and products what could be the accessible market in a more general approach. We compare project key performance indicator defined with specific conditions to requirements derived from standards' requirements and market needs.

2.1 ***Key performance indicators***

Table 1 shows objectives and associated KPIs description and target value.

Objective	KPI label	KPI description and value
Objective 1 - Inclusive and versatile toolset towards efficient and easy renovation for buildings	KPI 1	Final energy consumption < 50 kWh/m²/year
	KPI 2	Carbon emission < 4 kgCO$_2$/m²/year
Objective 2 - Durable performance gain for thermal insulation	KPI 3	Gain in thermal performance, +20%
Objective 3 - Low embodied energy and CO$_2$ of EASI ZERo bio-based components	KPI 4	Embodied energy relative reduction, -30%, compared to market available products with LCA analysis
	KPI 5	CO$_2$ emissions savings of opaque panels, -30% (panels), compared to a similar standard insulation product (mineral wool), CO$_2$ emissions savings of opaque panels, -60% (accessories), compared to actually available similar products in terms of performance
	KPI 6	CO$_2$ savings of window frames, -35%, compared to polymer frame with no bio-based products
Objective 4 - Easy, fast and reliable installation of panels, accessories and finishing materials	KPI 7	Cost reduction of installed material, -15%, cost analysis of components production, including logistics
	KPI 8	Installation worktime, -30%
	KPI 9	Drying time of plaster 20% faster, drying time for a usual thickness range
Objective 5 - Contribution to circular economy via recycling and material resources savings	KPI 10	Design for renovation allowing re-use >80%
Objective 6 – Sustainable material system demonstrated in zero energy buildings renovation	KPI 11	3 use case evaluation completed including initial performance evaluation, renovation development with EASI ZERo design methodology, performance simulation with full material system after renovation, financial evaluation
	KPI 12	Net energy use reduction of 5% (absolute minimum)
	KPI 13	Net zero energy for single family with PV < 35 kWh/m²/year (45 kWh/m²/year for Nordic climate zone
Objective 7 - Conformity to regulation and standards (fire, acoustics, pollutants, IAQ)	KPI 14	Pollutants and particles matter generation of indoor paint, plasters and panels < 25µg/m3 Particles up to 2.5µm, < 50µg/m3 Particles up to 10µm, < 2µg/m3 VOC measurements
	KPI 15	VOC neutralization efficiency 60%
	KPI 16	Fire resistance of materials A2, for bio PUR, coated mycelium, wood fibre panels
	KPI 17	Acoustic performance Rw 40dB, measured according to standard on mycelium panels
Objective 8 - Low Short payback time through affordable material system and installation processes	KPI 18	Payback time, <7 years
	KPI 19	Cost to reach R=1 m²K/W = 0.5 EUR/m², for a 30 mm thickness

Table 1: Project objectives and their KPIs

2.2 *Product performance targets*

Product performance targets include some of the key performance indicators and additional energy and CO_2 emission targets. Complete list of product performance targets can be found in Table 2.

KPI associated to product performance target	Product performance target description
KPI 3	Gain in thermal performance, +20%
KPI 4	Embodied energy relative reduction, -30%, compared to market available products with LCA analysis
KPI 5	CO_2 emissions savings of opaque panels, -30% (panels), compared to a similar standard insulation product (mineral wool), CO_2 emissions savings of opaque panels, -60% (accessories), compared to actually available similar products in terms of performance
KPI 6	CO_2 savings of window frames, -35%, compared to polymer frame with no bio-based products
KPI 7	Cost reduction of installed material, -15%, cost analysis of components production, including logistics
KPI 8	Installation worktime, -30%
KPI 9	Drying time of plaster 20% faster, drying time for a usual thickness range
KPI 10	Design for renovation allowing re-use >80%
KPI 11	3 use case evaluation completed including initial performance evaluation, renovation development with EASI ZERo design methodology, performance simulation with full material system after renovation, financial evaluation
KPI 12	Net energy use reduction of 5% (absolute minimum)
KPI 14	Pollutants and particles matter generation of indoor paint, plasters and panels < 25µg/m3 Particles up to 2.5µm, < 50µg/m3 Particles up to 10µm, < 2µg/m3 VOC measurements
KPI 15	VOC neutralization efficiency 60%
KPI 16	Fire resistance of materials A2, for bio PUR, coated mycelium, wood fibre panels, paint
KPI 17	Acoustic performance Rw 40dB, measured according to standard on mycelium panels
KPI 18	Payback time, <12 years
KPI 19	Cost to reach R=1 m²K/W =. 5 EUR/m², for a 30 mm thickness
Energy performance target 1	Marginal savings in final energy consumption <3%, achieved at building stock level
Energy performance target 2	Marginal reduction in net zero energy <3% for single family houses with PV, achieved at building stock level
CO_2 performance target	Marginal reduction in CO_2 emissions <3%, achieved at building stock level

Table 2: Product performance targets

Initial analysis on KPIs 1, 2, 12, 13 and 18[4] shows that some project KPIs are not completely suitable for defining insulation product requirements. This is due to:

- final energy consumption and CO_2 emissions KPIs are ambitious to be reached with insulation materials only (that is our scope in this deliverable). These KPIs will be achieved

4 Explained in D2.3.

and verified with use cases (WP6) where synergies between insulation materials, energy systems, and design methodologies will be analysed.

- Payback time has been set at highly ambitious level as well, for a specific building typology. Some preliminary KPI 18 results showed that simple payback period of 7 years cannot be easily reached in all considered countries.

To compensate for these, the following energy and CO_2 performance targets were introduced:

- **Energy performance target 1**: Marginal savings in final energy consumption <3%, achieved at building stock level
- **Energy performance target 2**: Marginal reduction in net zero energy <3% for single family houses with PV, achieved at building stock level
- **CO_2 performance target**: Marginal reduction in CO_2 emissions <3%, achieved at building stock level

In addition, net energy use reduction (KPI 12) and payback time (KPI 18) are updated so that:

- To be in line with energy and carbon building stock performance targets, KPI 12 is implemented at building stock level
- To introduce lower ambition in economic performance, payback period used in KPI 18 has been increased to 12 years.

Complete list of product performance targets, consisting of selected KPIs and energy and CO_2 performance targets is shown in Table 2.

2.3 *Products covered with product requirements*

Product requirements are defined for seven EZ0 products shown in Table 3.

Product ID	Product name
P1	Mycelium-based inside-the-wall thermal insulating panels
P2	Mycelium-based decorative insulating panels for inner walls
P3	Bio-based sprayable PUR foam and paint with sprayable method
P4	Wood-fibre insulation panels
P5	Thermal insulating render
P6	BioPUR moulded frames for windows
P7	VOC removal painting

Table 3: Product described with product requirements

These products will be developed under WP4 by using materials developed under WP3. Analysis of the product requirements took into account the materials used for producing each of the products.

2.4 *Key performance indicators applied to different products*

Each product is assigned with between 5 and 15 product performance targets. Each product performance target contributes to exactly one product requirement.

Product performance targets and products they cover can be found in Table 4. KPI 12, as well as energy and CO_2 performance targets result in R- value of insulating products or window frames. While R-values are not product requirements, they contribute to defining either thickness of an insulating material or U-value as a product requirement. The link between R-values and product requirements is explained in section 4.

	P1: Mycelium-based inside-the-wall thermal insulating panels	P2: Mycelium-based decorative insulating panels for inner walls	P3: Bio-based sprayable PUR foam and paint with sprayable method	P4: Wood-fibre insulation panels	P5: Thermal insulating render	P6: BioPUR moulded frames for windows	P7: VOC removal painting
KPI 3	Thermal conductivity, λ (W/mK)	-	Thermal conductivity, λ (W/mK)	Thermal conductivity, λ (W/mK)	Thermal conductivity, λ (W/mK)	U window frame (W/m2K)	-
KPI 4	Energy LCS A1-A3 (MJ/m3)	Energy LCS A1-A3 (MJ/m3)	Energy LCS A1-A3 (MJ/m3)	Energy LCS A1-A3 (MJ/m3)	Energy LCS A1-A3 (MJ/m3)	Energy LCS A1-A3 (MJ/m2)	-
KPI 5	GWP LCS A1-3 (kg CO_2eq/m3)	GWP LCS A1-3 (kg CO_2eq /m3)	GWP LCS A1-3 (kg CO_2eq /m3)	GWP LCS A1-3 (kg CO_2eq /m3)	GWP LCS A1-3 (kg CO_2eq /m3)	-	-
KPI 6	-	-	-	-	-	GWP LCS A1-3 (kg CO_2eq /m2)	-
KPI 7	Production cost (EUR/m3)	-	Production cost (EUR/m3)	Production cost (EUR/m3)	Production cost (EUR/m3)	Production cost (EUR/m2)	Production cost (EUR/m3)
KPI 8	Installation time (hours)	Installation time (hours)	Installation time (hours)	Installation time (hours)	Installation time (hours)	Installation time (hours)	-
KPI 9	-	-	-	-	-	-	Drying time (hours)
KPI 10	Share of reused material (%)	Share of reused material (%)	Share of reused material (%)	Share of reused material (%)	Share of reused material (%)	Share of reused material (%)	-
KPI 11	-	-	-	-	-	-	-
KPI 12	Thermal resistance, R (Km2/W)	-	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	U window frame (W/m2K)	-
KPI 14	-	Max concentration of pollutants and particles (µg/m3)	Max concentration of pollutants and particles (µg/m3)	-	-	-	Max concentration of pollutants and particles (µg/m3)
KPI 15	-	-	-	-	-	-	VOC neutralization efficiency (%)
KPI 16	Fire resistance level	Fire resistance level	Fire resistance level	Fire resistance level	Fire resistance level	-	Fire resistance level

KPI 17	Acoustic performance, Rw (dB)	Acoustic performance, Rw (dB)	Acoustic performance, Rw (dB)	Acoustic performance, Rw (dB)	Acoustic performance, Rw (dB)	-	-
KPI 18	Production cost (EUR/m3)	-	Production cost (EUR/m3)	Production cost (EUR/m3)	Production cost (EUR/m3)	Production cost (EUR/m2)	-
KPI 19	Production cost (EUR/m3)	-	Production cost (EUR/m3)	Production cost (EUR/m3)	Production cost (EUR/m3)	-	-
Energy performance target 1	Thermal resistance, R (Km2/W)	-	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	U window frame (W/m2K)	-
Energy performance target 2	Thermal resistance, R (Km2/W)	-	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	U window frame (W/m2K)	-
CO_2 performance target	Thermal resistance, R (Km2/W)	-	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	Thermal resistance, R (Km2/W)	U window frame (W/m2K)	-

Table 4: KPIs and products

2.5 *Product requirements provided for different products*

Following the relationship between product performance targets and products, product requirements applicable to each product can be found in Table 5.

	P1: Mycelium-based inside-the-wall thermal insulating panels	P2: Mycelium-based decorative insulating panels for inner walls	P3: Bio-based sprayable PUR foam and paint with sprayable method	P4: Wood-fibre insulation panels	P5: Thermal insulating render	P6: BioPUR moulded frames for windows	P7: VOC removal painting
Thermal conductivity λ (W/mK)	YES	-	YES	YES	YES	-	-
Energy LCS A1-A3 (MJ/m3)	YES	YES	YES	YES	YES	-	-
GWP LCS A1-3 (kg CO_2eq/m3)	YES	YES	YES	YES	YES	-	-
Installation time (hours)	YES	YES	YES	YES	YES	YES	-
Share of reused material (%)	YES	YES	YES	YES	YES	YES	-
Fire resistance level	YES	YES	YES	YES	YES	-	YES
Acoustic performance Rw (dB)	YES	YES	YES	YES	YES	-	-
Insulation thickness (cm)	YES	-	YES	YES	YES	-	-
Production cost (EUR/m3)	YES	-	YES	YES	YES	-	YES

Max concentration of pollutants and particles (µg/m3)	-	YES	YES	-	-	-	YES
Energy LCS A1-A3 (MJ/m2)	-	-	-	-	-	YES	-
GWP LCS A1-3 (kg CO_2eq/m2)	-	-	-	-	-	YES	-
U window frame (W/m2K)	-	-	-	-	-	YES	-
Production cost (EUR/m2)	-	-	-	-	-	YES	-
Drying time (hours)	-	-	-	-	-	-	YES
VOC neutralization efficiency (%)	-	-	-	-	-	-	YES

Table 5: Product requirements provided for different products[5]

3. Inputs used for defining the product requirements

Product requirements for each product are defined using several inputs:

- D2.2 product requirement inputs database issued from the project,
- Results from the Product Requirements Tool described in D2.3,
- Market research covering costs and performance of different construction products, such as insulating materials and windows,
- Analysis of EU environmental performance declarations (EPD) databases, providing information on energy used for and global warming potential (GWP) of emissions from production life cycle stages (stages A1-A3), and
- Feedback from EASI ZERo project partners.

3.1 *Product requirement inputs*

We have analysed existing construction product databases relevant for EZ0 products and provided inputs needed for proper definition of individual product requirements. These inputs included physical properties (such as U-values or mass) and other characteristics (e.g., fire resistance or application potential) of the state-of-the-art insulating solutions.

Where applicable, the database provided either national or EU requirements for different physical properties of EZ0 or similar products. For instance, when produced and sold, a mycelium panel should have a thermal conductivity lower than 0.035 W/mK. Product limitations imposed in this way were eventually considered when defining product requirements.

5 Production cost, Energy LCS A1-A3, and GWP LCS A1-3 are listed more than once due to different units and products they apply to.

3.2 *Results from the Product Requirements Tool*

The Product Requirement Tool covered in D2.3 provided the following results which have been used for defining product requirements:

- Thermal resistance, i.e., R-value (m^2K/W) of additional insulation needed to reach specific energy and carbon performance targets when the insulation is added to existing:
    - Walls only,
    - Ground floors, walls, and roofs together,
- Thermal resistance, i.e., R-value (m^2K/W) of window frames[6] needed to reach specific energy and carbon performance targets when these window frames replace existing window frames,
- Product selling price (EUR/m^2) of additional insulation needed to reach specific payback period (economic performance), when the insulation is added to existing:
    - Walls only,
    - Ground floors, walls, and roofs together,
- Product selling price (EUR/m^2) of window frames needed to reach specific payback period (economic performance), such as required by target performance on payback time, when these window frames replace existing window frames.

3.3 *Market research on costs and performance*

Market research on costs and performance was provided for 3 construction products:

- Insulating panels,
- Window frames, and
- VOC-removal paints.

From the market research it was possible to obtain selling price of the product offered by some of the biggest construction material retailers. Gross profit margin[7] typical for construction material retailers was used to reduce the selling price and arrive at production costs[8]. Gross profit margin used for this purpose equals 25%[9].

The list of retailers and links to their online stores can be found in section **Erreur ! Source du renvoi introuvable.**.

[6] When analysing window frames, change in glazing is not considered. It was assumed that new windows will have the same glazing as the old ones.

7 https://www.investopedia.com/terms/g/gross_profit_margin.asp

8 Retail price and gross profit margin allow calculation of costs of goods sold (when goods i.e., a construction product is sold by the retailer). Cost of goods sold is assumed to be equal to production costs borne by the producer.

9 https://www.prosalesmagazine.com/news/financial/survey-sets-median-pro-dealers-margin-at-26-62_o and https://cfohub.com/what-is-a-good-gross-profit-margin/

3.3.1 Insulating panels

Market research on insulating panels included 146 data points collected from the biggest construction material retailers operating in the countries covered by the project.

Data collected and used for market analysis collected covered insulating panels made of expanded polystyrene (EPS), rock wool, glass wool, and extruded polystyrene (XPS).

The main result of the research was a dependency between thermal conductivity (λ, W/mK) and retail price (EUR/m3) of insulating panels. These results are provided for insulating panels in general and for all the countries analysed, i.e., without making a distinction between insulating materials used and markets covered. This was due to a) small number of samples obtained per a combination of insulating material and country, and b) small differences in results obtained at national and material level.

The dependency between thermal conductivity (λ, W/mK) and retail price (EUR/m3) of insulating panels obtained from the market research is presented in Equation 1 and Figure 2.

$$Insulating\ panel\ production\ cost\ \left(\frac{EUR}{m3}\right)$$
$$= 512 - 10\ 573 * \ Insulating\ panel\ thermal\ conductivity\ (\frac{W}{mK})$$

Equation 1: Dependency between thermal conductivity (λ, W/mK) and retail price (EUR/m3) of insulating panels

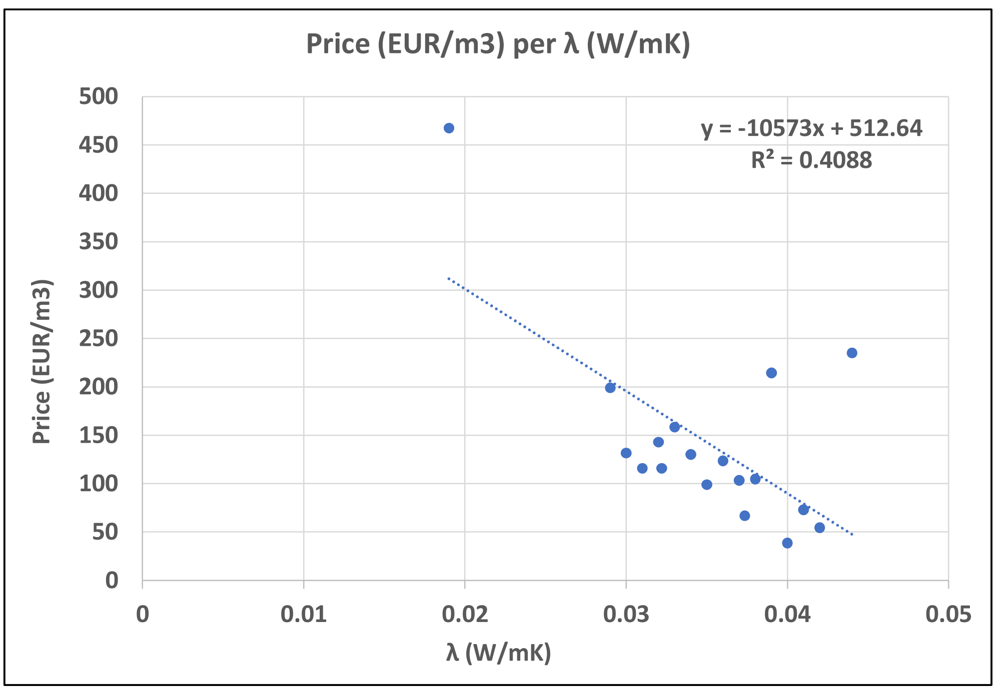

Figure 2: Price per thermal conductivity for insulating panels[10]

10 Each point visible in the graph represents average price per thermal conductivity. This explains why number of points in the graph is significantly lower than 146 data points collected.

3.3.2 Window frames

Market research on insulating panels included 32 different windows sold by the biggest EU construction material retailers. In addition to its size, for each window it was possible to obtain U-values of window components (frames and glazing) and selling price.

The target of the research was to obtain a dependency between U-value (W/m2K) of a window frame and it price per area (EUR/m2 frame). Since details information on window components, i.e., frame and glazing, were not available, it was necessary to assume:

- Share of frame price in window price, and
- Share of frame area in window area.

For the purpose of this report, both shares are assumed to be equal to 25%[11].

Obtained relationship between frame U-value and it price per area can be found in Equation 2 and Figure 3 3.

$$Window\ frame\ production\ cost\ \left(\frac{EUR}{m2\ frame}\right) = 307 - 93 * \ Window\ frame\ U\ value\ \left(\frac{W}{m2K}\right)$$

Equation 2: Dependency between window frame production cost (EUR/m2 frame) and U-value (W/m2K)

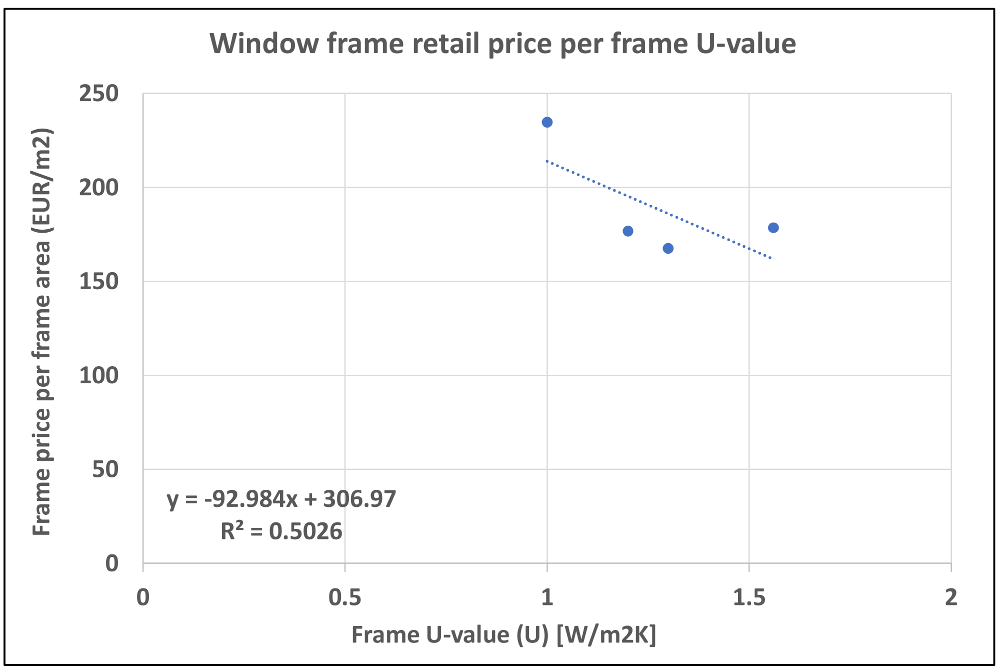

Figure 3: Window frame production cost per frame U-value[12]

11 Share of frame area in window area of 25% was already used in D2.3. The price share was assumed to be equal to the area share.
12 Points visible in the graph are obtained as average prices per each U-value. This explains why number of points used in the graph is lower than 32 data points collected.

3.3.3 VOC-removal paints

Market research covering VOC removal paints included much lower number of data points due to a) less data available from the market, and b) the fact that expected results did not include dependencies (e.g., between product price and performance), which allowed a smaller sample.
VOC removal paint market research aimed at:

- Production cost of VOC-removal paint per area (EUR/m2), and
- VOC-removal paint drying time.

The results obtained can be found in Table 6.

Product characteristic	Result
VOC-removal paint production cost	1.05 EUR/m2
VOC-removal paint drying time	10 hours

Table 6: VOC-removal paint characteristics

3.4 *Cost and product performance*

KPI 19 requires that the cost to reach R=1 m²K/W equals 5 EUR/m2 for the material 3 cm thick. This implies that material with thermal conductivity of 0.030 W/mK has production cost of 167 EUR/m3. A dependency between thermal conductivity (λ, W/mK) and production cost (EUR/m3) of a product is needed. KPI 19 provided single point (λ = 0.030, price = 167) in the λ - price graph and it was necessary to assume the slope of the λ - price curve. Since the point provided by KPI 19 matches well the λ - price relationship for insulating panels, it was decided that λ - price slopes for insulating panels and KPI 19 are the same.
Simple manipulation of KPI 19 point and the λ - price slope obtained for insulation panels provided the following relationship applicable to this target performance:

$$Production\ cost\ \left(\frac{EUR}{m3}\right) = 484 - 10\,573 * Thermal\ conductivity\ (\frac{W}{mK})$$

Equation 3: Dependency between thermal conductivity (λ, W/mK) and production cost (EUR/m3)

3.5 *Market research on environmental performance declarations (EPD)*

An important input to defining product requirements was the analysis of environmental performance declarations (EPD) available from several national EPD databases. Full list of EPD databases used can be found under **Erreur ! Source du renvoi introuvable.**.
Market research on environmental performance declarations (EPD) included 38 data points covering insulating panels, PUR foams, and window frames from 5 project countries[13] and Austria[14].

13 France. Italy, Norway, Spain, and Denmark.
14 Although not a project country, Austria was added to increase the number of data points and the sample used for research.

The result of the research was to obtain:

- Global warming potential (GWP) of life cycle stages A1-A3, expressed in $kgCO_2eq$ per functional unit of the product, and
- Total energy used during the life cycle stages A1-A3, expressed in MJ per functional unit of the product.

Product functional unit equals m3 in case of insulating panels and PUR foams, and m2 in case of window frames.

EPD market research did not try to define dependencies between GWP and energy used on one side and product performance on the other since these might be outside of the project scope. This is mostly because a) finding such dependency would require a sample much bigger than what may be obtained (within a reasonable period) from available sources, and b) A1-A3 GWP and energy used depend on several factors[15].

The most important results of the analysis can be found in Table 7 and Table 8 below. Several conclusions are important for understanding how the results can be used for developing product requirements.

- The range of GWP and energy values for each product/main material is wide enough to question the usefulness of the results for defining EZ0 product requirements. For example, collected GWPs of mineral wool can be found between 147 and 437 with average value of 293. Due to such large range of possible values, simple GWP average or any other available statistics[16] may not be fully appropriate for defining product requirements[17]. Consequences on defining product requirements are described in other parts of the report.
- Some of the materials were described with 1 or 2 points collected. These samples are indeed extremely small and therefore excluded from the analysis.

15 Such as final and/or primary energy mix used in the production facilities, or transportation distance between the raw material extraction and the production site.

16 E.g., mode, median, or similar.

17 This conclusion is in line with previously mentioned dependency of GWP and energy on several factors, that has not been considered in this report.

Product	Functional unit	Main material	Number of data points	Average GWP A1-3 (kg CO_2eq)	Min GWP A1-3 (kg CO_2eq)	Max GWP A1-3 (kg CO_2eq)
Insulation panel	m3	EPS	6	58.0	30.8	127.0
		Mineral wool	4	293.2	147.4	437.1
		Rockwool	9	77.9	32.3	121.8
		Wood fibre	2	61.3	8.4	114.3
		XPS	1	59.8	59.8	59.8
PUR foam	m3	Polyurethane	7	113.6	32.5	144.7
		PUR foam	1	224.3	224.3	224.3
Window frame	m2 of frame	Aluminium	5	239.8	93.6	460.0
		PVC	1	199.5	199.5	199.5

Table 7: GWP in life cycle stages A1-A3 for analysed products and materials

Product	Functional unit	Main material	Number of data points	Average energy used A1-A3 (MJ/m3)	Min energy used A1-A3 (MJ/m3)	Max energy used A1-A3 (MJ/m3)
Insulation panel	m^3	EPS	6	1 941	1 509	2 998
		Mineral wool	4	7 337	4 176	13 600
		Rockwool	9	1 313	1 313	1 313
		Wood fibre	2	2 596	1 031	4 160
		XPS	1	1 354	1 354	1 354
PUR foam	m^3	Polyurethane	7	2 961	2 860	3 062
		PUR foam	1	4 434	4 434	4 434
Window frame	m^2 of frame	Aluminium	5	2 593	604	5 310
		PVC	1	3 608	3 608	3 608

Table 8: Energy used in life cycle stages A1-A3 for analysed products and materials

4. Defining product requirements

This section explains how product requirements for each product listed in Table 3 are derived from the list of product performance targets. In general, product requirements can be described as:

- Simple, i.e., product requirements for which target values are defined by some of the product performance targets (key performance indicators),
- Complex, i.e., product requirements that either depend on several product performance target or that require additional analysis (e.g., market research on costs and performance).

4.1 *Simple product requirements*

Simple product requirements, product performance targets that defined them, and benchmark values can be found in Table 9. Benchmarks listed in Table 9 remain the same for all the products covered by one product requirement. For instance, wherever applicable, required acoustic performance is equal to 40 dB.

Product requirement	Benchmark value	Product performance target
Installation worktime	30% faster than in a standard renovation process	Related to KPI 8
Design allowing re-use	> 80% of reused material	Related to KPI 10
Pollutants and particles matter generation	Indoor paint, plasters and panels < 25µg/m3 Particles up to 2.5µm, < 50µg/m3 Particles up to 10µm, < 2µg/m3 VOC measurements	Related to KPI 14
VOC neutralization	60%	Related to KPI 15
Fire resistance of materials	A2	Related to KPI 16
Acoustic performance	40 dB	Related to KPI 17

Table 9: Simple product requirements

Note that installation worktime shows impact on the cost of the renovation but also relies on efficient construction and renovation methods. This is also related to environmental value as the reduction of waste (described in D7.1 and evaluation of environmental impact of EZ0 solutions). In the same way, design for re-use derives directly from R principles (especially R8, R13 and R14). Please refer to D7.1 for a description of this approach implemented in the project.

4.2 *Complex product requirements*

Complex product requirements and product performance targets they are derived from are listed in Table 10. Lifecycle services will be evaluated with principles defined in D7.1.

Product requirement	Product performance target
Thermal resistance, R (Km2/W)	Energy performance target 1, Energy performance target 2, CO_2 performance target, KPI 12
Thermal conductivity, λ (W/mK)	Related to KPI 3
Energy LCS A1-A3 (MJ/m3)	Related to KPI 4
GWP LCS A1-3 (kg CO_2eq/m3)	Related to KPI 5
GWP LCS A1-3 (kg CO_2eq/m2)	Related to KPI 6
Production cost (EUR/m3)	Related to KPI 7, KPI 18, KPI 19
Drying time (hours)	Related to KPI 9

Table 10: Complex product requirements

In general, there are three different approaches used for defining complex product requirements. These approaches and products they apply to are explained below.

4.2.1 Products P1, P3, P4, and P5

The approach presented here was applied to:

- P1: Mycelium-based inside-the-wall thermal insulating panels,
- P3: Bio-based sprayable PUR foam and paint with sprayable method,
- P4: Wood-fibre insulation panels, and
- P5: Thermal insulating render.

4.2.1.1 Thermal conductivity

Starting from values proposed for thermal conductivity performance target, required thermal conductivity of a product was obtained as a minimum of a) thermal conductivity required by national standards reduced by 20%, and b) thermal conductivities required by the project proposal, as shown in Table 11.

Material	Target thermal performance
Wood fibre panels	λ < 0.032 W/mK
Biopolymer foam	U = 0.8 W/m2K
Waterglass foam	λ < 0.025 W/m2K
Insulating render	λ < 0.03 W/m2K

Table 11: Target values for thermal performance, as per EZ0 description of work

4.2.1.2 Insulation thickness

Product Requirements Tool analysed energy performance targets, CO_2 performance target, and KPI 12 and defined R-values that products should reach in different EZ0 countries. The link between the Tool results and products P1, P3, P4, and P5 is explained in Table 12.

Product code	Product	Renovation measure
P1	Mycelium-based inside-the-wall thermal insulating panels	Walls (W)
P3	Bio-based sprayable PUR foam and paint with sprayable method	Ground floor, walls, roof (GFRW)
P4	Wood-fibre insulation panels	Ground floor, walls, roof (GFRW)
P5	Thermal insulating render	Ground floor, walls, roof (GFRW)

Table 12: Renovation measures used for product requirements

For each product and country, benchmark R-value was obtained as a minimum of 4 R-value results corresponding to energy performance targets, CO_2 performance target, and net energy use target (KPI 12). Benchmark insulation thickness is obtained after combining benchmark values for thermal conductivity and the benchmark R-value.

It is important to note that insulation thicknesses are not product requirements. Instead, insulation thicknesses are indicative values that show how buildings should be renovated to reach energy performance targets, CO_2 performance target, and KPI 12 in different EZ0 countries.

4.2.1.3 Production cost

Product Requirement Tool analysed payback time (related to KPI 18) and at country level provided retail price of a product per area it covers (EUR/m2). After adjusting the retail price with gross profit margins and thickness obtained in step 2, production cost per volume required in each country (EUR/m3) was obtained.

After combining thermal conductivity obtained under step 1 with Equation 1 and Equation 3, it was possible to obtain production costs per volume (EUR/m3) for KPI 7 (cost reduction) and KPI 19 (thermal resistance unit cost), respectively.

Finally, cost per volume (EUR/m3) as a product requirement for each product and country was obtained as the minimum of costs per volume provided for KPI 7, KPI 18, and KPI 19.

4.2.1.4 Embodied energy and CO_2 performance

Results of the EPD research were used to define benchmark A1-A3 energy (MJ) and A1-A3 GWP (kg CO_2eq) for producing one volume unit (m3) of each product. LCA reference materials used for each product are listed in Table 13.

Product code	Product	LCA reference material
P1	Mycelium-based inside-the-wall thermal insulating panels	Mineral wool
P3	Bio-based sprayable PUR foam and paint with sprayable method	PUR foam
P4	Wood-fibre insulation panels	Mineral wool
P5	Thermal insulating render	Mineral wool

Table 13: LCA reference materials used for product requirements

4.3 *P2 Mycelium-based decorative insulating panels for inner walls*

The approach presented here was applied to P2 Mycelium-based decorative insulating panels for inner walls. Contrary to the previous group of products, thermal conductivity does not play a role in defining P2 product requirements. This fact reduced the number of P2 product requirements and simplified their definition.

4.3.1 Embodied energy and CO_2 performance

In the first step, using mineral wool as LCA reference material, maximum A1-A3 energy (MJ) and A1-A3 GWP (kg CO_2eq) allowed for producing one m3 of each product were provided.

4.4 *P6 BioPUR moulded frames for windows*

One of the main characteristics of the approach applied to P6 is that the most important requirement is not thermal conductivity but U-value (W/m2K) of the frame.

4.4.1 U-value of the window frame

Starting from energy performance targets, CO_2 performance target, and KPI 12, the Tool provided 4 different U-values[18] of window frames. At the same time, KPI 3 asked for 20% of improvement in national standards on U-values. U-value as a product requirement at country level was obtained as the minimum of a) 4 U-values provided from the Tool and b) 20% improved U-values required by the national standards.

4.4.2 Production cost

Once benchmark U-value was obtained, Equation 2 resulted in production costs per m2 of window frame. These costs were reduced by 20% to satisfy KPI 7.

In addition, payback time was analysed by the Tool to provide retail prices of frames per m2 of window in different countries. The results were adjusted by a) applying retailers' gross profit

[18] U-value=1/R-value

margins and b) changing the unit to m2 of window frame. In this way, it was possible to obtain cost per m^2 of window frame that satisfies payback time in each country.
Required production cost of window frame per m^2, when the frame is used in different countries, was eventually provided as the minimum of costs that satisfy KPI 18 and KPI 7.

4.4.3 Embodied energy and CO_2 performance

Using window frames as reference material, maximum A1-A3 energy (MJ) and A1-A3 GWP (kg CO_2eq) allowed for producing one m2 of window frames were provided.

4.5 *P7 VOC-removal paint*

Similar to P2, VOC-removal paint is characterised by lack of thermal conductivity or U-value, which simplified definition of product requirements.

4.5.1 Production cost

Results of the market research on VOC-paints, presented in Table 6, were used to define production cost per m^2 of area covered with the paint. When reduced by 20% this cost satisfies KPI 7.

4.5.2 Drying time

Results of the market research on drying time of VOC-paints (Table 6) reduced by 20% fulfils KPI 9.

5. Results

5.1 *P1 Mycelium-based inside-the-wall thermal insulating panels*

PRODUCT NAME	COUNTRY	Thermal conductivity λ (W/mK)	Energy LCS A1-A3 (MJ/m3)	GWP LCS A1-3 (kg CO_2eq/m3)	Installation time (hours)	Share of reused material (%)	Fire resistance level	Acoustic performance Rw (dB)	Insulation thickness (cm)	Production cost (EUR/m3)
Mycelium-based inside-the-wall thermal insulating panels	Denmark	0.028	7 338	294	30% faster than in a standard renovation process	80%	A2	40	8	48
	France	0.028	7 338	294	30% faster than in a standard renovation process	80%	A2	40	7	32
	Germany	0.028	7 338	294	30% faster than in a standard renovation process	80%	A2	40	8	54
	Italy	0.028	7 338	294	30% faster than in a standard renovation process	80%	A2	40	7	10
	Norway	0.028	7 338	294	30% faster than in a standard renovation process	80%	A2	40	8	105
	Poland	0.028	7 338	294	30% faster than in a standard renovation process	80%	A2	40	8	34
	Spain	0.028	7 338	294	30% faster than in a standard renovation process	80%	A2	40	7	0

5.2 *P2 Mycelium-based decorative insulating panels for inner walls*

PRODUCT NAME	COUNTRY	Energy LCS A1-A3 (MJ/m3)	GWP LCS A1-3 (kg CO_2eq/m3)	Installation time (hours)	Share of reused material (%)	Max concentration (µg/m3)	Fire resistance level	Rw (dB)
Mycelium-based decorative insulating panels for inner walls	Denmark	7 338	294	30% faster than in a standard renovation process	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40
	France	7 338	294	30% faster than in a standard renovation process	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40
	Germany	7 338	294	30% faster than in a standard renovation process	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40
	Italy	7 338	294	30% faster than in a standard renovation process	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40
	Norway	7 338	294	30% faster than in a standard renovation process	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40
	Poland	7 338	294	30% faster than in a standard renovation process	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40
	Spain	7 338	294	30% faster than in a standard renovation process	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40

5.3 *P3 Bio-based sprayable PUR foam and paint with sprayable method*

PRODUCT NAME	COUNTRY	Thermal conductivity λ (W/mK)	Energy LCS A1-A3 (MJ/m3)	GWP LCS A1-3 (kg CO_2eq/m3)	Installation time (hours)	Share of reused material (%)	Max concentration of pollutants and particles (µg/m3)	Fire resistance level	Acoustic performance Rw (dB)	Insulation thickness (cm)	Production cost (EUR/m3)
Bio-based sprayable PUR foam and paint with sprayable method	Denmark	0.024	4 435	225	30% faster than standard renovation	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40	14	36
	France	0.024	4 435	225	30% faster than standard renovation	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40	11	57
	Germany	0.024	4 435	225	30% faster than standard renovation	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40	12	50
	Italy	0.024	4 435	225	30% faster than standard renovation	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40	15	41
	Norway	0.024	4 435	225	30% faster than standard renovation	80%	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	A2	40	11	72
	Poland	0.024	4 435	225	30% faster than standard renovation	80%	< 25µg/m3 Particles up to 2.5µm, < 50µg/m3 Particles up to 10µm, < 2µg/m3 VOC measurements	A2	40	12	24
	Spain	0.024	4 435	225	30% faster than standard renovation	80%	< 25µg/m3 Particles up to 2.5µm, < 50µg/m3 Particles up to 10µm, < 2µg/m3 VOC measurements	A2	40	15	27

5.4 ***P4 Wood-fibre insulation panels***

PRODUCT NAME	COUNTRY	Thermal conductivity λ (W/mK)	Energy LCS A1-A3 (MJ/m3)	GWP LCS A1-3 (kg CO_2eq/m3)	Installation time (hours)	Share of reused material (%)	Fire resistance level	Acoustic performance Rw (dB)	Insulation thickness (cm)	Production cost (EUR/m3)
Wood-fibre insulation panels	Denmark	0.026	7,338	294	30% faster than in a standard renovation process	80%	A2	40	15	36
	France	0.026	7,338	294	30% faster than in a standard renovation process	80%	A2	40	11	57
	Germany	0.026	7,338	294	30% faster than in a standard renovation process	80%	A2	40	13	50
	Italy	0.026	7,338	294	30% faster than in a standard renovation process	80%	A2	40	16	41
	Norway	0.026	7,338	294	30% faster than in a standard renovation process	80%	A2	40	11	72
	Poland	0.026	7,338	294	30% faster than in a standard renovation process	80%	A2	40	13	24
	Spain	0.026	7,338	294	30% faster than in a standard renovation process	80%	A2	40	16	27

5.5 *P5 Thermal insulating render*

PRODUCT NAME	COUNTRY	Thermal conductivity λ (W/mK)	Energy LCS A1-A3 (MJ/m3)	GWP LCS A1-3 (kg CO_2eq/m3)	Installation time (hours)	Share of reused material (%)	Fire resistance level	Acoustic performance Rw (dB)	Insulation thickness (cm)	Production cost (EUR/m3)
Thermal insulating render	Denmark	0.027	7,338	294	30% faster than in a standard renovation process	80%	A2	40	16	36
	France	0.027	7,338	294	30% faster than in a standard renovation process	80%	A2	40	12	57
	Germany	0.027	7,338	294	30% faster than in a standard renovation process	80%	A2	40	13	50
	Italy	0.027	7,338	294	30% faster than in a standard renovation process	80%	A2	40	17	41
	Norway	0.027	7,338	294	30% faster than in a standard renovation process	80%	A2	40	12	72
	Poland	0.027	7,338	294	30% faster than in a standard renovation process	80%	A2	40	13	24
	Spain	0.027	7,338	294	30% faster than in a standard renovation process	80%	A2	40	17	27

5.6 *P6 BioPUR moulded frames for windows*

PRODUCT NAME	COUNTRY	Energy LCS A1-A3 (MJ/m2)	GWP LCS A1-3 (kg CO_2eq/m2)	Installation time (hours)	Share of reused material (%)	U window frame (W/m2K)	Production cost (EUR/m2)
BioPUR moulded frames for windows	Denmark	2 763	234	30% faster than in a standard renovation process	80%	1	15
	France	2 763	234	30% faster than in a standard renovation process	80%	1	211
	Germany	2 763	234	30% faster than in a standard renovation process	80%	1	210
	Italy	2 763	234	30% faster than in a standard renovation process	80%	0	6
	Norway	2 763	234	30% faster than in a standard renovation process	80%	1	211
	Poland	2 763	234	30% faster than in a standard renovation process	80%	1	<0
	Spain	2 763	234	30% faster than in a standard renovation process	80%	1	<0

5.7 *P7 VOC removal painting*

PRODUCT NAME	COUNTRY	Production cost (EUR/m3)	Drying time (hours)	Max concentration of pollutants and particles (µg/m3)	VOC neutralization efficiency (%)	Fire resistance level
VOC removal painting	Denmark	0.8	9	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	60%	A2
	France	0.8	9	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	60%	A2
	Germany	0.8	9	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	60%	A2
	Italy	0.8	9	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	60%	A2
	Norway	0.8	9	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	60%	A2
	Poland	0.8	9	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	60%	A2
	Spain	0.8	9	< 25µg/m3 Particles up to 2.5µm < 50µg/m3 Particles up to 10µm < 2µg/m3 VOC measurements	60%	A2

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6. Conclusions

In conclusion, this report has described the process of defining product requirements within the scope of the EZ0 project, focusing on innovative and sustainable construction materials. The objectives of the report were to establish clear specifications for various construction products while considering factors such as thermal performance, energy efficiency, environmental impact, installation time, and production cost.

The inputs used for defining product requirements were diverse. These inputs included data from product requirement inputs database (D2.2), outcomes from the Product Requirements Tool (D2.3), market research on costs and performance of construction products, analysis of EU environmental performance declarations (EPD) databases, and feedback from EasiZero project partners. Each input played a crucial role in shaping the final product requirements.

The process of defining product requirements was structured into two main categories: simple and complex requirements. Simple requirements, directly linked to specific Key Performance Indicators (KPIs), were outlined for installation worktime, design allowing re-use, pollutants and particles matter generation, VOC neutralization, fire resistance, and acoustic performance. Complex requirements, derived from multiple KPIs or requiring additional analysis, encompassed thermal resistance, thermal conductivity, energy and global warming potential in life cycle stages, production cost, drying time, and maximum concentration of pollutants and particles.

Each product within the EZ0 project, including mycelium-based inside-the-wall thermal insulating panels, mycelium-based decorative insulating panels for inner walls, bio-based sprayable PUR foam and paint, wood-fibre insulation panels, thermal insulating render, bioPUR moulded frames for windows, and VOC removal painting, underwent detailed assessment to define its unique set of requirements. These requirements were tailored to meet specific performance criteria while ensuring environmental sustainability and cost-effectiveness.

The results of the analysis provided valuable insights into the characteristics and performance metrics of different construction products that can support activities in materials and components developments (WP3, WP4), but also to enrich the exploitation of these materials on markets (WP8). Further validation of products against requirements defined in this report will come with tests in WP5 (laboratory scale) and WP6 (real use cases with virtual renovation process) and WP7 (environmental impact evaluation). Each product underwent an evaluation to determine its thermal conductivity, energy and global warming potential in life cycle stages, installation time, and other critical parameters.

By defining precise product requirements, this report lays the foundation for the development of cutting-edge construction materials that align with the EZ0 project's goals of promoting sustainability and innovation in the construction industry.

7. Annex: Market research sources

7.1.1 Insulating panels

Country	Retailer	Link to online store
Denmark	10-4	https://www.10-4.dk/
	Bygmax	https://www.bygmax.dk/
France	Bricoman	https://www.bricoman.fr/
	Leroy Merlin	https://www.leroymerlin.fr/
Germany	Bauhaus	https://www.bauhaus.info/
	Windowo	https://www.windowo.de/
	Baustoffshop	https://www.baustoffshop.de/
	Daemmstoffshop	https://www.daemmstoffshop.de/
Italy	Tecnomat	https://www.tecnomat.it/it/
Norway	Maxbo	https://www.maxbo.no/
Poland	Realbud	https://realbud.com/
	Izosystems	https://izosystems.pl/
Spain	Generador-de-precios (construction products database)	https://info.cype.com/es/software/generador-de-precios/

7.1.2 Window frames

Country	Retailer	Link to online store
Denmark	Sparvinduer	https://www.sparvinduer.dk/
France	Fenetre 24	https://www.fenetre24.com/
Germany	Fensterdepot 24	https://www.fensterdepot24.de/
	Deutscher-fenstershop	https://deutscher-fenstershop.de/v
Italy	Finestre	https://www.finestre.com/
	Modaedile	https://www.modaedile.com/index.asp
Spain	Generador-de-precios (construction products database)	https://info.cype.com/es/software/generador-de-precios/

7.1.3 VOC-removal paints

Country	Retailer	Link
France	Peinture-destock	https://peinture-destock.com/
	Castorama	https://www.castorama.fr/
Spain	Leroymerlin	https://www.leroymerlin.es/
Germany	Waschbaer	https://www.waschbaer.de/

7.1.4 EPD databases

Country	National database	Link
France	Inies	https://www.inies.fr/
Italy	EPD Italy	https://www.epditaly.it/en/
Norway	EPD-Norway	https://www.epd-norge.no/
Spain	Opendap	https://node.opendap.es/
Denmark	Epddanmark	https://www.epddanmark.dk/
Austria	Baubook	https://www.baubook.at/oea/?SW=16&lng=2