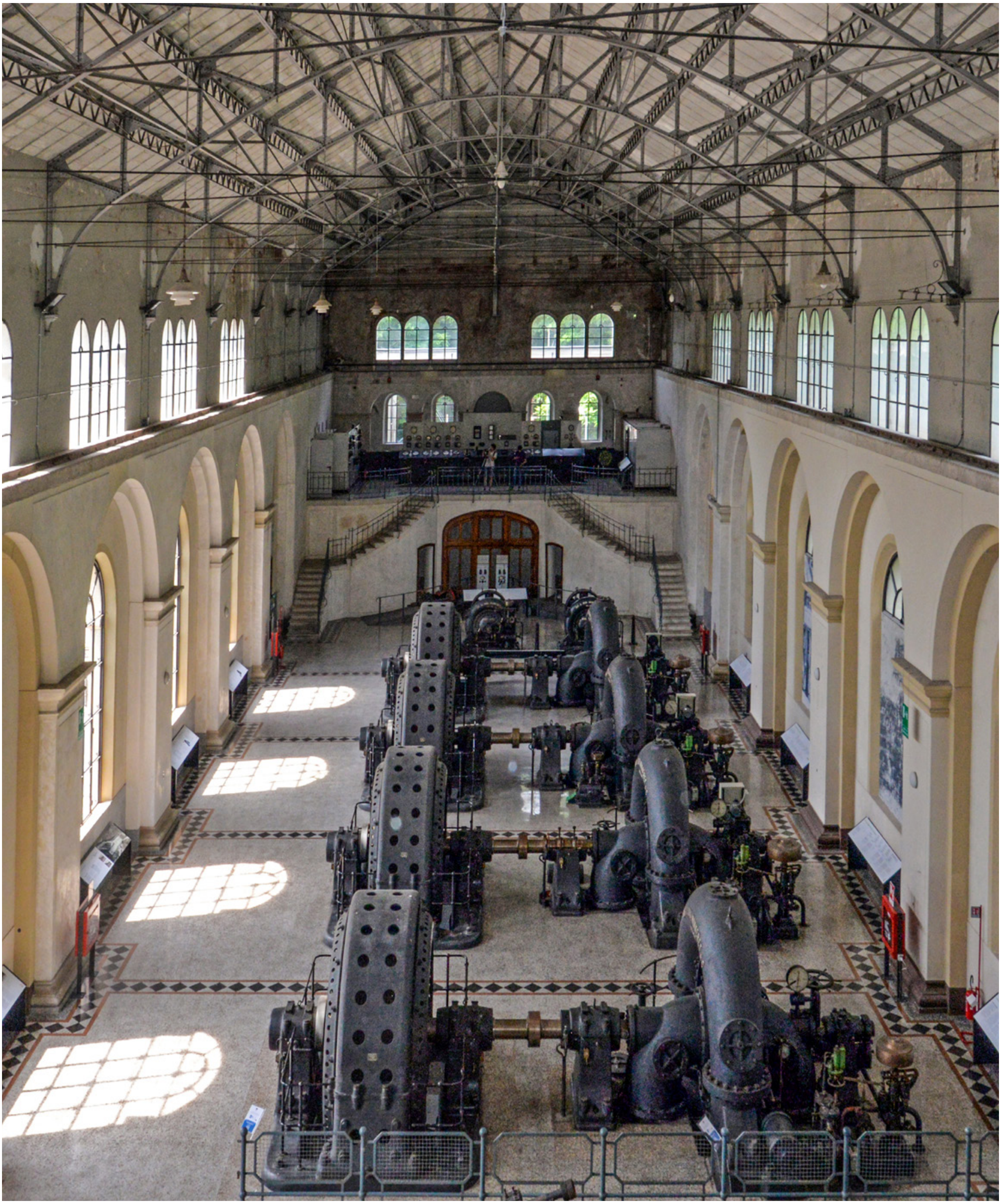

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40136 Bologna - Italy
Phone: +39 051 2093155
Email: info@artecweb.org - tema@artecweb.org

**Media Partner:**
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# THE SYNTHETIC THERMAL INSULATION PRODUCTION CHAIN – MOVING TOWARDS A CIRCULAR MODEL AND A BIM MANAGEMENT

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Ornella Fiandaca, Alessandra Cernaro

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## Highlights

On a sample of sustainable synthetic thermal insulators, three investigations (correlative method) were undertaken to highlight: 1) the winter and summer thermo-hygrometric profile; 2) the compliance with "CAM" but more extensively their bio-ecological vocation; 3) the conception of "pre-packaged" BIM objects. The results, although not homogeneous, have revealed very promising production lines to resolve prejudices about these insulation materials.

## Abstract

One of the most debated issues of sustainability in the last century concerned the insulation layer, placing it at the center of technological innovation with a primary role in the design of the building shell; this change has generated an increasingly complex functional model. Its nature, morphology, and location guided the most appropriate choice: vegetable, animal, mineral or synthetic; inconsistent, panel or mat; in external, of interspace or internal position; until now, the products selection has been based on energy savings during the management phase of the building and not looking at production and disposal.

This study, expanding the look at the life cycle of thermal insulators, focused on the most controversial in terms of sustainability, those of "plastic" derivation to understand with a correlative method: the trends prepared by companies to reduce "from cradle to gate" the use of fossil resources, the carbon footprint, the amount of water and energy consumed; what are the resolutions adopted to respond, with a renewed "conscious" production, to the Minimum Environmental Criteria (CAM Italian acronym) required in the Green Public Procurement (extended by virtue of state incentives also to private construction); the opening of the production system to industry 4.0 which will require a BIM (Building Information Modelling) approach for any type of intervention.

After an extensive exploration to select a sample of synthetic thermal insulators, emblematic of the recent path of sustainable innovation, three investigations were undertaken aimed at highlighting: the congruity of performance of the winter and summer thermo-hygrometric profile; compliance with CAM but more extensively the attestation of their bio-ecological vocation; the conception of BIM objects for immediate use in the professional field. The results, although not homogeneous, have highlighted a great ferment in the sector, with a very promising technological level of some production lines to resolve prejudices and closures towards the synthetic thermal insulators.

## Keywords

Synthetic thermal insulators, Sustainability, Minimum Environmental Criteria (CAM), Thermo-hygrometric profile, Building Information Modelling (BIM).

**Ornella Fiandaca***
*Dipartimento di Ingegneria, Università degli Studi di Messina*

**Alessandra Cernaro**
*Dipartimento di Ingegneria, Università degli Studi di Messina*

** Corresponding author: e-mail: ofiandaca@unime.it*

## 1. INTRODUCTION: THE SUSTAINABILITY OF THERMAL INSULATING MATERIALS

To test the energy efficiency and environmental compatibility of thermal insulators, we have collated data related to their sustainability paradigms. The latter comprises reducing the exploitation of virgin resources; reliance on secondary raw materials; eliminating harmful substances and revising production processes, pursuing water and energy-saving policies by adopting renewable sources; reducing and reusing waste; accreditation through labeling or LCAs (Life Cycle Assessments).

The study revealed various approaches manufacturers have adopted to experiment with innovation factors throughout the product chain, from the incubation of raw materials to construction site delivery. These initiatives include:

- introducing fractions of regenerated/recycled materials and reusing scraps or waste in the same production cycle;
- recovering or reducing greenhouse gas emissions;
- adopting company policies to limit grey energy production from fossil fuels by turning to renewable energy sources;
- reducing or recovering water used in production or washing processes.

It emerged that a transition phase is underway, in which the signals may still be tentative, but the trends are quite evident.

The 5R revolution (R for Reduction of waste, separate Raising, Reuse of useful objects, Recycling of materials and energy Recover) was most readily embraced in the area of plant-based insulation, where the recycling of textile or wood fibers could be considered an intrinsic prerogative of the sector [1]. A similar development has occurred in the construction market, where new manufacturers have started to exploit "resources" derived from the transformation of solid municipal or industrial waste, which demanded alternative disposal strategies rather than waste-to-energy or landfill. This is the case of glass transformed into fibers, paper into cellulose fiber, and shredded or pulverized tires [2].

Associating "recycled" production chains with conventional manufacturing cycles has proven to be more problematic, with established systems obliged to implement modifications to accommodate innovation, as in the case of mineral or synthetic insulators. Nonetheless, also stakeholders in this category are revising their choices and strategies in terms of material sourcing, production cycles, and quality in a manner that impacts far more than management phase energy efficiency. Therefore, such a revision scenario warrants an in-depth technical study that considers the entire life cycle [3].

Therefore, with reference to this third production cross-section, we proceeded to identify the most "vulnerable" category of thermal insulators, placed on the outside of the casing, to evaluate through this study a "professional" sustainability profile. We wondered about what are still the reticences to be addressed, having as paradigms three tools that in the last period have proved to be significant in guiding innovation: the life cycle beyond management in use; the minimum environmental criteria (CAM), the availability of BIM objects.

## 2. STATE OF THE ART: FOR A REASONED CHOICE OF THE FIELD OF INVESTIGATION

A reflection on the sustainability of the production chain of each category of thermal insulation revealed the major problems affecting synthetic products (polystyrene and polyurethane) and mineral products (rock wool and glass wool) with different specificities but all harmful to people and the environment. Synthetic products are unsustainable because high water consumption is required (due to evaporation during the synthesis and cooling phases), and they consume considerable grey energy in initial production: 600 kWh/m$^3$ for EPS, 800 kWh/m$^3$ for XPS, and 1230 kWh/m$^3$ for PU. With regard to mineral products, although they consume less non-renewable fossil fuel in comparison to synthetic products (approximately 400 kWh/m$^3$), coke is burned to melt basaltic rocks and to reduce the temperature of glass fusion; furthermore, processing uses high environmental impact cohesives (resins derived from petrochemicals) [4, 5].

Considering the direction manufacturing companies have taken, with diverse evolutionary stages and heterogeneous peaks of innovation, in the meantime, we examined them from an environmental perspective, observing how they handled plastics to offset critical issues deriving from the use of non-renewable materials, energy, and water resources. We also studied how manufacturers control emissions, production waste, and shipment packaging.

Corporate policies have evolved in recent years, prompted by Italian Ministerial Decree No. 259 of 11/10/2017 on Minimum Environmental Criteria (CAM Italian acronym) [6]. This legislation also prescribed several sustainability requirements for thermal insulators specified in "green tenders" called by Public Administrations (Green Public Procurement - GPP) [7]. Our study revealed that the transition to more sustainable production and commercial framework occurred by proposing two versions of the same product, one traditional and the other aimed at satisfying certain parameters destined to become increasingly stringent. Such an approach did not involve significant differences in performance or costs per square meter that would encourage professionals to choose thermal insulation solutions in line with prevailing energy and environmental criteria.

Trade associations have taken up the challenge of the circular dynamics of production processes and the global demands to "safeguard the planet" by encouraging their members to adopt collective strategies for the attainment of bio-ecological certification and specific production line accreditation. Here are some representative cases: AIPE (the Italian Expanded Polystyrene Manufacturers Association) has undertaken various initiatives to spread the culture of recycling, both through the development of technical dossiers based on the LCA methodology [8] and the new life of EPS [9] and with the opening of a coordination center (CREA) to recover scraps and waste for recycling [10]; the EPSItalia Business Network has introduced Second Life Plastic (PSV, Certificate issued by IPPR – Italian Institute for the promotion of recyclable plastics) [11], a quality mark for secondary raw materials derived from plastic waste to be adopted in the production of EPS insulation; ANIT (National Association for Thermal and Acoustic Insulation) has activated working groups to develop guidelines and manuals to disseminate technical insights, regulatory updates, aspects related to energy efficiency, environmental sustainability and fire safety [12].

The effects we observed for various supply chains still under development include the pairing or replacement of virgin raw materials with secondary raw materials through the use of processing waste or Municipal Solid Waste (MSW) or the recycling of "homologous" waste in order to reduce its production; the choice of new oriented blends, coloring white EPS in grey, blue or orange to designate different performance profiles; the revision of production processes to obtain the reduction/recovery of water resources for manufacturing and to limit the emission of replaced or reused greenhouse gases; the testing of innovative supply chains aimed at devising products in which fossil resources are replaced with energy derived from renewable sources; the adoption of LCAs to optimize the factors that contribute to sustainable bio-eco quality [3].

In this complex scenario, given the significant number of aspects to be examined and possible future opportunities, we were obliged to organize the study in a systematic manner. We believe that the category of synthetic thermal insulators is still perceived as ecologically problematic and poses an interesting challenge in the pursuit of sustainability goals. Synthetic insulation is objectionable for its use of a notoriously non-renewable and fossil-derived virgin raw material, its environmental impact attributable to its energy-intensive and polluting manufacturing process, and for the difficulty of creating a circular supply chain by reintroducing not only waste but post-consumer waste to be recycled into the mixture. Another cause for concern of this category is the significant amount of "plastic-derived" panels comprising harmful gases and additives which, at the end of their life in the 21st century, will have to be classified as special "hazardous" waste and removed [13]. This problem is underpinned by the discontinuation of obsolete or ineffective solutions induced by state incentives (e.g., the Italian "110% super-ecobonus") for energy requalification interventions.

The company policies [3], the analysis of the trade associations [8], and the scientific studies [14] consulted show a path undertaken, still in the initial phase, to which we want to contribute with a new piece that intends to fill some gaps found in essential issues, to orient the energy redevelopment according to circular logic.

## 3. METHODOLOGY: THE CORRELATIVE INVESTIGATIONS FOR A CONSCIOUS PROFESSIONAL DECISION

We used the correlational methodology adopted in scientific research to address issues that are still poorly investigated in the exploratory stage, such as to require the identification of factors on which to focus the attention. In the specific case, we carried out a re-analysis of the available data of synthetic thermal insulators according to different points of view, which emerged in the scope of new application needs.

After an extensive technical exploration of production panorama, initially without any conditioning, we proceeded to the selection of a sample of products, placed on the construction market, symptomatic of a commercial path oriented towards sustainable innovation, thus capturing any element of production novelty throughout the entire life cycle [3]. On the filtered and systematized repertoire for external insulation systems, identifying the products with the highest thermo-hygrometric performance, without additional integrated layers, we undertook three investigations deemed essential to validate their use:

1. performance congruity of the thermo-hygrometric profile in both winter and summer;
2. compliance with CAM but extended to certification of their bio-ecological suitability in a broader sense;
3. development of BIM objects to ensure immediate use in the professional field.

The results obtained will be discussed below, highlighting the development, limits, and perspectives of each issue addressed.

## 4. RESULTS

### 4.1. RECYCLED VS. CONVENTIONAL MATERIALS: COMPARISONS BETWEEN PERFORMANCE PROFILES

In the first phase of the analysis conducted, we examined the synthetic thermal insulation market by analyzing product datasheets, inventories prepared by regional green building offices or environmental associations (Legambiente, CasaClima, etc.), and the recommendations set out by the Standard UNI 10351/2015 (Thermohygrometric properties - Procedure for the selection of design values). These were explored to identify “sustainable” production lines and ascertain how their performance compares with that of conventional equivalents.

We then selected Sintered Expanded Polystyrene (EPS), Extruded Expanded Polystyrene (XPS), and Poly-Ethylene Terephthalate (PET) for our representative sample as they are made using the most advanced production processes in terms of technological innovation. We found that the manufacturers involved, also when addressing potential rather than fully developed strategies, were in favor of optimizing product performance characteristics in line with a bio-sustainable perspective. This implies the achievement of 004 ETAG system accreditation (the European Technical Approval Guideline), compliance with the Minimum Environmental Criteria defined by Italian Ministerial Decree 11/10/2017, attainment of environmental certifications (EPD, PSV, Self-Declared Environmental Claims and definition of an LCA from the cradle to the gate with end-of-life options).

In the case of EPS and XPS thermal insulation – conventional products with well-established supply chains – the environmental compliance and energy efficiency have been pursued by developing innovative blends of Virgin Raw Materials (VRMs) with Secondary Raw Materials (SRMs), hybridizing production processes to combine sintering and extrusion as well as replacing fossil resources with renewable ones at the polymer synthesis stage. The case of r-PET, a material obtained from the recycling of municipal solid waste (in particular water and soft drink bottles), differs in that the production chain has been expressly organized to manufacture construction products. We excluded Polyurethane (PU) thermal insulators from the study because effective end-of-life regeneration technologies have not yet been tested. We also omitted the opportunities offered by the use of Acrylonitrile Butadiene Styrene (ABS) since, by virtue of its elasticity, shredded tires are used to produce acoustic insulation or anti-vibration materials.

Our choice of thermal performance indicators to classify the selected products required us to extend the survey to all descriptive behavioral parameters under stationary and dynamic conditions. We added the latter due to a recent awareness of thermal and hygrometric well-being, highlighting how indispensable they are to evaluate the contribution of the various envelope layers during the summer months.

In this sense, the lack of tests carried out to indicate how synthetic thermal insulators respond to high external temperatures became immediately evident. No technical data sheet among those examined to select the sample includes the periodic thermal transmittance Yie (24 h), which expresses the ability of a product to attenuate and dephase the heat flow from outdoors over a 24-hour period. This denounces the absence of any analysis on the contributions guaranteed/denied by each type of insulating material [15]. This shortcoming is not restricted to recycled production lines because until now; also the measured data for conventional production lines only describe potential winter energy savings. It has to be said that this issue is now garnering greater attention because it has been noted that, in certain cases, the addition of recycled material degrades thermal performance during hot weather. The same applies to diffusivity (the ratio between conductivity and thermal inertia), which is declared in only a few cases, whereas only the value of the volumetric thermal capacity is indicated, but not the parameters that quantify thermal inertia. No data is provided for the phase shift or attenuation factors that are used to deduce a performance indicator, now "standardized" in classes, from I (excellent) to V (mediocre), and used to limit the use of summer air conditioning [16].

We should emphasize that thermal cladding for buildings, the prevalent application of the products we selected, and where the thermal insulation is applied externally is solely characterized in terms of winter heat retention, whereas the remainder of the envelope is tasked with providing massive thermal inertia. However, whatever its position, if an imbalance occurs between low volumetric heat capacity and low diffusivity, heat would easily accumulate and, due to inadequate dissipation, it would flow to adjacent layers.

By having identified qualitatively the performance indicators that should be recognized for a correct and complete assessment of a cladding's seasonal contribution to the thermo-hygrometric behavior of the building envelope, regarding the representative sample, we drew up an initial comparison chart of these values (Tab. 1) taken from the product datasheets and certified by the Declarations of Performance (DoPs). The latter is used to validate CE marking, which has been mandatory for the category since 2010, and it was provided by the manufacturers themselves (in some cases upon explicit request). Within each selected production line, we considered the products with the most efficient thermo-hygrometric values.

Subsequently, not without difficulty due to the lack of data, we added a second chart (Tab. 2) to also examine, alongside the winter behavior, the summer behavior of these synthetic insulators comprising recycled materials. Thus, in this first phase of the study, we additionally considered what manufacturers should examine to achieve innovative products in the pursuit of sustainability.

A comparison between the performance indicators of recycled EPS and XPS thermal insulators in winter conditions with the equivalent products from conventional production lines does not show any difference when the declared percentages of recycled polyester are added. The best value for thermal conductivity, equal to 0.030 W/mK, is typically achieved with a density between 15 and 25 kg/m$^3$ and with a resistance to vapor diffusion in the 20–40 range. However, we should highlight certain innovative factors that are not yet widespread but that do distinguish a subgroup of manufacturers committed to streamlining their research and manufacturing processes in line with eco-sustainability principles. With regard to EPS, irrespective of the minimal quantity of Secondary Raw Materials (SRMs) used and the prevalent use of NEOPOR as a Virgin Raw Materials (VRMs), which reduces conductivity by 15% (as well as improving mechanical performance) [17], we noted an attempt to blur the distinction between the sintering and extrusion process to obtain "synto-laminated" (λ'isolante) products. With the first mode of production, they acquire the best characteristics of breathability and thermal insulation, constant even with increasing thicknesses, and with the second the homogeneous distribution of polystyrene and continuous "lamination", ensuring stability, flatness, and mechanical resistance of the sheet produced. At the pioneering stage, and therefore not included in the sample, a new hybrid material (Greydur by TermolanLAPE) [3] is challenging XPS as the prime performer in mechanical

| *Company* | *Product* | *VRM (%)*<br>*SRM (%)* | *λ [W/mK]*<br>*ρ [kg/m³]* | *$C_p$ [J/kgK]* | *μ* | *$W_{lp}$ [kg/m²]*<br>*WL(T)i* [%] |
|---|---|---|---|---|---|---|
| Maiano | *Sintherm Evo*<br>Panel in thermo-bonded PET fibers | Polyester<br>PET fibers (85%) | 0.034<br>25 | 1200 | 3.1 | nd<br>nd |
| Isolconfort | *Eco espanso 100*<br>White EPS panel | PS<br>PS (≥ 10%) | 0.036<br>18* | 1450 | 20-30 | nd<br>WL(T)3 |
| | *Eco Por G031*<br>Graphite EPS Panel | PS (NEOPOR BASF)<br>PS (≥ 10%) | 0.031<br>18* | 1450 | 20-30 | nd<br>WL(T)3 |
| λ'isolante | *Tatanka-100C-R*<br>White EPS panel | PS<br>PS (≥ 15%) | 0.035<br>18* | 1340 | 30-70 | $W_{lp}$≤0,5<br>WL(T)2 |
| | *Isoray Performa-R*<br>Graphite EPS Panel | PS (NEOPOR BASF)<br>PS (≥ 15%) | 0.031<br>18* | 1340 | 20-40 | $W_{lp}$≤0,5<br>WL(T)2 |
| sinto | *Sintoray Cover R*<br>Graphite EPS Panel with external surface in synto-laminated PS | PS (NEOPOR BASF)<br>PS (≥ 15%) | 0.030<br>18* | 1340 | 20-40 | $W_{lp}$≤0,5<br>WL(T)5 |
| λ'isolante [Caparol] | *Reverso* [*Capatect PS Dalmatiner 162 Green*]<br>Synto-laminated Graphite PS panel produced with the BioMass Balance method | PS (NEOPOR BASF BMB) | 0.030<br>18 | 1340 | 20-40 | $W_{lp}$≤0,5<br>WL(T)5 |
| Termolan LAPE | *Lape EPS 120 TK8 RE*<br>White EPS panel | PS<br>PS (≥ 15%) | 0.034<br>20 | 1450 | 60 | $W_{lp}$≤0,5<br>WL(T)0.7 |
| | *Greypor G600 T RE*<br>Graphite EPS Panel | PS (GREYPOR)<br>PS (≥ 15%) | 0.031<br>23 | 1450 | 70 | $W_p$≤0,5<br>WL(T)0.7 |
| Sive | *Isolpiùgraf Secondavita K8*<br>Graphite EPS Panel | PS (NEOPOR BASF)<br>PS (25%) | 0.031<br>15 | 1450 | 20-40 | $W_{lp}$=0,5<br>WL(T)3 |
| EPS Italia [Weber] | *ReLife 36 Etics* [*Webertherm F100 Eco]*<br>White EPS panel | PS<br>EPS certified PSV (15%) | 0.036<br>15 | 1500 | 20-40 | $W_{lp}$=0,5<br>WL(T)3 |
| Ursa | *Ursa XPS Plus*<br>XPS Panel with wafer surface | PS<br>PS (45%) | 0.032 (t=3 cm)<br>0.033 (t=4 cm)<br>0.034 (t=5÷6 cm)<br>0.035 (t=8÷24 cm)<br>30 | 1450 | 100 (t=3÷8 cm)<br>50 (t=10÷24 cm) | nd<br>WL(T)1.5 |

**Acronyms:** SRM (Secondary Raw Material); VRM (Virgin Raw Material); nd (not declared); PSV (*Plastica Seconda Vita* - Plastic Second Life).

**Properties codes:** λ (thermal conductivity - declared); ρ (density); Cp (specific heat capacity); μ (resistance to vapour diffusion); Wlp (water absorption by partial immersion); WL(T)i (long-term water absorption by immersion at 28 days; "i" indicates the maximum percentage of volume of water absorbed); t (thickness).

**Notes to the table:** The values for EPS and XPS insulators comply with the related harmonized technical standards (UNI EN 13163 and UNI EN 13164); for those in PET no product prescription has yet been formulated; The thermal conductivity of the Neopor BASF sheet, used by most companies such as VRM, is almost 20% better than that of a traditional EPS sheet (for density values equal to 15 Kg/m3) ; in 2005 Termolan LAPE patented Greypor, defined as "the natural evolution of Neopor".

*The missing density values, because they were not communicated by the companies, were estimated using the following source: https://neopor.de/portal/load/fid1225941/Neopor_Neopor%20%26%23226%3B%26%23836%3B%26%238220%3B%20Guida%20Rapida.pdf

Tab. 1. *Performance indicators provided by companies for the thermo-hygrometric behavior of insulators obtained with recycled plastic material [The values for EPS and XPS insulators comply with the related harmonized technical standards (UNI EN 13163 and UNI EN 13164); for those in PET no product prescription has yet been formulated] [3].*

resistance and permeability to water while retaining the thermal insulation and vapor transpiration properties of EPS; these characteristics are achieved thanks to a particular blend based on orange polystyrene beads of unspecified composition and a special molding process. It is likely that ecological upgrading will soon lead to a hybrid with an optimized performance profile compared to conventional EPS or XPS insulation boards.

Unlike EPS and XPS thermal insulation, for which specific product standards exist (respectively UNI EN 13163 and UNI EN 13164), standardization has not yet been applied to polyester fiber products (r-PET). In any case, the analysis of commercial products revealed that their thermal conductivity and density values do not deviate significantly from those of polystyrene derivatives, even if the resistance to vapor diffusion is

| | | Winter behaviour | | | Summer behaviour | | |
|---|---|---|---|---|---|---|---|
| **Product** | **Thicknesses in production [cm]** | **$R_D$ [m²K/W] ($t_r$=10 cm)** | **U [W/m²K] ($t_r$=10 cm)** | **S [J/m³K]** <br> **$C_p$ [J/kgK** | **Fa[1]** <br> **φs (hours)[1]** | **Yie [W/m²K] ($t_r$=10 cm)** | **α [m²/sec]** |
| *Sintherm Evo* [Maiano][2] Panel in thermo-bonded PET fibers | t=3÷7 | 2.06 (t=7 cm) | 0.49 (t=7 cm) | 30000 <br> 1200 | nd <br> nd | / | $1.13 \times 10^{-6}$ |
| *Eco espanso 100* [Isolconfort] White EPS panel | t=4÷20 | 2.75 | 0.36 | 26100 <br> 1450 | 0.9630 <br> 0h27' | 0,35 | $1.38 \times 10^{-6}$ |
| *Eco Por G031* [Isolconfort] Graphite EPS Panel | t=4÷20 | 3.20 | 0.31 | 26100 <br> 1450 | 0.9630 <br> 0h27' | 0,30 | $1.19 \times 10^{-6}$ |
| *Tatanka-100C-R* [λ'isolante] White EPS panel | t=3÷30 | 2.85 | 0.35 | 24120 <br> 1340 | 0.9630 <br> 0h27' | 0,34 | $1.45 \times 10^{-6}$ |
| *Isoray Performa-R* [λ'isolante] Graphite EPS Panel | t=3÷30 | 3.25 | 0.31 | 24120 <br> 1340 | 0.9630 <br> 0h27' | 0,30 | $1.29 \times 10^{-6}$ |
| *Sintoray Cover R* [λ'isolante] Graphite EPS Panel with external surface in synto-laminated PS | t=6÷18 | 3.30 | 0.30 | 24120 <br> 1340 | 0.9630 <br> 0h27' | 0,29 | $1.24 \times 10^{-6}$ |
| *Reverso* [λ'isolante; Caparol] Synto-laminated Graphite PS panel produced with the BioMass Balance method | t=6÷22 | 3.30 | 0.30 | 24120 <br> 1340 | 0.9630 <br> 0h27' | 0,29 | $1.24 \times 10^{-6}$ |
| *Lape EPS 120 T RE* [Termolan LAPE] White EPS panel | t=2÷30 | 3.00 | 0.33 | 29000 <br> 1450 | 0.9630 <br> 0h27' | 0,32 | $1.17 \times 10^{-6}$ |
| *Greypor G600 T RE* Termolan Lape Graphite EPS Panel | t=4÷14 | 3.20 | 0.31 | 33350 <br> 1450 | 0.9630 <br> 0h27' | 0,30 | $0.93 \times 10^{-6}$ |
| *Isolpiùgraf Secondavita K8* [Sive] Graphite EPS Panel | t=1÷25 | 3.23 | 0.31 | 21750 <br> 1450 | 0.9630 <br> 0h27' | 0,30 | $1.43 \times 10^{-6}$ |
| *ReLife 36 Etics* [EPS Italia, Weber] White EPS panel | t=4÷20 | 2.75 | 0.36 | 22500 <br> 1500 | 0.9630 <br> 0h27' | 0,35 | $1.60 \times 10^{-6}$ |
| *Ursa XPS Plus* [Ursa] XPS Panel with wafer surface | t=3÷24 | 2.85 | 0.35 | 43500 <br> 1450 | 0.9624 <br> 0h33' | 0,34 | $0.81 \times 10^{-6}$ |

**Properties codes:** $R_D$ (thermal resistance - declared.)=t/λ; U (thermal transmittance)=1/ $R_D$; S (thermal inertia)=Cp*ρ; Fa (attenuation factor); φs (phase-shift); Yie (periodic thermal transmittance)=Fa*U; α (thermal diffusivity)= λ/S.

**Notes to the table:** 1. The values relating to the attenuation factor and the phase shift of the EPS and XPS insulators were taken from Calzolari M., *Insulating Materials*, available at the link: http://www.unife.it/architettura/lm.architettura/insegnamenti/laboratorio-di-costruzione-dellarchitettura-i/materiale-didattico/materiale-didattico-lca1-2018-2019/lezione-n-16_calzolari_mat-isolanti-25-10.18; 2. For the Sintherm Evo insulation, some performances have been calculated for the maximum thickness in production (t = 7 cm) and it was not possible to calculate the periodic thermal transmittance in the absence of the attenuation factor.

Tab. 2. *Performance indicators calculated to evaluate the thermal behavior in winter and summer.*

closer to the unit value, which risks compromising their insulating properties. Comparative analysis of summer behavior against EPS/XPS insulators revealed medium-low thermal capacity and diffusivity, indicating susceptibility to accumulating heat and an inability to dissipate it, which is incompatible with good performance in hot climates. It is recommended for installation in wall cavities or ventilated external walls: in the first case, this combination of parameters certainly equates to an additional thermal load, but also in the second, although reduced by ventilation, the effect would reduce its efficacy.

These two issues, vapor permeability and summer behavior are at the center of a transitional phase that will determine whether or not r-PET insulation will be able to surpass the prevailing potential demonstrated in the field of acoustics. Only one of the boards in production (Sintherm Evo by Maiano), deliberately retained in the analyzed sample as evidence of the ferment in the category, does not incorporate a vapor barrier, but the manufacturer recommends (when explicitly so requested) that it should be used on its warm side and declares better dynamic thermal performance than other products in the same category.

### 4.2. RECYCLED THERMAL INSULATING MATERIALS AND MINIMUM ENVIRONMENTAL CRITERIA

Demonstrating the technical efficiency of "recycled" insulators is not, in any case, sufficient to establish acceptable environmental sustainability and does not reassure end users because they have not yet been explicitly discussed and/or advertised in this respect.

Therefore, in the second phase of the study, we analyzed company policies in order to verify the replacement or combination of fossil energies with renewable sources. Subsequently, by consulting the sustainability-related technical specifications (expressed with engineering measurement parameters), we proceeded to compare the results with the provisions of Italian Ministerial Decree No. 259 of 11/10/2017 for the Minimum Environmental Criteria (CAM) in the construction sector as envisaged for thermal insulators under point 2.4.2.9 (Tab. 3) [6].

The outcome of this study is presented in a third chart (Tab. 4) in which we listed the parameters taken from the technical datasheets of the selected sample to highlight the approach taken by manufacturers in terms of energy efficiency and environmental compliance, healthiness/harmfulness, and safety in use.

*Insulators must respect the following indications:*
*- they must not be produced using flame retardants that are subject to restrictions or prohibitions provided for by applicable national or community regulations;*
*- they must not be produced with blowing agents with an ozone reduction potential greater than zero;*
*- they must not be produced or formulated using lead catalysts when sprayed or in the course of plastic foaming;*
*- if produced from an expandable polystyrene resin, the blowing agents must be less than 6% of the weight of the finished product;*
*- if made up of mineral wools, these must comply with note Q or note R established by the Regulation (EC) no. 1272/2008 (CLP) and subsequent amendments (29);*
*- if the finished product contains one or more of the components listed in the following table, these must be made up of recycled and / or recovered material according to the minimum quantities indicated, measured on the weight of the finished product.*

| | **Insulation in the form of a panel** | **Crammed, spray/blown insulation** | **Insulation in mats** |
|---|---|---|---|
| Cellulose | --- | 80% | --- |
| Glass wool | 60% | 60% | 60% |
| Rock wool | 15% | 15% | 15% |
| Expanded perlite | 30% | 40% | 8%-10% |
| Polyester fibers | 60-80% | --- | 60-80% |
| Sintered Expanded Polystyrene | 10-60% depending on the technology adopted for the production | 10%-60% depending on the technology adopted for the production | --- |
| Extruded Expanded Polystyrene | 5-45% depending on the type of product and the technology adopted for the production | --- | --- |
| Polyurethane foam | 1-10% depending on the type of product and the technology used for production | 1-10% depending on the type of product and the technology used for production | |
| Polyurethane agglomerate | 70% | 70% | 70% |
| Rubber agglomerates | 60% | 60% | 60% |
| Reflective aluminium insulation | --- | --- | 15% |

*Verification: the designer must make technical project choices that allow to satisfy the criterion and must prescribe that, in the procurement phase, the contractor must ensure compliance with the criterion. The percentage of recycled material must be demonstrated through one of the following options:*
*- an Environmental Product Declaration (EPD) of Type III, compliant with the UNI EN 15804 standard and the ISO 14025 standard, such as EPDItaly © or equivalent;*
*- a product certification issued by a conformity assessment organisation certifying the recycled content through the specification of the mass balance, such as ReMade in Italy®, Plastic Second Life or equivalent (Type II);*
*- a product certification issued by a conformity assessment organisation certifying the recycled content through the specification of the mass balance which consists in the verification of a self-declared environmental declaration, compliant with ISO 14021 standard (Type II).*

Tab. 3. *The requirements of CAM (Decree No. 259 of 11/10/2017) for thermal and acoustic insulation.*

| *Product*<br>*[functional unit kg o mc]*[1]<br>*[Modules LCA [A1-4; C2-C4; D]]*[2] | *SRM (%)*<br>*Scrap-waste derivation* | *Compliance CAM*<br>*Verification of the recycling percentage* | *Labels*<br>*Certificates* | *LCA: GER, GWP, WF*<br>*Tr EG-$CO_2$* | *Bio-eco toxicological certificates* | *Durability* |
|---|---|---|---|---|---|---|
| *Sintherm Evo* [Maiano]<br>Panel in thermo-bonded PET fibers | Polyester (85%)<br>MSW - plastic bottles | In compliance<br>Type II verification | ESD ISO14021<br>ITACA Credits<br>LEED Credits | 50,56 MJ [kg]<br>1,24 Kg $CO_2$ [kg]<br>EP [10cm] 3 months<br>$CO_2$[10cm] 11 months | Oeko-Tex® standard100 Classe I | nd |
| *Eco espanso 100* [Isolcomfort]<br>White EPS panel | PS (≥ 10%)<br>Production | In compliance<br>Type III verification | EPDItaly 2017-22<br>EPD-ICMQ 2018 | 1508 Mj [mc]<br>65,19 Kg $CO_2$ [mc]<br>199 Lt/mc<br>no data | ---- | >50 years |
| *Eco Por G031* [Isolcomfort]<br>Graphite EPS Panel | PS (≥ 10%)<br>Production | In compliance<br>Type III verification | EPDItaly 2017-22<br>EPD-ICMQ 2018 | 1600 Mj [mc]<br>65,19 Kg $CO_2$ [mc]<br>198,60 Lt/mc<br>no data | ---- | >50 years |
| *Tatanka-100C-R* [λ'isolante]<br>White EPS panel | PS (≥ 15%)<br>Post-consumer recycled material | In compliance<br>Type II verification | ICMQ (P287) | no data<br>no data | ---- | Generic [stated] |
| *Isoray Performa-R* [λ'isolante]<br>Graphite EPS Panel | PS (≥ 15%)<br>Post-consumer recycled material | In compliance<br>Type II verification | ICMQ (P287) | no data<br>no data | ---- | Generic [stated] |
| *Sintoray Cover R* [λ'isolante]<br>Graphite EPS Panel with external surface in synto-laminated PS | PS (≥ 15%)<br>Post-consumer recycled material | In compliance<br>Type II verification | ICMQ (P287) | no data<br>no data | ---- | Generic [stated] |
| *Reverso* [λ'isolante]<br>Synto-laminated Graphite PS panel produced with the BioMass Balance method | VRM from renewable sources<br>Organic waste/vegetable oils | Not in compliance<br>Mass balance | TÜV SUD for BioMass Balance | $CO_2$ reduced ≥50%<br>FR saved 100%<br>no data | ---- | Everlasting [stated] |
| *Lape EPS 200 T RE* [Termolan]<br>White EPS panel | PS (≥ 15%)<br>Generic recovered material | In compliance<br>Type II verification | ICMQ (P264) | GER 960 Mj [mc]<br>no data | ---- | >60 years [DoP] |
| *Greypor G600 T RE* [Termolan]<br>Graphite EPS Panel | PS (≥15%)<br>Generic recovered material | In compliance<br>Type II verification | ICMQ (P264) | GER 960 Mj [mc]<br>no data | ---- | nd |
| *Isolpiùgraf Secondavita K8* [Sive]<br>Graphite EPS Panel | PS (25%)<br>Packaging in post-consumer EPS | In compliance<br>Type II verification | $PSV_{mix\ ECO}$<br>ITACA Credits<br>LEED Credits<br>EPD Eumeps EPS | EPD Eumeps values<br>no data | ---- | nd |
| *ReLife 36 Etics* [EPS Italia]<br>White EPS panel | PS (15%)<br>Post-consumer recycled material | In compliance<br>Type II verification | $PSV_{mix\ ECO}$<br>EPD Eumeps EPS | EPD Eumeps values<br>no data | ---- | Unvaried λ [DoP] |
| *Ursa XPS Plus* [Ursa]<br>XPS Panel with wafer surface | PS (45%)<br>Post-consumer recycled material | In compliance<br>Type II verification | ICMQ (P220)<br>EPD Exiba XPS | EPD Exiba values<br>no data | ---- | Generic [stated] |

**Acronyms:** ESD (Environmental Self-Declaration); FR (Fossil Resources); GE (Grey Energy); GER (Gross Energy Requirement); GWP (Global Warming Potential); LCA (Life Cycle Assessment); MSW (Municipal Solid Waste); nd (not declared); Tr GE-CO2 (Return time of Gray Energy and CO2); WF (Water Footprint).

**Notes to the table:** 1. The functional unit for the evaluation of the indicators for the LCA can be the cubic meter or the kilo, as explained in the table in square brackets. 2. Phases from the production of raw materials to the production of the finished and packaged product (A1-A3), distribution to the final customer (A4), end of life of the product including transport (C2), energy recovery (C3) and landfill (C4), any energy credits (D).

Tab. 4. *Sustainable profile of the selected sample.*

We found that the policies adopted to pursue sustainability do not merely address the Minimum Environmental Criteria requirements; they also envisage new as yet unregulated guidelines for the protection of fossil resources, the assurance of non-hazardous emissions, and the recovery of CO2 in virtuous manufacturing processes.

The choice to adopt the minimum percentage of recycled EPS/XPS (mainly deriving from post-consumer packaging or processing scraps/waste), as required by the Minimum Environmental Criteria to qualify for Public Administration green tenders, has not driven the sector to radical renewal. Nevertheless, as demonstrated by initiatives underway, stakeholders are pushing for more incisive innovation in terms of energy efficiency and environmental compliance, which leads the way to the chemical recycling of insulating panels discarded from buildings undergoing envelope restoration, eliminating polluting products or emissions in the manufacturing phase and reducing consumption of non-renewable energy and water resources (down by 10% to date), as well as modifying manufacturing processes to reduce grey energy or optimize thermal performance to achieve timely heat recovery during the management phase.

In any case, compliance with Minimum Environmental Criteria alone does not guarantee the absence of toxicity in the products manufactured with SRMs of arbitrary origin because the obligations envisaged for flame retardants, blowing agents, and lead catalysts refer to production activated starting with VRMs. The restrictions do not apply to the use of non-compliant recycled materials manufactured in the past before the Criteria were introduced [13].

Indeed, the conditions imposed on thermal insulators include the prohibition "to use flame retardants during manufacturing that have been banned by national or EU standards". Although producers are required to specify that they have adopted environmentally friendly flame retardants, also HBCDD (hexabromocyclododecane) should also be eliminated from the recycled materials to respect VRMs criteria. Since 21 August 2015, this substance has been registered in the list of bromine-based persistent organic pollutants banned or subject to restrictions [18], absent in packaging materials but present in insulating panels produced up to that date. For this purpose, the mechanical recycling of EPS/XPS is not sufficient, and therefore, in late 2017, the PolyStyreneLoop Consortium [13] launched a European project (also supported by AIPE) to build a "chemical" regeneration plant in the Netherlands. This plant processes styrene-based insulating materials with CreaSolv technology (developed by the Fraunhofer Institute), the only technology capable of reclaiming extruded or sintered polystyrene. The facility launch was scheduled for the end of 2018 to cope with the expected disposal of a significant number of insulating panels from energy-efficiency renovations.

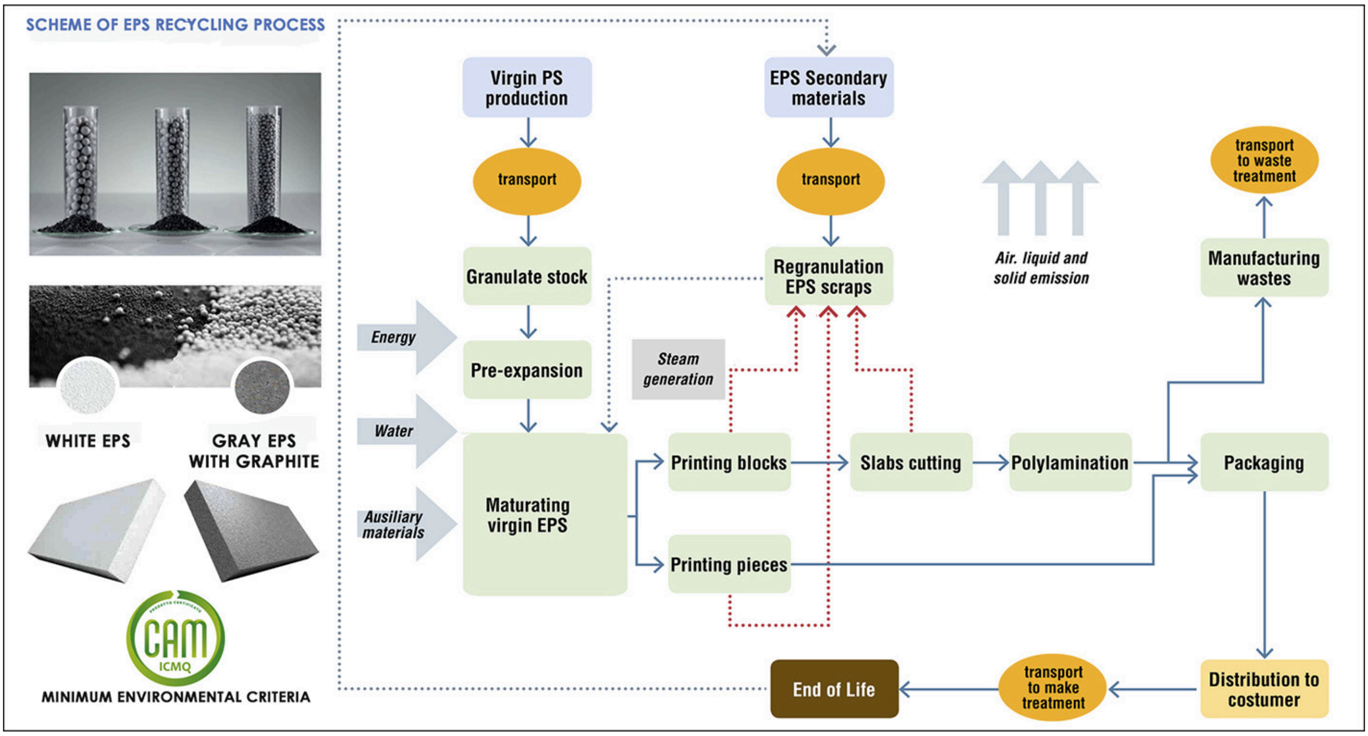


Fig. 1. *The scheme of synthetic thermal insulators production process with recycled material. Elaboration of the authors (ISOLCOMFORT, EPDITALY 2017-2022 - ENVIRONMENTAL PRODUCT DECLARATION (ECO ESPANSO100 and ECO POR G031).*

Environmental policies for EPS and XPS also address expansion gases. With reference to the established prohibition on CFCs and HCFCs, we observed that manufacturers have opted for pentane or, according to an even more virtuous policy, for recycled CO2. This achieves a hundredfold greenhouse effect reduction compared to what was produced by older generation gases emitted into the atmosphere [3].

A second limitation of the current Minimum Environmental Criteria approach is the concept of reducing the consumption of material resources by resorting exclusively to the use of scraps/waste and not contemplating the possibility of producing synthetic products starting from renewable resources to replace fossil ones. This is the case of the BioMass Balance (BMB) process, a BASF patent that produces polystyrene, with or without graphite, reducing CO2 emissions by up to 80% [19]. Despite meeting superior sustainability requirements, this innovation is currently not compliant with Minimum Environmental Criteria; the unfortunate paradoxical consequence is that derivative products cannot be used in Public Administration green tenders.

Therefore, we trust that the following list of objectives still to be pursued will be widely implemented: the standardization of waste recycling technologies for secondary raw materials (Fig. 1), accompanied by "certified" quality certificates (Fig. 2); biannual updating of the Minimum Environmental Criteria to include innovative approaches in line with sustainability principles (Fig. 3); the application of LCA procedures, possibly managed by trade consortia and applied according to data from member companies, obtaining aggregate environmental indicators for each type of thermal insulation, to be renewed at intervals to be defined (according to models currently adopted by AIPE and EUMEMPS for EPS and by EXIBA for XPS).

## 4.3. BIM INFORMATION OBJECTS AND "GREEN" PUBLIC (ALSO PRIVATE) TENDERS

The target goal over the next decade is to update the construction industry to 4.0 dynamics.

It is necessary to metabolize the computerization of the entire process, from production to design, from execution to management, from the end of life to reusing resources and waste [20].

BIM (Building Information Modelling), the foremost protagonist of the IT-based renewal of the construction


Fig. 2. *EPS recycling phases as claimed by the requirements for the Second Life Plastic certification. Elaboration of the authors (SIVE, Second Life 2019).*

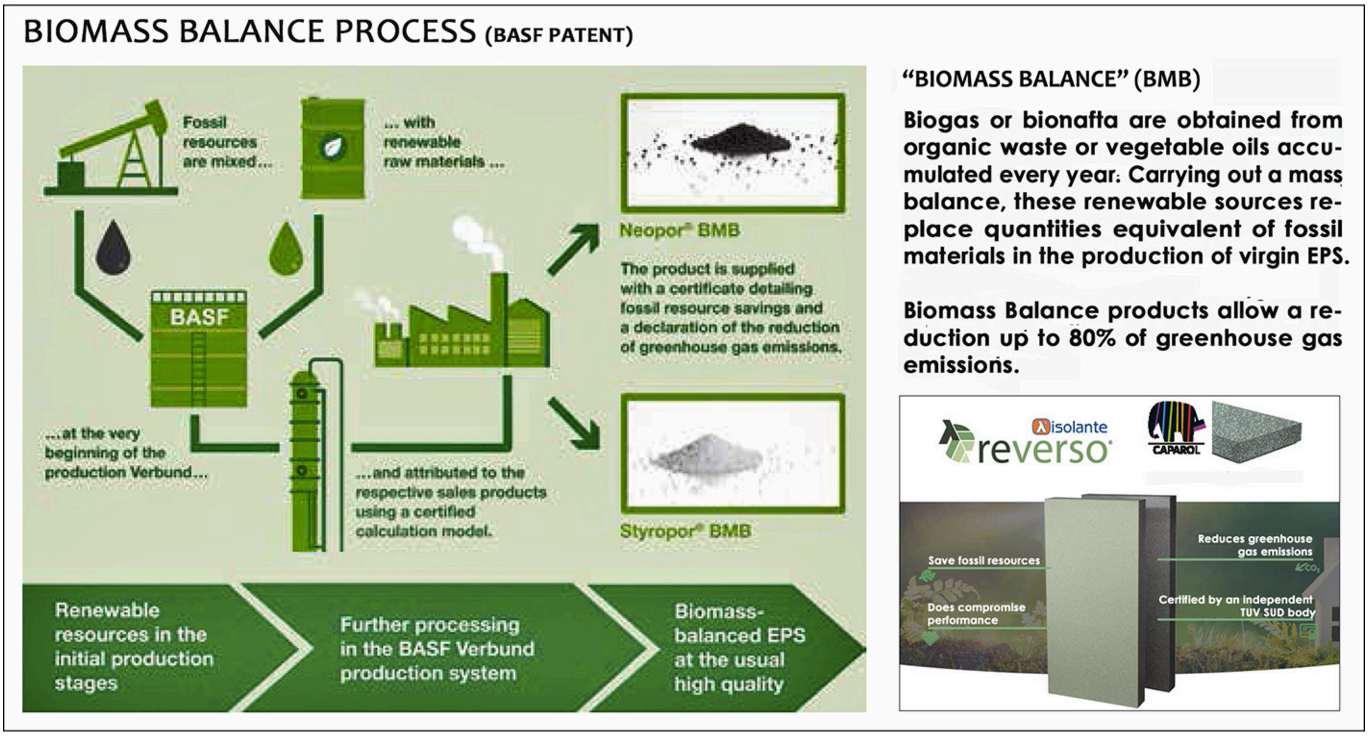


Fig. 3. *BASF's BMB approach for the production of NEOPOR / STYROPOR. Elaboration by the authors (Casaclima 2 degrees, n. 1 / January 2019).*

process, is the tool that has acted as the catalyst for this process. Since 2019, BIM has been a requirement for submitting projects to Public Administration bodies. With contract bid caps destined to decrease over the years as tenders are extended to smaller works as of 2022, BIM is set to accompany the sector towards the radical transformation now underway.

If BIM is imposed alongside code provisions that enforce the application of Minimum Environmental Criteria in GPP construction projects (and now also for private interventions eligible for state incentives), it must be ensured that the adopted methodology conforms with sustainability demands [6, 7].

After verifying the suitability of the performance profile of synthetic thermal insulators supplemented with variable percentages of secondary raw materials, having ascertained the degree of compliance with Minimum Environmental Criteria, and having assessed the environmental strategies undertaken, our third challenge was to investigate relevant market's readiness and the willingness of manufacturers to market BIM information objects for such products. The latter should be designed to add the Minimum Environmental Criteria specifications related to minimum basic and bonus criteria to the descriptive fields.

We undertook this investigation by initially searching through the content provided by the manufacturers and, subsequently, by exploring specific IT platforms where it is generally possible to find BIM objects for project design, thereby extending the libraries of various parametric modeling software programs [21].

Among the manufacturers we examined to select the "sustainable" sample, only a few (Caparol and Ursa) have launched projects to digitize their products to obtain virtual equivalents in which geometric information is associated with performance data. For the remaining manufacturers, failure to develop such BIM modeling is largely motivated by two different reasons, sometimes explicitly stated, otherwise easily inferable. The first is a pending commitment to include the relevant effort in future planning if the market requires it. The second is that such an effort is not deemed necessary since, when defining the characteristics of a stratified envelope in parametric modeling software, a building designer can autonomously and manually enter the properties of the insulating layer, which can be obtained from the technical documentation provided.

Therefore, in terms of BIM libraries, the analyzed category of materials is not sufficiently represented to make the study truly comprehensive; nevertheless, we can already perceive a trend that offers food for thought on the effective relationship between methodology, i.e., parametric modeling software with data content, and green contracts for energy requalification projects that draw on state, public or private funding.

The search for BIM objects for insulation products gave results for two IT tools, Archicad by Graphisoft and Revit by Autodesk. That said, we carried out the verification of the associated indications for Revit, as we found it to be the more popular tool. The small number of objects found reproduce modifiable configurations of "basic walls", i.e., multi-functional packages in which several technical properties have already been configured, either for a single insulating layer (Ursa) or a complete stratigraphy with insulation (Caparol) which may be used when a company also produces other components incorporated in the envelope design (Fig. 4) [22].

It is well known that the major innovation brought about by BIM methodology consists of the possibility of reconnecting a set of parametric data with a virtual entity, through which users can make the model more similar to the real object itself. The aim is not to reduce modeling to a mere three-dimensional perception of the project design but rather to achieve a more effective qualitative and quantitative control of a building or its parts, which is necessary for the design phase, but also during operation and at the end of its life. It would thus be necessary to trace the specific characteristics from the numerical and descriptive data associated with "sustainable" thermal insulators, both to be able to reconstruct their performance profiles and to ascertain, in

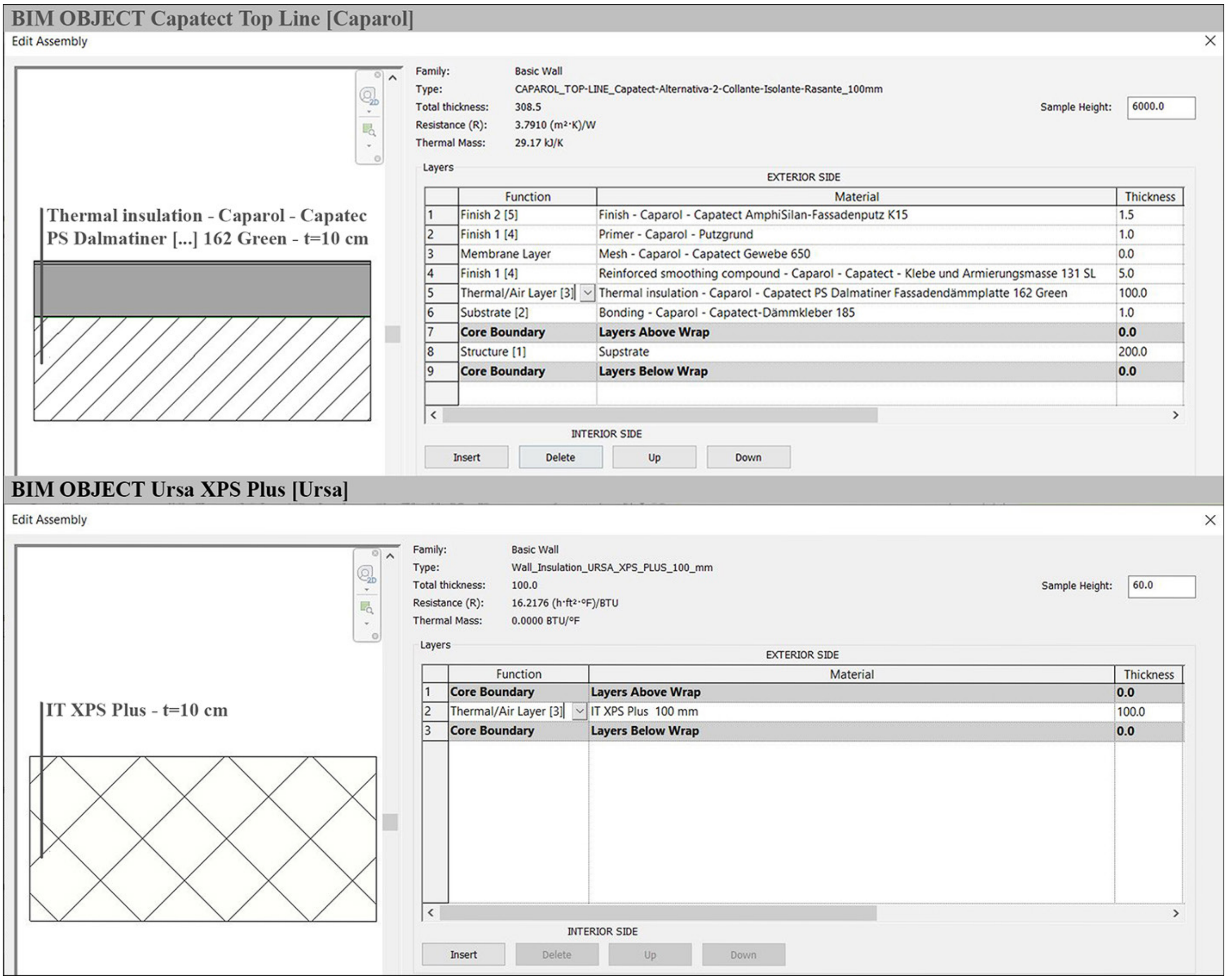


Fig. 4. *BIM objects distributed by companies. Elaboration of the authors (Caparol, Ursa; Source: bimobject.com).*

the case of interventions in public buildings, their compliance with Minimum Environmental Criteria and, in any case, with environmental quality indicators.

Our findings indicate that provided models may be customized in terms of typology, geometry, and dimensions. However, we noted a significant "loss" of information when we compared the insulation materials' "hard-copy" technical datasheets with data that can be deduced from the associated pre-processed BIM objects.

In Revit, the characteristics of the materials used in the design are attributed via a specific function called the "MaterialBrowser". The materials are configured by completing the fields prepared and organized in the five project component tabs labeled: "Identity", "Graphic", "Appearance", "Physical", and "Thermal". Thus, for each material, the program enables users to enter values of predetermined technical properties regarding its physical and thermal behavior, as well as general descriptions [23].

In the case of the products we examined, however, the informative content is not entirely satisfactory because certain parameters which should be indicated, both in relation to the product's reference standards and to advocate design conscientiousness, are absent due to the lack of specific fields and the impossibility of introducing additional ones. Hence, the resulting thermal profile is incomplete and not easily customizable.

Values may be entered for the following indicators: thermal conductivity, specific heat, density, emissivity, permeability, porosity, reflectivity, and electrical resistivity. However, resistance to vapor diffusion along with partial or total water absorption are excluded. Properties that depend on design thickness, such as transmittance and thermal resistance, can be entered or calculated with reference to an entire stratigraphy. However, users cannot detail these properties for individual insulating layers and resistant or infill walls, on which the heat exchange between the inside and outside of an opaque wall depends.

Furthermore, the absence of descriptive parameters for summer behavior (attenuation and dephasing factor, periodic thermal transmittance, and thermal diffusivity), already ascertained when examining the insulation product technical documentation, obviously also applies to the BIM objects that represent the transposition of the same (or part thereof) in a virtual framework.

Having assessed the difficulty of providing an all-encompassing performance profile, we attempted to understand if and how "environmental sustainability" was included in BIM object information fields. Where such information is envisaged, however, it is reduced to the single specification item stated as descriptive information in the project design component sheet labeled "Identity", which was designed for registering purposes and generically refers to the product and relevant material manufacturer. The results of the study, therefore, contradicted expectations that both BIM and material sustainability would become prerequisites for public works in respect of a commitment already undertaken in the context of a distribution of comprehensive information objects. This expectation remains premature due to the limits of applying the methodology to a specific building sector and high expenditure budgets.

However, we believe that in the few cases in which this approach has been taken, the effort has been limited to the simple compilation of predefined fields made available in the software, effectively not availing of a substantial part of product knowledge acquired by the manufacturers and which could be transmitted to designers via BIM objects. We found this mainly applied to the certification of the eco-sustainable profile. Although it is not yet possible to boldly customize materials project component tabs, the obstacle could have been more simply circumvented by detailing the descriptions and inserting a direct link to relevant technical documentation in the "URL" (Uniform Resource Locator) field, which is generally available on manufacturers' websites.

Currently, the only way to associate Minimum Environmental Criteria compliance with a given building model is to "manually" enter data in software via BIM Tools that support BIM Authoring applications [24] for the analysis of specific building behavior, e.g., its thermal behavior [25].

The change of course that we should have started to see in the planning and management of public sector construction with the introduction of BIM methodology, enhanced by the additional incentive of satisfying Minimum Environmental Criteria, is still a long way off…

## 5. CONCLUSIONS: CIRCULAR LOGICS AND DIGITAL PERSPECTIVES FOR THE SYNTHETIC THERMAL INSULATORS

The aim of this study was to verify whether the "circular" reconversion of a category of widely used products considered non-ecological – due to inevitable intrinsic characteristics – was ongoing or promising. This was done by pursuing a multidisciplinary approach based on three lines of investigation, namely performance efficiency, sustainability, and digitalization, which will increasingly characterize the renovation process of the construction sector.

From the performance point of view, the thermo-hygrometric profiles show no differences with the insulating panels obtained only with virgin raw material, probably because the percentage of secondary raw material used is still low and therefore any variations, positive or negative, to the properties of the finished product are not appreciable. A reflection should also be made on the summer behavior of the solutions commercialized for external insulation systems to verify whether the contribution to the stratification of the wall can be positive, negative, or null.

However, even if the sustainable innovation has not yet homogeneously affected the whole production landscape, our analysis has revealed the existence of certain manufacturers whose strategic policies include production plants implementing regenerative cycles with low atmospheric emissions and reduced liquid effluent, waste separation, logistics with low-emission vehicles and continuous environmental product assessments through LCAs. These manufacturers have managed to interweave their evolution on the market with the advancement of environmental sustainability, with a renewed awareness that their endeavor not only adheres to the current environmental and cultural context but is also necessary for a "proper" financial return.

In light of the considerations discussed, the major discriminating element in the choice of thermal insulators cannot be solely identified with the need to certify the reduced use of non-renewable resources by augmenting the percentage of recycled resources, thus complying with the Minimum Environmental Criteria imposed by Public Administration green tenders.

The development of synthetic thermal insulators with a different eco-sustainable profile, such as the Bio-Mass Balance products and the GreyDur line by Termolan LAPE, proves this, with manufacturers engaging in experimentation in the pursuit of a pioneering mission.

However, the regulatory requirements introduced have driven manufacturers to initiate or accelerate – in the case of policies already underway – the green conversion of their production, with investment in research and innovation, independently or as members of business consortia (for example, EPS Italia, AIPE, ANIT, etc.).

In the future, the sustainability of this 'plastics' category might not be oxymoronic and could be compared, on an equal application and performance basis, with that of products whose ecological vocation is more readily understood due to the extractive nature or renewability of the raw materials used.

To achieve this goal, synergistic and strategic work is needed to broaden current outlooks, acting both on a technological and a regulatory level.

The first aspect could include the efforts made by a number of forerunners to publicize the quality of secondary raw materials through a Plastic Second Life certification mark. Also, tentative adherence to the ITACA and LEED energy-environmental quality assessment protocols would count, alongside the first LCA formulations from cradle to gate with options that, while not individual in nature, have been developed for product categories (EUMEMPS for EPS, EXIBA for XPS).

With regard to standards, the countless number of national (UNI), European (UNI EN), and international (UNI EN ISO, EN ISO, ISO) norms is an issue to be addressed; it is truly a challenge to move among them without feeling disoriented by the sensation that fundamental aspects have been left out. A consolidating act, or, in any case, a simplification, would also provide essential support in the interest of sustainability.

Finally, the 5R revolution will have to run its course alongside the innovation that BIM is driving in construction management. The necessary inclusion of environmental policies in design practice and the now inevitable consequences of digitalizing information for construction projects will require that sustainability be considered as an indispensable design factor. As such, it must be clearly highlighted in technical product documentation as well as in the increasingly sought-after BIM objects. For the category of thermal insulation we analyzed, this approach is still in its infancy and requires a greater commitment from manufacturers to experiment with the potential of parametric modeling.

Sustainability, circularity, and computerization: the paradigm spectrum is expanding to optimize production chains in the construction industry.

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