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D4.1 – Detailed design of the EENSULATE envelope system

WP4

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Executive Summary

The Deliverable 4.1 “Detailed design of the EENSULATE envelope system” reports the results achieved within the Work Package 4 and its task 4.1, directed to the design and optimization of Eensulate module for Curtain Wall Façade.

Starting from the main results achieved in the previous WPs (WP1 with preliminary design of Eensulate façade, WP2 with bi-component foam and WP3 with VIG technological solutions achieved), the present deliverable reports the integration of the Eensulate components. The result is the design of a prefabricated solution for Curtain Wall Façade, providing a lightweight solution with high technological components to improve the energy performances of building envelope.

The deliverable reports the methodology adopted, the main questions and challenges faced, showing the general critical points and main achievements.

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Abbreviations and Acronyms

D - Deliverable

VIG – Vacuum Insulated Glass

WP – Work Package

TGU - Triple Glazed Unit

PB - PlasterBoard

1 Introduction

The study and development of high performing innovative technological components represent a key element to meet energy performance standard and direct new improvement to reduce energy consumption in building. The role of building envelope is particular important and Eensulate module has the scope to demonstrate the applicability of Eensulate components in a façade solution to prove their scalability and applicability in a pre-market solution. The utilization of innovative components as the Eensulate foam and Eensulate VIG represents a challenge to meet specific expectations by a façade element. Indeed, in addition to traditional specific performance targets to pursued – energy, acoustic, air-water tightness, resistance to impacts –, façade engineering aspects – reduction of material to be used, cost-effective solution, in line with architectural design –, there are the issues emerged during the VIG and foam design and prototyping. In particular, VIG development and its innovative components request the design of specific solution for Eensulate façade module.

With this purpose, Eensulate module has been developed during the progress of other connected WPs to provide a valuable solution for building envelope under different disciplinary point of views. On the base of the main pilot case of Eensulate module (Dzierzoniow School considered as a reference), the general architectural drawing has been done and the system design has been initially implemented facing step by step the weak points and providing an optimized designed for the EENSULATE façade system. The result is a façade solution that answers to industrial needs for massive use and wide replication in market.

2 Methodology

The present chapter synthetizes the key elements of the methodology used to develop the Eensulate façade system.

1. **Identification of preliminary boundary conditions**:
   a. *Preliminary design solutions* – starting from the WP1 design outputs, the Eensulate module has been implemented with the information and results elaborated in WP2 and in WP3.
   b. *Market benchmark* – identification of components, especially profiles, to be used in Eensulate module. In addition, the identification of the current market benchmark under transmittance performance has been investigated.
   c. *Safety issue* – despite all the necessary solutions have been adopted to guarantee a safety installation of VIG, the behavior of the VIG will need further investigation. For this reason, the Eensulate façade system has not been designed for structural silicon as expected in WP1 activities. The consequence is an improvement of thermal bridge, issue to be faced during the design.
2. **Eensulate module design and optimization**:
   a. *Façade engineering design* – some key elements need to be considered and balanced in façade engineering:
      i. Thermal performances;
      ii. Performances of the façade (UNI EN 13830:2005)
      iii. Acoustic performance;
      iv. Replacement strategy.
   b. *Façade architectural design* – requests emerged by architect and demo partners to balance aesthetical appraisal of the module and homogenize the façade with similar solutions adopted in the dame demo (in particular glazing beads and colors)
3. **Identification of pitfalls:**
   a. *Scalability* – elements emerged as relevant to be faced to supply an industrialized solution;
   b. *Industrialization* –industrial needs for massive use and wide replication.

Following the methodology here presented, the deliverable reports the main achievement and further steps to meet marketability of the Eensulate façade system.

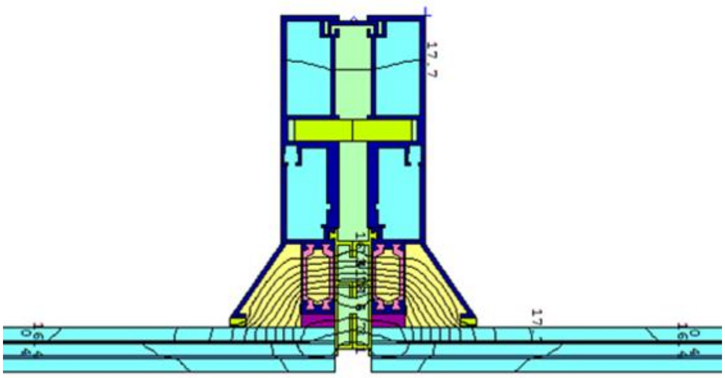

Figure 1: Eensulate facade system: preliminary design. This solution was designed with 15 mm sealant, structural silicon and was used in WP1 to define the transmittance targets.

3 Eensulate façade system design

3.1 Boundary conditions

Differently from standard design process architect-driven, the Eensulate module is a technological driven façade. Indeed, the specific needs of foam and, in particular, of VIG have requested for a continuous improvement of the solution designed to meet specific progress in technological components evolutions emerged by the previous WPs.

In the design phase, the most relevant component to be integrated and implemented in the Eensulate façade system is the VIG. While the foam can be integrated in the system as a traditional insulation guaranteeing higher thermal performances, but requesting to face acoustic issue, the VIG requests specific consideration due to its composition, thermal and aesthetic solution.

For this reason, in addition to the issues emerged during other WPs' activities, the following elements have been considered in the Eensulate façade system design, suggesting also solutions for Eensulate VIG and foam improvement.

- **Eensulate VIG**:
  - *Laminated glass* – lamination is fundamental to guarantee a safety installation of façade and avoid falling risk in case of glass break.
  - *Sealant dimension* – the sealant guarantees the adhesion between the glass panes, but it is a thermal bridge to be considered.
  - *Sealant and getter dimension* – their dimension is an aesthetical issue faced.
  - *Pumping hole position* – its position is an aesthetical issue faced.
- **Eensulate foam**:
  - *Thermal vs acoustic* – foam guarantees very low value for thermal transmittance and the utilization of peer is not expected to affect this results. However, acoustic insulation can have lower performances and other alternative solution need to be adopted.
  - *Foaming of spandrel* – how to introduce the foam in the spandrels is an aspect faced.

All these aspects have been joined with the initially characterization of façade system preliminary assessed in WP1 (D1.3). In particular, the conclusive consideration of WP1 defined a transmittance target for the unit with an Eensulate module dimension of 1.500 x 3500 mm is **0,586 W/m²K for VIG with 15 mm of sealant** (thermal bridge). However, this value referred to an Eensulate module designed with structural silicon. As we mentioned, this choice for safety reason has been discarded with consequence on transmittance achievable. Indeed, the introduction of a glazing bead for VIG restrain causes a thermal bridge in the module that affects the thermal behaviour of the system. A worse transmittance than the one expected is conceivable.

Another consideration during the Eensulate module system design has been introduced: to pursue this thermal transmittance in Dzierżoniów school and guarantee a high performing module, the dimension of reference have been considered the one provided by the initial survey on the school with unit of 1261 x 3640 mm (Figure 2). This choice is more precautionary to pursue the planned target, being a worse thermal scenario than the one previously described.

In line with these preliminary considerations, the Eensulate façade system has been designed.

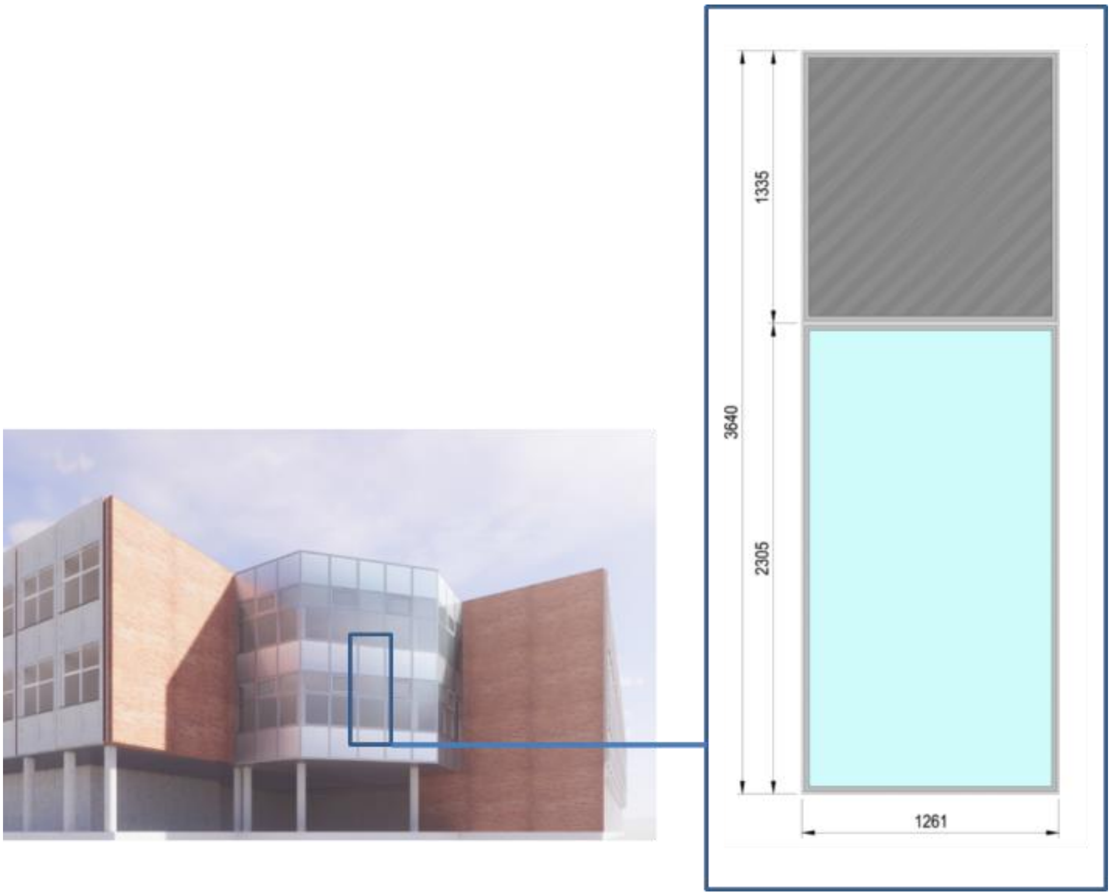

Figure 2: Eensulate module: the reference dimension 1261 x 3640 is based on the first survey conducted on Dzierżoniów School.

3.2 From preliminary design to optimization

3.2.1 Eensulate facade system: 1st solution.

The 1st solution of Eensulate module has been designed taking into consideration the utilization of on market profiles and VIG's sealant of 15 mm. Since the very early phase, the thermal bridge cause by the sealant and its meaningful dimension has been identified as a critical point. For this reason, in the profile has been introduced an insulating material (preformed element to be inserted in the profile) to purse the Eensulate module target expected to be achieved.

The thermal analysis (Figure 4) shows has the well-known pitfall of the thermal bridge is a critical point, which needs for a further study to decrease its incidence on the façade system.

The results achieved by the profile does not allow to achieve the target transmittance with a value of 0,79 W/m^{2}K.

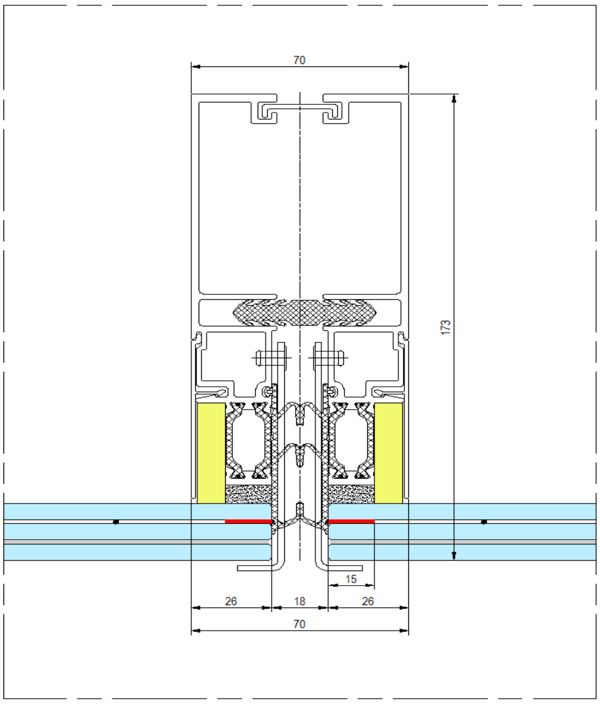

Figure 3: Eensulate facade system: 1st solution. The Eensulate module is designed with commercial available profiles.

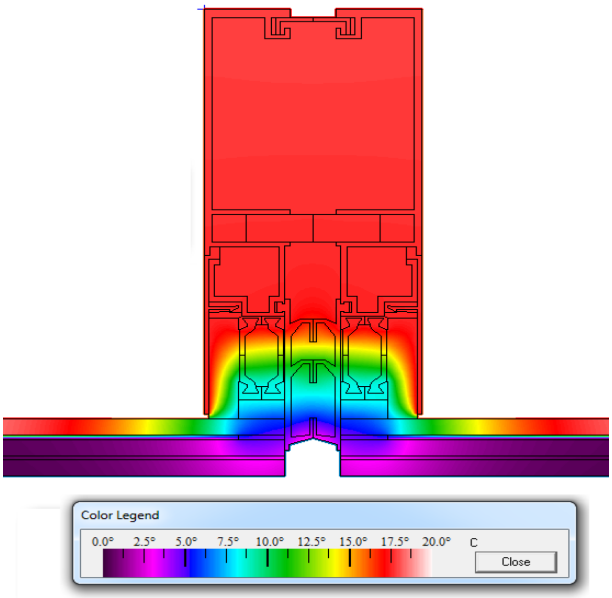

Figure 4: Eensulate facade system: 1st solution thermal assessment. The thermal bridge due to sealant identifies critical points of the system.

Table 1: Eensulate facade system: 1st solution. Key points of the solution.

Solutions adopted	Issues emerged	Transmittance achieved
Sealant 15mm Insulation in profile (marked in yellow)	Thermal bridge	0,79 W/m^{2}K

3.2.2 Eensulate facade system: 2nd solution

Starting from the 1st of the Eensulate module design and thermal bridge issue, the 2nd solution design a profile with a cover-cap to reduce the thermal bridge caused by 15 mm sealant positioning.

The solution designed demonstrates its effectiveness. Indeed, the overall transmittance of the Eensulate module achieves 0,58 W/m^{2}K.

However, this design demands for further improvement due to aesthetical reason. With this purpose, a further design implementation is needed.

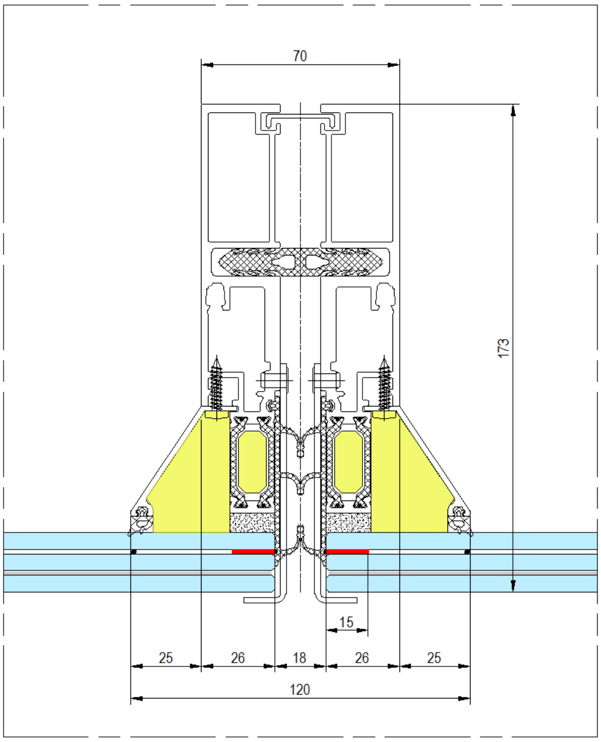

Figure 5: Eensulate facade system: 2nd solution. The Eensulate module is designed with a new profile to reduce thermal bridge.

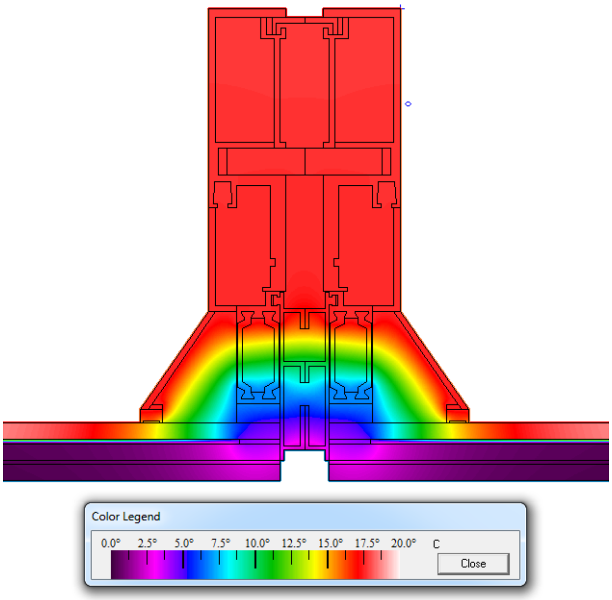

Figure 6: Eensulate facade system: 2nd solution. The thermal bridge of the 1st solution is reduced, but an aesthetical issue emerges.

Table 2: Eensulate facade system: 2nd solution. Key points of the solution.

Solutions adopted	Issues emerged	Transmittance achieved
Profile design for thermal reason	Profile design for aesthetic issue	0,58 W/m^{2}K

3.2.3 Eensulate facade system: 3rd solution

The 2nd design solution and need to aesthetical improvement have introduced a new curved cover-cap to connect VIG surface and profile. Despite this solution provides a better aesthetic result, there is a worsening of transmittance achieved by Eensulate module with 0,62 W/m^{2}K.

Despite this value could be considered not completely acceptable with 15 mm sealant (target was 0,586 W/m^{2}K) and needed for further development, another issue emerged during VIG design in WP3. Indeed, in the development of VIG in WP3, a 25 mm sealant was indicated, with a consequent increase of thermal bridge. This change answered for further updates to have a high performing energy system and the expected transmittance target is **0,641 W/m^{2}K for VIG with 25 mm of sealant**.

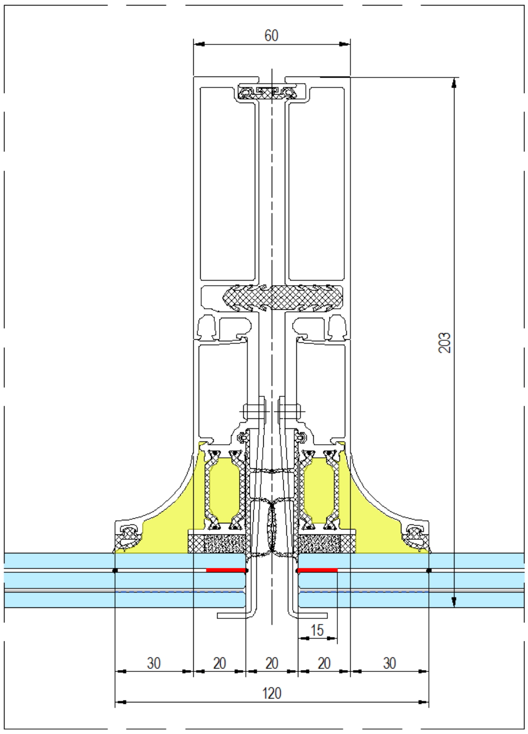

Figure 7: Eensulate facade system: 3rd solution. The Eensulate module is designed with a new curved cover-cap.

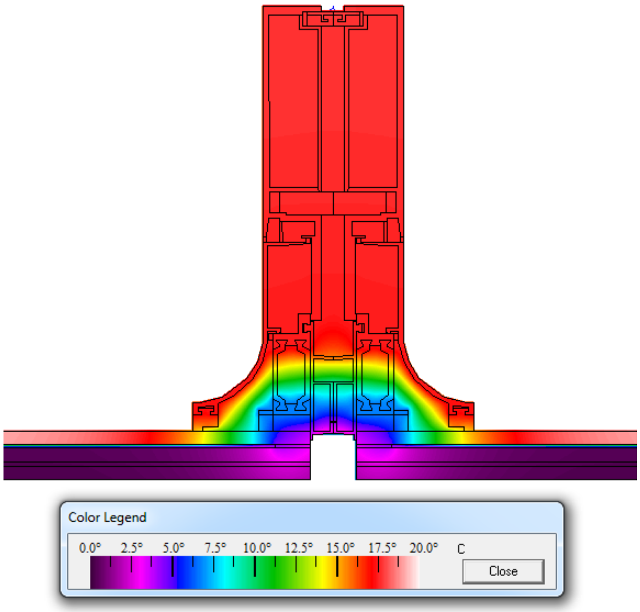

Figure 8: Eensulate facade system: 3rd solution thermal assessment. The profile adopted uses a curved profile to meet aesthetical appraisal of the module.

Table 3: Eensulate facade system: 3rd solution. Key points of the solution.

Solutions adopted	Issues emerged	Transmittance achieved
Curved profile for aesthetic and thermal reasons	Sealant to 25 mm	0,62 W/m^{2}K

3.2.4 Eensulate façade system optimization

3.2.4.1 Material aspect for profiles

The different issues emerged and the willingness to keep improving the thermal transmittance of the overall Eensulate module, direct the design improvement of Eensulate façade system. The focus has been to identify a node solution (profile-VIG) able to contain the thermal loss through the opportunity to use pultruded material. Some scenarios of pultruded solutions have been thermally analysed:

- **Eensulate façade system – pultruded 1** – 25 mm sealant, pultruded profile, aluminum glazing bead;
- **Eensulate façade system – pultruded 2** – 25 mm sealant, pultruded profile, pultruded glazing bead;

Among the solutions evaluated, the only adoptable would be the *Eensulate façade system – pultruded 2* the one with pultruded glass bead.

Despite this solution seemed valuable from a thermal point of view, the utilization of pultruded would have caused some critical issues. Indeed, this material, despite the important thermal property it has, it is not considered a market ready product for façade market because of the cost and time of procurement. These reasons have addressed the final Eensulate façade system solution another step of investigation using both for aluminium frame as well as for polyamide components, new profiles not available on the market.

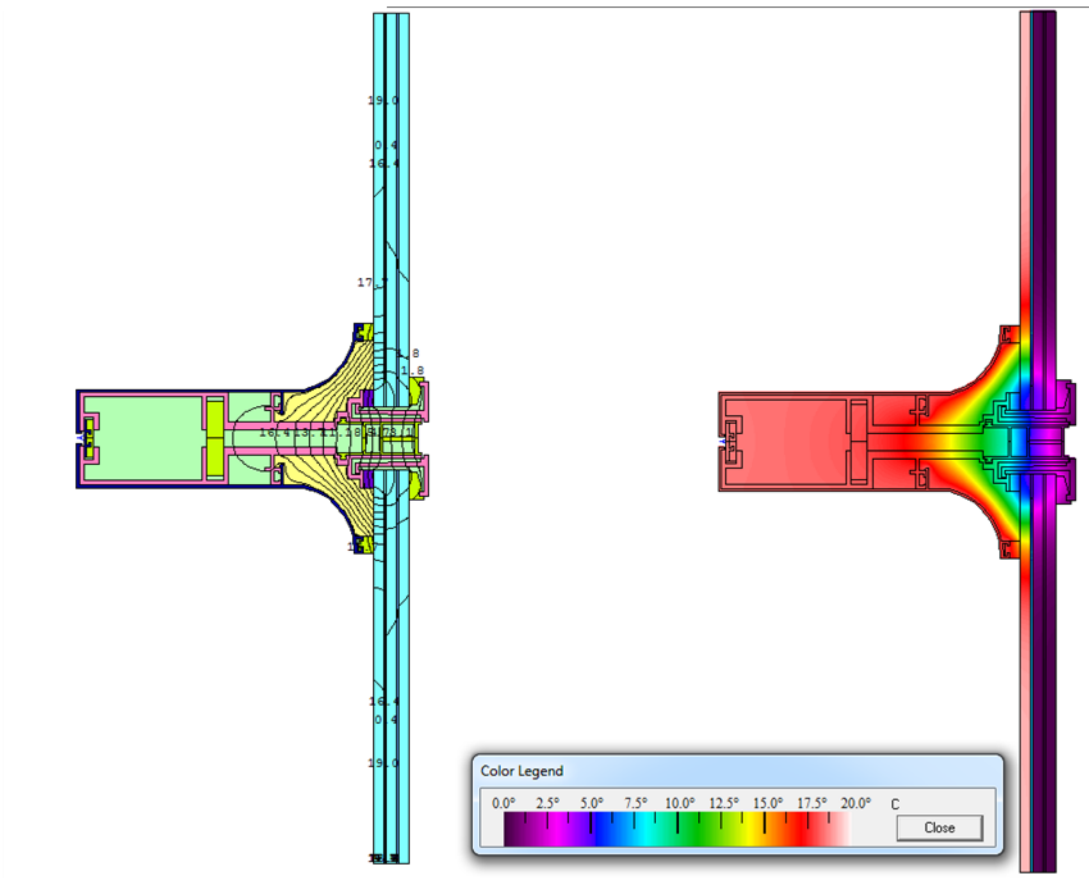

Figure 9: Eensulate facade system with pultruded profile solution.

3.2.4.2 Architectural and demo requirements

In addition to the decision to design and manufacture new profiles, the final design has been also addressed due to architectural reasons (Figure 10: architectural issues emerged during the system design). Even if Eensulate façade system di designed dependent on the Eensulate technologies, the relationship between engineering and architectural issue guarantee an improvement able to be market responsive. For this reason, many issues have been faced: profile shapes, cover-cap shapes, glazing bead dimension and shapes, colours to be used. All these architectural observations have been shared among the partners involved in this process (Focchi and Unstudio) and evaluated for their applicability. The result achieved by Eensulate façade system is a synthesis of the aspects adopted and the ones discarded.

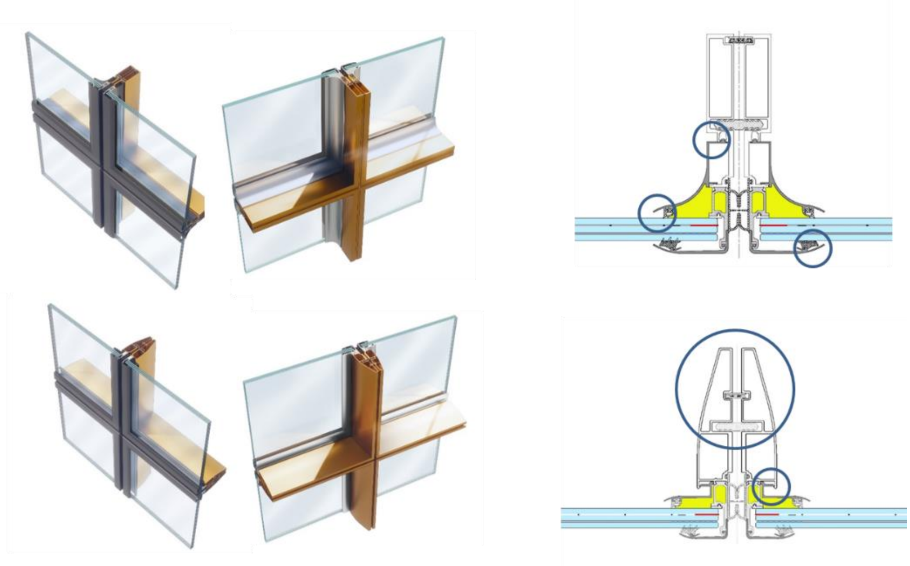

Figure 10: architectural issues emerged during the system design. Among the architectural aspects emerged, some of them have been faced and adopted, while other have been dismissed for thermal and manufacturing reasons.

Figure 11: Dzierżoniów School colour study with RAL 4001. Exterior view.

Figure 12: Dzierżoniów School: colour study with RAL 4001. Interior view.

3.2.4.3 Market benchmark and replacement strategy

Another issue considered is the risk of failure of VIG. Indeed, the VIG is an innovative product of research and in this moment, its behaviour is unknown; for this reason, it appears necessary to provide a replacement strategy for demo buildings in case of failure of VIG using the most similar performing solution in glass sector that is the Triple Glazed Unit (TGU). This specific strategy to use TGU is also valuable because it is the current market benchmark for VIG, offering the opportunity to compare the VIG performance with TGU, which is the direct competitor for thermal performance. With some minor on-site intervention (cutting or replacement of the internal cover-cap cup), the Eensulate system should be adaptable for TGU installation in case of replacement.

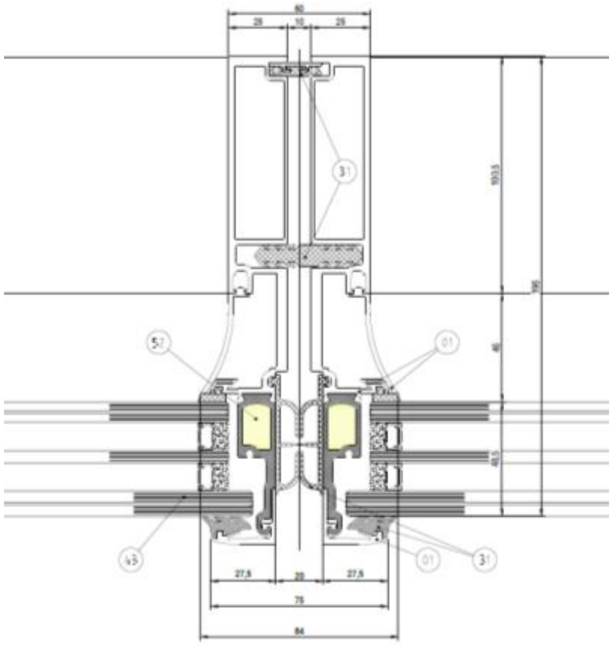

Figure 13: Eensulate module system design with a TGU for replacement strategy.

3.2.4.4 Eensulate facade system: design solution due to foam performances

Final considerations emerge by Eensulate foam application in the Eensulate façade system. The foam is an insulating material with a low conductivity (0,24 W/m^{2}K) good for thermal reason, but being an open cells and rigid insulation, acoustic property is poor considering other insulating material. Within the Eensulate Project, an acoustic insulation of 52 dB is planned and during WP2 some investigation have been conducted on foam acoustic capacity to identify the most valuable composition to fill the Eensulate module spandrel. Considering the mineral wool as benchmark commonly used in façade solution, different foam formulas have been tested. In addition, a test with the introduction of a plasterboard (Figure 14) in the spandrel has been conducted exploiting the alternation of materials to achieve better acoustic performance.

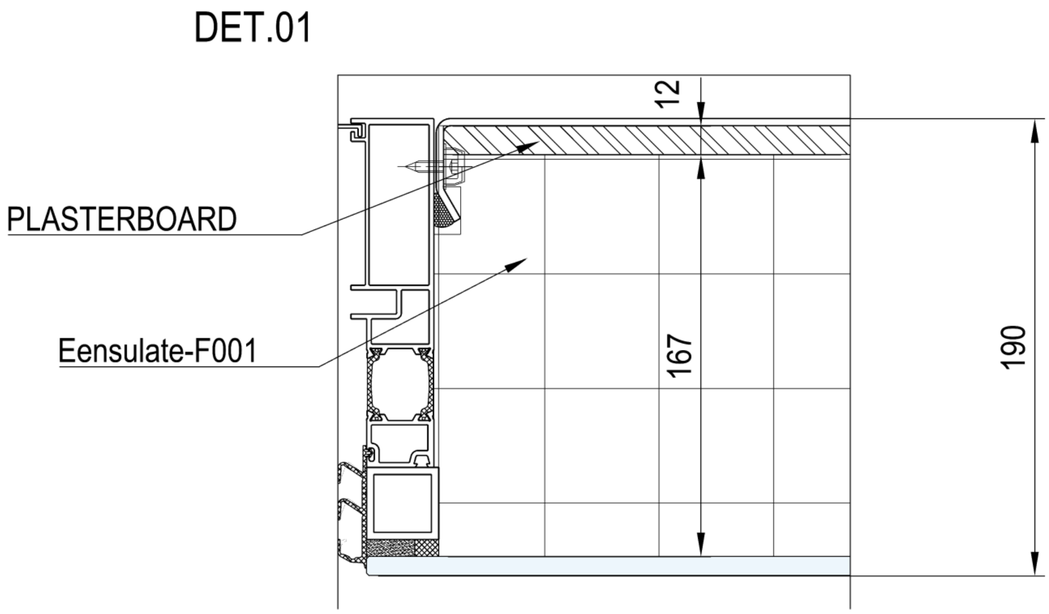

Figure 14: Eensulate foam and plaster board. Solution designed and tested in comparative activities in WP2. Note: the profile used is not the Eensulate profile, not available when the tests have been conducted.

Table 4: Eensulate facade system: acoustic and thermal data.

Sample name	Description	λ [W/m*K]	Acoustic insulation (dB)
MW	Mineral Wool	0,034	49 dB
Foam 00	EE 27.3.4 new & black	0,024	40 dB
Foam 01	EE 27.3.4 new & new poliolpolieterol & LDH	0,022	43 dB
Foam 02	EE 27.3.4 new & orange	0,025	44 dB
Foam 01 + PB	EE 27.3.4 new & new poliolpolieterol & LDH with 12,5 mm of plaster board	0,023 (calculated)	47 dB

By the analysis of the results achieved, the most promising solution to be adopted in Eensulate façade spandrel is the "*Foam 01 + PB*". The introduction of a plasterboard allows to increase the acoustic insulation of the spandrel not significantly affecting the final transmittance of the system.

3.3 Eensulate facade system: Final design

The present chapter presents the final design of the Eensulate façade system. With all the information collecting all the intermediate investigations and analysis conducted, the Eensulate module integrates Eensulate components (foam and VIG) in a solution able to face the major key points emerged. In particular, focusing on energy performance, the overall transmittance is **U_{module} = 0,64 W/m²K**, in line with expected target assessed in WP1 even if more restrictive characteristics have been considered (unit dimension, glazing beads).

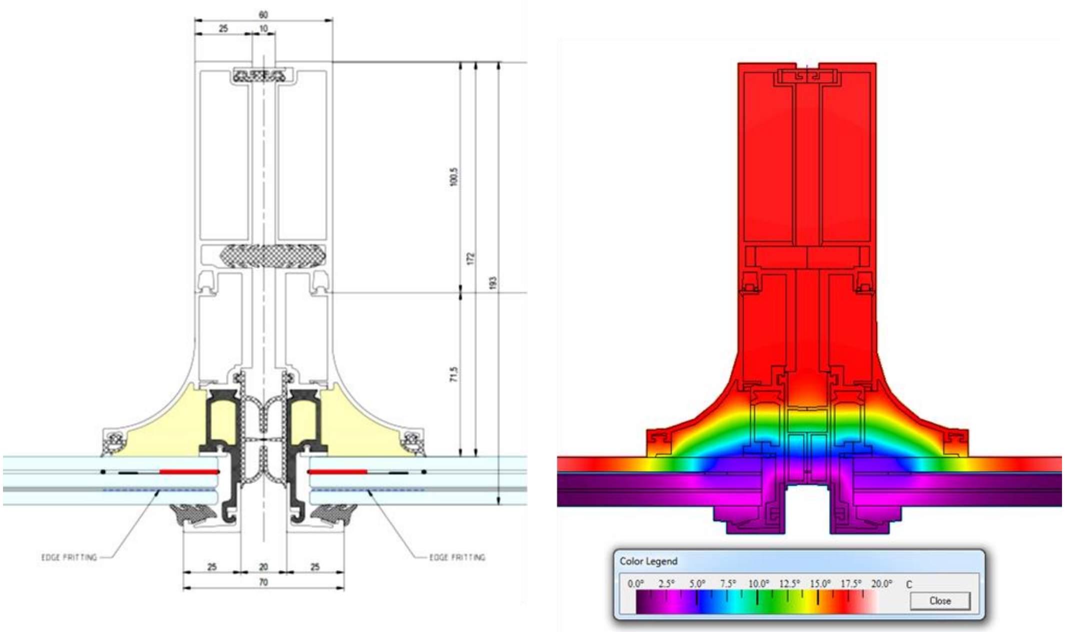

Figure 15: Eensulate module system design for the vision part.

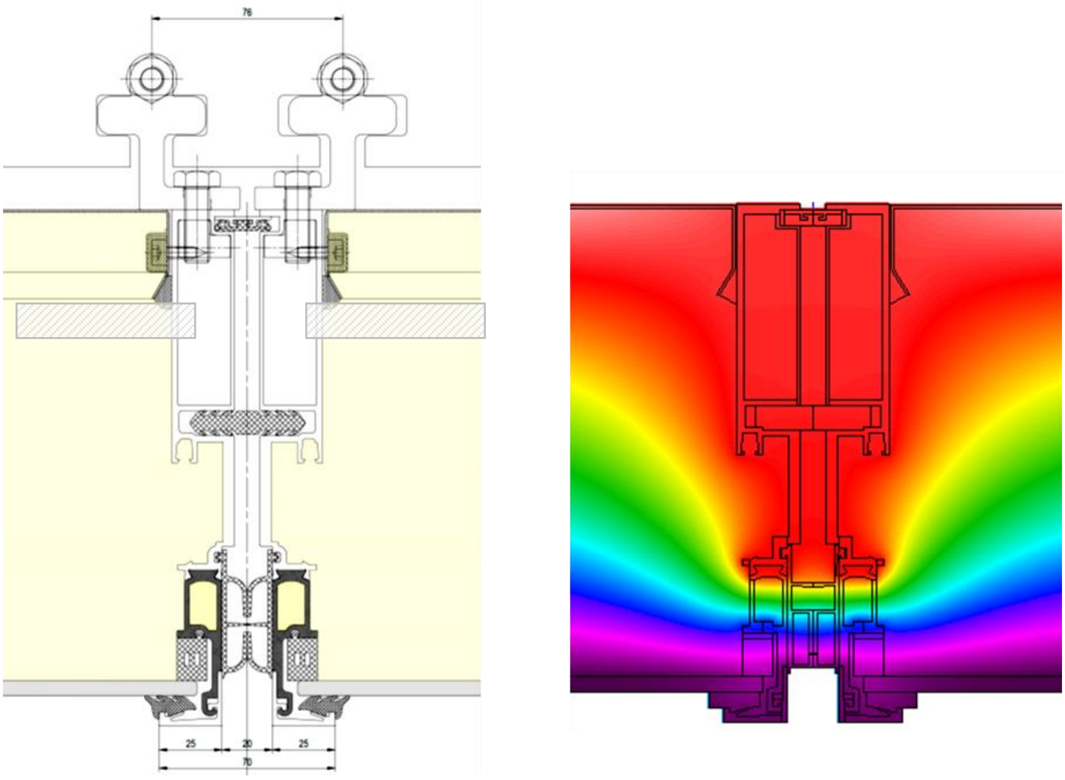

Figure 16: Eensulate module system design for the spandrel part.

With the calculation and the improvement due to manufacturing issue (dies for profile, gaskets), the design has been implemented for all the nodes and conjunctions with reference of the typical unit for Dzierżoniów School where the Eensulate module will be installed including intermediate transom and opening.

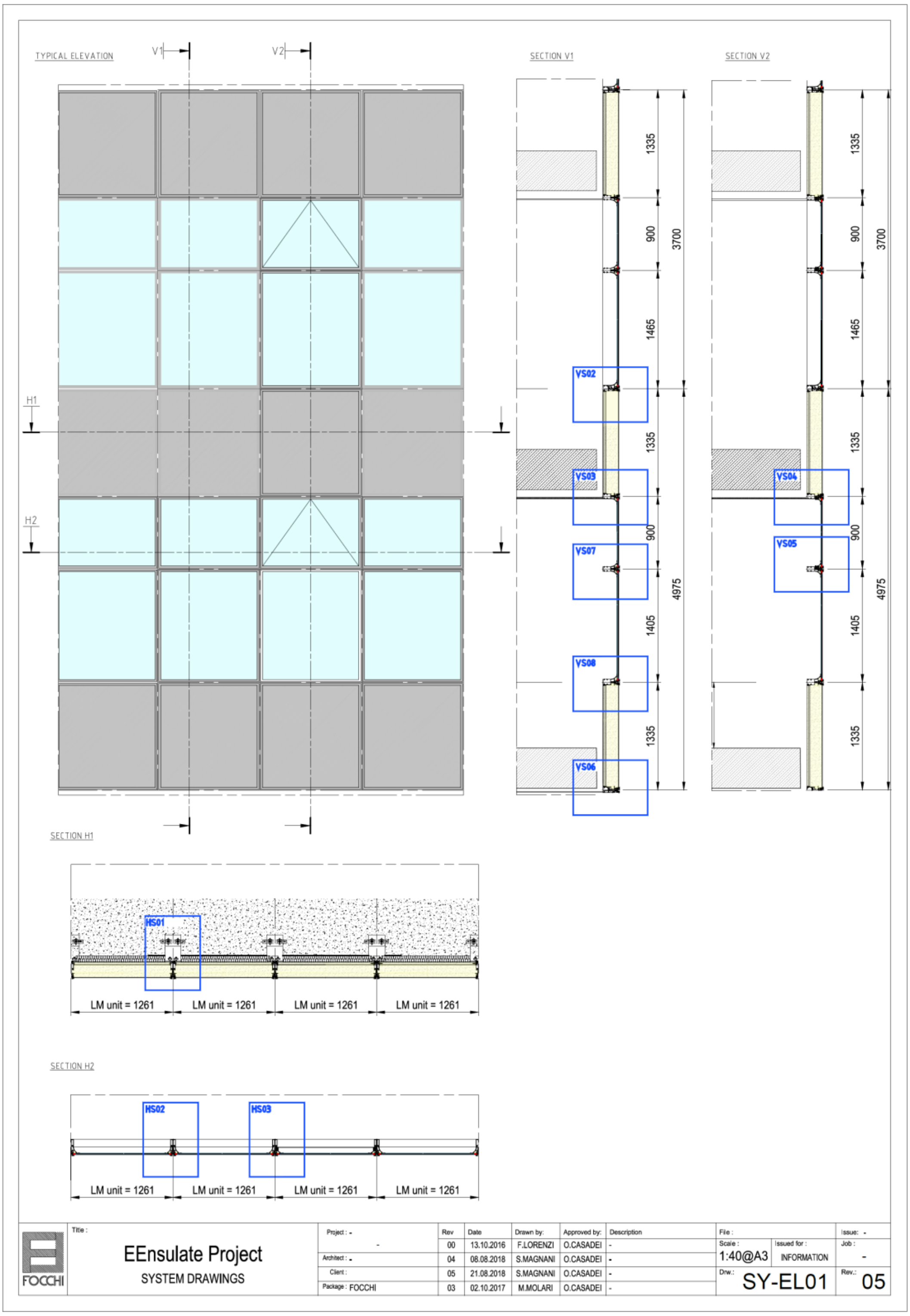

Figure 17: Eensulate module system design. System design and nodes developed.

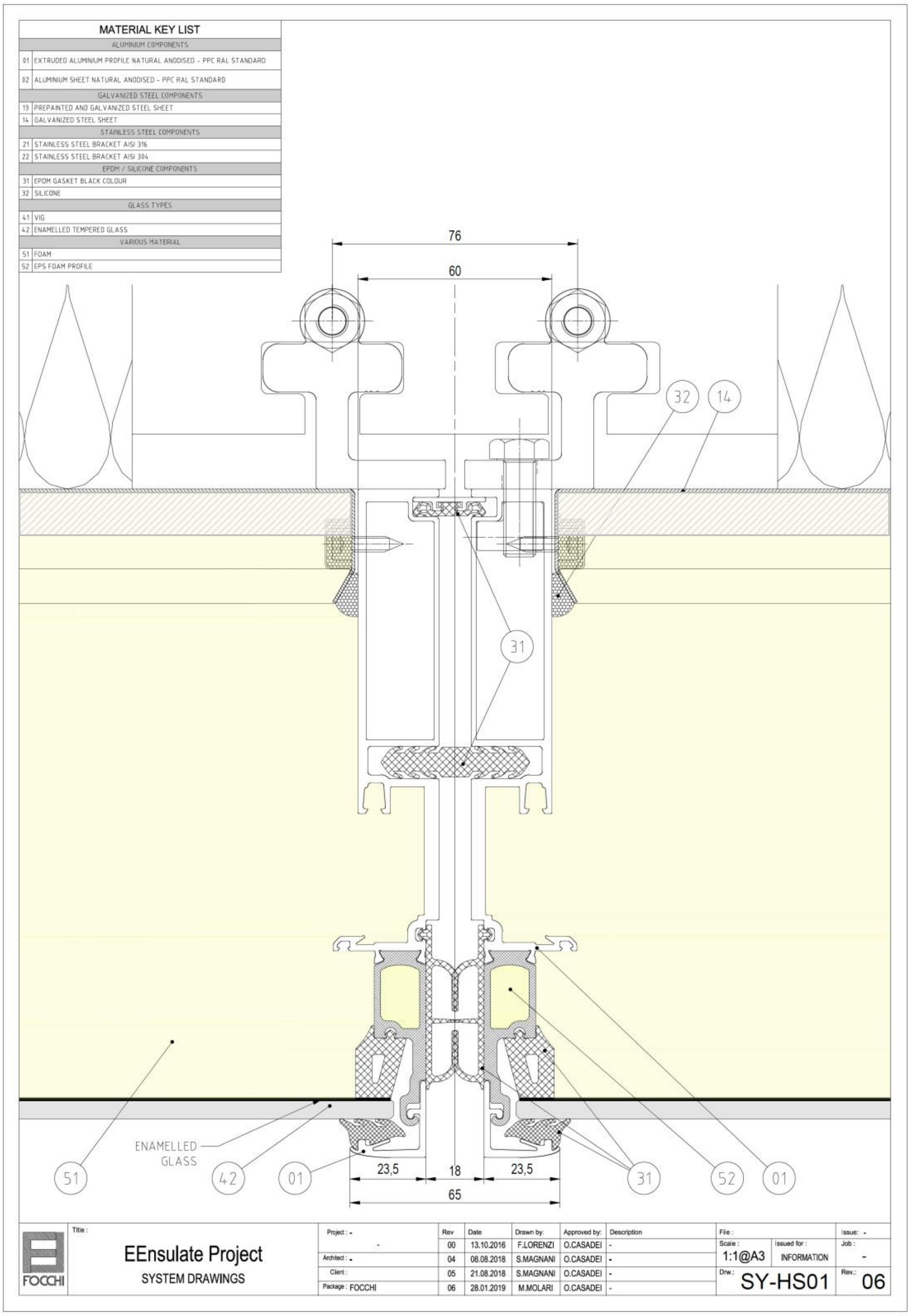

Figure 18: Eensulate module system design: spandrel-spandrel.

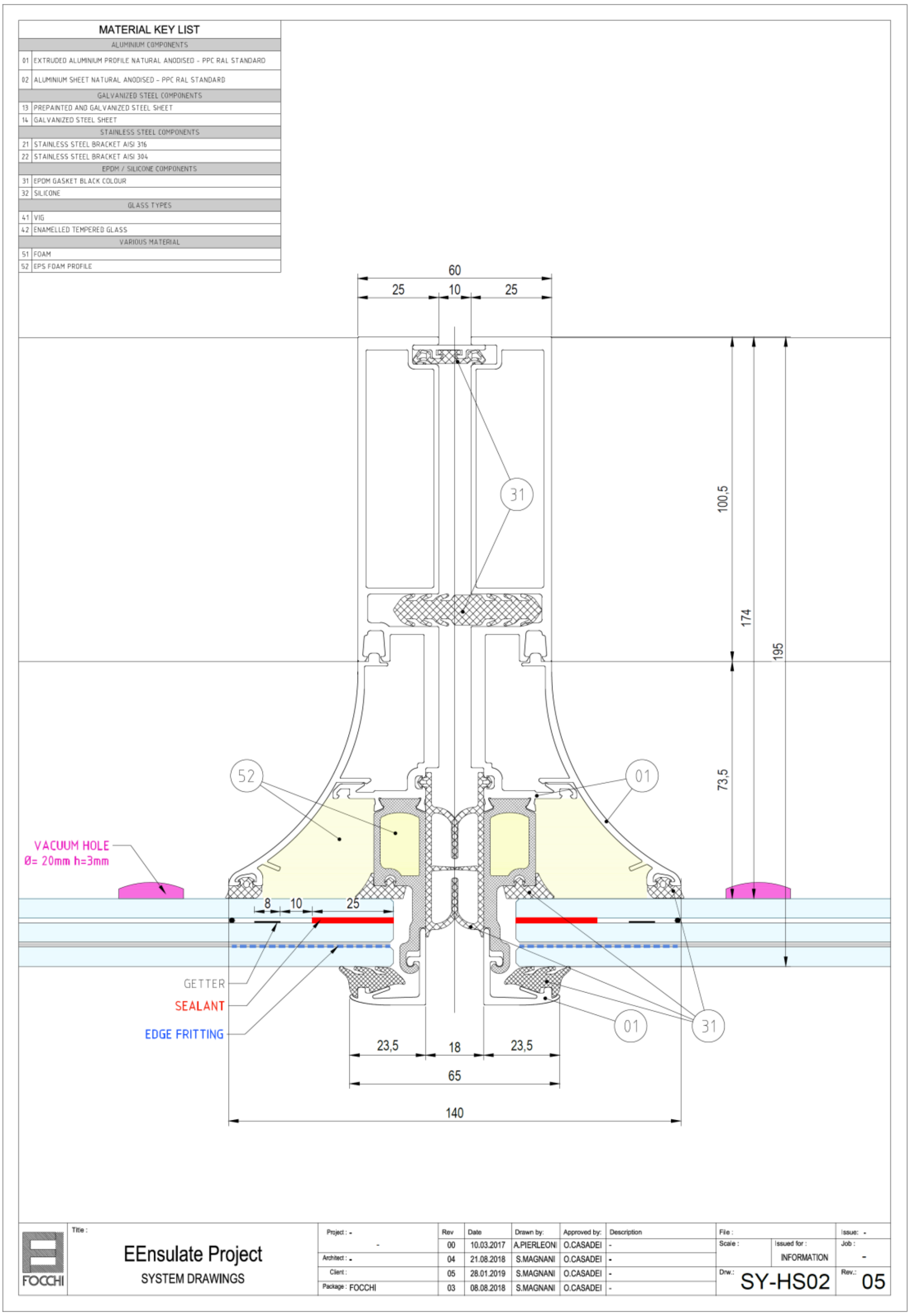

Figure 19: Eensulate module system design: vision-vision.

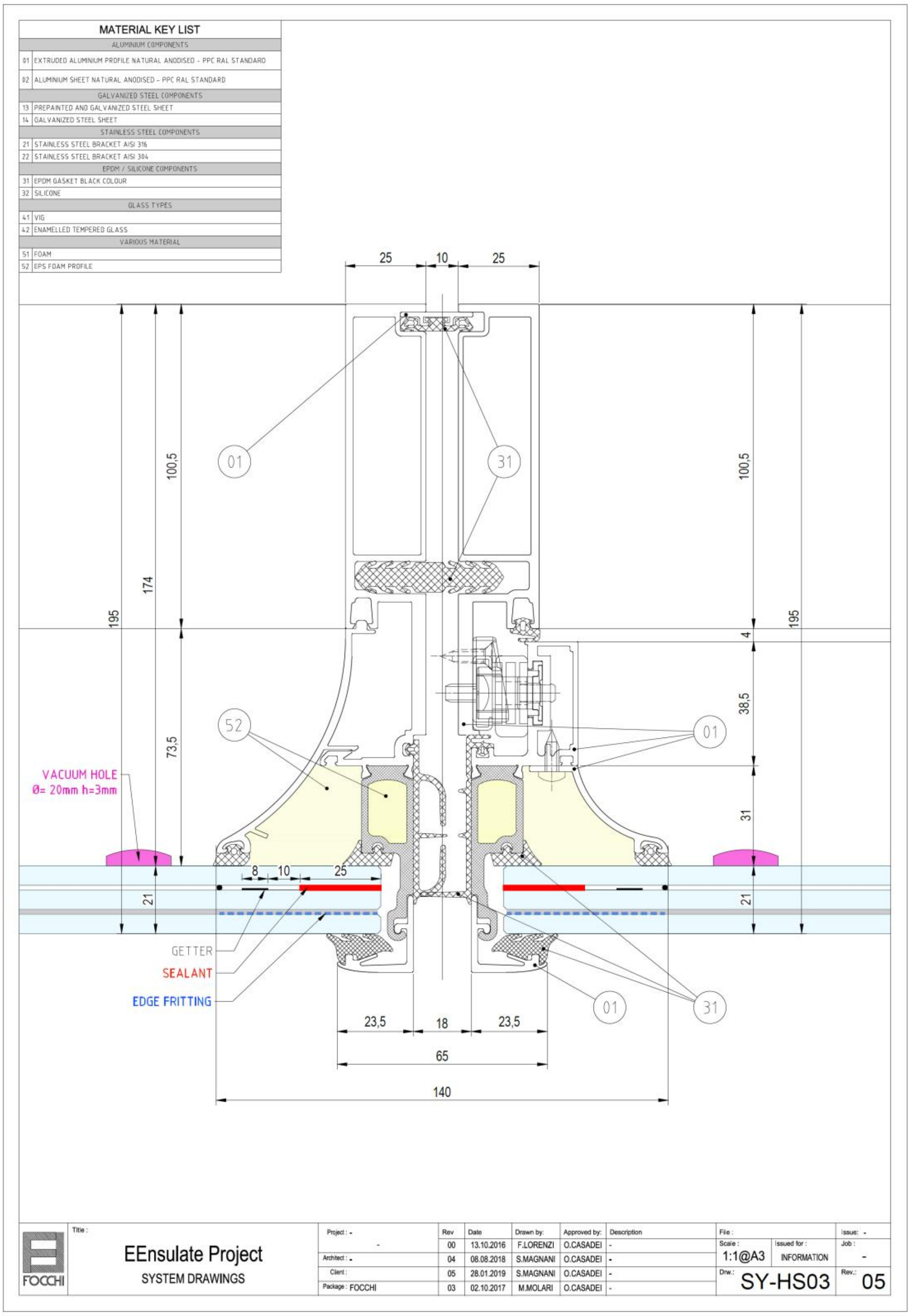

Figure 20: Eensulate module system design: vision-opening.

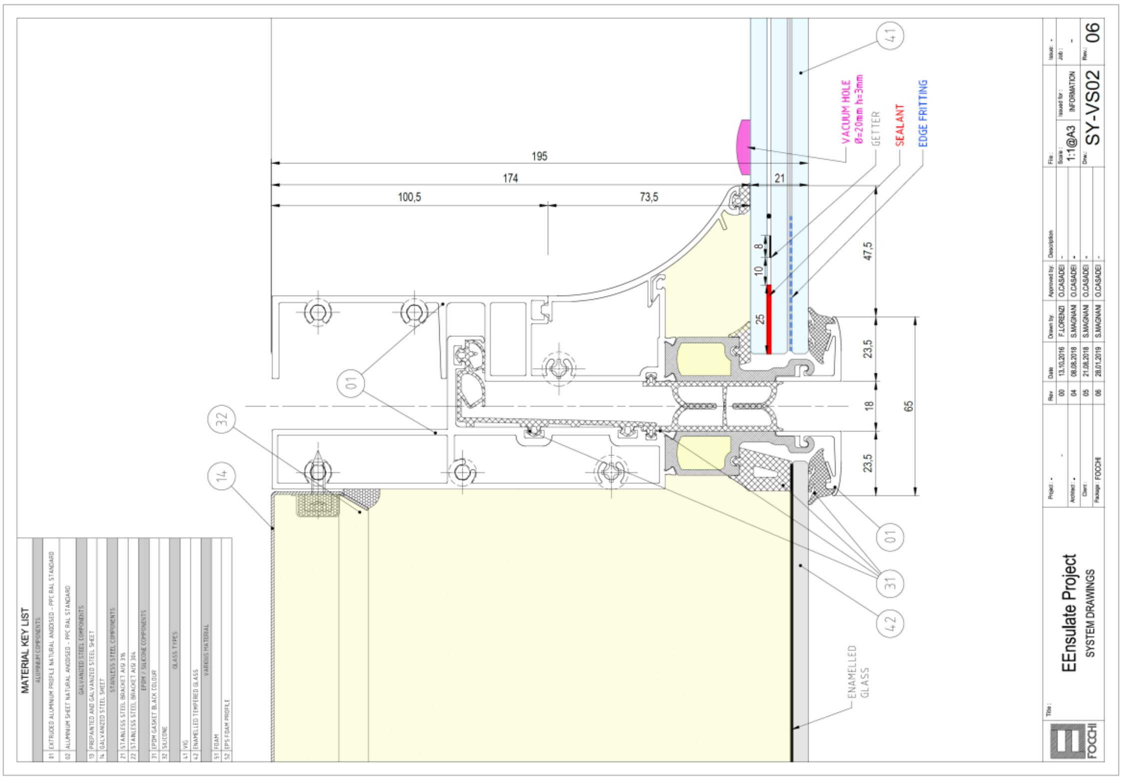

Figure 21: Eensulate module system design: stack joint in spandrel-vision.

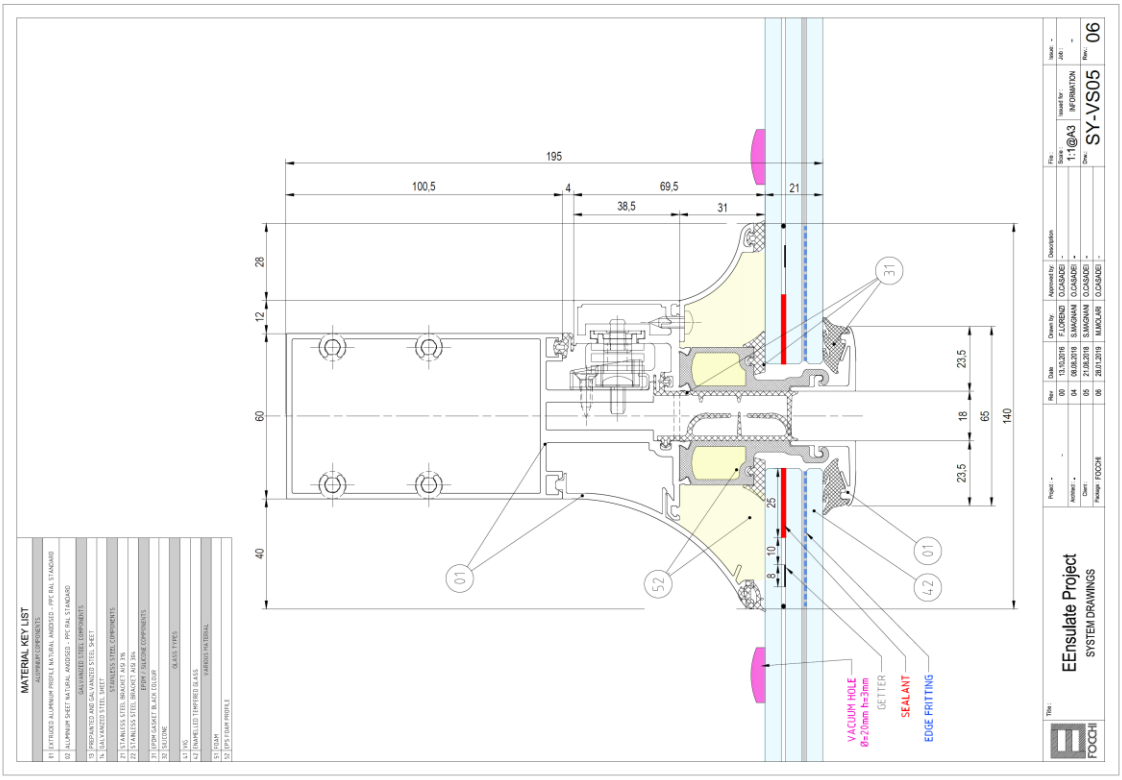

Figure 22: Eensulate module system design: vision-opening.

Each node has been analysed specifically defining the transmittance for each node. The results are in line with the performances defined during the previous phases.

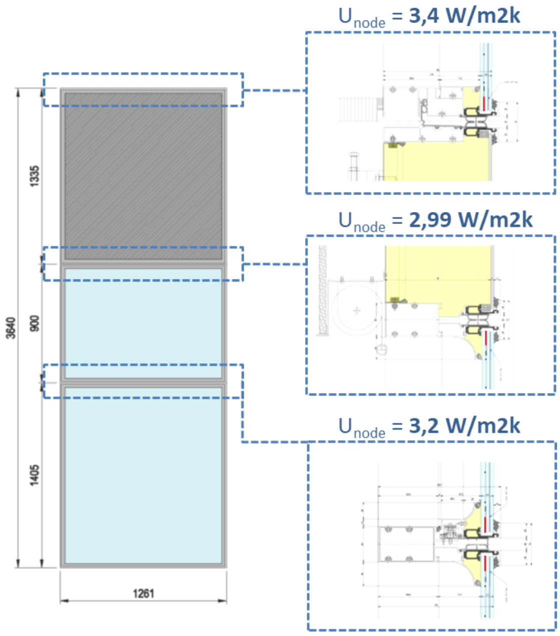

Figure 23: design of the key nodes of the Eensulate modules

3.3.1 Eensulate facade system: VIG specifications

An additional item, it is the one of VIG. In the scale up process of the VIG prototyped in WP3, also aesthetic consideration should be included. The Figure 24 shows the VIG sheet with specific aspects of the scale up face and for an integration in Eensulate module and in the demo building of reference. In particular, the following additional elements have been included:

- **VIG lamination** – the external glass panes are laminated to avoid falling risk in case of VIG break meeting the safety specification of public building;
- **Fritting and bright glass** – sealant and getter design a frame all around the VIG of 43 mm total (sealant 25 mm, space between sealant-getter 10 mm, getter 8 mm) that can have consequences on aesthetic of the glass. For this reason, two solutions have been adopted to minimize the visual effect of this frame: a gradient fritting to hide partially sealant and getter and a bright glass to increase the reflectance of the surface and, consequently reduce the visibility of the sealant and getter.

These VIG specifications are the reference for the glass manufacturer procurement.

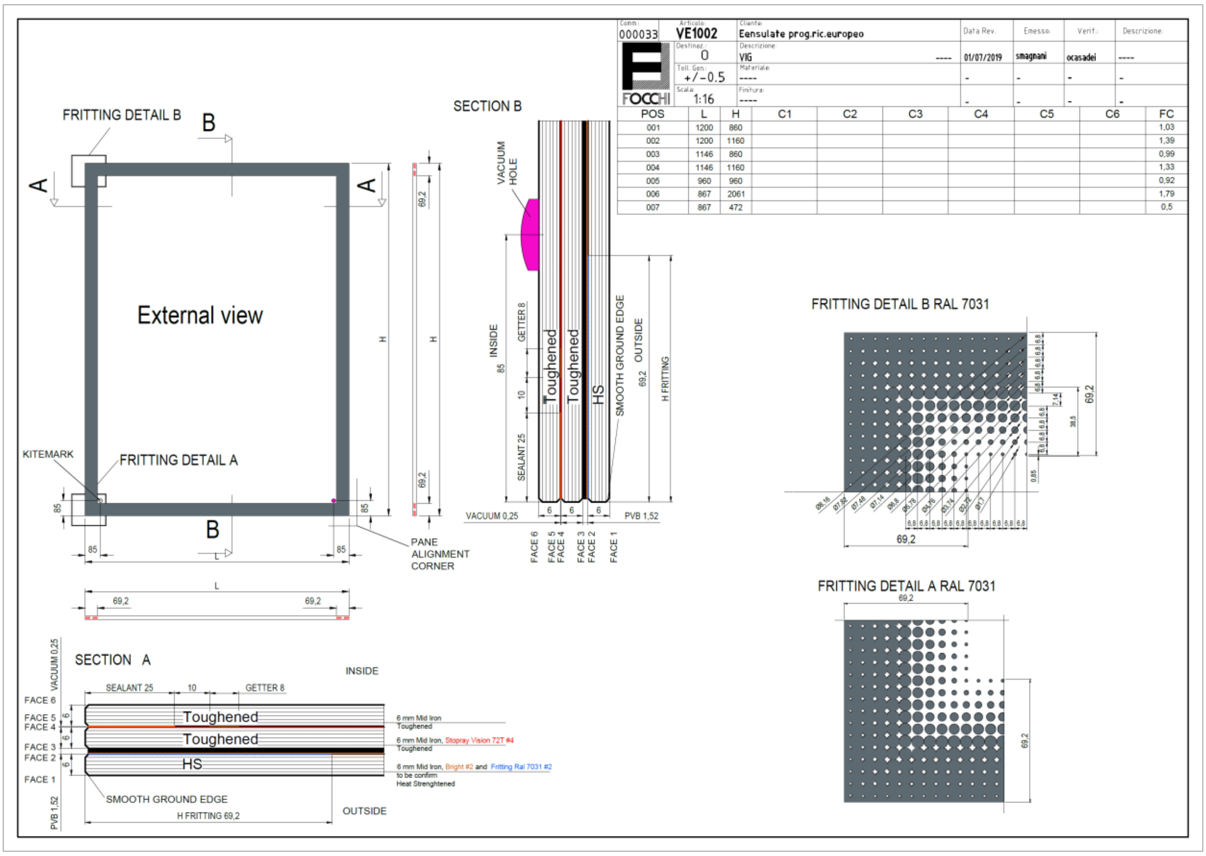

Figure 24: VIG sheet.

4 Conclusions

The results achieved in the Eensulate system design demonstrate how Eensulate components (foam and VIG) can play an important role in the definition of a high-energy standard in building envelope. Indeed, their integration in façade solution has demonstrated to be possible with significant step forward in façade industry. The main achievement of the Eensulate system design are:

- **Integration of innovative Eensulate components** – both Eensulate foam as well as Eensulate VIG can be integrated in a façade solution as the one described in the report;
- **High energy efficiency of Eensulate module**– the overall transmittance of the Eensulate module (1261 x 3640 mm) is 0,64 W/m^{2}K, a significant step in relation to the market benchmark;
- **New profiles definition** – to integrate properly the VIG, new aluminum profiles with internal insulation and a new polyamide profile for thermal break have been identified, providing further solutions for the market;
- **Valuable architectural aesthetic** – the final aesthetic of the Eensulate module respects the architectural target for Curtain Wall façade.

Despite the relevant achievements, there are some open issues to be faced in the next steps in relation to façade development within the project:

- **Detail design for demo building** – a specific design for demos should be conducted to solve some points and provide a full solution (base profile, coping, interface with existing wall, corners).
- **Spandrel foaming** – not a design issue, but a process issue. The application of foam has demonstrated during WP2 to be quite challenging for unit because of temperature and speed of foaming;
- **Tests** – specific test will be conducted to validate the façade with UNI EN 13830:2005, acoustic insulation (target is expected to be 52 dB) and fire test in furnace (in comparison with a benchmark solution).

In addition, some further developments are suggested as output of this system design to keep improving the Eensulate components beyond the project:

- ***Sealant dimension*** – the sealant is a relevant thermal bridge and its dimension is a challenging topic. Identify if the sealant dimension can be reduced is relevant to improve furtherly the transmittance of the façade with impact on architectural issue binding in this moment (fritting and bright in VIG or curved cover-cap in profile).
- ***Foam acoustic performance*** – the acoustic issue is relevant for foam and only the introduction of plasterboard. In hypothetical improvement of foam property, acoustic represent a challenge to be faced without losing thermal advantage of Eensulate foam utilization.