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D1.1 – Requirements and drivers of EENSULATE module

WP1

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Executive Summary

In this report, firstly the current technical, safety, health and environmental directives, standards and regulations applying to curtain wall façade construction at European and national level have been reviewed.

Besides the thermal insulation performance, more general targets set by EU for potential applications of the novel technology have been also taken into account, e.g. targets set for acoustic insulation and indoor environment in buildings, as well as health and safety regulations.

The review has led to the identification of actual performance requirements when developing the novel components of the proposed unitized curtain wall system, fostering market awareness of these new technologies.

The activity has also assessed the relevancy of the existing quality certification and rating protocols and procurement practices, both at component and system level, in order to derive specifications for the product development.

Finally, a preliminary market analysis has been made in order to qualitatively assess the compliancy of the developed technology with the identified market drivers.

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Abbreviations and Acronyms

[CARG] - Compound Annual Rate Growth
[EC] - European Commission
[EU] - European Union
[HVAC] - Heating, ventilation and air conditioning
[TRL] - Technology Readiness Level
[UAE] - United Arab Emirates

1 Introduction

This report "Requirements and drivers of EENSULATE module" provides the value chain requirements and specifications for the development of the individual technologies and the integrated EENSULATE system and presents preliminary a preliminary market analysis. The document has been prepared in the framework of WP1, whose aims are the collection and analysis of all national and European requirements related to the development of the EENSULATE system, as well as the preliminary investigation of the market drivers to be considered during the project development. The document is therefore organised in three parts:

- Part A - Regulatory requirements, certification and procurement practices – refers to the requirements derived from the legislative context at a European and national level;
- Part B – Review of market drivers – market analysis of curtain wall and European green market is conducted to reveal market drivers and upcoming trends in building sector.
- Part C - Conclusions - presents the conclusions of the present study and includes the value chain requirements and specifications of the EENSULATE system.

PART A: REGULATORY REQUIREMENTS, CERTIFICATION AND PROCUREMENT PRACTICES

2 EU legislative and programmatic context for buildings and products

About 40% of overall energy consumption in Europe is related to the building sector. It is responsible for 36% of the European Union's total CO_2 emissions. Over 50% of all materials extracted from earth are transformed into construction materials and products.

With more than 70% of the building stock built before the first energy crisis (1970's) energy retrofitting (plus nearly zero) of buildings is envisaged as the most promising strategy to reach EU's "20-20-20" targets.

When improving the level of energy performance of buildings in operation, embodied energy in materials presents an increasingly high percentage of the energy spent in the whole life cycle of a building. The same applies for CO_2. Therefore, the development of new sustainable construction materials with lower embodied energy and lower CO_2 emissions is needed. New approaches in material science and production technologies will help to minimize the embodied energy of the main construction materials such as concrete, glass, gypsum, ceramics or steel, involved in the structure, envelope and other building components of energy efficient buildings. At the same time, components with improved insulation and air tightness properties (which are influenced by construction tolerances) are needed, aiming at the overall target of reducing energy consumption and CO_2 emission during the whole life cycle. Higher insulation can be achieved by improving bulk or surface properties in combination with novel mortars, plasters and coatings.

The present chapter goes through those documents which enclose the meaning and elaborate on the concepts of the energy retrofitting of buildings.

Additionally, more general targets set by EU will be also taken into account, e.g. targets set for thermal and acoustic insulation and indoor environment in buildings, as well as health and safety regulations for building occupants but also for manufacturers and people working during building construction/retrofitting will be reviewed.

There are then other needs of the building sector, that new components like EENSULATE may also contribute to satisfy, among which: enhanced durability for increased use duration, reduced maintenance and consequently reduced costs, respect of sustainability principles (the sustainability should be evaluated via life cycle assessment studies carried out according to the International Reference Life Cycle Data System - ILCD Handbook); application to both new build and renovation; lightweight construction and ease of installation; realistic solutions at a reasonable price; increased comfort and noise reduction. Recycling/reuse of materials may also be addressed.

2.1 Directives

Directives are the operative way the European Union uses in order to achieve specific results from the member states without dictating the means of achieving those results. These legal acts are therefore important to be known since are going to influence national regulations. According to the European targets related to the building sector, the directives reported in the following paragraphs are worth to be mentioned:

2.1.1 Construction Products Regulation (CPR) 305/2011

From 1 July 2013, under the Construction Products Regulation 305/2011 (CPR), it became mandatory in the EU member states for manufacturers to draw up a declaration of performance and apply CE marking to any of their construction products that are covered by a harmonised European standard (hEN) or conform to a

European Technical Assessment (ETA) which has been issued for it, when such a product is placed on the market.

Under the CPR, harmonised technical specifications are harmonised European product standards (hENs) or European Assessment Documents (EADs) for products not covered by hENs.

The harmonised technical specification for a product defines EEA-wide methods of assessing and declaring all the performance characteristics required by regulations in any Member State which affect the ability of construction products to meet seven basic requirements for construction works. These cover:

1. Mechanical resistance and stability
2. Safety in case of fire
3. Hygiene, health and environment
4. Safety and accessibility in use
5. Protection against noise
6. Energy economy and heat retention
7. Sustainable use of natural resources

2.1.2 Directive 2002/91/EC, EPBD: First Directive on Energy Performance of Building.

The Directive concerns the residential sector and the tertiary sector (offices, public buildings, etc.), but does not, however, include some buildings, such as historic buildings, industrial sites, etc. It covers all aspects of energy efficiency in buildings in an attempt to establish a truly integrated approach. The four key points of the Directive are:

- a common methodology for calculating the integrated energy performance of buildings;
- minimum standards on the energy performance of new buildings and existing buildings that are subject to major renovation;
- systems for the energy certification of new and existing buildings and, for public buildings, prominent display of this certification and other relevant information. Certificates must be less than five years old;
- regular inspection of boilers and central air-conditioning systems in buildings and in addition an assessment of heating installations in which the boilers are more than 15 years old.

The common calculation methodology should include all the aspects which determine energy efficiency and not just the quality of the building's insulation. This integrated approach should take into account of aspects such as heating and cooling installations, lighting installations, the position and orientation of the building, heat recovery, etc. The minimum standards for buildings are calculated on the basis of the above methodology.

2.1.3 Directive 2009/28/EC: Promotion of the use of RES (energy from renewable sources)

This Directive establishes a common framework for the production and promotion of energy from renewable sources.

The Member States are to establish national action plans which set the share of energy from renewable sources consumed in transport, as well as in the production of electricity and heating, for 2020. These action plans must take into account the effects of other energy efficiency measures on final energy consumption (the higher the reduction in energy consumption, the less energy from renewable sources will be required to meet the target).

2.1.4 Ecodesign Directive 2009/125/EC & Energy Labelling Directive 2010/31/EC

The Ecodesign Directive allows setting of minimum eco-design requirements (threshold values) and/or generic requirements (information only) for specific product groups. The Energy Labelling Directive promotes best performing products by providing indication by labelling and standard product information of the consumption of energy and other resources. Initially focused on Energy-using Products (EuPs), the two Directives were extended to Energy related Products (ErPs) in 2009 and 2010 respectively. The implementation of the Directives follows the following five main steps:

1. Establishment of European Commission Working Plans containing indicative lists of product groups to be studied during 3 consecutive years.
2. Preparatory study for priority product groups, concluding on the best policy mix to be deployed Ecodesign &/or Energy Labelling or self-regulation[1], following MEErP Methodology[2].
3. A draft Commission Regulation is submitted to the Consultation Forum (representation of EU, EEA Members States and stakeholders) for comments, and a thorough impact assessment follows.

2.1.5 Directive 2010/31/EU) on the energy performance of building

This Directive aims at promoting the energy performance of buildings and building units.

Member States shall adopt, either at national or regional level, a methodology for calculating the energy performance of buildings which takes into account certain elements, specifically:

- the thermal characteristics of a building (thermal capacity, insulation, etc.);
- heating insulation and hot water supply;
- the air-conditioning installation;
- the built-in lighting installation;
- indoor climatic conditions.

The positive influence of other aspects such as local solar exposure, natural lighting, and electricity produced by cogeneration and district or block heating or cooling systems are also taken into account.

Building elements that form part of the building envelope and have a significant impact on the energy performance of that envelope shall also meet the minimum energy performance requirements set by the Member States when they are replaced or retrofitted, with a view to achieving cost-optimal levels.

2.1.6 Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011.

This regulation lays down harmonised conditions for the marketing of construction products and repeals Council Directive 89/106/EEC. This Regulation sets out the conditions for the marketing of construction products. It also defines criteria for assessing the performance of such products, and the conditions of use for CE marking.

[1] The case of self-regulation is not analysed, since this is not foreseen in the context of the EENSULATE project.

[2] http://ec.europa.eu/growth/industry/sustainability/ecodesign/index_en.htm (see Support tools for experts)

2.2 Other programmatic documents

Other reference documents, relevant to the building sector development are the following:

2.2.1 International Energy Agency (IEA)[3] - Technology Roadmap Energy-Efficient Building Envelopes, 2013.

The building envelope is the boundary between the conditioned interior of a building and the outdoors. The energy performance of building envelope components, including external walls, floors, roofs, ceilings, windows and doors, is critical in determining how much energy is required for heating and cooling. The building envelope's impact on energy consumption should not be underestimated: globally, space heating and cooling account for over one-third of all energy consumed in buildings, rising to as much as 50% in cold climates and over 60% in the residential sub-sector in cold climate countries.

Overall, buildings are responsible for more than one-third of global energy consumption. While whole-building approaches are ideal, every day building envelope components are upgraded or replaced using technologies that are less efficient than the best options available. These advanced options, which are the primary focus of this roadmap, are needed not only to support whole-building approaches but also to improve the energy efficiency of individual components.

2.2.2 European Construction Technology Platform (ECTP)[4] - ECTP-Vision 2030, 25 Feb 2005: Challenging and Changing Europe's Built Environment - A vision for a sustainable and competitive construction sector by 2030

The European Construction Technology Platform (ECTP) is an initiative to mobilise the whole construction sector – contractors, authorities, architects and other designers, purchasing bodies, and the full range of suppliers, clients and users – to find a clear set of common priorities. Construction change is increasingly client-driven, sustainable and knowledge-based.

Research has a vital role to play in this process of transformation. The ECTP will act as an umbrella for research initiatives. The key goals are linked: to *maximize client potential* in *reaching sustainable development*. The strategic research themes are: *Materials and technology*, *Industry transformation*, and *Service*. Material and technology changes will come with the full integration of the developments in the fields of bio-, nano- and information technology. Industry transformation involves bridging the gap in communication between the technical and human side of things in order to discover new business opportunities. Service issues include the pursuit of health, safety and sustainability by meeting human needs and improving accessibility, quality of life and work.

[3] www.iea.org , accessed 20th March 2015.

[4] www.ectp.org ,accessed 20th March 2015.

3 Regulatory and standards requirements

In this section, the results derived from the survey on the current European regulations, member state building codes and standards addressing the EENSULATE system and the main components, are presented analytically. The collection of such data is essential in order to develop a product that could be adjusted to the specific requirements of each country and as a result it would be applicable to every EU country.

3.1 National legislative context for building and products

For defining the critical requirements that the EENSULATE system has to fulfil, an extensive survey on collecting information on the relevant national building codes was conducted. Most specifically, the survey included information on the performance parameters related to:

- ENERGY
  - the maximum allowable thermal transmittance values for curtain-walls of new and renovated buildings of the residential and tertiary sector;
  - the limiting values for thermal transmission along linear and at point thermal bridges;
- SAFETY
  - the fire performance, which is mainly associated with the reaction to fire,
  - the burglar resistance;
  - the impact resistance;
  - the wind load resistance;
- COMFORT
  - the maximum permitted temperature factor and requirements related to surface condensation;
  - the air-tightness;
  - the water-tightness;
  - the acoustic performance;

In the following sections, a detailed presentation of the information gathered is presented for each group of performance parameters.

3.1.1 Energy performance requirements

This section provides sets of threshold values and criteria that the system to be developed must meet in order to be usable (i.e. applicable according to building regulations) in various European countries. Specifically, the issues related to vertical building components' thermal performance (maximum allowable thermal transmittance values for walls of new and renovated buildings of the residential and tertiary sector in the current and in the forthcoming regulations, limiting values for thermal transmission along linear and at point thermal bridges), were investigated.

3.1.1.1 Thermal transmittance coefficient

The thermal transmittance coefficient (U value) of a building component expresses the amount of heat flow (rate of transfer) in watts per square meter of this component with the temperature difference of 1 Kelvin

(W/m²K); in this coefficient, the effect of thermal radiation and convection, apart from thermal conduction, is also included. The value of the thermal transmittance coefficient of a building element is calculated with the use of mathematical relationships referred to in national regulations and international standards; in these relationships, the material layers composing the element, their properties and thicknesses, as well as the boundary conditions are taken into consideration. U-values of various building envelope elements have a major impact of buildings' energy efficiency and performance since they indicate the heat losses and gains through the buildings envelope, and therefore significantly contribute to the calculation of the demanded energy amount.

This European Standard EN 13947 specifies a method for calculating the thermal transmittance of curtain walls consisting of glazed and/or opaque panels fitted in, or connected to, frames. The calculation is made by combining the values of thermal transmittance of the different components of the assembly as reported in Table 3-1.

Table 3-1 – Sources of input data for the calculation of the thermal transmittance according to EN 13947.

Values of thermal transmittance	Source
U_g	EN 673, EN 674, EN 675
U_f	EN 12412-2, EN ISO 10077-1, EN ISO 10077-2
U_m, U_t	EN 12412-2, EN ISO 10077-2 (and Annex C)
Ψ_g and Ψ_p and $\Psi_{m,f}$ / $\Psi_{t,f}$	Annex B EN ISO 10077-2
U_p	prEN ISO 6946

Since the thermal transmittance of the whole curtain wall module has a high performance target (U-value < 0.4 W/m^{2}K) which is mainly dependant on the VIG performance, the main interest here is to provide information about the requirements for the opaque part of the module. Therefore, it is noted that the U-values investigated hereafter are the ones concerning the opaque vertical building components in contact with the exterior environment.

The thermal transmittance value of a building element is influenced to a crucial degree by the presence of an insulation layer, its thickness and its thermal conductivity value. Therefore, the maximum allowable U-values of building elements, as listed in the building regulations of various countries, define the minimum acceptable thickness of the insulation layer (of course in dependence on the thermal conductivity value of the selected insulation material). This basic requirement is essential for the configuration of EENSULATE system, as it is directly related to one of its components (insulation layer) and indirectly related to several of the rest of its components. In this context, the regulatory requirements for U-values of walls in European countries were considered to be a parameter of great importance, since they would form the limits for insulation protection that should be provided by the system. Additionally, the research has been extended to include the limiting U-values in the forthcoming regulations. The basis of this decision lies on the fact that currently several national regulations are being revised in order to conform to the European directives and new, stricter requirements are expected to be set. In this context and for allowing EENSULATE system to be applicable also in the future conditions, the expected limiting U values for walls in the forthcoming regulations have been listed for the countries, for which relative information could be found. In Table 3-2, the maximum allowable U-values for walls of new residential buildings in the current legislation in various European countries are listed.

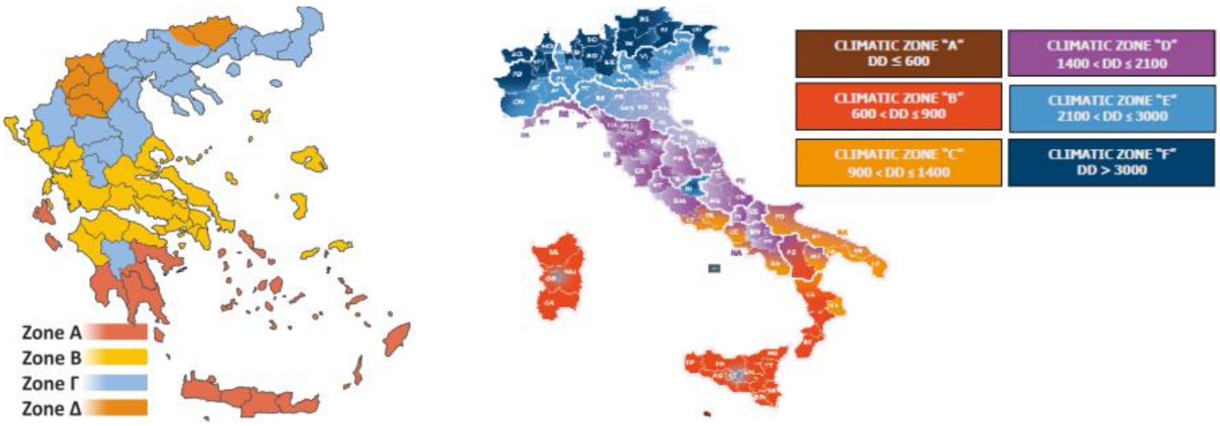

Figure 3.1 – Climatic zones of Greece [1] and Italy [9].

As the values in Table 3-2 show, there is a clear differentiation among the values used for southern countries and for northern countries, which was expected on the basis of the climatic load that the buildings are subjected to. Also, in some cases, there are different climatic zones in the same country, to each one of which different limiting U-values for external walls are assigned. In other cases, different climatic zones are related to different energy performance requirements (e.g. Figure 3.1).

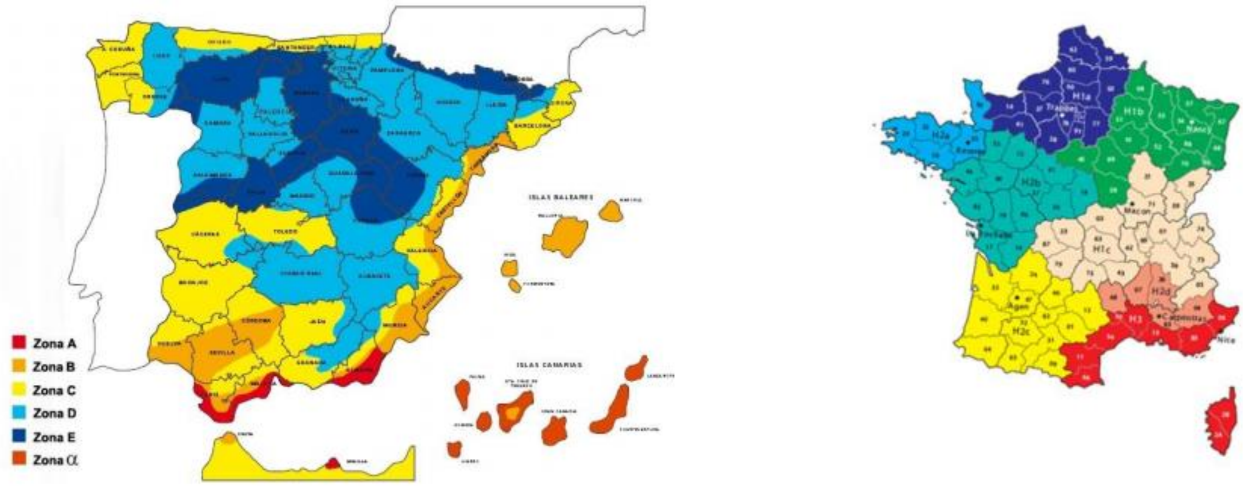

Figure 3.2 – Climatic zones of Spain [10] and France [11].

Since the EENSULATE system is designed to be used in the future, an elementary research was conducted with regard to the requirements set by future regulations information. The data are still presented in Table 3-2.

Table 3-2 – Maximum allowable U-values for opaque vertical building elements (residential).

Country		Max U-value [W/m²K]	Max U-value [W/m²K] - 2021	Source
Belgium		0.24	-	[1]
Croatia[5]		0.30 ÷0.60	-	[2], [3]
Czech Republic		0.30	0.2	[1]
Denmark		0.30	-	[4]
England		0.30	-	[6]
Greece	Zone A	0.60	-	[7]
	Zone B	0.50		
	Zone C	0.45		
	Zone D	0.40		
Ireland		0.21	-	[8]
Italy	Zone A	0.62	0.40	[1]
	Zone B	0.48	0.40	
	Zone C	0.40	0.34	
	Zone D	0.36	0.29	
	Zone E	0.34	0.26	
	Zone F	0.33	0.24	
Latvia		0.23	-	[12]
Poland[6]		0.25÷0.45	0.2	[4]
Romania		0.56	-	[1], [3]
Slovakia		0.32	-	[1]
Slovenia		0.28	-	[1]

Furthermore, for Cyprus the maximum allowable U value is 0.72 W/m²K. In most countries, the maximum allowable U-values for new buildings of the residential and of the tertiary sector are the same. However, in some countries there is a differentiation among the limits of U values set for new residential buildings and new buildings of the tertiary sector but, in this case, it can be seen ([12]-[14]) that the values of U-max for the buildings of the tertiary sector are usually higher than the ones set for the residential sector, so at this point, an indication that by considering the residential sector's U-max values one would be on the safe side is derived.

[5] Function of θe,month,min: mean monthly temperature of the outdoor air at the coldest month of the year at the building's location, and θind: indoor air temperature

[6] Function of θind: indoor air temperature.

Whether in most countries the regulatory requirements with regard to U value of exterior walls are the same for new buildings and for major refurbishments, this is not the case for all of them. Among the investigated national regulations and on the basis of the data that could be accessed, differences between maximum permissible U values for walls of new buildings and of buildings undergoing major renovation have been detected for:

- England, where the U values of the "renovated thermal elements" are approached via a different route (threshold U-values and target U-values). Under no circumstances should the exterior wall's U value exceed 0.70W/m²K, value which is also prescribed in [15] in order to prevent localised surface condensation and mould growth from occurring, but the approach regarding the thermal protection are described in [16] and [17] for buildings of the residential and of the tertiary sector respectively; there it is stated that the target U values for renovated walls, when applicable, are 0.30W/m²K.
- Ireland, where a difference is detected for the new buildings and the ones under major renovation in the residential sector; this difference varies with regard to the approach that will be selected, but, in any case, the maximum permitted U-value for walls of renovated buildings are bigger than the respective quantity for new buildings.
- Romania, where the maximum permitted U value for the wall of a residential building under renovation is 0.71W/m²K [3], [18], [19].

In the French regulations, restrictive values for building elements are not cited. For the replacement or the new installation of an exterior wall of an existing residential building, the following U_{max} is required: U_{max}=0.435 W/m²K [4].

In Germany a minimum requirement for walls is set by DIN 4108:2 to U_{max}=0.83W/m²K [21]. The requirements set for hygienic reasons are stricter, and for the achievement of energy performance target much lower values are required. For new buildings the reference value in the new energy efficiency regulation is 0.28W/m²K (residential) and 0.28 (0.35) W/m²K (tertiary/depending on the indoor temperature). For refurbishments, in case of replacement or the new installation of an exterior wall of an existing residential building the following U_{max} is required: U_{max}=0.24 W/m²K [4]. Moreover, it is worth noting that in Sweden, for small buildings of specific area, geometry and operation, maximum U_{values} (0.1/0.18W/m²K) are set for exterior walls in the context of an alternative approach to the achievement of the basic requirements (overall energy performance, airtightness, heat recovery) set by the regulation [4].

3.1.1.2 Linear and point thermal bridges

Thermal bridges, i.e. thermally weak parts of the building's thermal envelope, through which the heat flow is bigger in comparison to the neighbouring building elements, affect significantly the thermal protection provided by this envelope and the building's energy performance. The consideration of thermal bridges existence increases the actual energy consumption of a building in comparison to the theoretically calculated one without taking into them account, by a considerable proportion that depends for each case on their type and multitude.

Thermal bridges can be categorized in two types:

- Linear thermal bridges and
- Point thermal bridges

These two types of thermal bridges differ in their dimensions and in the characteristics of the heat flow along or at the respective positions.

The type of EENSULATE's structure induces a number of thermal bridges (i.e. point thermal bridges where the anchoring system contacts the substructure wall). Therefore, it is of big importance to identify the limits for thermal transmittance along linear or at point thermal bridges set in national regulations. With regard to linear thermal bridges, the research revealed that, although there are reference values for linear thermal bridges in almost all regulations, as well as recommendations for the avoidance of excessive thermal losses at the respective positions (in some cases even thorough guidance for this avoidance, e.g. England's regulation, Irish regulation), limiting values-as regulatory requirements - for linear thermal bridges are rare. The limitations regulatory related to linear thermal bridges, as they were found in national regulations are listed in Table 3-3.

Table 3-3 – Regulatory requirements for linear thermal bridges.

<table>
<tr><th>Country</th><th>Approach</th><th>Source</th></tr>
<tr><td>Czech Republic</td><td>Requirements for linear thermal transmittance are stated in CSN 730540-2; for each thermal bond between the structures the following condition must be satisfied: ψ≤ψN [W/(mK)] where ψ is the calculated linear factor of thermal transmittance between structures and ψN is the standard setpoint.
Required linear factor of thermal transmittance ψN
<table>
<tr><th></th><th>Required values ψN</th><th>Suggested values ψ_{rec}</th><th>Suggested values for pasive houses ψ_{pas}</th></tr>
<tr><td></td><td>[W/(m·K)]</td><td>[W/(m·K)]</td><td>[W/(m·K)]</td></tr>
<tr><td>Contact of the outer walls and other structures except filler opening (e.g. Liaison foundation, roof, another wall, roof, balconies etc.)</td><td>0,20</td><td>0,10</td><td>0,05</td></tr>
<tr><td>Contact of the outer walls and filling the hole (sill, jambs, lintels)</td><td>0,10</td><td>0,03</td><td>0,01</td></tr>
</table></td><td>[23]</td></tr>
<tr><td>France</td><td>for intermediate floor for new building the average Psi value must be under 0.8 W/mK</td><td>Partner</td></tr>
<tr><td>Latvia</td><td>Linear thermal bridge heat design transfer coefficient≤0.15k (residential buildings)</td><td>[12]</td></tr>
</table>

Limiting values for point thermal bridges are even less frequent; generally, the references to point thermal bridges are usually abstract (for example, in the Greek regulation, point thermal bridges are disregarded). Only for very few countries are requirements for point thermal bridges set in the regulations (e.g. Czech republic: required point thermal transmittance χ =0.40 W/K [23]).

In the Spanish building regulation limits are set for the linear thermal transfer coefficient at jambs and windows, while for Denmark, limiting values for linear thermal loss at various positions are cited in building regulations [5][7]. Furthermore, Irish regulations for non-domestic buildings [14] include a list of maximum values of linear thermal transmittance (ψ) for selected locations, mainly for doors, windows and roofs.[8]

3.1.2 Safety performance requirements

The objective of this section is to analyse and reveal the design barriers of building structures against fire, burglar and other loads and actions, based on the existing legislation framework regarding the majority of countries in Europe (national building codes). Based on this examination it is feasible to define the main attributes of the under development EENSULATE system (requirements and specifications). Thus, the

[7] The minimum requirements, in the context that was explained for the maximum U-values for Denmark presented in Table 2.1 are the following: Foundations around rooms/ spaces that are heated to a minimum of 5°C: 0,40W/mK; Foundations around floors with underfloor heating: 0,20W/mK; Joint between external wall and windows or external doors and hatches: 0,06W/mK; Joint between roof structure and rooflights or skylight domes: 0,20W/mK [5]

[8] In this context, and depending on the construction details used, there is a requirement for maximum values of linear thermal transmittance (ψ) at junctions with external element: Ground floor, intermediate floor, Party wall: 0,16W/mK.

collection of such data is essential in order to develop a product that can be adjusted to the specific requirements of each country and as a result can be implemented to every EU country.

3.1.2.1 Fire Performance Aspects – Fire Resistance and Fire Reaction

First of all, it is important to point out the main concerns of national regulations regarding the fire safety of buildings [30]-[32] and to make a distinction between fire reaction and fire resistance [33]-[36].

- The fire resistance of building components and constructions are classified in different fire resistance classes or combinations of those. The different fire resistance classes specify different performance criteria. As a rule the fire resistance classification is followed by as a time limit in minutes (i.e. 30, 60, 90, 120 et al.), which specifies the time the performance criteria is fulfilled during a standardized fire test. Hence, fire resistance indicates the length of time, during a fire, in which a construction can: (a) conserve its mechanical properties [*Criterion R – load bearing capacity*], (b) avoid the spread of flames, combustion gases, inflammable gases and smoke on the non-affected side [*Criterion E – integrity*] and (c) prevent the temperature rise in the not exposed to the fire surface (by 140°C on average and by 180°C at maximum) [*Criterion I – insulation*].
- The fire reaction shows the way by which the material behaves as a combustible. Combustibility corresponds to the quantity of heat emitted by absolute combustion of the material. Inflammability corresponds to the quantity of more or less inflammable gases emitted by the material under the action of a heat source. Based on appropriate tests materials or building products can be classified to Euroclasses (A1, A2, B, C, D, E and F). The Euro Class system is recognized in almost all European Union member countries and has replaced most national classification approaches. Moreover, the present rating scheme takes into account the smoke development (S for smoke: s1, s2 and s3) and the potential projected burning droplets (D for drop or droplets: d0, d1, d2 and d3). Thus, the examined reaction properties are ease of ignition, spread of flame, evolution of smoke and toxic gases, and heat release rate of the burning material. In overall, the above analysed aspects are important to assess whether a fire is likely to start and/or how it will be developed.

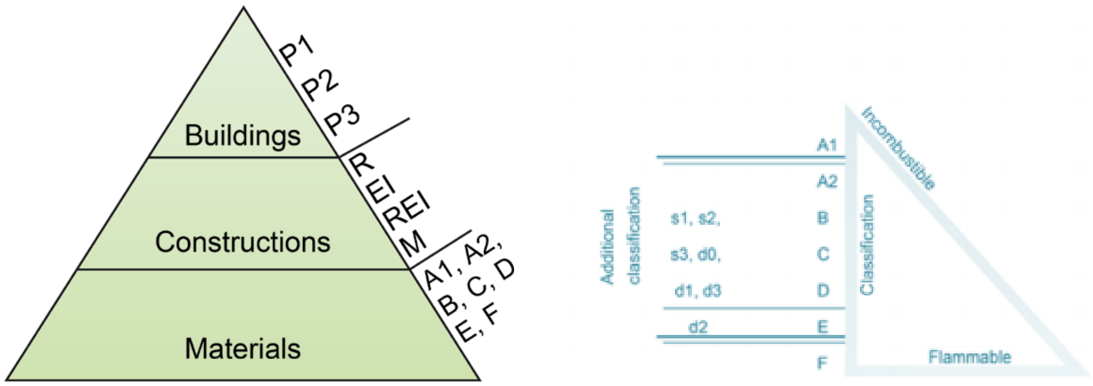

Figure 3.3 – Fire resistance and fire reaction classification standards.

As shown in Table 3-4, in Belgium, Denmark, Finland, Iceland, Italy, Norway, Poland and Spain requirements to **reaction-to-fire** for building materials exist. In Finland, few requirements are valid; building materials used in external walls in buildings of class P1 shall be mainly of at least class B–s1, d0 (this requirement prohibits the use of non-flame retarded EPS/XPS). Furthermore, in Italy regulations entail restrictions depending on the use and the characteristics of the building. In Poland for multiple dwellings and public buildings, where over 50 persons are present, fixed finished materials must be made of at least hardly ignitable materials (at least Euroclass E). At last in Spain at least a class D-s3,d0 is a basic requirement (although in most applications Euroclass E is required).

Table 3-4 – EU countries providing minimum fire reaction and resistance requirements for building envelopes.

	Performance aspects	
	Reaction to fire (EN 13501-1)	Resistance to fire (EN 13501-2)
Building materials (excluding insulation)	*Belgium, Denmark, Finland, Iceland, Italy, Norway, Poland, Spain*	Germany
Insulation materials	*Belgium, Denmark, Finland, France, Germany, Iceland, Italy, Norway, Poland, Spain, Sweden, United Kingdom*	*Germany*
Flame retarded insulation materials	*France, Germany, Iceland, Italy, Norway, Poland, Spain, Sweden, United Kingdom*	*Germany*
Walls	*Czech Republic, Denmark, Finland, Germany, Iceland, Italy, Spain, Sweden, United Kingdom*	*Cyprus, Czech Republic, Finland, Germany, Greece, Italy, Poland, Spain*
Sandwich Panels	*France, Germany, Iceland, Italy, Norway, Poland, Spain*	*Czech Republic, Germany, Italy*
Façades	*Czech Republic, Denmark, Finland, France, Germany, Poland, Spain, Sweden*	*Czech Republic, Germany, Italy, Spain*
Cladding systems or complete products	*Germany, Italy, Poland, Spain*	*Italy*

Still from Table 3-4 it is extracted that for the most part (in Belgium, Denmark, Finland, France, Germany, Iceland, Italy, Norway, Poland, Spain, Sweden and United Kingdom) requirements on reaction-to-fire for insulation materials appear [37]. For example in Belgium no specific classification for EPS/XPS other than for all other construction products exist. In Denmark the general requirement for insulation materials is D-s2, d2 but products with lower performance are allowed in several applications if certain conditions are fulfilled. In Finland thermal insulation which is inferior to class B–s1, d0 shall be protected and positioned in such a manner that the spread of fire into the insulation, from one fire compartment to another and from one building to another building is prevented (this requirement means that non-flame retarded EPS/XPS can be used provided it is properly protected against being involved in the spread-of-fire). In France it appears that: (a) Public Buildings: EPS and XPS insulations have to be at least Euroclass E; (b) Domestic Applications: No specific requirement for reaction-to-fire in individual houses and small collective buildings limited to 3 storeys (1st and 2nd families); (c) High-rise buildings - both public and domestic usages: Insulation materials requires classification as, at least, A2-s2,d0. In Germany, it should be A1/A2 for ventilated systems or large scale test, while the minimum requirement for EPS/XPS is class E or DIN 4102 (German B2). However, in practice all EPS/XPS sold in Germany today meats DIN 4102 B1. Flame retarded EPS/XPS is therefore needed in all applications, at present and most likely in the future. In Italy regulations entail restrictions depending on the use and the characteristics of the building. Hence it is: (a) uncovered EPS/XPS material insulation B-s2, d0 or B-s1, d1; (b) covered EPS/XPS material [b1] protective cover A2-s3, d0 / insulation C-s2,d1 (wall), [b2] protective cover A1 / insulation Ds2,d1 (wall), [b3] protective cover EI30 / insulation E. In Poland Euroclass E is the general requirement for EPS/XPS. If the height of building > 25 m, euroclass A (no contribution to fire). In Spain the baseline regarding insulation materials is D-s3, d0. At last, in the United Kingdom specific applications exist where only non-combustible insulation are allowed; in these applications PS foam would not be used.

in France, Germany, Iceland, Italy, Norway, Poland, Spain, Sweden and United Kingdom the national regulations entail the use of flame retarded insulation materials, although in some countries the existing reaction-to-fire requirements result in the use of flame retardant insulation material (i.e. Belgium, Denmark) [8]. For example in Belgium no direct requirements for flame retardants exist. Analogously, in Denmark the general requirement for insulation materials is D-s2, d2 but products with lower performance are allowed in several applications if certain conditions are fulfilled. On the other hand, in France it is: (a) Public Buildings: Producer of raw material has to prove flame retardancy to reach Euroclass D level for raw XPS in 60 mm and for raw EPS in 40 mm; (b) Domestic Applications: No specific requirement for reaction-to-fire in individual houses and small collective buildings limited to 3 storeys (1st and 2nd families). Furthermore, in Germany specific requirements apply for ETICS (particular steel structures), while the minimum requirement for EPS/XPS is class E or DIN 4102 (German B2). However, in practice all EPS/XPS sold in Germany today meats DIN 4102 B1. Flame retarded EPS/XPS is therefore needed in all applications, at present and most likely in the future. In Italy regulations entail restrictions depending on the use and the characteristics of the building; it can be mentioned that EPS/XPS is normally flame retarded, except for the use in Euroclass E applications. In Norway there are no reaction-to-fire requirements on testing that exclude the use of non-flame retarded EPS/XPS products in buildings, except as exposed surface linings. Therefore non-flame retarded EPS/XPS are allowed as insulation materials. In Poland flame retarded EPS/XPS foam grades are used in most applications; this condition applies for height of buildings < 25 m. In Spain it is unclear if nonflame retarded products are actually used in some applications; for applications where Euroclass E or higher classes are required the EPS/XPS would be flame retarded. In Sweden there are no reaction-to-fire requirements on testing that exclude the use of non-flame retarded EPS/XPS products in buildings, except as exposed surface linings. Finally, in the United Kingdom the safety requirements from insurance companies regulates the use of EPS/XPS in the construction phase. This situation has resulted in that most EPS and all XPS for the UK market is flame retarded. When flame retarded the PS foam is meeting Euroclass E according to EN 13501-1.

As it is seen, in Czech Republic, Denmark, Finland, Germany, Iceland, Italy, Spain, Sweden and United Kingdom national regulations can also define the design decisions for building facades. In Finland it is: (a) for building materials used in fire separating building elements the class requirement A2–s1, d0 is imposed for fire-separating walls in exits in buildings of class P1 with more than 2 storeys; (b) for internal walls it is mostly D-s2, d2; (c) for external walls it is mostly B–s1, d0. In Germany fire safety constraints for wall elements depend on the building type; at least walls must be Euroclass E or higher (German B2-B1). In Italy regulations entail restrictions depending on the use and the characteristics of the building. In Spain for walls it is D-s3, d0 (EI-30, 60, 120 function of fire sectioning). In Sweden for wall applications the minimum and maximum requirements are D-s2, d0 and C-s2, d0 or B-s1, d0, respectively; this condition applies only when the surface lining shall be mounted on a A2-s1, d0 product. Additionally, in the United Kingdom specifications of the regulations are related to the surface of walls; thus, when the thermal insulation is covered there is no requirement.

As seen in France, Germany, Iceland, Italy, Norway, Poland and Spain national regulation consider the occurrence of sandwich panels. On the other hand, in Cyprus, Finland, Greece and Sweden the national regulations ignore sandwich panels. More specifically, in France it is: (a) Public Buildings: For sandwich panels made of B-s1, d0 wood-wool skins and EPS/XPS core the producer of raw material has to prove flame retardancy to reach Euroclass D level for raw XPS in 60 mm and for raw EPS in 40 mm; (b) Domestic Applications: No specific requirement for reaction to-fire in individual houses and small collective buildings limited to 3 storeys (1st and 2nd families). In Germany and Italy, the barriers imposed by sandwich panels depend on the application type. Furthermore, in Iceland the Euroclasses required for this case are A2-s1, d0 or B-s2, d0, depending on application. However, it is not clear whether it would be possible for a sandwich panel containing EPS/XPS to pass this classification, even if it were flame retarded; it would not be possible for a nonflame retarded EPS/XPS material to obtain such a classification. Then again, in Norway the Euroclasses required in this case are B-s1, d0 or D-s2,d0, depending on application. In this region it is not clear whether it would be possible for a sandwich panel containing EPS/XPS to pass this classification, even if it were flame retarded; mostly, it would not be possible for a non-flame retarded EPS/XPS material to obtain such a classification. In Poland requirements of at least Euroclass E define the core material selection. In addition, for buildings with a height of more than 25 m the regulations require the implementation of sandwich panels with a Euroclass A (no contribution to fire). At last, in Spain it is basically D-s3, d0, while for sandwich panels containing EPS/XPS the requirements are Euroclass B-s2, d0 or C-s2, d0, depending on the kind of application.

The national regulations in Czech Republic, Denmark, Finland, France, Germany, Italy, Poland, Spain and Sweden make provision for building facades. Hence, in the Czech Republic it is: (a) For non-flamable products: - façade insulation of class A1 (MW), - plasterboard or gypsum board of class A2; (b) For flamable products: - ETICS with EPS (ie. System including plaster façade insulation or Twinner system) of class B, -façade phenolic foam insulation of class C, - structural timber D, - facade insulation EPS E. In Finland building materials of class D–s2, d2 may be used to a small extent for the fixing of façade boards in buildings of not more than 8 storeys. Moreover, in France it is: (a) Public Buildings: All façade elements have to be classified as, at least, D-s3, d0. When additional rules apply and are not fulfilled, all materials have to be classified as C-s3, d0. Furthermore, if the system is based on EPS/XPS insulation, it has to be protected by a A2-s3, d0 surface material reinforced with fibreglasses. The facade test will not restrict the use of EPS/XPS if the constructive system protects it enough from the fire; (b) Domestic Applications: No specific requirement for reaction-to-fire in individual houses and small collective buildings limited to 3 storeys (1st and 2nd families). In Germany for facades it is Euroclass E or higher class (German B2-B1). In Poland for buildings with a height of more than 25 m the regulations require the formation of facades with a Euroclass A (no contribution to fire). In Spain facades should at least fulfil the limit D-s3, d0 (EI-60 whole system). At last, in Sweden for facade applications the minimum requirement is D-s2, d0, while under specific circumstances the facade must be capable to pass SP fire 105; agreement with the SP FIRE 105 requirement for facades of multi storey buildings does not prohibit the use of non-flame retarded EPS.

In Germany, Italy, Poland and Spain national regulations take into account the use of cladding systems, while in Cyprus, Finland, Greece and Sweden regulations neglect this issue. In Germany the minimum requirement is Euroclass E, while in general it is Euroclass B or C. For particular buildings the limitations may require a Euroclass A. Furthermore, in Italy the regulations mention Euroclass B-s3-d0. In Poland for buildings with a height of at least 25 m the demand is Euroclass A (A1; A2-s1, d0; A2-s2, d0 ; A2-s2,d0; no contribution to fire). At last, in Spain the requirement for cladding systems or complete products is Euroclass C-s3, d2.

It is also essential to mention that in Finland, mostly the load-bearing constructions shall be made by materials of at least Euroclass A2–s1, d0; however, if the load-bearing constructions do not fulfil the A2–s1, d0 Euroclass (i.e. building class P2 with 3-4 storeys D-s2,d2), then the insulation materials of the building should be made by materials of at least Euroclass A2–s1, d0 (this requirement prohibits the use of EPS/XPS).

Table 3-4 illustrates also the status of regulations across Europe, when **resistance** to fire is considered. Clearly it can be seen that all national regulations take into account the fire resistance of wall assemblies. Furthermore, in Germany fire regulations assess the fire resistance of building materials; mostly, information concerns insulation materials, as well as flame retarded insulation materials. Additionally, in the Czech Republic, Germany and Italy the regulations specify constraints in buildings that incorporate sandwich panels which may somehow associated to the spandrel conception of the EENSULATE module**.** In a number of countries including the Czech Republic, Germany, Italy and Spain special attention is also given for building facades. At last, in Italy regulations make some discussion upon cladding systems and their required resistance against fire.

The investigation of national fire regulations for building structures has revealed also that exists the necessity of **large scale facade testing** for a few countries across the European region (Czech Republic, Germany, Spain, Sweden and United Kingdom). The above constraint makes it necessary to carry out proper tests based on exact national standards.

In many countries specific guidelines are typically comprised of common international guidelines, such as the International Fire Engineering Guidelines (IFEG), ISO standards and the SFPE Handbook of Fire Protection Engineering and SFPE guidelines. British standards are also used, both within and outside UK. In addition, a number of countries publish and implement their own guidelines, which cover various aspects for special structures (i.e. cladding systems) [38]-[42].

Technical Barriers

Fire safety design (FSD) is a tool to allow for non-traditional approaches, which is being adopted rapidly across Europe. From the outcomes presented in the previous section it becomes clear that fire safety design methods are more and more common within the European region. While there are many differences between European countries, there are also many similarities. It is critical to mention that many big countries, such as Germany, France, Spain and Italy, started allowing fire safety engineering (FSE) only in the last decade.

Evidently, most countries face new challenges and have lately modified their legislation framework in order to be in accordance with a common approach practice; fire safety requirements in the national building regulations are often based on the above fire safety approaches. Consequently, by examining carefully the national fire regulations across the European region it is possible to define the main attributes of the proposed system against fire actions. As it is seen in this report, an undertaking of this kind by its nature is nebulous and not easy to carry out due to the minutiae of diversities in interpretation of seemingly analogous regulations in their individual application. Based on the analysis of the building regulations and/or reports for each country it is revealed that:

- Insulation which is inferior to class B–s1, d0 shall be adequately protected and placed against spread of fire.
- For external walls in buildings the materials should be at least of class B–s1, d0 (this prohibits all types of EPS/XPS, including flame retarded).
- In most countries across Europe, large scale façade testing requirements are not obliged by national building regulations. However, in some European countries large scale façade testing demands exist. This constraint should be considered in order to develop a suitable system for the entire European region.

3.1.2.2 Impact resistance

For impact resistance, the reference standards in Europe are the EN 12600 (flat glass) and EN 14019 (curtain-walls). The EN 14019 standard defines the requirements and classification for impact resistance of curtain walling under an impact load (drop object).

The classes are then determined according to the maximum impact load, in terms of drop height, for which the curtain wall does not suffer any breakages, any holing, any permanent deformation and depending on the side tested (Internal or External).

These classes are listed in Table 3-5 together with the associated load tests that must be made in order to ensure that the class is reached.

Table 3-5 – Impact resistance classes according to EN 14019.

Drop Height [mm]	Class
Not applicable	I0/E0
200	I1/E1
300	I2/E2
450	I3/E3
700	I4/E4
950	I5/E5

3.1.2.3 Wind load resistance

The design pressures are typically established by the project's structural engineer and are based on the building's exposure classification, the building's height, type and configuration. The window and curtain wall components need to be designed to resist deflection and failure at the specified design pressure which is generally calculated according to EN 1991-2-4. However, depending on the country, local annexes should be investigated in order to get the wind speed values for the local context.

For special applications such as high rise buildings (e.g. >80 m in Italy) or building with irregular shapes, wind tunnel tests are often prescribed in order to assess the dynamic coefficient of the load.

Requirements are set by the EN 13116, mainly in terms of allowable deflections and recovery of deformation. Deflections under the design wind load must be < min (1/200 of L, 15 mm) where L is the length of the longer frame element. 95% of the accounted deformation under the design wind load must be recovered in 1 h.

3.1.3 Comfort performance requirements

This section makes a review of those aspects which may affec both the indoor comfort (e.g. air quality, protection from noise) and the building materials deterioration mechanisms.

3.1.3.1 Acoustic performance

The present section is aiming to describe sound insulation regulations in European countries. The research focuses on façade sound insulation requirements that should possibly be taken into account for the EENSULATE system installation.

National building regulations in most European countries define specific limits for the sound insulation of the building façade, according to a set of parameters (outdoor noise conditions, traffic, building use etc). While there are countries which have limits only for new buildings, there is a great number of countries that have sound insulation requirements in case of renovation of existing buildings. This means that for the application of the EENSULATE system the level of sound insulation requirements on the façade should be defined in each case, according to the country regulations.

Acoustic regulations of 17 European countries were examined and, as it is concluded by the research on national sound insulation regulations, there are no common descriptors for the sound insulation limits in European countries. In some countries the descriptor defines the minimum sound insulation level while, in others the maximum permitted indoor noise level. Table 3-6 gives the description of the most common sound insulation descriptors that are met in the sound insulation regulations of European countries. As shown in

Table 3-6, there are different façade sound insulation descriptors and they may be divided into two big categories: the former, including D_w, DA and R_w expressing the performance directly, the latter, including the L_A, and L_{Aeq} expressing it indirectly [45]. It should also be observed that L_{Aeq} is the most commonly used descriptor for the maximum permitted indoor noise level. Moreover, some countries have different day and night noise limits while, others have the same limit for the whole 24 hours. Sound insulation limits also differ according to the building type or building use. This means that the sound insulation index is different for residential or office buildings.

Table 3-6 – Different façade sound insulation descriptors used in regulations across EU countries.

Symbol	Descriptor	N. of countries
$D_{2mnT,w}$	Weighted standardized sound level difference	2
$D_{2mnT,Atr}$	A-weighted standardized level difference adapted to traffic noise	1
$D_{nT,w} + C_{tr}$	Weighted standardized level difference with spectrum adaption Term C_{tr}	2
R'_w	Weighted apparent sound reduction index	2
R_A	dB(A) index (standard absorption area for the receiving room is used)	1
L_A	A-weighted, sound Leve	1
L_{Aeq}	A-weighted, equivalent sound level	6
L_{AFmax}	A-weighted, fast, maximum, sound Level	1

3.1.3.1.1 Façade indoor noise level or sound insulation level

Some countries define the requirements indirectly limiting the L_p and/or L_{eq} index values measured inside the buildings. In these cases, the $R_{\theta,w}$ or $R_{tr,w}$ are not evaluated directly but must be specified in the projects so that the building is able to respect the regulations for a certain urban area [46].

Czech Republic, Denmark, Finland, Greece, and Norway use descriptors defining the maximum permitted indoor noise level. In contrast, Austria, Belgium, France, Germany, Netherlands, Portugal and Spain use descriptors defining the minimum insulation level of the façade. According to minimum façade sound insulation level the Austrian regulation appears to have the stricter value ($R'_{res,W+Ctr}$ = 28dB for rating level in front of the façade: day ≤ 50 and night ≤40). In Table 3-7, façade sound insulation criteria are described for 14 European countries. The table describes the descriptor used in each country, the existing sound classes and the limits (indoor level or sound insulation) for each one, as well as the limits and classes required for building renovation in case they exist. It should be noted that table is an extended version from [47].

Table 3-7 – European schemes for acoustic classification of dwellings – Façade sound insulation criteria (Bold: legal requirements) – extended from [47]

Country	Indoor level or sound insulation	Class A	Class B	Class C	Class D	Class E
		Netherlands Class 1, Germany III	*Netherlands Class 2, Germany II*	*Netherlands Class 3, Germany I*	*Netherlands Class 4*	*Netherlands Class 5*
Denmark	$L_{Aeq,24h}$ (indoor)	≤ 20	≤ 25	**≤ 30**	≤ 35	-
Finland	$L_{Aeq,7-22}$ (indoor)	≤ 25	≤ 30	**≤ 35**	≤ 35	-
	$L_{Aeq,22-7}$ (indoor)	≤ 20	≤ 25	**≤ 30**	≤ 30	-
Iceland	$L_{Aeq,24h}$ (indoor)	≤ 20	≤ 25	**≤ 30**	≤ 35	-
	$L_{Amax,22-6}$ (indoor)	≤ 35	≤ 40	**≤ 45**	NA	-
Norway	$L_{Aeq,24h}$ (indoor)	≤ 20	≤ 25	**≤ 30**	≤ 35	-
	$L_{Amax,23-7}$ (indoor)	≤ 35	≤ 40	**≤ 45**	≤ 50	-
Sweden	$L_{Aeq,24h}$ (indoor)	≤ 22	≤ 26	**≤ 30**	≤ 34	-
	$L_{AFmax,22-6}$ (indoor)	≤ 37	≤ 41	**≤ 45**	≤ 49	-
France	$D_{nT,,w} + C_{tr}$	$D_{nTA,,tr}$ ≥ 32		$D_{nTA,,tr}$ ≥ 30		-
Germany	$R'_{res,w}$	≥ DIN 4109 + 5 dB	≥ DIN 4109	**≥ DIN 4109**	-	-
Lithuania	$D_{2m,nT,,w}$	≥ 40 (32)[1]	≥ 35 (33)[1]	≥ 30	≥ 25 (28)[1]	≥ 23 (28)[1]
Netherlands	$D_{2m,nT,,w} + C$*					
	$D_{2m,nT,,w} + C_{tr}$*	Min/Max 28/32	Min 28	**Min 23**	Min 18	Min 18
	Goal***: L_{den} (indoor)	≤ 30***	≤ 30***	**≤ 30*** **	≤ 35***	≤ 45***
Austria	$R'_{res,w} + C_{tr}$	≥ ONORM B 8115-2	≥ ONORM B 8115-2	**≥ ONORM B 8115-2**	≥ ONORM B 8115-2	≥ ONORM B 8115-2
Belgium	D_{atr} (Living room and kitchen)	≥ 26[4]	**≥ 26[4]**	Lower than class B	-	-
	D_{atr} (Bedroom close to airport/railway)	≥ 34 + m dB	**≥ 34 + m dB**	Lower than class B	-	-
Italy	$D_{2m,nT,,w}$	≥ 43	**≥ 40**	≥ 37	≥ 32	-
Greece	$L_{Aeq,h}$ (residencies)	≤ 30	**≤ 35**	Lower than class B	-	-
Poland	R_a (day: ≤45dB / night: ≤35dB)	-	**≥20** (classB)	-	-	-
	R_a (day: 71-75dB/night: 61-65dB)	-	**≥38** (classB)	-	-	-

As already mentioned, some countries such as Austria, Czech Republic, Denmark, Italy, Norway and Poland have different day and night limits for façade sound insulation. These limits differ not only in the descriptor definition but also in the outdoor noise levels taken into account. For example in Austria the outdoor noise levels in front of the facade for the day sound insulation limits vary from 50 to 80 dB and for the night insulation limits from 40 to 70 dB. The corresponding limits for the sound insulation of the façade vary from 28 to 48 dB (Table 3-8).

Table 3-8 –Requirements for the sound insulation of the façade in Austria according to ONORM B 8115-2 [48].

Requirements for the sound insulation of the façade in Austria according to ONORM B 8115-2								
Rating level in front of the façade	Day	≤ 50	51-55	56-60	61-65	66-70	71-75	76-80
	Night	≤ 40	41-45	46-50	51-55	56-60	61-65	66-70
$R'_{res,w} + C_{tr}$ (dB)		28	33	33	38	38	43	48

In Denmark, the sound insulation limit of the façade is defined according to day and night hours for four different classes ranging from 25 to 38 dB for the day limit and from 20 to 30 dB for the night limit (Table 3-9).

Table 3-9 –Maximum sound level L_{Aeq} (dB) in rooms for living caused by a sound source outside the building for Denmark [49].

Maximum sound level L_{Aeq} (dB) in rooms for living caused by a sound source outside the building				
Class	A	B	C	D
Day 07:00-22:00	25	30	35	38
Night 22:00-07:00	20	25	30	30

On the contrary in Finland, the indoor sound level is defined for each one of the four classes for a 24 hour period according to Table 3-10

Table 3-10 –Maximum sound level L_{Aeq} (dB) in rooms for living caused by a sound source outside the building for Finland [49].

Maximum sound level L_{Aeq} (dB) in rooms for living caused by a sound source outside the building				
Class	A	B	C	D
L_{Aeq} (dB)	20	25	30	30

The National standard, in Italy, defines maximum differences of residual noise indoor which are 5 dB during the day (from 6.00 am to 10.00 pm) and 3 dB during the night (from 10.00 pm to 6.00 am). In Poland, there are also different day and night limits for the sound insulation level of the façade as presented in Table 3-11.

Table 3-11 –Requirements for the sound insulation off the façade in Poland [50].

Requirements for the sound insulation of the façade in Poland			
Outdoor rating level	day	≤ 45	71-75
	night	≤ 35	61-65
R_A (dB)		20	38

In Czech Republic the sound insulation limit is adjusted for the day and night limit by a correction factor (L_{Aeq} ≤ 50 + correction [dB]). Although the above limits cannot be easily compared Finland appears to have the strictest regulation with the maximum sound level ranging between 20 and 30 dB. However, taking into account that only the limits for class C are mandatory, the Austrian and Polish regulations remain stricter than the Finnish.

With reference to the outdoor noise level, this is also an issue that is taken into account in most European sound insulation regulations when defining the limits for the indoor noise level or the sound insulation level of the façade. It is a fact that in each country traffic or outdoor noise in general are taken into account using different outdoor noise level classes or environmental noise mapping. This is why the description can only be made by country and for each case. For exterior walls some countries (France, U.K., Sweden) use specific "traffic noise sources". In Norway also noise from transport and general outdoor sources is taken into account. In UK Rw (C;Ctr) = 37 (-4;-9) This means that the sound insulation value for a facade is 37 dB and is reduced by 9 dB for traffic noise. The French regulations demand between 30 to 40 dB(A) for the insulation of the facades using a D_{nAT} index and a standard French traffic noise source. The sound insulation requirement depends on the distance to the road and the classification of the road (for example, class 1: d<300m, $D_{nTA,tr}$ ≥ 32dB, worst case: $D_{nTA,tr}$ ≥ 45dB. Sweden uses L_p and L_{eq} indexes which represent the maximum instantaneous and equivalent levels measured inside the building in dB(A) due to all normal traffic outside the building. Values range between 25 to 40 dB(A) for L_{eq} and between 40 to 50 dB(A) for L_p [51]. In Austria, Belgium, Germany Spain and Portugal sound insulation regulations define different limits according to the outdoor noise level.

In Greece there are not noise maps yet although a new regulation is being prepared since 2010 in order to replace the existing one (ΦΕΚ 59/Δ/3.2.1989), However, it has not been implemented yet. At the moment only police order or public health policies define the limits of airborne sound as following: max 35 dB(A), in residential areas for public quiet hours, from every kind of neighbouring installations.

In Belgium for the general case in which railway and/or air traffic noise is not dominant, there are different requirements for "day rooms" (living room, kitchen) and "night rooms" (bedroom, study). No differentiation is made for the comfort classes. The required façade sound insulation depends on the sound level measured 2m in front of the façade of the constructed room for the period 07h-23h and for the period 23h-07h. The façade sound insulation index D_{Atr} is defined as a function of the outdoor noise exposure (L_A) which is either calculated or estimated [52].

Table 3-12 –Façade noise insulation limits in Belgium according to the outdoor noise exposure [53].

Criteria for the sound insulation D_{Atr} of the façade		
Type of room	**Normal Acoustic Comfort (NAC)***	**Enhanced Acoustic Comfort (EAC)***
Living room, kitchen, study room, bedroom	$D_{Atr} \geq L_A - 34 + m$ dB and $D_{Atr} \geq 26$ dB	$D_{Atr} \geq L_A - 30 + m$ dB and $D_{Atr} \geq 26$ dB
Bedrooms near airports and railways	$D_{Atr} \geq L_A - 34 + m$ dB and $D_{Atr} \geq 34$ dB	$D_{Atr} \geq L_A - 30 + m$ dB and $D_{Atr} \geq 34$ dB

* m = 0 dB except m = 3dB when the room has both more than 2 façade panes containing building elements $R_{Atr} < 48$ dB and when $L_A > 60$ dB in front of each façade pane.

In Spain, the traffic factor can be approximated using a fixed value obtained for each case (element) by the manufacturer, or the Catalogue for Constructive Elements. Table 3-13 describes the permitted minimum insulation levels defined in the Spanish regulation according to the different day and night external noise levels.

Table 3-13 – Minimum permitted sound insulation levels in Spain.

External noise Ld, dBA	**Building use**			
	Residential / hospital		**Cultural, sanitary, school, offices**	
	Bedroom	Living room	Living room	Classroom
Ld ≤ 60	30	30	30	30
60 <Ld ≤ 61	32	30	32	30
65 <Ld ≤ 70	37	32	37	32
70 <Ld ≤ 75	42	37	43	37
Ld > 75	47	42	47	42

In Portugal classification of the neighbourhood ranges from quiet to very noisy. This type of area should be classified in accordance with land use planning regulations, based on environmental noise mapping.

In Germany, the requirements for sound insulation and their verification are described in DIN 4109. DIN 4109 defines 7 different noise level classes and the corresponding airborne sound insulation levels ranging from 30 to 50 dB.

The "definitive outdoor noise level" outside building walls for typical street traffic situations is calculated according a nomogram (DIN 18 005 Part 1/05.87).The noise level can be calculated for several typical street traffic situations with the use of a nomogram according to DIN 18 005 Part 1/05.87, Section 6 (Figure 3.4). The additional correction factor of 3 dB(A) compared to unhindered propagation in the open air can also been taken into account.

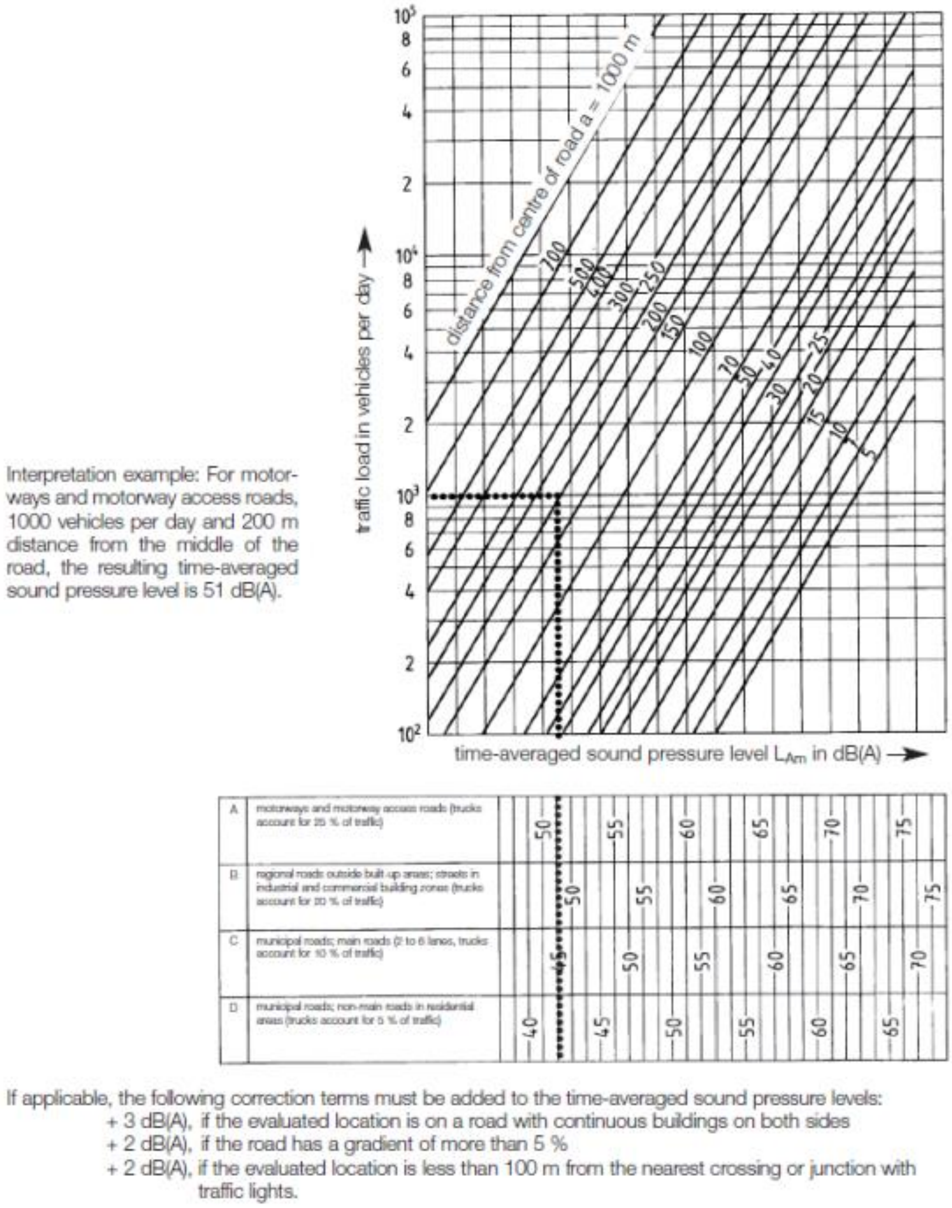

Figure 3.4 – Nomogram to determine the “definitive outdoor noise level” (from DIN 4109 [54])

Although the limits are not directly comparable it could be noted that the strictest criteria are set in Austria, for lowest outdoor noise level (28 dB, for outdoor noise level: day ≤50, night ≤40). However, for more noisy exteriors (51-55dB) Spanish and German regulations have stricter limits for the indoor noise level.

3.1.3.1.2 Acoustics relevant frequencies

It should be noted that when referring to sound insulation all units are frequency dependent; for decades the frequency range of 100 – 3150 Hz has usually been considered; in the last years the frequency range has been enlarged to 50 Hz to lower frequencies and to 5000 Hz to higher frequencies.

In a new edition of ISO 717-1 two supplementary spectrum adaptation terms were introduced, C for pink noise (equal levels over the whole frequency range, representing approximately living activities like talking, music, radio, TV, and railway traffic at medium and high speed) and C_{tr} for noise with predominantly low frequencies (representing approximately urban road traffic, many factories, disco music and so on). With the sum of R_w and the relevant spectrum adaptation term (according to the relevant spectrum) the difference of

A-weighted levels may be calculated. The spectrum adaptation terms may be stated for the frequency range 100-3150 Hz (used for decades) as well as for the enlarged frequency ranges of 50-3150 Hz, 50-5000 Hz or 100-5000 Hz; the relevant frequency range has then to be stated as an index, e.g. $C_{50\text{-}5000}$ or $C_{tr,50\text{-}5000}$.

According to the information collected, the EU countries taking somehow into account low frequencies are Austria, Belgium, Germany, Portugal, Spain and UK.

In Spain there are no specific regulations for lightweight facades. It just applies on lab trials, separating the cases of large influence (ISO 10848-2:2006) or small influence (ISO 10848-3:2006).

In Portugal the legal requirements do not consider spectrum adaptation terms except for façades when the translucent area is greater than 60% of the façade element in which case, and taking into account the characteristics of outside noise, the terms C or C_{tr} must be added, keeping the legally established limits.

In UK approved Document E introduced a new rating system. This introduced a correction factor when measuring sound that takes particular account of low frequency noise, e.g. bass sound – which is frequently cited as a cause of noise disturbance. This means that the measures are much more difficult to achieve in practice on site.

3.1.3.2 Surface condensation

Surface condensation and mould formation on the internal surface of building elements is related to specific values of surface air relative humidity, which is connected to a certain internal surface temperature. The temperature factor, otherwise known as f-factor, is a quantity that describes the “thermal quality” of the envelope in terms of surface condensation and mould formation avoidance; an essential quantity included in the temperature factor coefficient calculation formula is the internal air temperature. The minimum allowable temperature factor is derived as following: by considering the limiting surface relative humidity values for condensation and mould formation, as these values are set by international standards and national regulations, and given the climatic conditions, the corresponding internal surface temperature is determined; this temperature is used as indoor air temperature and on the basis of this value, the minimum permissible temperature factor is identified. The temperature factors are usually calculated at the most weak positions of the envelope (e.g. thermal bridges), for the possibility of the afore-mentioned adverse phenomena to be assessed. The temperature factor at every position must be higher or equal to the minimum permissible temperature factor. Minimum permissible temperature factors are listed in several European countries’ regulations. In Table 3-14, the limit f – factors, as set in the building codes. It must be noted that, as mentioned earlier, these values are based on given, specific outdoor climatic conditions and on the consideration of specific critical surface relative humidity values. The critical relative humidity values range in the different regulations from 75% (Sweden [24]) to 100%. Based on these critical surface relative humidity values, the $f_{Rsi,min}$ can be derived for any set of climatic data[9]. The derivation of both $f_{Rsi,min}$ (or $f_{Rsi,cr}$) and f_{Rsi} are based on well established relationships referred to in the regulations. In several of these regulations, reference to EN ISO 13788 methods is made, which forms their basis as well. Apart from the values listed in Table 3-14, surface condensation and mould formation is taken into consideration as a serious problem that should be dealt with in several countries’ regulations (mostly countries of central and northern Europe). For example, in Bulgaria surface condensation possibility (ϕcritical =100%) must be taken into consideration while in Croatian regulations, at thermal bridges with psi value over a threshold and specific indoor conditions a condensation check is required, with this requirement being extended to surfaces of certain spaces. In Romanian regulation it is stated that the interior surface temperature must not drop below the dew temperature [18], [28]. In Slovakian regulations, it is pointed out that for opaque structures the criterion is the formation of mould exclusion, while for windows the exclusion criterion is the surface vapour

[9] For example, when the avoidance of corrosion is under assessment, the critical value of ϕ is 60%. Nevertheless, with regard to mould formation and surface condensation the critical values of ϕ taken into consideration in the studied accessible regulations are 75%-100%.

condensation. The critical relative humidity of the inner surface taken into consideration is 80%. For Denmark, provisions are made already through the minimum permissible U-value (as explained in the respective paragraph), while for England (as also explained in the respective paragraph), the requirement of Umax=0.70W/m²K for walls is based on the same considerations [15].

Table 3-14 – Limit f-factors as indicated in several national regulations of EU countries.

Country	Minimum f-factor $f_{Rsi,cr}$ [-]	Comments	Source
Czech Republic	0.75	Requirements for the temperature factor are set differently for opaque structures and fill openings. For opaque structure the criterion is the formation of mould exclusion, for windows the exclusion criterion is the surface vapour condensation. Critical relative humidity of the inner surface 80% (mould formation).	[23]
Germany	0.7	Critical relative humidity of the inner surface 80%	[21]
England*	0.30	Storage buildings	[25]
	0.50	Offices, retail premises	
	0.75	Dwellings, public buildings	
	0.80	Sports halls, kitchens, canteens (buildings with un-flued gas heaters	
	0.90	Buildings with high humidity e.g. swimming pools, laundries, breweries	
Ireland	0.75 (0.70 at corners)	Temperature factor at thermal bridges positions	[8] [14]
Italy	0.766**	Critical internal surface relative humidity: 80%	Partner
Poland	0.72		[26]
Spain	0.42÷0.90	Critical internal surface relative humidity: 80%. The values of frsi,cr as given in the relative regulatory document differ with regard to the hygrometric class and to climatic zone[10]	[27]

* *Minimum critical temperature f-factors based on likely internal environments.*

** *This is the maximum fr,si,cr that is calculated for specific conditions of indoor and outdoor climate. For example, for another month characterised by less severe conditions, this value would be lower.*

3.1.3.3 Water and air tightness

Any form of water infiltration to the interior side of a building, excessive air leakage resulting in: 1) discomfort to building occupants; 2) the formation of excessive condensation on the interior side of the building or 3) the formation of icicles on the exterior side of the building, would be unacceptable to any building owner or occupant. This being said, one of the primary performance criteria for any window or curtain wall system is that they provide an appropriate level of resistance to water penetration and air leakage resistance. It is also

10 *Temperature factor fRsi,min from [27]*

	Winter climatic zone					
Room's category	a	A	B	C	D	E
Hygrometric class 5	0,7	0,8	0,8	0,8	0,9	0,9
Hygrometric class 4	0,56	0,66	0,66	0,69	0,75	0,78
Hygrometric class 3 or inferior to 3	0,42	0,50	0,52	0,56	0,61	0,64

worth mentioning that the majority of the problems associated with the in-service performance of building envelopes are due to either water infiltration or air leakage issues.

Resistance to water penetration performance requirements will vary depending on the building's height, geographic location and exposure classification.

For watertightness, the reference standard in Europe are the EN 12154 and EN 12155. The EN 12154 standard defines the requirements and classification of watertightness performance of both fixed and openable parts of curtain walling under positive static air pressure. According to the standard, five classes are defined in order to adequately cover all locational and regional conditions likely to be experienced. These classes are listed in Table 3-15 together with the associated pressure tests that must be made in order to ensure that the class is reached.

Table 3-15 – EN 12154 pressure steps and corresponding watertightness calsses.

Class	**Pressure steps in Pa and test duration in minutes Pa/T**	**water spray rate l/min m^2.**
R4	0/15; 50/5; 100/5; 150/5	2
R5	0/15; 50/5; 100/5; 150/5; 200/5; 300/5	2
R6	0/15; 50/5; 100/5; 150/5; 200/5; 300/5; 450/5	2
R7	0/15; 50/5; 100/5; 150/5 200/5; 300/5; 450/5; 600/5	2
RE xxx	0/15; 50/5; 100/5; 150/5 200/5; 300/5; 450/5; 600/5; above 600/5 in steps of 150 Pa and 5 minutes duration.	2

Specimens with water leakage at less than 150 Pa cannot be classified.

Specimens without water leakage at more than 600 Pa are classified E (Exceptional)

For airtightness, the reference standard in Europe are the EN 12152 and EN 12153. The EN 12152 standard defines the requirements and classification of airtightness performance of both fixed and openable parts of curtain walling under positive and negative static air pressure. The standard makes specific reference to EN 12207 for Windows and doors air permeability classification and EN 1991-2-4 for wind pressure calculation. According to the standard, classes of airtightness are determined starting from the maximum testing air pressure which is 0.25 of the design wind load calculated according to EN 1991-2-4.

The classes are then determined according to the length of the fixed joint or to the total area of the testing envelope.

These classes are listed in Table 3-16 together with the associated pressure tests that must be made in order to ensure that the class is reached.

Table 3-16 – air-tightness classes according to EN 12152.

Max Pressure P_{max} [Pa]	Allowed Permeability [m³/m h]		Class
	length of fixed joint	total area	
150	0.5	1.5	A1
300	0.5	1.5	A2
450	0.5	1.5	A3
600	0.5	1.5	A4
>600	0.5	1.5	AE

For air permeability > 0.5 (1.5) m3/m h at pressure <150 Pa there is no classification possible.

For air permeability < 0.5 (1.5) m3/m h at pressure >600 Pa modules are classified as E (Exceptional).

Looking at the international context, in the United States, the resistance to water penetration rating and air leakage is typically established as a function of the design wind pressure. In Canada, the CAN/CSA-A440 Standard includes a user's guide which recommends minimal performance levels for each major Canadian city based on geographic location and installation height.

Below, a list of the principal industry standards which are commonly used to establish the laboratory and field performance criteria for windows and curtain walls in North America is reported:

- AAMA/NWWDA-101: Voluntary Specifications for Windows and Glass Doors

  Primarily outlines laboratory performance requirements for resistance to water penetration, air leakage resistance and wind load resistance for windows and glass doors (United States).
- CAN/CSA-A440: Windows

  Primarily outlines laboratory performance requirements for resistance to water penetration, air leakage resistance and wind load resistance for windows (Canada).
- AAMA 501: Methods of Test for Metal Curtain Walls

  Primarily outlines laboratory performance requirements for resistance to water penetration, air leakage resistance and wind load resistance for metal curtain walls (United States).
- AAMA 502: Voluntary Specification for Field Testing of Windows and Sliding Glass Doors

  Primarily outlines field performance requirements for resistance to water penetration and air leakage resistance for windows and glass doors (United States).
- AAMA 503: Voluntary Specification for Field Testing of Storefronts, Curtain Walls and Sloped Glazing Systems

  Primarily outlines field performance requirements for resistance to water penetration and air leakage resistance for Storefronts, Curtain Walls and Sloped Glazing Systems (United States).
- CAN/CSA-A440.4 (appendix D): Field Testing of Window and door Installations

  Primarily outlines field performance requirements for resistance to water penetration and air leakage resistance for windows and doors (Canada).

3.1.4 Product requirements

Besides the standards and regulations requirements to be considered regarding the overall performance of the EENSULATE module, more standards are listed hereafter for single components (products) involved in the assembly.

3.1.4.1 Glass

Aiming at a fast approach to the market, the external pane of the EENSULATE vision glass must comply with safety standards as already mentioned in section 3.1.2.

A specific requirement affecting the type of glass concerns the portion of the glass pane located in the height of 1 m from the ground of each floor; this portion is required to be toughened, laminated or both.

Table 3-17 – EENSULATE glass references.

Glass Type	Reference
Toughened	EN 14179-1, EN 14179-2
Laminated	EN ISO 12543-1, EN ISO 12543-2, EN ISO 12543-3, EN ISO 12543-4, EN ISO 12543-5, EN ISO 12543-6

3.1.4.2 Minor components

The provided list is mainly consisting of UNI (Italian) standards since it is derived from the EENSULATE consortium current practice an localized facilities, i.e. as per FOCCHI expertise. Therefore, while it can be assumed that the most of the mentioned references have counterparts in the other EU countries (derivation of EN), the list has not to be intended as necessarily representative of the practice in the whole European region.

Table 3-18 – Minor EENSULATE components references.

Component Descriptor	Reference
Self-tapping screws	UNI 6947, UNI 6955
Rivets	UNI 9200A

4 Certification protocols and procurement practices

Here the potential of the EENSULATE product has been assessed by looking at the currently available certification protocols. Certification is an independent confirmation by an expert third party that a product, system or service meets, and continues to meet, appropriate standards. Indeed, a certification distinguishes products and services from their competitors, and gives customers confidence about their performance.

Therefore, several certification protocols have been considered, the most of them in the context of sustainable building design. After a brief description of each certification protocol, the potential of the EENSULATE product is discussed.

The majority of the certification systems consider only some of the variables deemed fundamental for a comprehensive evaluation of a building; control of energy consumption and environmental compatibility are particularly common. Among the SoA certification systems, only few evaluate building performance with “cross-disciplinary” criteria that embrace different thematic or scientific areas (systems performance, management model, services, energy performance, etc.). There is no internationally recognized system to rate buildings according to the definitions applied by the trading industry (Class A) or, at least, a system that takes into account shared parameters and standards. Many of the methods are inevitably linked to the context for which they were developed. This characteristic concerns in particular the systems designed to evaluate energy performance (labelling systems) which, by nature, often have to refer to regulations and provisions that differ from country to country.

Thus, given the very different national regulatory frameworks and other conditions across the EU, it is neither possible to set universal standards to be used in the procurement of building construction works in all circumstances. Instead a series of concrete criteria and guidelines have been proposed providing alternative approaches which may be used. The public authority wishing to use these guidelines will need to determine which alternative is most appropriate for their situation.

4.1 GBC (International)

A Green Building Council (GBC) is a national non-profit, non-government organization that is part of the World Green Building Council[11], a global network aiming to strengthen Green Building Councils in member countries by connecting them to a network of knowledge, inspiration and practical support.

At the end of 2014 there are around 100 Green Building Councils at various stages of their development, each country providing its own certification protocols (e.g. GBC Home in Italy).

The World GBC’s Green Building Councils are member-based organisations that empower industry leaders to effect the transformation of the local building industry toward sustainability.

Many green building councils operate voluntary building labelling systems, such as Leadership in Energy Efficiency and Environmental Design (LEED), BREEAM and Green Star. These rating tools verify best practice projects and reward leadership.

4.2 BREEAM (UK)

Among the first instruments for the assessment the sustainability of buildings is the BREEAM[12] (Building Research Establishment Environmental Assessment Method). The UK system was developed in 1990 by the BRE (Building Research Establishment) and represented a reference point for the elaboration of the methods later. Since 1990, the debut year of of BREEAM with the first version on buildings for the tertiary sector, the

[11] www.worldgbc.org , last accessed 13th October 2016.
[12] www.breeam.org , last accessed 13th October 2016.

BRE has adapted the scheme of the method to a range of building types: offices, new construction and existing offices, supermarkets, industrial units and new homes. The application of the method is voluntary and after a certificate is issued which certifies the performance of the building. BREEAM sets the standard for best practice in sustainable building design, construction and operation and has become one of the most comprehensive and widely recognised measures of a building's environmental performance. It encourages designers, clients and others to think about low carbon and low impact design, minimising the energy demands created by a building before considering energy efficiency and low carbon technologies.

A BREEAM assessment uses recognised measures of performance, which are set against established benchmarks, to evaluate a building's specification, design, construction and use. The measures used represent a broad range of categories and criteria from energy to ecology. They include aspects related to energy and water use, the internal environment (health and well-being), pollution, transport, materials, waste, ecology and management processes.

According to the BREEAM scoring and rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the credits where the major impact is foreseen:

- MAT01 – Life cycle impacts (credits calculated through the green guide[13])
- MAN03 – Construction site impacts (e.g. reduced energy consumption and reduced water consumption)

However, impact may also occur on other sections of the BREEAM rating system, such as the ENE or other aspects of the MAT section, depending on the findings that may be demonstrated during the project.

4.3 BRE (UK)

BRE Environmental Methodology

Methodology and Green Guide was first published 1996 and revised and republished in 2008. Green Guide ratings are used to gain credits for whole building assessments (BREEAM and Code for Sustainable Homes) and is widely used by architects & designers. The data are also used in IMPACT, (which is a methodology which allows the integration of LCA data in BIM (Building Information Modelling)). Can be applied Europe-wide (although the Green Guide is UK only)

BRE EN15804 EPD scheme

Scheme was established in 2013 and is applicable throughout Europe. This route generates a verified EPD (complying with EN15804). The verification can be carried out by BRE or any other programme operators which have developed PCRs in accordance with EN15804.

BRE Product Standard (BPS)

This is a product standard developed in the UK by BRE Global in conjunction with stakeholders including manufacturers, specifiers and end users. A BPS could be created for EENSULATE, against which a third party product certification scheme could be developed. The BPS would contain both technical and sustainability elements, and would be based around an assumed working life (durability) of 50 years.

Key aspects to the certification scheme would include:

- Initial testing and assessment of the product
- Initial assessment of manufacturer's factory production control process
- On-going audit testing of the product
- On-going surveillance of manufacturer's factory production control process
- Withdraw of non-conforming product

[13] http://www.bre.co.uk/greenguide, last accessed 13th October 2016.

4.4 LEED (USA)

The certification system certainly more widespread globally is the model LEED[14] (Leadership in Energy and Environmental Design), defined and promoted by the U.S. Green Building Council (USGBC) in 1993, this in more than 110 countries. LEED certification is a voluntary standard adopted from the market and is an essential tool to achieve a transformation of the market.

Each rating system groups requirements that address the unique needs of building and project types on their path towards LEED certification. Once a project team chooses a rating system, they'll use the appropriate credits to guide design and operational decisions.

There are five rating systems that address multiple project types:

LEED BD+C Building Design and Construction
LEED ID+C Interior Design and Construction
LEED O+M Building Operations and Maintenance
LEED ND Neighborhood Development
LEED HOMES Homes

The realization of benefits associated with LEED starts with a transformation of the design process itself. Success in LEED and green building design is best accomplished through an integrative design process that prioritizes cost-effectiveness over both the short and long terms and engages all project team members in discovering beneficial interrelationships and synergies between systems and components. By integrating technical and living systems, the team can achieve high levels of building performance, human performance, and environmental benefits.

Conventionally, the design and construction disciplines work separately, and their solutions to design and construction challenges are fragmented. These "solutions" often create unintended consequences—some positive, but mostly negative. The corollary is that when areas of practice are integrated, it becomes possible to significantly improve building performance and achieve synergies that yield economic, environmental, and human health benefits.

According to the LEED rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the credit sections where the major impact is foreseen:

- ***Energy and Atmosphere (EA) credit category***: it approaches energy from a holistic perspective, addressing energy use reduction, energy-efficient design strategies, and renewable energy sources. Energy efficiency in a green building starts with a focus on design that reduces overall energy needs, such as building orientation and glazing selection, and the choice of climate-appropriate building materials. The EA section supports the goal of reduced energy demand through credits related to reducing usage, designing for efficiency, and supplementing the energy supply with renewables.
- ***Materials and Resources (MR) credit category***: it focuses on minimizing the embodied energy and other impacts associated with the extraction, processing, transport, maintenance, and disposal of building materials. The requirements are designed to support a life-cycle approach that improves performance and promotes resource efficiency. Each requirement identifies a specific action that fits into the larger context of a life-cycle approach to embodied impact reduction.
- ***Indoor Environmental Quality (EQ) credit category***: it rewards decisions made by project teams about indoor air quality and thermal, visual, and acoustic comfort. Green buildings with good indoor environmental quality protect the health and comfort of building occupants. This category addresses

[14] www.usgbc.org/leed , last accessed 13th October 2016.

the myriad design strategies and environmental factors—air quality, lighting quality, acoustic design, control over one's surroundings—that influence the way people learn, work, and live.

4.5 GREEN GLOBES (USA)

The Green Globes[15] system is a building environmental design and management tool. It delivers an assessment protocol, rating system and guidance for green building design, operation and management. It provides market recognition of a building's environmental attributes through third-party verification. It is suitable for new buildings and existing buildings.

Green Globes utilizes weighted criteria in its recognized assessment protocol, comprehensively assessing building environmental impacts on a 1,000-point scale in seven categories for new buildings and six categories for existing buildings.

According to the Green Globes rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the categories where the major impact is foreseen:

- ***Energy:*** Performance, Demand, Metering, Measurement and Verification, Building Opaque Envelope, Lighting, HVAC Systems and Controls, Efficient Equipment, Renewable Energy, Energy Efficient Transportation
- ***Materials & Resources:*** Building Assembly, Interior Fit-outs, Re-use, Waste, Building Service Life Plan, Resource Conservation, Building Envelope
- ***Emissions:*** Heating, Ozone-depleting Potential, Global Warming Potential
- ***Indoor Environment:*** Ventilation, Source Control and Measurement, Lighting Design and Systems, Thermal Comfort, Acoustic Comfort

4.6 DGNB (Germany)

DGNB[16] (German Sustainable Building Council) is a certification procedure practice in the assessment and planning of sustainable buildings. DGNB certification covers all essential aspects of sustainable buildings awarding scores for ecological, economical, sociocultural and functional aspects as well as technology, processes and site.

According to the DGNB rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the quality sections where the major impact is foreseen:

- ***sociocultural and functional quality (SOC)***: criteria to be fullfilled in the health, comfort and user-friendliness evaluation topics, such as thermal comfort;
- ***technical quality (TEC)***: criteria to be fullfilled in the quality of technical implementation evaluation topics, such as fire safety and building envelope quality:
- ***process quality (PRC)***: criteria to be fullfilled in the quality of construction evaluation topics, such environmental impact of construction.

4.7 ITACA (Italy)

Protocollo ITACA[17] is promoted by the Italian Regions and it has a public origin. The assessment system is managed by ITACA (Federal Association of the Italian Regions) with the scientific support of iiSBE Italia and

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[15] www.greenglobes.com , last accessed 18th October 2016.
[16] www.dgnb.de ,last accessed 18th October 2016.
[17] www.itaca.org/valutazione_sostenibilita and www.icmq.it/en/buildings_itaca , last accessed 18th October 2016.

ITC-CNR. Protocollo ITACA is based on the international assessment methodology SBMethod of iiSBE and it has been contextualized at local level by several regions: Piemonte, Liguria, Valle d'Aosta, Veneto, Friuli Venezia Giulia, Lazio, Marche, Toscana, Umbria, Puglia and Basilicata. At regional level the Protocollo ITACA is mostly used to support specific policies to promote sustainable building. In particular in the framework of the social housing programs, where economic incentives are given on the base of the environmental performance achieved.

Beside the regional versions, in 2011 a national version of Protocollo ITACA has been delivered and a national certification process was implemented also. This national certification is intended to create a point of reference for the market stakeholders. The certification system is voluntary, apart from the region Friuli Venezia Giulia that has made it mandatory for some interventions and destinations of use of buildings.

Protocollo ITACA is based on a multi-criteria analysis for the assessment of the environmental sustainability of buildings and for their classification by assigning a score of performance according to ecological, economical, functional, technological, processes and site criteria. Object of evaluation is a single building and its outdoor area of relevance.

According to the Protocollo ITACA rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the criteria where the major impact is foreseen:

- ***Energy (B)*** Energy demand; building envelope performance,
- ***Emissions (C)*** Heating, Ozone-depleting Potential, Global Warming Potential
- ***Indoor Environment (D)*** Ventilation, Lighting Design and Systems, Thermal Comfort, Acoustic Comfort.

4.8 LEED Italia (Italy)

LEED Italia, launched in 2010, is managed and promoted by GBC Italia[18] (Green Building Council) and it is the Italian adaptation of the U.S. LEED. The origin of the system is mainly from the private/industrial sector. **LEED Italia is supported and recognized by the Province of Trento.** The certification LEED Italia is voluntary. The system is articulated in different versions for new buildings, existing buildings, small houses and neighborhoods. The Province of Trento adopted LEED in incentive based polices for green building. LEED Italia is the unique European adaptation of the US LEED. GBC Italia is a no profit association open to all the stakeholders of the building sector and it is part of the World Green Building Council.

The rating concept of LEED Italia is similar to the U.S. LEED.

According to the LEED rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the credit sections where the major impact is foreseen:

- ***Energy and Atmosphere (EA) credit category***: it supports the goal of reduced energy demand through credits related to reducing usage, designing for efficiency, and supplementing the energy supply with renewables.
- ***Materials and Resources (MR) credit category***: it focuses on minimizing the embodied energy and other impacts associated with the extraction, processing, transport, maintenance, and disposal of building materials.
- ***Indoor Environmental Quality (IQ) credit category***: it rewards decisions made by project teams about indoor air quality and thermal, visual, and acoustic comfort. Green buildings with good indoor environmental quality protect the health and comfort of building occupants.

[18] www.gbcitalia.org last accessed 30th October 2016.

Casaclima Nature

Casaclima Nature[19] is an „expansion” of the Casaclima energy standard. The certification is managed by the Agenzia Casaclima, a public organization located in Bolzano. The Casaclima certification has been the first in Italy introducing the energy rating for buildings and it is **mandatory in the Province of Bolzano**, while outside the province it is voluntary.

The Casaclima agency focuses on influences of the environment and has developed an evaluation method. The energy requirements for living are still the central issue, but in addition the energy used for building materials will be evaluated. There is an enormous potential to reduce energy already during construction. Using the Casaclima Nature every constructor can evaluate the sustainability of the building.

According to the Casaclima Nature rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the criteria where the major impact is foreseen:

- ***Materials***
- ***Indoor air quality***

4.9 BRaVe (Italy)

BRaVe[20] (Building Rating Value) is an Evaluation and Certification System of the BUILDING GLOBAL QUALITY and EFFICIENCY developed by the Technical University of Milan (BEST Department).

BRaVe System examines the main building performances according to functional and/or technological criteria. Buildings can have different characteristics depending on the type of core business they host but, at the same time, they have to respect some rules in order to be market attractive. The uncertainty of clients (property companies, investing institutions, investment funds, etc.) looking for a rating system is further fed by the presence of two methods that have different objectives: - the first is that of “standards”, or systems that evaluate the presence of services, the types of installations, the infrastructure, etc, and that are inspired by the best practices adopted by property market players in the choice of buildings; - the second type is that of the “labels”, more widely acknowledged by the market. They are prevalently oriented at evaluating environmental aspects, can be applied to all buildings and therefore have no specific application solely for offices. BRaVe method can be used to evaluate the performance of existing, new, or occupied buildings, or those waiting to be occupied. It can also be used to simulate project implementation and verify the consequences of interventions on the overall performance of a building. During the testing phase diverse simulations can be done to represent different scenarios following specific project interventions. The system, in fact, is able to represent graphically the actual status (AS IS) and the project status (TO BE).

The Rating Model is divided into 14 sections, with over 220 items to be filled in:

According to the BRaVe rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the criteria where the major impact is foreseen:

- Building Frame
- Energy
- HVAC Heating, Ventilation, Air Conditioning
- Efficiency of Surfaces

[19] www.agenziacasaclima.it/it/certificazione/sostenibilit%C3%A0/casaclima-nature , last accessed 18th October 2016.
[20] www.braverating.com , last accessed 18th October 2016.

4.10 HQE (France)

The first national French certification system is HQE[21] (Haute Qualité Environmentale). It is promoted by the no profit Association pour la Haute Qualité Environnementale (ASSOHQE), located in Paris and founded in 1996.

The HQE certification is voluntary. It is applicable to new and existing buildings for different uses. The certification system is managed by AFNOR Certification with the official name of „NF ouvrage – Démarche HQE". AFNOR Certification appointed three certification bodies (Cerqual, Cequami, Certivea) to operate the certification system as third independent party. The first HQE certification (NF Office Buildings) was launched in 2005, the certification for residential buildings in 2007. **The HQE certification is applied in all France.** The BDM (Bâtiments Durables Méditerranéens) label is proposed by the BDM no profit association that was established in 2008, recognized as «Pôle Régional d'Innovation et de Développement Economique Solidaire (PRIDES)» by the Région PACA. The main principle of the label, as for the Italian Protocollo ITACA, is the total contextualization of the assessment criteria to the local level. The BDM assessment system is under adaptation for other French regions also in the Alpine and Atlantic areas. The certificate is issued by the BDM association.

4.11 TBQ (Austria)

The TQB[22] (Total Quality Building) certification system is managed by the ÖGNB a non-profit organization (Austrian Sustainable Building Council). The first version of the assessment system (Total Quality) was developed in 2001 with subsidies from the Austrian Federal Government and based on the GBC's (Green Building Challenge) GBTool. In 2010 the TQB system has been updated with regard to the international trends and to other Austrian building assessment systems. It is possible to certify residential buildings, offices, commercial buildings; schools, hotels, and shopping centers. TQB is the most applied environmental certification system in Austria.

TQB assesses building environmental impacts on a 1,000-point scale in several categories.

According to the TQB rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the categories where the major impact is foreseen:

- B: Economy and Technical quality
- C: Energy and Supply
- D: Health and Comfort

4.12 Minergie – ECO (Switzerland)

The most relevant Swiss certification system is Minergie – ECO[23], supported by the Swiss Confederation, the Swiss Cantons along with Trade and Industry. The certification is operated by the Minergie non profit organization. Minergie – ECO integrates the Minergie label with issues related to the environment and the comfort, such as:

Health requirements:

high percentage use of daylight instead of electricity
sound insulation
indoor air quality

[21] www.assohqe.org/hqe , last accessed 18th October 2016.
[22] www.oegnb.net/en/tqb , last accessed 18th October2016.
[23] www.minergie.ch/minergie-eco , last accessed 18th October 2016.

Ecological requirements:

readily available raw materials
high proportion of recycled building materials
building materials with low environmental impact (rely on other ecolabels)
environmentally friendly disposable building materials
long lifetime, flexibility, dismantling ability

To ensure a minimum quality standard, exclusion criteria are defined, which must be strictly implemented

The evaluation method is based on the following principles: with the fulfillment of requirements points are generated, which are measured by the overall achievable score. The relevance of a specification for the specific object is taken into account. One requirement is considered met if it is implemented at least 80%. The exclusion criteria, however, must be 100%implemented. The evaluation is done by a division of the project value in one of the following three areas: "insufficient" (red), "sufficient" (yellow) and "good" (green). The overall rating is then performed using a simple traffic light system. For a sufficient result, only yellow or green results may be present, a red result leads to exclusion.

It's possible to certify residential buildings, office buildings and schools.

According to the Minergie-ECO rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the categories where the major impact is foreseen:

- sound insulation
- indoor air quality
- building materials with low environmental impact

4.13 GREEN STAR (Australia)

Green Star[24] is an internationally recognised sustainability rating system. Launched by the Green Building Council of Australia in 2003, **Green Star is Australia's only national rating system for buildings and communities. It is adopted also in New Zealand and South Africa.**

Green Star – Design & As Built provides a rating across nine categories: management, energy, water, indoor environment quality, transport, materials, emissions, land use and ecology, innovation. Each category contains 'credits' which address specific issues.

Green Star - Design & As Built rewards buildings with ratings from 4 Star (Best Practice) to 6 Star (World Leadership).

According to the Green Star rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the categories where the major impact is foreseen:

- Energy
- Indoor environment quality
- Materials
- Innovation

4.14 HK-BEAM (Hong Kong)

HK-Beam[25] is a comprehensive environmental assessment scheme for buildings recognised by the Hong Kong Green Building Council, available for new buildings and existing buildings. It includes six aspects of a project:

[24] www.gbca.org.au/green-star/certification , last accessed 18th October 2016.
[25] www.hkgbc.org.hk/eng/certification , last accessed 18th October 2016.

Site Aspects, Energy Use, Indoor Environmental Quality, Materials Aspects, Water Use, Innovations and Additions.

According to the HK BEAM rating system, the EENSULATE products may demonstrate potential in relationship with different aspects. The following are the categories where the major impact is foreseen:

- Energy use
- Indoor environment quality
- Materials
- Innovation

4.15 CASBEE (Japan)

CASBEE[26] (Comprehensive Assessment System for Built Environment Efficiency) is a tool for assessing and rating the environmental performance of buildings and built environment.

4.16 Other relevant procurement practices

4.16.1 Green Public Procurement Criteria

Green Public Procurement (GPP) consists in inviting Europe's public authorities to use their purchasing power to choose environmentally friendly goods, services and works. It can help to stimulate a critical mass of demand for more sustainable goods and services which otherwise would be difficult to get onto the market.

Although GPP is a voluntary instrument.

GPP criteria that may be relevant for EENSULATE:

- Office buildings: set of criteria available from June 2016

More info: http://ec.europa.eu/environment/gpp/index_en.htm

4.16.2 ICLEI Procura+ Guidelines

ICLEI is an international association of 1100 local authorities dedicated to sustainable urban development founded by local authorities for local authorities in 1990 at UN in New York but strongly present in 32 European countries with 200 European members among local governments and associations.

ICLEI has developed the:

- Procura+ manual (http://www.procuraplus.org/manual/)

which apply, among the others, to the building construction and renovation sector. Then, with specific reference to this sector, the guidelines principally apply to the energy performance of buildings and the use of sustainable building materials.

The Procura+ Manual is published by ICLEI – Local Governments for Sustainability and produced as part of the SPP Regions project[27].

[26] www.ibec.or.jp/CASBEE , last accessed 18th October 2016.

[27] http://www.sppregions.eu/home/ last accessed 18th October 2016.

The 3rd Edition of the Procura+ Manual was launched at the Procura+ Seminar in Rome on 13 and 14 October 2016. This fully updated and revised edition of the Procura+ Manual aims to position sustainable procurement in the current economic, political and legal framework.

PART B: REVIEW OF MARKET DRIVERS

5 Review of market drivers

This part of the Deliverable will focus on the market drivers of the EENSULATE. First, market analysis of curtain wall and European green market will be conducted to reveal market drivers and upcoming trends in building sector in general and architecture and design in particular. Second, identified market drivers will be applied on the EENSULATE products. The final stage will summarize the market drivers reflecting EENSULATE characteristics.

5.1 Nearly-Zero Energy Buildings as a Component to 2020 Strategy for Sustainable Future

The EC has identified the building sector as one of the key sectors to achieve the 2020 strategy of the EU. The goal of the 2020 strategy is to create conditions for smart, sustainable and inclusive growth. In regards to the building sector, the emphasis has been placed on two key principles – the principle of 'nearly zero-energy building' and the principle of 'cost optimality'. The shift of direction towards sustainable buildings is a step forward to a better environment, as well-designed curtain walls can reduce energy consumption and associated CO_2 emissions while making a contribution to combating climate change. According to several independent studies, should all buildings in Europe become fit with advanced energy saving glazing, more than 100 million tonnes of CO_2 can be saved every year. Examples for such energy saving glazing are Low-Emissivity and Solar Control Glass[28].

European legislation has been one of the key drivers to improve the energy-efficiency of newly built buildings as well as of old buildings, including historical ones. It regulates that by 31 December 2020, member states must ensure that all new buildings are nearly zero-energy buildings and by 31 December 2018, all new buildings occupied and owned by public authorities must be nearly zero-energy buildings.

5.1.1 Definition of Nearly Zero-Energy Buildings

The term "Zero-energy building" refers to a building with zero energy consumption. In practice it means that the total amount of energy used by these buildings come from renewable energy created on the site. This example is hardly ever possible in practice and thus the buildings, which are closest to the model, are referred to as 'nearly zero-energy buildings'.

According to article 2.2 of the Energy Performance of Building Directive[29], "nearly zero-energy building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". Annex I, article 1 stipulates that "The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs

[28] TNO Report 2008-DR1240/B by TNO Built Environment and Geosciences, Delft, the Netherlands
[29] Directive 2010/13/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), L 153/13

and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs."

5.1.2 Definition of Cost Optimality

The principle of cost optimality is embodied in articles 5, 6 and 7 of the Energy Performance of Building Directive[30]. It gives guidance for the energy performance requirements of new and existing buildings that are undergoing renovations. The EC has set rules concerning the method, i.e. methodology to calculate cost optimal levels; however, each member state is required to calculate cost optimality based on relevant parameters, such as climatic conditions. They then need to compare it with minimum energy performance requirements.

5.1.3 EENSULATE

The EENSULATE technology is expected to provide a highly affordable set of material innovations for thermal and acoustic insulation of curtain wall glazed buildings. Its products consist of EENSULATE Glass and EENSULATE insulation spray foam. Two modules will be offered – EENSULATE Basic and EENSULATE Premium. The components of this project offer superior performance at lower cost with reduced maintenance. Chapter 3 will further describe the EENSULATE characteristics. Its characteristics make the final product both cost effective and positively contribute to nearly zero-energy buildings.

5.2 Market identified with significant potential for EENSULATE technology

The following chapter aims to analyse the curtain wall market; it will focus on trends, demand, profitability, etc. To fully identify market drivers for EENSULATE, the examination of European market, particularly green market, and trends in green construction building sector, is essential.

5.2.1 Curtain Wall Market

5.2.1.1 What is curtain wall?

Both commercial and public buildings have been using, while built, glass curtain walls widely over the last many decades. The technology is based on the use of mullion materials and glazing units. These are carefully chosen and designed to reach the performance-required standards, both in aesthetic requirements and structural, thermal and day-lighting concerns. Said systems aim to curtail air and water infiltration while keeping the moderate environment in. Curtain wall systems are widely used for offices, public or functional buildings, hotels, shopping centres and residential buildings. Today, curtain walls are associated with modern architecture and their popularity is rapidly increasing. The popularity of curtain wall systems stems from its reduced construction period and cost, lightweight nature, simplification of temporary construction and strong performance.

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[30] Directive 2010/13/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), L 153/13

5.2.1.2 Curtain wall industry

The curtain wall industry has witnessed three generations of products. The first generation of curtain walls refers to those that were mostly stick curtain walls composed of a variety of components assembled onsite, with individual mullions and transoms forming a supporting grid for curtain wall panels. Unitized curtain walls represented the second generation, and the third generation is characterized by energy efficiency, the use of new technologies or diverse functions. The latter is expected to continue to shape the industry.

5.2.1.3 Curtain wall market trends

The world economy drives the curtain wall market in general and the construction industry in particular. Specifically, the growth of the world economy drives fixed assets investments, including construction of various public facilities, commercial buildings and high-end residential buildings, which in turn drives the market demand for curtain walls. This reality has been serving as the foundation for the growth of the curtain wall market. The global gross output of the curtain wall market increased from approximately $12.6 billion in 2005 to approximately $24.5 billion in 2012, representing CARG of 9.5%[31].

The following chart shows the increase in the market output of the **construction industry**, which allows for the expansion of curtain wall market.

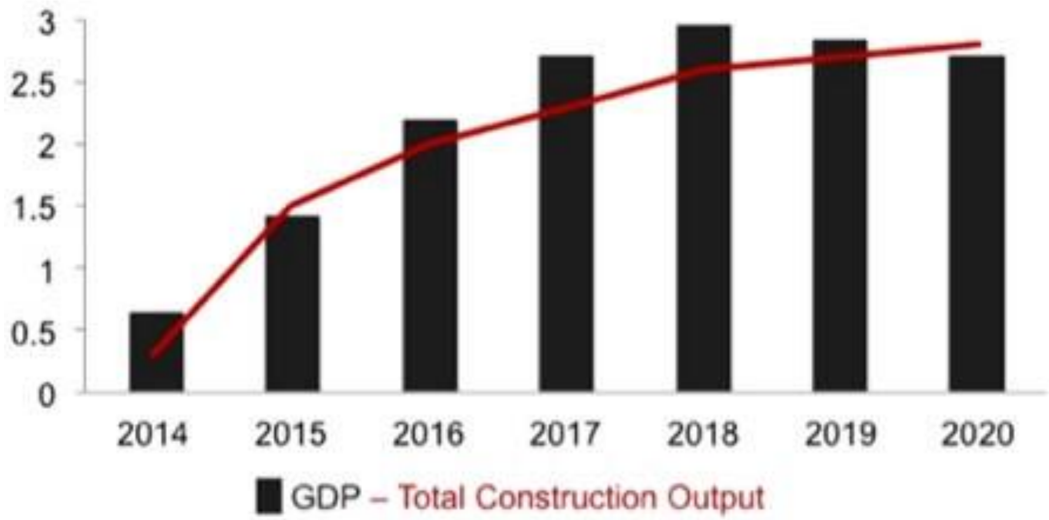

Figure 5.1 – Total output of the European construction industry in specific time period.

The following chart illustrates the total market value of the global **curtain wall industry** for the periods specified.

[31] Curtain Wall Industry Overview, Synovate Ltd., http://www.hkexnews.hk/listedco/listconews/sehk/2011/0420/02789_1057382/EWF114.pdf

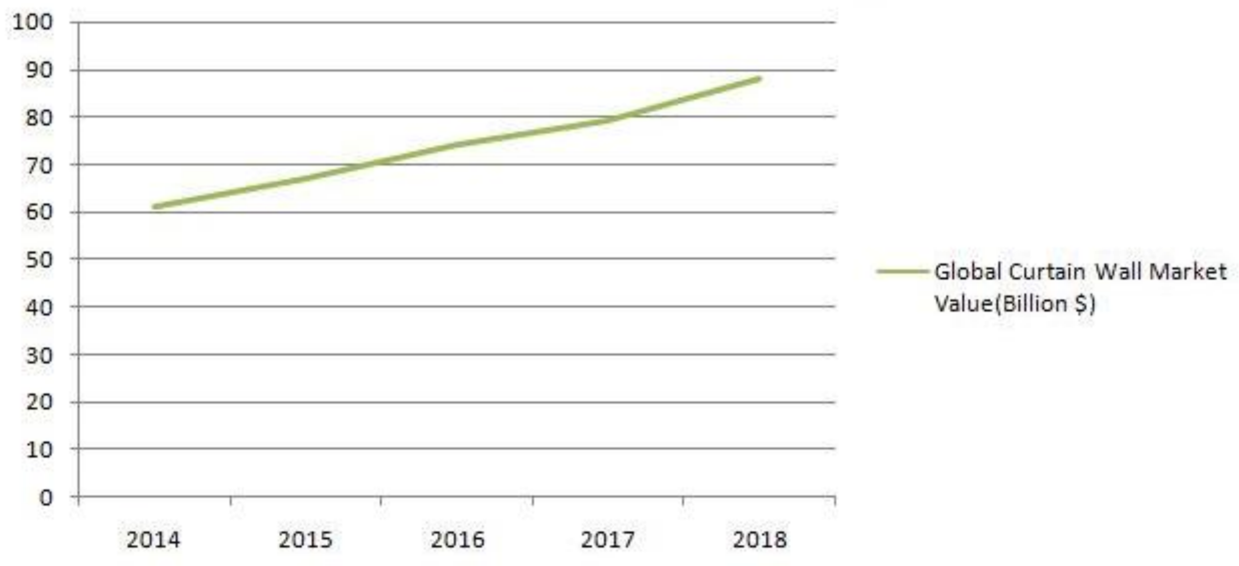

Figure 5.2 – Total market value of the global curtain wall industry in specific time period.

The market shares serve as the primary characteristic of the curtain wall market, as opposed to market volume, for instance. The market is divided to residential and non-residential building stocks. The non-residential building stock consists of commercial and public buildings and accounts for 25% of the EU total building stock. The remaining 75% of residential buildings split into 64% of single-family houses and 36% of multi-family apartment blocks.

The three main types of facilities are the commercial, public and residential buildings. The commercial sector has constituted the largest segment of the market and consists of office buildings, hotels, shopping centres, exhibitions and convention centres. However, in recent decade it has been on a decrease. On the other hand, the other two are on the rise. The public facilities segment is made of government buildings, schools, libraries, and stadiums and it accounted for about 17.6% of the curtain wall industry in 2005. It gradually grew, and in 2012 it already constituted 20.2% of the market[32]. The data for current year and forecasts for upcoming ones were not available. The data presented aims at illustrating the gradual increase in demand for curtain walls in public buildings.

Market demand has been shifting towards unitized curtain walls, in terms of structure. Unitized curtain walls rely less on skilled on-site labour, are more capable of offering advanced technological products and provide more consistent quality due to increased production in a factory setting. The advantage of unitized curtain wall is that it offers an option to make the renovation easier. According to the Federation of European Window and Curtain Walling Manufacturing, the market share of unitized curtain wall structures in the total market is expected to increase to approximately 60% in 2016[33]. The demand of particular types of curtain

[32] Curtain Wall Industry Overview, Synovate Ltd., http://www.hkexnews.hk/listedco/listconews/sehk/2011/0420/02789_1057382/EWF114.pdf

[33] Curtain Wall Industry Overview, Synovate Ltd., http://www.hkexnews.hk/listedco/listconews/sehk/2011/0420/02789_1057382/EWF114.pdf

walls is available only in the period 2005-2012 - the following graph aims to provide an illustration of market segmentation of the global curtain wall industry by product type.

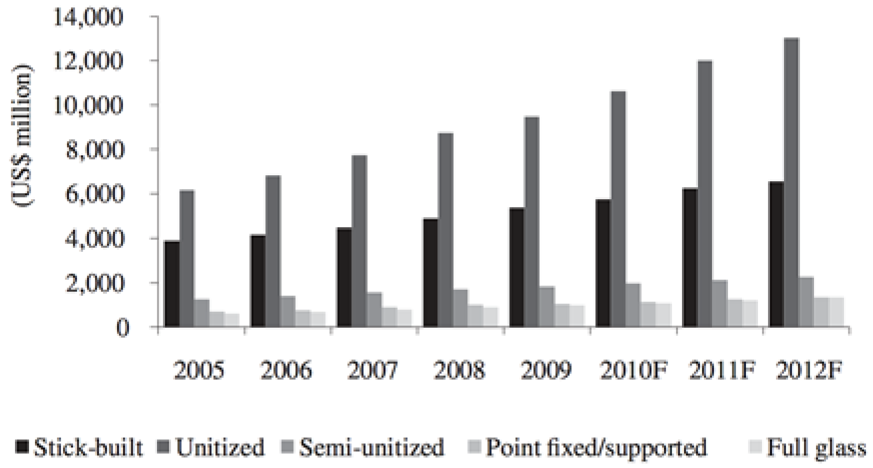

Figure 5.3 - Market segmentation of the global curtain wall industry by product type in specific time period

Although Europe and the United States are currently the two largest regional markets for curtain walls, accounting for approximately 26.5% and approximately 25.5% of global curtain wall market in 2009, China has been demonstrating the fastest increase in demand. China's curtain wall market is expected to further grow at a CARG, surpassing the 20.9%[34].

5.2.2 European Green Market

The increasing demand for sustainable products has been noted worldwide in general and in Europe in particular. Over the span of one year, the willingness to pay more for environmentally friendly products has increased from 55% in 2014 to 72% in 2015[35]. According to a recent study, "green building" continues to double every three years as customers' demand sustainability for both energy-efficiency and occupant benefit. Figure 5 demonstrates expected increase in the amount of sustainable materials in building sector worldwide.[36]

[34]Curtain Wall Industry Overview, Synovate Ltd., http://www.hkexnews.hk/listedco/listconews/sehk/2011/0420/02789_1057382/EWF114.pdf

[35] The Nielsen Company, *Green Generation: Millennials Say Sustainability is a Shopping Priority*, The Nielsen Company (Nov. 5, 2015). http://www.nielsen.com/us/en/insights/news/2015/green-generation-millennials-say-sustainability-is-a-shopping-priority.html.

[36] Zion Research Analysis, 2015

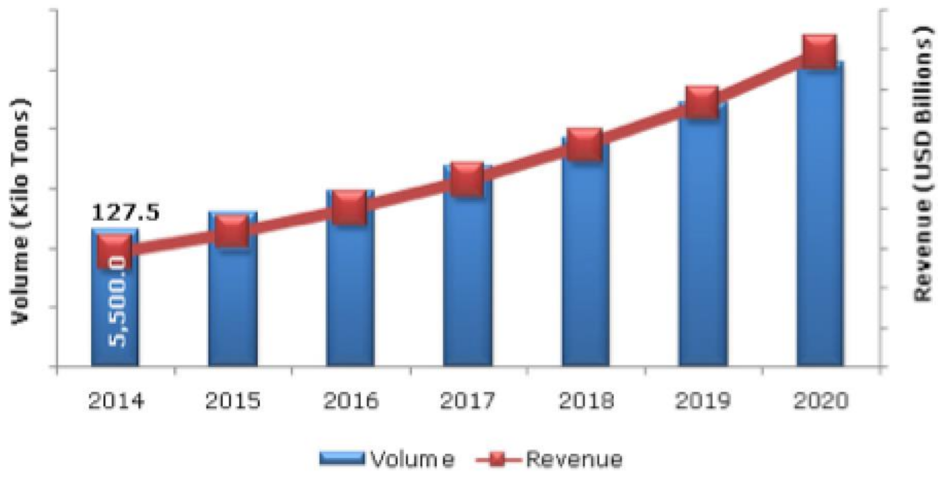

Figure 5.4 – Global Green Building Material Market, 2014-2020.

5.2.2.1 European Structural and Investment Funds

As previously noted, the EC has identified the building sector as one of the key sectors through which the 2020 targets of the EU can be achieved. One of the means for reaching the goals is through building nearly zero-energy buildings. In order to deal with the financing of this goal, the EC offers assistance for economically less-developed member states. The EU Structural and Investment Funds might be used in the new building projects via Operational Programme *Environment*, to build new public buildings and via Operational Programme *Enterprise and Innovation for Competitiveness* to build new commercial buildings as nearly zero-energy. A study[37] shows that there is a link between the funds and green growth, i.e. the green products are demanded if the EU assists with finances.

5.2.2.2 Facts and Figures

- 26% of EU citizens often buy environmentally friendly products, 54% of them sometimes do.
- Environmental impact is the third most important factor for EU consumers, after quality and price.
- More than 1/3 of 250 business executives said that they could not keep up with consumer demand for sustainable products and services and 62% declared that sustainable investments were motivated by consumer expectations for green products.

5.3 Trends in green building sector

The following findings regarding the green building trends are taken from the Dodge Data & Analytics[38] analysis of global green building sector. The study, conducted in 2015, examined a wide range of respondents from 69 countries. Among those are architects, engineers, contractors, owners, specialists and consultants. Since 2008, the green building has been doubling every three years. The percentage of firms expecting to

[37] Štreimikiene, Mikalauskiene, 2016, Green Growth and Use of EU Structural Funds in Baltic States, Czech Republic and Slovakia
[38] Dodge Data & Analytics, 2016, World Green Building Trends, SmartMarket Report

have more than 60% of their projects certified green is anticipated to more than double from 18% currently to 37% by 2018. The client demand has been marked as the greatest trigger of the green buildings in 2015, while higher cost has been listed as a primary hesitation for building green.

When it comes to green building, commercial construction seems to be the leading sector. Nearly half of the respondents indicated that they are expecting to undertake a green commercial project in the next three years. The sector of public construction expects to steadily grow, especially in Europe and the US, due to legislation. In the commercial segment, the trends are directed towards nZEB buildings as architects wish to implement façade innovation (such as Building Integrated PV) with the aim to reach the highest building certification levels for their projects. Glass coatings provide the ability to have light transmittance to ease lighting needs along with low-e and solar control to achieve good thermal performances. Architects' priority is the environmental impact of all building materials used. Retrofitting projects are becoming common; over 40% of respondents believe that they will carry out green retrofit projects within the next three years. BGTEC has estimated that in Poland alone, 50.000 energy efficient window replacements per year, through the year of 2025, are foreseen. If we consider the European market findings from 3Encult project and the data from "Caresana reports", there is an expected growth of up to 500 thousands energy efficient windows retrofit in buildings older than the year 1919, per year, by 2025 in enlarged Europe. For both residential and non-residential sector, easiness to perform retrofit is a priority.

As previously mentioned, a key driver for green building activity is a client demand. Jason Prior, chief executive of buildings and places at AECOM, claims that buildings that are sustainable are more appealing to customers – "its attractiveness is tied to the quality of life provided through sustainability". Another reason for building green has been the reduction of energy consumption (84% of respondents). Moreover, energy efficiency in buildings reduces CO_2 emission significantly. Governments often provide subsidies for such buildings, which serve as incentives for customers to build or renovate.

Another study conducted by Synovate Ltd.,[39] concluded that architects demand high-transparency of glass to allow in light while maintaining heat resistance. According to the study, in order to increase sustainability and energy efficiency, it is expected that the demand for the high performance curtain wall systems with energy-saving functions and solar-control glass will increase in the near future. It is especially true in regards to triple-glazed curtain wall structures, due to their being energy-efficient and having lower U-value than the older double-glazed structures. The reduced thickness of the triple-glazed glass is considered an advantage in terms of weight. Nowadays, the sales of single glazing and ordinary double-glazing are almost non-existent. The data for sales of coated glass products are limited; however, in the UK, it represents approximately 80% of all energy-efficient glass products (coated double and triple glass units).

Architects have been dictating the needs and expectations of the curtain-wall market, and the next three years in construction are expected to be characterized by these focal points. There is currently a growing demand from architects for photovoltaic curtain wall systems of different colours and sizes. Architects also focus on the quality and variety of materials and coatings used for curtain wall products. At the same time, cost effectiveness is a key concern in the market for both developers and end-users, including cost effectiveness related to future energy consumption. In the near future, demand will shift towards disaster-resistant curtain wall systems. Future technological enhancement may focus also on the prevention of water leakage and cracking of glass.

[39] Curtain Wall Industry Overview, Synovate Ltd., http://www.hkexnews.hk/listedco/listconews/sehk/2011/0420/02789_1057382/EWF114.pdf

5.4 Market drivers identified based on the analysis

Energy Efficiency – in various fields, the preferences of energy efficient products has been demonstrating a steady growth.

Technological Innovation – in the field of curtain walls, as well as in other fields, technological innovation attracts end users and producers. It is one of the main characteristics of the third generation of curtain walls. An example can be photovoltaic curtain wall.

Varying Sectors Applicability – the type of product is applicable to all three main sectors in which it is used; public, commercial, and residential.

Growing Demand for Unitized Curtain Walls – gradually becoming the preferred type of curtain walls.

Prioritization of Environmentally Friendly Products – in Europe, we witness growing willingness to invest in such products and in some cases, the demand has been surpassing the supply.

EU Contribution – EU financed projects have been linked to growth in the demand for green products.

Legislation and Regulation – nearly zero energy building has been anchored in the EU legislation, which pushes forward the use of green technology compulsorily.

Cost Effectiveness – serves as the first priority of the customer for choosing a product.

Improved Quality - serves as the second priority of the customer for choosing a product.

Green Projects Popularity – a growing demand in green projects and investment in them has been noted.

Fit for Retrofitting Projects – widening demand to retrofit

Reduced Weight – construction companies desire lighter materials.

Aesthetic Considerations – designers prefer comfortable variety of sizes and colours, which allows them free hand in creation of new designs. Important is also high transparency of the glass.

Worldwide Demand – wider potential market promises more potential buyers, as well as more clients interested in EENSULATE know-how

5.5 EENSULATE Responses to Market Drivers

The EENSULATE technology is expected to provide a highly affordable set of material innovations for thermal and acoustic insulation of curtain wall glazed buildings. These products have a potential to develop up to Technology Readiness Level (TRL) 7; the scale of TRL ranges between 1 and 9. The developers foresee the product's future as a 'game changer' on the market. EENSULATE should not only fulfil the requirements of the call, but is expected to exceed them. Furthermore, EENSULATE products are expected to be suitable for both new and old buildings, which expands potential market.

The two EENSULATE modules are called EENSULATE Basic and EENSULATE Premium. EENSULATE Basic expects to tackle both the vision glass and spandrel, and drastically reduce thermal bridges associated with interfaces between the spandrel and the sub-structure. EENSULATE Premium adds, through thermo tuneable coating, dynamic solar control behaviour in a cost-effective way and integrate multi-functionalities such as self-cleaning and anti-fogging properties. During the installation of these products, special spray foam – EENSULATE spray foam – is used to increase insulation of the building. EENSULATE foam is highly insulating mono-component and environmentally friendly spray foam for the cost-effective automated manufacturing and insulation of the opaque components of curtain walls as well as for the significant reduction of thermal bridges.

5.5.1 Energy efficiency

The main purpose of the curtain walls is to curtail air and water infiltration while keeping the moderate environment in. As curtain walls are usually criticized for poor insulation values, EENSULATE sets a goal to reach the historically lowest U-value, also known as the rate of transfer of heat through a structure. The final product is expected to achieve the U-value of 0.4, which means the EENSULATE presents close to 50% improvements compared to the currently best performing curtain wall. Furthermore, the use of EENSULATE spray foam is expected to double thermal resistance (R-value) of the EENSULATE curtain wall.

The developers conducted a simulation comparative study of average office building from the 70's and the 80's and an office, which uses EENSULATE technology. The first office examined was a standard office with centralised HVAC, energy efficient lighting, and 60% vision glass ratio. The results reported 250kWh/m^{2}a of energy use with 34% associated to space heating and cooling. Its counterpart that uses EENSULATE Basic technology is expected to save 50kWh/m^{2}a of the energy use and EENSULATE Premium as much as additional 10% reduction. UCL has estimated energy savings above 200 W/m^2.

5.5.2 Cost-effectiveness

EENSULATE developers bear in mind that high price and operational costs are frequently mentioned as a downfall of curtain wall systems. Currently, an average price for curtain walls, which used triple glazing and mineral wool for the spandrel, exceeds 350euro/m^2. A target price for the EENSULATE Basic is set at 250euro/m^2 for a 60% vision glass/spandrel ratio. The use of spray foam for the manufacturing of the spandrel component will reduce its overall manufacturing cost by 25% due to the reduced cost of the foam per volume (expected 10% increase in price per kilo at 1.88euro/kg, which is compensated by a higher expansion volume from 55litres/kg to 65litres/kg) as well as it eliminates costs regarding the measure cuts and associated labour and waste. Easy fit of the EENSULATE components with the existing building structure reduce the need for costly adaptation of interfaces such as roof offsets, which can exceed 75euro/m^2. To demonstrate potential saving, a building, which uses 100m^2 of curtain wall system would save approximately 10.000 euro.

Moreover, EENSULATE will use materials that are highly durable and therefore will reduce maintenance requirements. The accurate and highly automated manufacturing of the components with a quality assurance guarantee will reduce the intervention to fix problems during use. It is expected to reduce the need to fix condensation problems due to local bridges. The reduction is estimated overall in 25%.

5.5.3 Wide sectors applicability

EENSULATE products are expected to be suitable for all three sectors of construction market – public, commercial, and residential. Furthermore, it is predicted that the innovative glass and spray foam will be widely used for retrofitting. Buildings with already existing curtain wall structures can be easily refurbished with new curtain walls. Other buildings must undergo further intervention to be able to attach a curtain wall on them. Unitized curtain walls are used to fasten the renovation of such building. This fact leads to the conclusion that the market potential is vast. It can be quantified as at least 1 to 2 million square meters of envelope surface. Moreover, public buildings have 50-100% higher energy consumption compared to a residential building with an equal floor area. In this framework, using EENSULATE curtain wall components to retrofit glazed public buildings is the most effective solution to meet the targeted 60% reduction of energy use when deep renovation is concerned.

5.5.4 Unitized curtain wall

The demand for unitized curtain walls is growing and the developers are aware of this statistics. EENSULATE answers the demand by providing top of the line unitized curtain wall solutions meeting the market standards and surpassing them.

5.5.5 Environmentally friendly product

According to the ReFoMo project, taking into consideration only half of the building suitable for EENSULATE project, the projected reduction of the total energy demand in the built environment would reach 5%. Considering the Global Warming Potential of the entire life cycle, EENSULATE could achieve a value of 16.0kg CO2-eqv./m2a, which is 40% better then best performing installed facades.

The Aluminium used allows the environmentally friendly recycling option and contributes in that manner to environmental protection. The developers will bear in mind the after-use of the product. The EU pushes for the principle of circular economy, which aims to re-use the waste material – in this case, glass and aluminium. The European glass sector is advanced in recycling of container glass with approximately 73% recycling rate and now aims to focus on recyclability of flat glass. EENSULATE glass falls within the category of flat glass, which is the second largest sector and represents about 25% of the total EU glass production. Most of the flat glass products used in the building construction can be dismantled, collected and recycled. The issue with flat glass in not in the product itself, but rather in collect and sort schemes. Since flat glass falls behind regarding its recycling, initiatives to collect and sort this glass have been launched. An example can be the VRN system in the Netherlands.

By the creation of a curtain wall, which lowers the U-value by about 50%, EENSULATE expects the prevention of heat escaping, energy wasting, and CO_2 emissions. It is expected to meet the European standards of creation of nearly zero energy buildings. Such buildings are considered green projects.

5.5.6 EU contribution and legislation

EENSULATE, by contribution to the effort to standardize nearly zero-energy building, is expected to receive support and financing from the EU. By being a green product and contributing to green projects, EENSULATE is marked as a promising solution to be adopted EU-wide and further.

5.5.7 Quality – long product life, disaster resistance

Currently, a product guarantee is set at 10 years; studies report that lifespan can reach 15 years in optimal conditions. EENSULATE components will have a target lifespan of at least 20 years. The innovative coating will provide superior self-cleaning and anti-fogging properties with direct impact on degradation of the vision glass. The EENSULATE products deal with disaster resistance and cracking prevention as growing trends of demand by architects, developers and end-users. The developers expect the product to be of top quality and outstanding performance in solving these challenges.

5.5.8 Transparency, size and colour

EENSULATE is designed in a manner, which will allow the architects and designers the artistic freedom and creative liberty by answering the aforementioned specifications requirements. It is expected to be provided in a selection of sizes; however, colours versions are yet to be determined.

5.5.9 Reduced weight

Weight reduction in the field of curtain wall installation serves as a determining factor in product selection. EENSULATE's ability to reduce the weight from 70kg/m^2 to 45kg/m^2 promises to ease the installation process, the transportation challenges and the maintenance obligations. EENSULATE is designed to answer the necessity in easy to install curtain wall in a manner, which enables maintenance, and replacement in a short period of time. It is an advantage, which allows the procedure to be done on site white the building is in use. The reduction of weight is caused by the reduction of glass used for the EENSULATE. Even though EENSULATE does not offer triple-layer glass system, the properties are superior.

5.5.10 Worldwide demand

The analysis illustrates that Europe and the United States possess the highest curtain wall market shares. However, China and UAE have the highest growth. The demand for curtain walls in these two countries is rapidly increasing and thus EENSULATE could find potential buyers outside Europe. The profit might not come only from the sales of the EENSULATE Glass and EENSULATE Spray Foam alone but also from the selling licenses to the Knowledge Centres. Potential buyers interested in the EENSULATE technology might operate even outside the European market. For instance, China and UAE demand for curtain walls is growing rapidly. Analysis from TechNavio's forecast the curtain wall market in China to grow at a CARG of 10.03% over the period 2013-2018[40].

[40] TechNavio, 2016, Curtain Wall Market in China 2016-2020 http://www.technavio.com/report/china-construction-curtain-wall-market

PART C: CONCLUSIONS

6 Conclusions

The aim of this report has been twofold: on one hand, to provide the relevant standards and regulations and certification/procurement practices to consider for the development of EENSULATE product in the subsequent project development. On the other hand, to inform about the most relevant market drivers.

In Table 6-1, the main standards and regulations of reference for the EENSULATE product are summarized.

Table 6-1 –EENSULATE reference standards and regulations and project objectives.

Topic	Performance aspect	Reference standards	EENSULATE project target	Market reference	Comment
Energy	Thermal performance	EN ISO 12631 EN ISO 10077 EN 673	U-value tot. = 0.4 W/m^{2}K	U-value tot. = 1.5 W/m2K **	Will always require CE marking
	Radiation properties	EN 410	Solar Factor G = 32%*	Solar Factor G = 67%**	Will always require CE marking
Comfort	Acoustic performance	EN ISO 16283 EN ISO 10140-2 EN ISO 140-3 EN ISO 717-1 EN ISO 10848	Rw = up to 52 db	Rw = 30 ÷ 40 db	Flanking sound transmission will always require CE marking in Scotland and will require CE marking in England and Wales for dwellings
	Surface condensation	EN ISO 13788	-	-	-
	Air tightness	EN 12153 EN 12152	-	-	Not explicitly required in Building Regulations
	Water tightness	EN 12155 EN 12154	-	-	Not explicitly required in Building Regulations but may be CE marked
	Light transmittance	ISO 9050	0.90	0.40 ÷ 80	-
Safety	Wind load resistance	EN 12179 EN 13116 EN 1991	-	-	Will always require CE marking for wind load safety
	Impact resistance	EN 12600 EN 14019	-	-	Not explicitly required in Building Regulations but may be CE marked
	Fire resistance	EN 1364-3 EN 13501-2	-	-	Only requires CE marking if performance required
	Fire reaction	EN 13501-1	-	-	Will always require CE marking
	Burglar Resistance	EN 1627 EN 1630	-	-	-
Products	Curtain wall	EN13830	-	-	-
	Glass	EN 14179-1, EN 14179-2, EN 1279 EN ISO 12543-1to6	-	-	-
	Screws and rivets	UNI 6947, UNI 6955, UNI 9200A	-	-	-

* EENSULATE basic.

** Pilkington Spacia.

In Table 6-2, the main certification protocols and the aspects impacted by the EENSULATE product are shown.

Table 6-2 – Potential of EENSULATE with reference to today certification protocols.

Certification protocol	Aspects impacted by EENSULATE	Level
BREEAM	MAT01 – Life cycle impacts (credits calculated through the green guide) MAN03 – Construction site impacts (e.g. reduced energy consumption and reduced water consumption) Other aspects in ENE (energy) section Other aspects in MAT (materials) section	UK (international relevance)
LEED	EA – Energy and Atmosphere credit category MR - Materials and Resources credit category EQ - Indoor Environmental Quality credit category	USA (International relevance)
GREEN GLOBES	Energy Materials & Resources Emissions Indoor Environment	USA
DGNB	SOC - sociocultural and functional quality TEC - technical quality PRC - process quality	Germany
ITACA	B - Energy C - Emissions D - Indoor Environment	Italy
Casaclima Nature	Materials Indoor air quality	Italy
BRaVe	Building Frame Energy HVAC Heating, Ventilation, Air Conditioning Efficiency of Surfaces	Italy
HQE	Environment and Energy (The assessment process is based on a method that is compatible with international indicators such as the Sustainable Building Alliance, CEN TC 350)	France
TBQ	B: Economy and Technical quality C: Energy and Supply D: Health and Comfort	Austria
Minergie-ECO	sound insulation indoor air quality building materials with low environmental impact	Switzerland
GREEN STAR	Energy Indoor environment quality Materials Innovation	Australia
HK-BEAM	Energy use Indoor environment quality	Hong Kong

	Materials Innovation	
CASBEE	L (Load): Built Environment Load, mainly concerning the resource efficiency Target Field	Japan

The preliminary assessment of the main market drivers for the project has instead provided the results summarized in Table 6-3.

Table 6-4 EENSULATE responses to market drivers.

Market Driver	Assessment	EENSULATE
Energy efficiency (A steady growth in demand for energy efficient products)	→ EENSULATE presents close to 50% improvements in U-value compared to the currently best performing curtain wall → Energy savings above 200 W/m^2 → Doubling R-value compared to the currently best performing curtain wall	✓
Technology Innovation (developing innovative product)	→ EENSULATE is referred as a market game-changer → Superior *properties* while keeping costs low → Innovation might be noted through combination of vacuum glass and insulation spray foam, which together improves U value, R-value and reduces costs	✓
Varying sectors applicability (public, commercial, residential sectors)	→ EENSULATE is suitable for public, commercial, and residential buildings	✓
Unitized curtain wall (becoming the preferred type of curtain wall)	→ EENSULATE answers the high demand for unitized curtain walls	✓
Environmentally friendly product (willingness to invest in such products)	→ Considering the Global Warming Potential reduction possibilities of the entire life cycle, EENSULATE reaches a value of 16.0kg CO_2-eqv./m^{2}a, which is 40% better then best performing facades → EENSULATE expects the prevention of heat escaping, energy wasting, and CO_2 emissions. → Recyclability of aluminium → Recyclability of flat glass	✓
EU financial contribution (through Structural and Operation Funds, the EU can assist with financing of the product)	→ Considering the state of art of EU structural and operational funds, EENSULATE is expected to fulfil the criteria as a suitable component of nearly zero energy buildings. Nearly zero energy buildings, currently, can be financed through the funds	Expected

Legislation and regulation (EU legislation pushes for green building, among others through building of nearly zero energy buildings)	→ Considering EENSULATE a component of nearly zero energy buildings, EU requires all new buildings to be nearly zero energy buildings by December 2020.	✓
Cost Effectiveness (Price is the top priority of the customer for choosing a product)	→ In average, 100 euro/m^2 of curtain wall saved → The use of spray foam for the manufacturing of the spandrel component will reduce its overall manufacturing cost by 25% → Easy fit of the EENSULATE components with the existing building structure reduce the need for costly adaptation of interfaces such as roof offsets, which can exceed 75euro/m^2 → 25% of maintenance costs reduction	✓
Improved Quality (Quality is the second most important priority of the customer for choosing a product)	→ Lifespan of at least 20 years → The EENSULATE products deal with disaster resistance and cracking prevention	✓
Green Project (Architects have noted the customers' demand for green projects)	→ Examining the energy efficiency of the product and a contribution to nearly zero energy buildings, EENSULATE can be seen as a green product suitable for green projects	✓
Fit for Retrofitting (Old buildings tent to be energy ineffective, and are responsible for major energy losses, authorities push for reconstructions to fix this issue)	→ EENSULATE is suitable for retrofitting of building with already existing structures for curtain walls. Other buildings must be further prepared to hang a curtain wall on them.	✓
Reduced Weight (construction companies desire lighter materials)	→ Average curtain wall currently weights approximately 70kg/m^2, EENSULATE aims to reach weight of 45kg/m^2. → Due to its reduced weight, installation becomes easier, cheaper, and faster	✓
Size and colour variations (designers prefer comfortable variety of sizes and colours, which allows them free hand in creation of new designs)	→ Developers promise that EENSULATE will come in different shapes; colour demands are yet to be specified.	n/a
Worldwide demand for curtain walls (possible demand for EENSULATE license)	→ China and UAE demand for curtain walls is rapidly growing → Selling licenses to produce EENSULATE curtain wall	✓

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