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D5.1 – Retrofit process application at the individual testing sites

WP5

Lead Partner: Focchi

Partner Contributors: BGTEC, UNSTUDIO, UNIVPM

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Topic	EEB-01-2016 Highly efficient insulation materials with improved properties
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Duration	49 Months

Executive Summary

The present Deliverable D5.1 "Retrofit process application at the individual testing sites" due at M44 (March 2020) of EENSULATE project reports the results achieved within the Work Package 5 "Validation of performance, sustainability and replicability" with particular reference to Task 5.1 "Retrofit process application at the individual testing sites" under FOCCHI responsibility, directed to the design and optimization of EENSULATE retrofitting solutions (EENSULATE VIG, EENSULATE foam and EENSULATE module) for the demo buildings application to be used as testing sites.

This deliverable reports the overall approach used for the retrofitting design methodology based on product development and achievements of the previous Work Packages, in particular WP2 "Optimization and scale-up of the innovative high insulating material for the spandrel and installation process - EENSULATE Foam" led by SELENA, WP3"Optimization and scale up of the innovative high insulating and dynamic vision glass component – EENSULATE glass" led by SAES and WP4 "Detailed design, prototyping and lab characterisation of EENSULATE façade modules" led by FOCCHI.

The activities conducted in the demo design phase are reported, presenting the project demos[1]: Polish Primary School (Demo 1) and Museum (Demo 2) both sited in Dzierżoniów (Poland), San Giovanni Public Library (Demo 3) located in Pesaro (Italy). This report includes also an additional pilot namely Focchi Headquarter (Demo 4) located in Poggio Torriana (Rimini, Italy) as originally planned according to the Description of Action (DoA) related to the Grant Agreement (GA) number 723868 but removed in the Amendment dated 20/01/2020. The Demos are planned to be object of intervention implementing EENSULATE solutions including preliminary analysis, critical issues and final retrofitting design. Additionally, the monitoring design for each demo is presented.

Finally, the conclusions identify some guidelines for the application of EENSULATE solutions for different retrofitting scenarios.

The attached Annex reports the activities conducted to assess the monitoring for the EENSULATE module on the base of Testing Lab in Focchi facility.

[1] The Grant Agreement 723868 expected four demos building then reduced to three with Amendment dated 20/01/2020

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Abbreviations and Acronyms

D - Deliverable

VIG – Vacuum Insulated Glass

WP – Work Package

DoA – Description of Action

GA – Grant Agreement

TGU - Triple Glazed Unit

DGU - Double Glazed Unit

OCF – One Component Foam

BCF – Bi-Component Foam

1 Introduction

The retrofitting of existing buildings is a crucial point for the achievement of European targets expected by 2030. Indeed, the role of existing buildings is relevant because they represent a huge stock of low technological solutions highly energy consumptive. In this filed, the EENSULATE allows to validate the solutions developed within the project and test them in different configuration demonstrating their applicability in various retrofitting scenarios. Three main EENSULATE products have been developed and in this report are presented for the retrofitting they enable:

- **EENSULATE foam** – developed in WP2 "Optimization and scale-up of the innovative high insulating material for the spandrel and installation process - EENSULATE Foam", this foam achieved a thermal conductivity of 0.024 W/m^2K and a reaction to fire of B1 representing a valuable opportunity to be used in different retrofitting scenarios. On this base, as expected by the project, two different solutions of the foam have been defined for different applications:
  - One component foam (OCF) to fill air gap especially in existing windows;
  - Bicomponent foam (BCF) to fill the spandrel volume in façade module.
- **EENSULATE VIG –** developed in WP3 "Optimization and scale up of the innovative high insulating and dynamic vision glass component – EENSULATE glass", the VIG has achieved good preliminary test result of transmittance of 0.37W/m^2K in an overall dimension of 18.5 mm. Its dimension allows a wide application in different retrofitting scenarios.
- **EENSULATE façade module –** developed in WP4 "Detailed design, prototyping and lab characterization of EENSULATE façade modules", the EENSULATE module is a unitized façade system for the retrofitting of curtain wall façade. The EENSULATE module integrates in a façade solution EENSULATE VIG and EENSULATE foam (BCF) and its combination with a customized profile allow to achieve a transmittance of 0.64 W/m^2K.

In order to demonstrate the applicability of EENSULATE solutions in different retrofitting scenarios, project demo buildings have been selected to demonstrate the wide adaptability in different retrofitting building cases.

2 Methodology

For the project demonstration cases, a common methodology has been used to select and design the retrofitting interventions using the EENSULATE components:

- **Analysis of demo building and available options:**
    - *Retrofitting options identification* – base on demo façade typologies and EENSULATE project expected outputs, an evaluation of different opportunities has been assessed.
    - *Architectural and normative issues to be respected* – the above identified options offer valuable solutions for the EENSULATE project but can have some critical issues due to architectural aspects, norms to be compelled with and limitation due to EENSULATE project activities (e.g. VIG manufacturing amount). All these elements have been analyzed to identify the best option to validate the retrofitting.
- **Retrofitting design*:***
    - *Detail design* – the retrofitting has been designed in detail defining the constructive drawings. The main output of this phase is the issue of documents need for production and procurement activities for the demos.
    - *Replacement strategy* - EENSULATE VIG is a protype and durability tests are needed to know its behavior during its time life. For this reason, replacement strategy could be estimated and in particular for Demo 1 (Polish Primary School) application using EENSULATE module, where the incidence of VIG is consistent due to the façade installation. The purpose it to have a strategy to preserve the operation of the building.
- **Monitoring design –** on the base of FOCCHI testing lab monitoring definition, the monitoring phase is specifically designed for the demo application to achieve the EENSULATE solution validation.

In the next chapters, the above described methodology is presented for each of the EENSULATE project demo applications.

3 EENSULATE retrofitting process design

In EENSULATE project four different demos are object of retrofitting design to validate and test the EENSULATE solutions. The demos have been selected for their typology, retrofitting degree and opportunity to use specific EENSULATE solutions. The four demonstrators are:

1. **Demo 1 - Polish Primary School –** Tertiary Building in Dzierżoniów, Poland. In this demo the retrofitting is designed to install the EENSULATE façade module.
2. **Demo 2 - Dzierżoniowie Museum –** Historical building in Dzierżoniów, Poland. In this demo the retrofitting is designed to install the EENSULATE VIG and EENSULATE foam to renovate the original windows.
3. **Demo 3 – San Giovanni Public Library –** Historical building renovated in 2002, Pesaro, Italy. In this demo the retrofitting is designed to install the EENSULATE VIG in the selected window door.
4. **Demo 4 - Focchi Headquarters[2] –** Tertiary Building, Poggio Torriana (Rimini), Italy. In this demo the retrofitting is designed to install the EENSULATE VIG.

In the next chapters, the demos are presented in detail and their retrofitting with EENSULATE solutions are demonstrated.

[2] Removed after approval of AMENDMENT Reference No AMD-723868-29

3.1 Demo 1 – Polish Primary School

3.1.1 Overview

The Demo 1 is a Primary School located in Dzierżoniów, Poland owned by Dzierżoniów Municipality (Gmina Miejska Dzierzoniow - GMD) partner of EENSULATE project. The building has been built in 80's and it has a total curtain wall façade surface of around 500 sqm. The EENSULATE project aims at working on a portion of this façade and install the EENSULATE module to increase energy efficiency of the building in line with EU and national targets for public buildings. Object of EENSULATE retrofitting is the façade in Figure 1.

Figure 1: Polish Primary School, Dzierżoniów (Poland). The façade object of retrofitting

3.1.2 Design for EENSULATE retrofitting

The school building façade is a curtain wall and represent an ideal example to test and validate the applicability of EENSULATE module.

3.1.2.1 Boundary conditions: Architectural and normative requirements

Some boundary conditions emerged during the design phase. On the base of activities about EENSULATE system design already conducted in the previous WPs, some key elements become evident and have been addressed through the following actions for the retrofitting:

- **Load bearing structure –** out of scope of the project is to work on structural components of the existing building, therefore the EENSULATE façade module needs to be installed on the existing load bearing structure of the building. With this purpose, the existing Curtain Wall Façade is a stick system installed on the front of the slab and the installation of EENSULATE module replicates this bearing solution. Once removed the existing façade, new brackets will be installed to support the EENSULATE modules.

- **Façade interfaces with existing elements –** the interfaces between EENSULATE module and building elements (walls, ceiling, roof) are other crucial parts to be designed. The concept to manufacture off-site the EENSULATE module is to guarantee a fast to be installed solution on-site. With this purpose as much as possible details need to be designed and solved off-site, reducing at minimum the intervention on-site. The Figure 2, the Figure 3 and the Figure 4 show some pictures of the nodes to be designed.

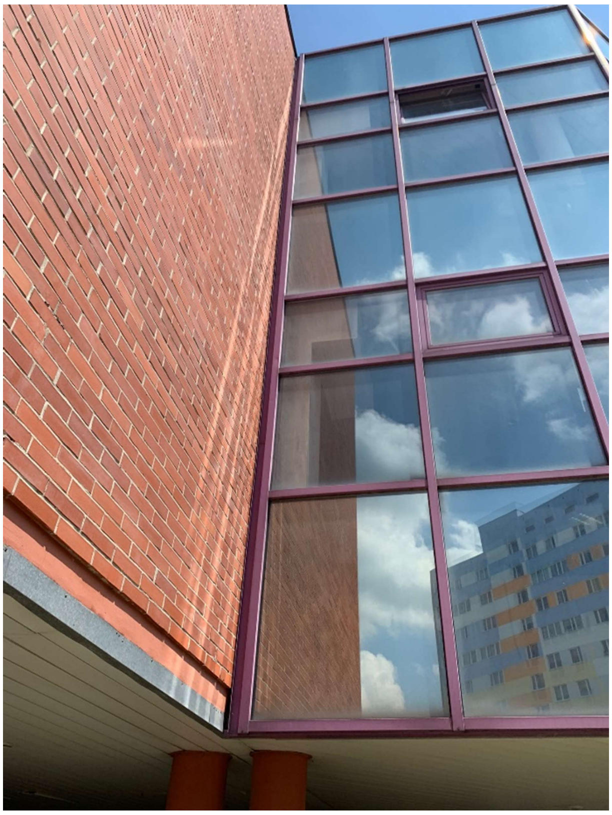

Figure 2: Interface between existing brick wall and façade

Figure 3: Interface between ground floor's ceiling and façade

Figure 4: Interface between roof and façade

- **Façade colors –** specific request of the municipality is to preserve the aesthetic homogeneity of the retrofitted façade in relation to the other existing façade not object of intervention. For this reason, the application of profile treatment to have similar colors to the ones already present in the building have been conducted.

Figure 5: Polish Primary School colour study with RAL 4001. Exterior view

Figure 6: Polish Primary School: colour study with RAL 4001. Interior view

3.1.2.2 Retrofitting design

On the base of above-mentioned considerations and thanks to the building school survey conducted on-site by BGTEC, FOCCHI carried out the EENSULATE façade retrofitting design.

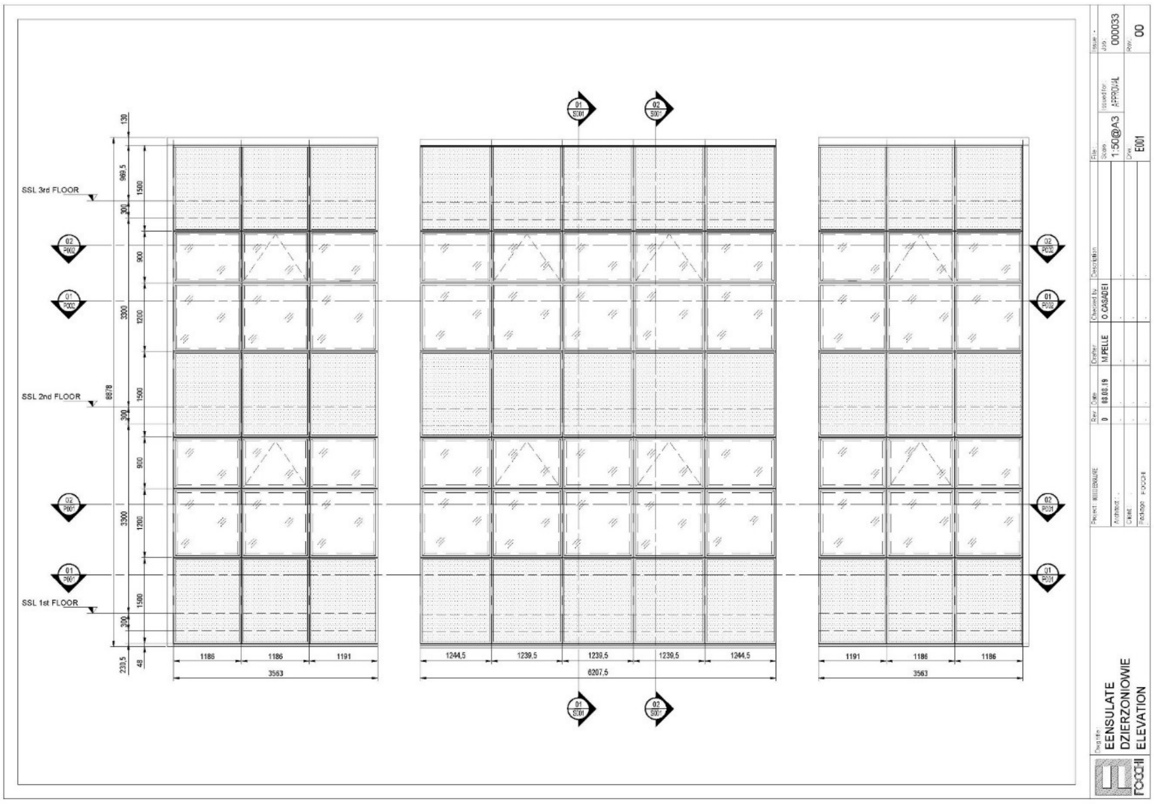

Figure 7 Polish Primary School: Elevation curtain wall facade

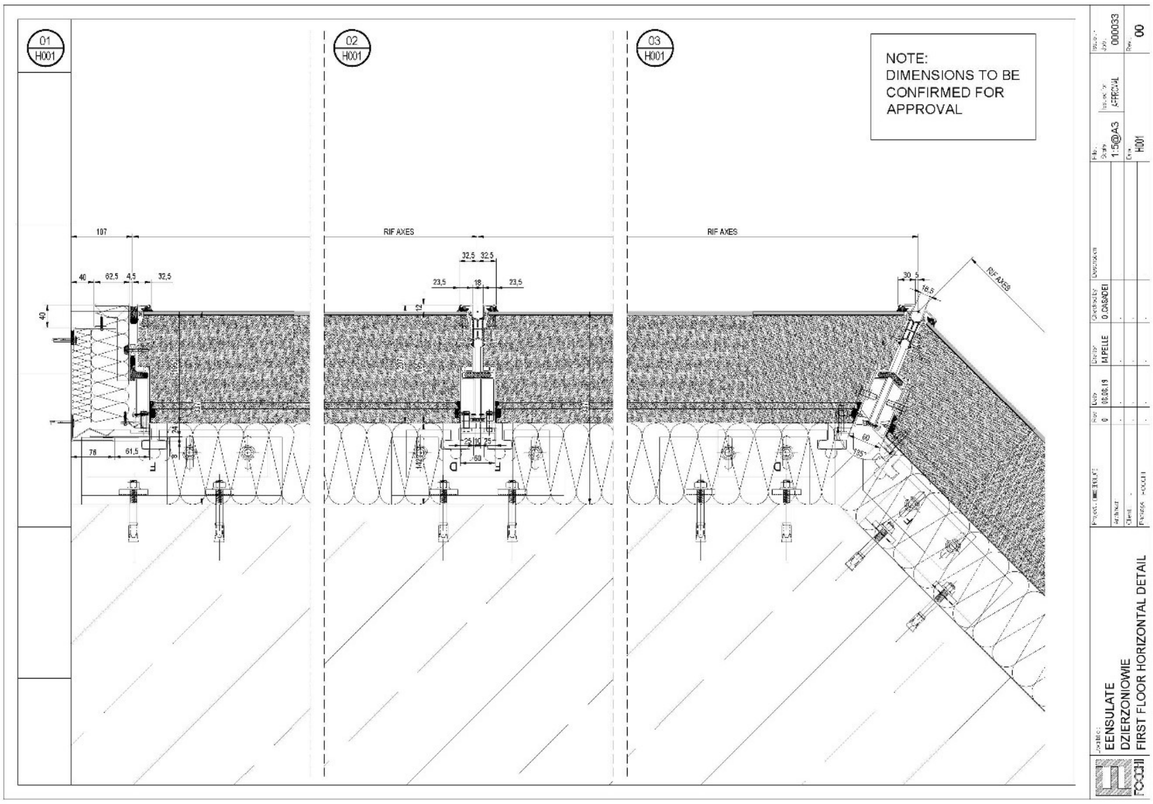

Figure 8 Polish Primary School: Curtain wall detail 1 (first floor horizontal detail)

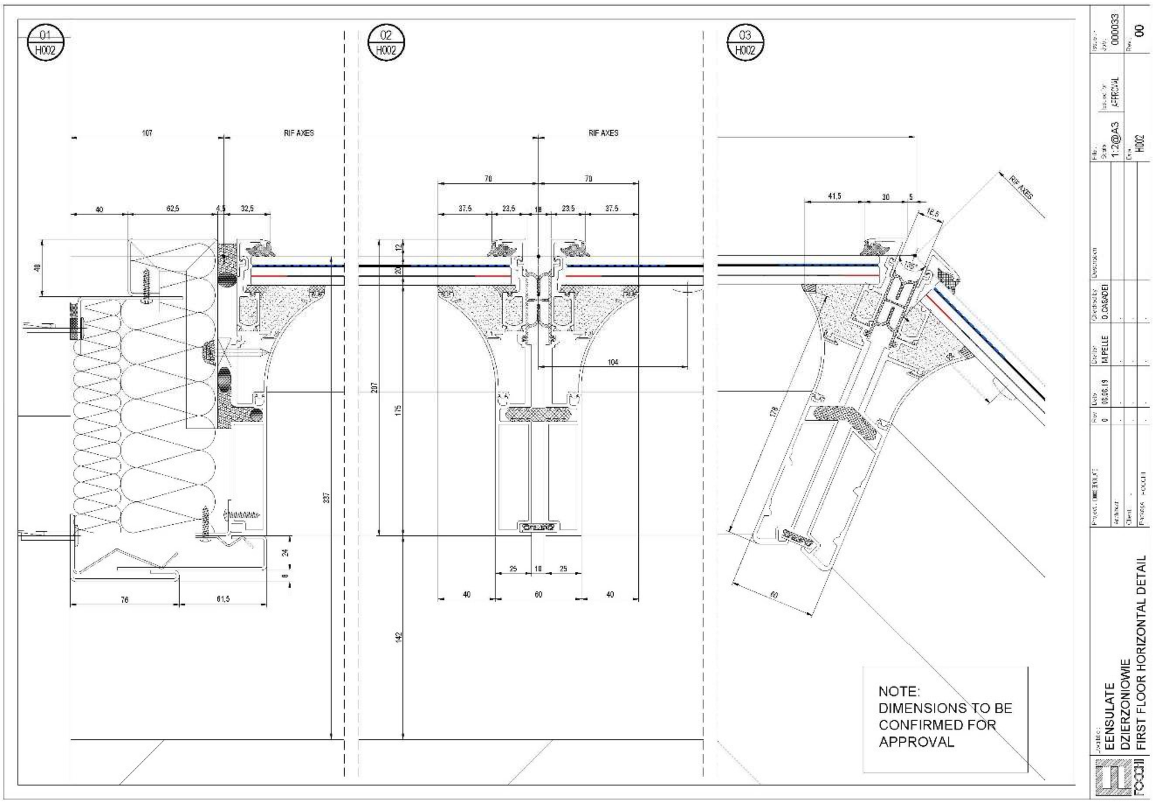

Figure 9 Polish Primary School: Curtain wall detail 2 (first floor horizontal detail)

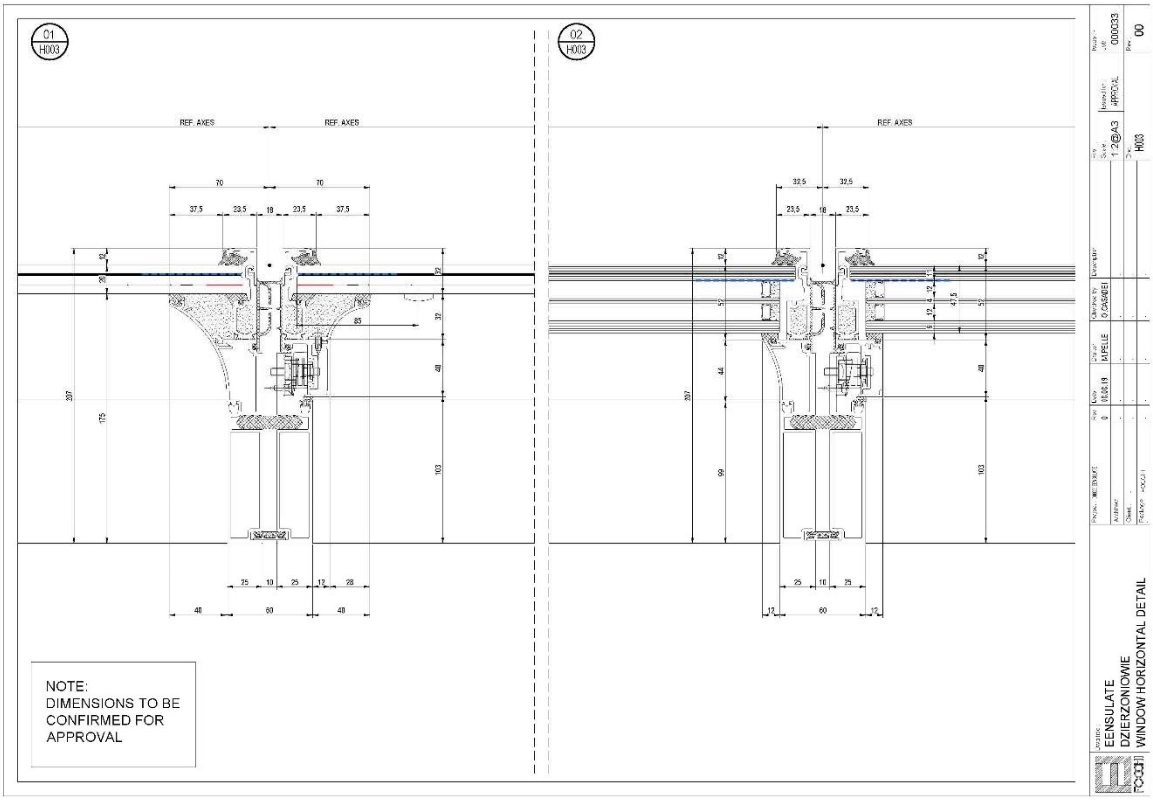

Figure 10 Polish Primary School: Curtain wall detail 3 (window horizontal detail)

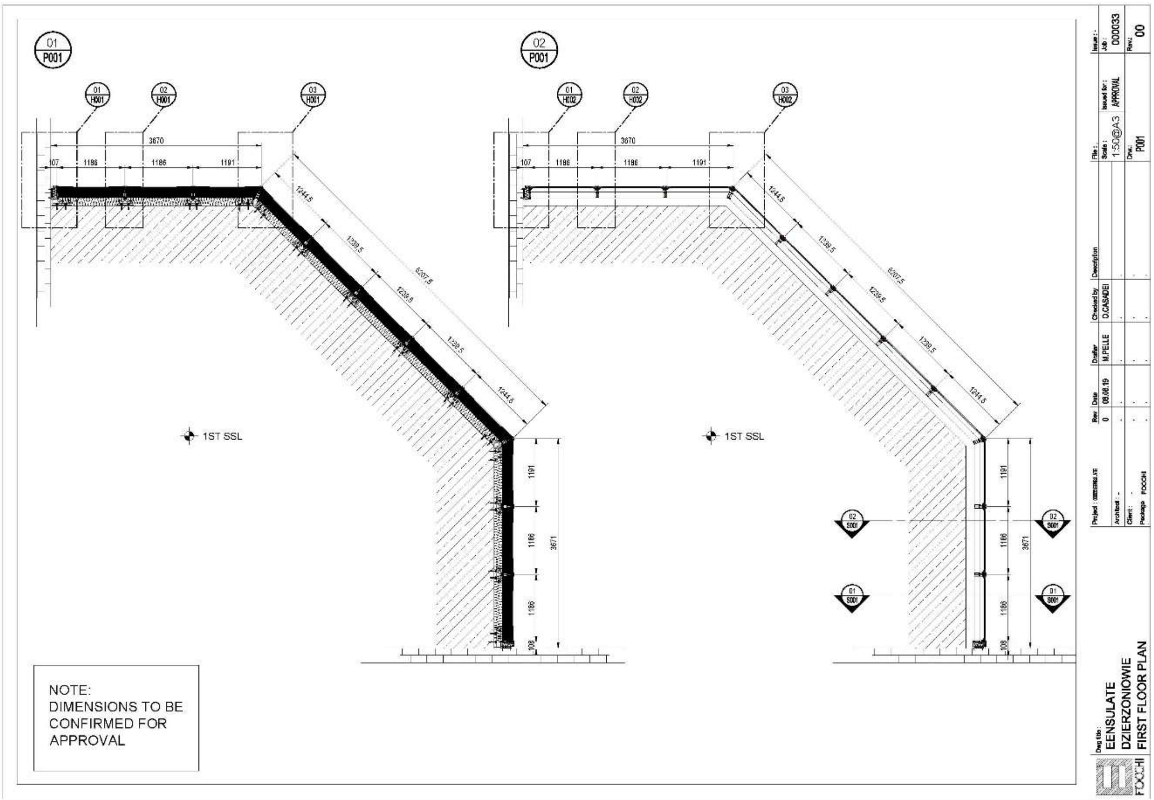

Figure 11 Polish Primary School: First floor plan.

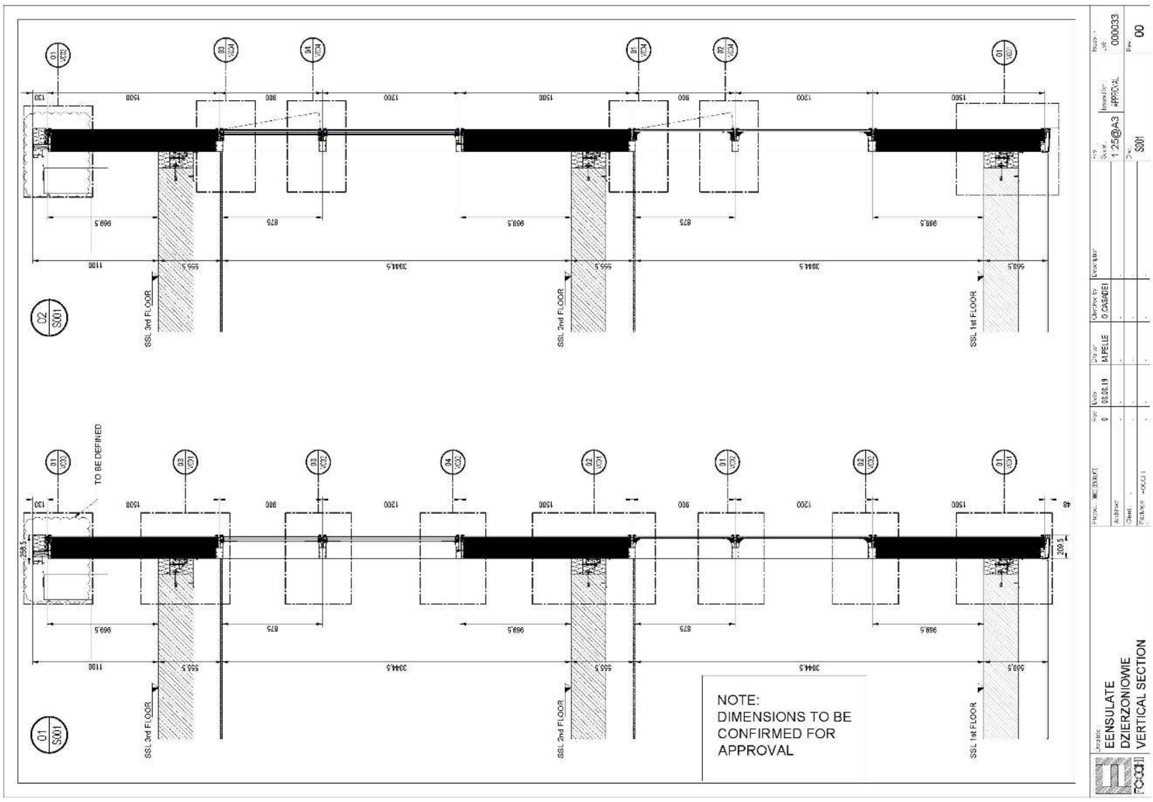

Figure 12 Polish Primary School: Vertical section.

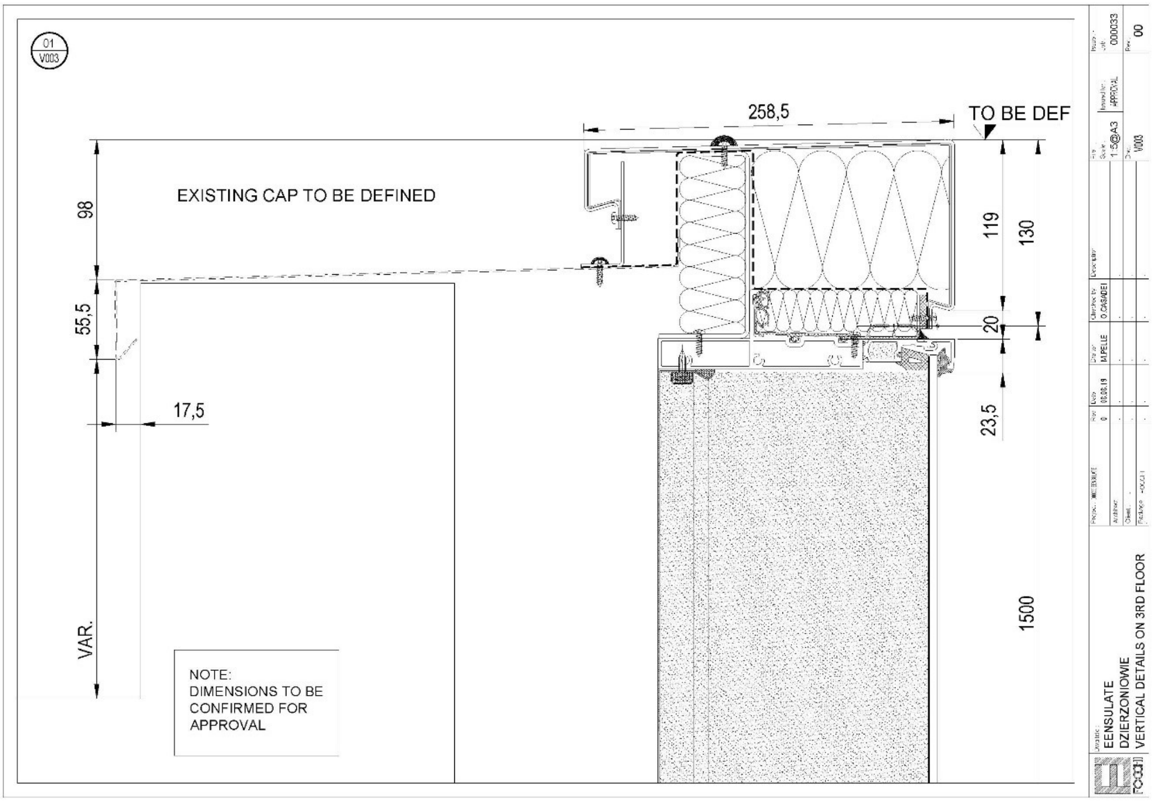

Figure 13 Polish Primary School: Vertical details on 3rd floor.

The detailed design has been object of several revisions (from April to August 2019) involving GMD (demo owner), BGTEC (EENSULATE VIG manufacturer and EENSULATE module installer) and FOCCHI (EENSULATE module supplier). Once the retrofitting design and the drawings were considered approved, the procurement phase has been addressed on the base of the shared documentation.

3.1.2.3 Replacement strategy

A relevant issue for the demo is the risk to lose the energy performance achieved with the retrofitting due to the failure of EENSULATE VIG. Indeed, the EENSULATE VIG is an innovative product and its durability is already under investigation. For this reason, a replacement strategy for demo buildings in case of EENSULATE VIG failure has been defined. The EENSULATE module measure are designed to include the opportunity to replace the EENSULATE VIG with a traditional Triple Glazed Unit (TGU) already available on the market which can achieve performance as much as possible closest to the VIG (0,6 W/sqm·K for TGU against 0,3 W/sqm·K for VIG). With some minor on-site intervention (cutting or replacement of the internal cover-cap cup), the EENSULATE system is adaptable for TGU installation in case of replacement.

This solution represents a valuable replacement strategy, but it has also been a valuable solution to meet EENSULATE contingency plan and reduce the amount of VIG to be manufactured to complete the demonstration phase in due time. Indeed, the TGU solution will be installed in Polish Primary School demo façade.

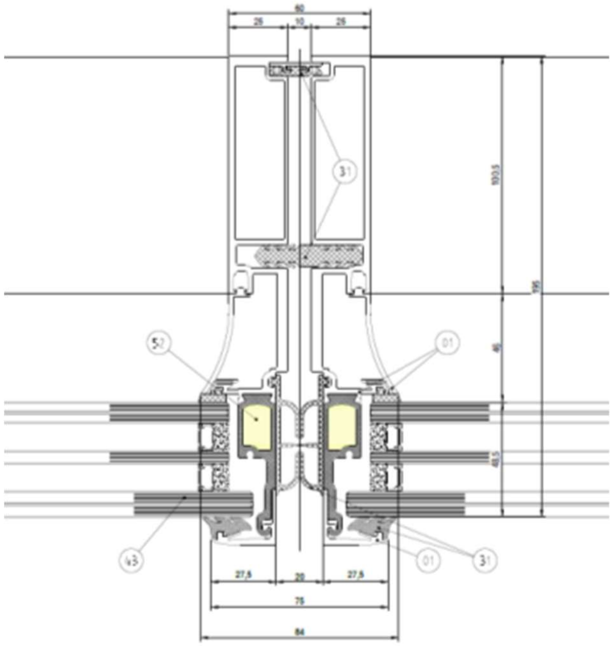

Figure 14: Eensulate module system design with a TGU for replacement strategy.

3.1.3 Monitoring design for validation phase

Demo 1 will be exploited to monitor the EENSULATE VIG system performances in a real installation in comparison to a common low energy triple glass (TGU). In order to perform the relative characterization both systems will be monitored with thermal and irradiance sensors. A picture of the Polish Primary School facade is reported in Figure 15, with evidenced in red the EENSULATE VIG system and in yellow the standard glass installed in a frame close to the EENSULATE one.

The main physical quantities to be monitored are:

- Internal and external glass surface temperature
- Indoor and outdoor air temperature
- Heat flux through the glass
- Visible external and internal radiation
- Solar external and internal radiation

From those data the thermal and optical transmittance of the glass can be calculated for the entire period of the monitoring activity.

Figure 15: Polish Primary School facade

3.1.3.1 Polish School Monitoring system architecture

The installation plan of all the sensors required for the measurement of the physical quantities listed in the previous section is detailed in Figure 16.

For the **thermal transmittance** evaluation the following devices will be employed:

- two thermocouples on the external surface of the glass
- two thermocouples on the internal surface of the glass (the two-temperature sampling will allow to have a more accurate measurement by performing an averaging process)
- a thermocouple in the immediate vicinity of the external glass surface for monitoring outdoor air temperature
- a thermocouple in the immediate vicinity of the internal glass surface for monitoring indoor air temperature
- a thermal flow meter, which measures the heat flow through the glass.

For the **radiating transmittance** estimation the following devices will be employed:

- three luxmeters: one placed outdoor and two placed indoor in the vicinity of the monitored glass for measuring the entering radiation energy in the visible range
- three pyranometers: one placed outdoor and two placed indoor in the vicinity of the monitored glass for measuring the entering radiation energy in the solar range.

Legend:

- Thermocouples
- Heat flux meter
- Pyranometer
- Luxmeter

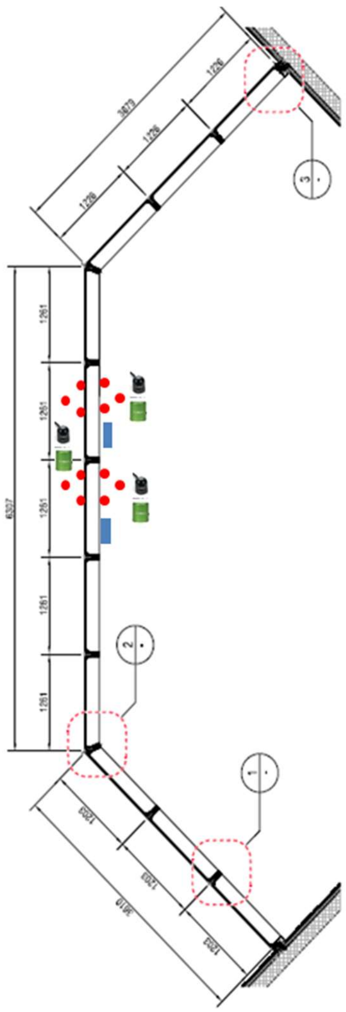

Figure 16: Set-up of the glass transmittance monitoring sensors - Demo 1

All the sensors will be connected to a National Instruments (NI) acquisition system consisting of two multi-channel Digital-to-Analogue (DAQ) boards:

- NI-9213 is a board specific for temperature measurements
- NI 9205 is a board specific for voltage measurements

The boards will be connected to a Mini PC Desktop NUC equipped with a router for communication with external and remote devices. The acquisition boards will be controlled and data will be registered via a software code developed in NI LabVIEW.

The list of the sensors to be installed, including their quantity and the acquisition system components is detailed in Table 1. The connection between sensors and acquisition system components are reported in Figure 17.

Table 1: Sensors list and acquisition/control system components - Demo 1

N°	**Sensors**	**Measurement unit**
Thermal transmittance measurement		
12	T type Thermocouples	°C
2	Heat Flux meter Hukseflux HFP-01	W/m^2
Visual and infrared radiation measurement		
3	Pyranometer SP-110-SS, Apogee output 0-250mV	W/m^2
3	Luxmeter SE-100-SS, Apogee output 0-200mV	klux
N°	**Acquisition/control system**	
1	NI cDAQ-9185 CompactDAQ Chassis (4-Slot Ethernet)	
1	NI 9213 Spring, 16-ch TC, 24-bit, 75 S/s AI module	
1	NI 9205 Spring Terminal, 32 Ch, +/-200mv To +/-10v, 16-Bit, 250 Ks/S Ai C Series Module	
1	Desktop Computer Intel NUC NUC8i5BEK SSD M.2 480GB -RAM Crucial 16GB DDR4-2400 SODIMM	
1	Industrial Router InRouter600 S-Series 4G, 4 Ethernet slots	

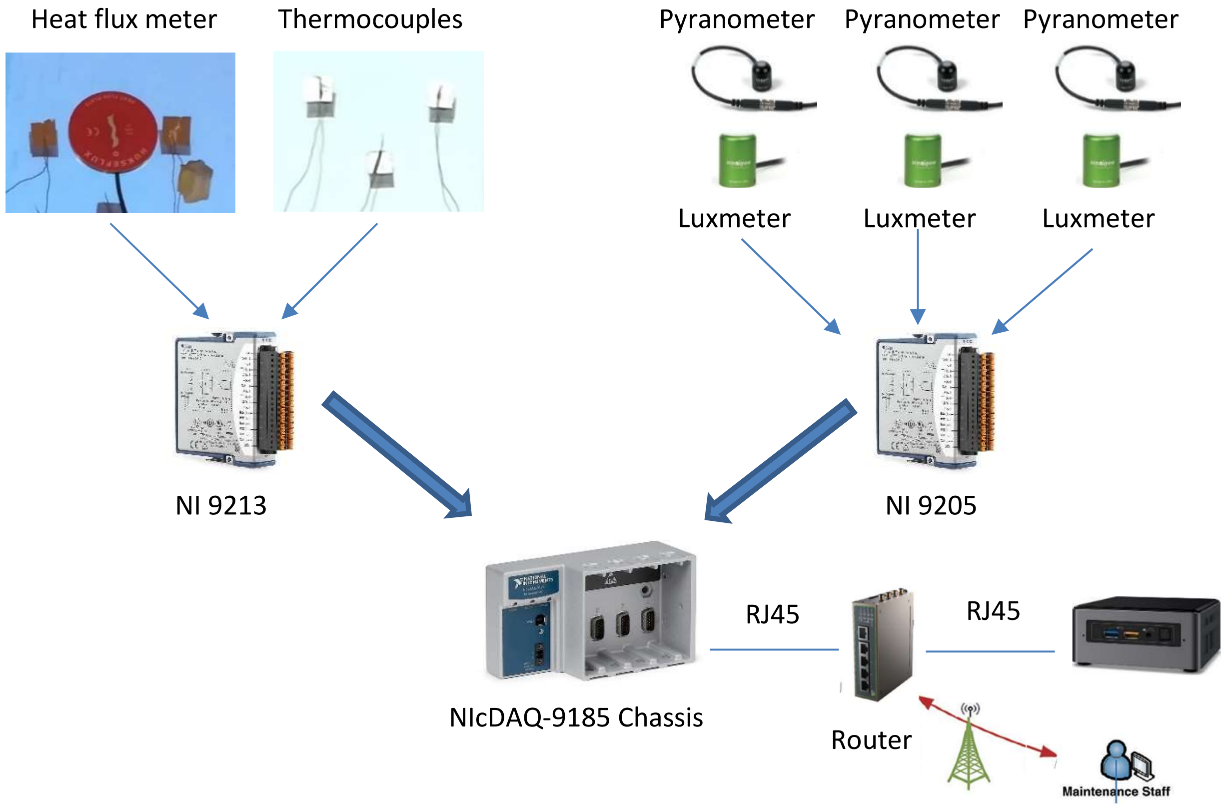

Figure 17: Connections scheme – Demo 1

3.2 Demo 2 - Dzierżoniowie Museum

3.2.1 Overview

The Dzierżoniów City Museum was established on May 1, 2011, by transforming the Regional Chamber operating at the Dzierżoniów Cultural Center. The Museum's seat is in the Cohn's villa at ul. Świdnicka 30. This house, built in 1897, originally belonged to Hermann Cohn, Cohn Gebrüder co-founder and one of the first mechanical weaving mill in Dzierżoniów. The building has been carried out many renovation and adaptation works which had to adapt the available space for museum purposes. Preserved elements of the interior, thanks to the conservation work carried out, gradually returned to its former glory. The eclectic building made of the red brick facade is enriched with sandstone detail as well as the transom beams of the structure at the top of one of the towers. The interiors of the building are also noteworthy: a magnificent staircase with a huge stained glass window, original paneling and beautiful ceilings. Today the museum hosts permanent exhibitions, including cartographic collections and documents concerning Dzierżoniów and the surrounding area. A large collection of artifacts illustrates the development of the region since the time of late Paleolithic to modern times.

Figure 18: Museum in Dzierżoniów - building façade

3.2.2 Design for EENSULATE retrofitting

3.2.2.1 Boundary conditions: Architectural and normative requirements

Being a historical building, Museum has its restrictions in regards with modification of elements of its construction. It is requested that the new windows appearance is exactly the same like existing ones. Thanks to VIG, EENSULATE project foresees possibility of substitution of existing poor performing old glass with high thermal Vacuum Insulating Glazing keeping the same construction of the windows thanks to the thickness and lightweight of the new glass (VIG). In case of replacing by new windows it is usually very challenging and costly to obtain the same details of window construction as shape and hardware. With EENSULATE solution the process is easier and faster facilitating long terms of obtaining special permissions.

According to the construction law, works on the monument require a building permit and the consent of the monument conservator that is not easy to be obtained due to several requirements to be respected to allow the renovation in this specific field.

3.2.2.2 Retrofitting design

In case of the Polish Museum, the scope of activities within EENSULATE project foresees renovation of a selected number of the windows in one room on the ground floor.

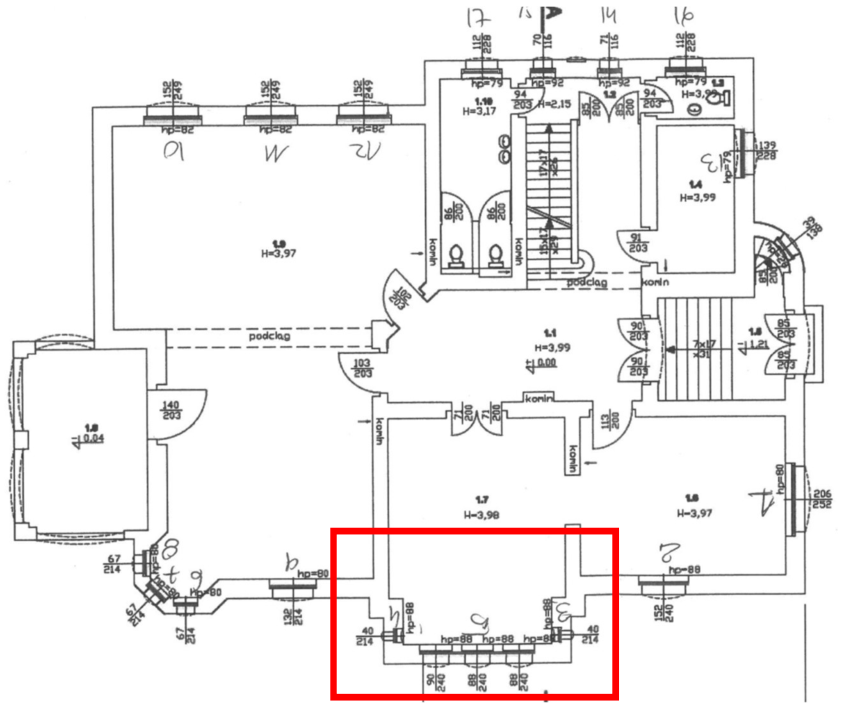

Figure 19: Polish Museum - Ground floor of the building with indicated proposed windows area to be renovated

Regarding Museum, it is important that the intervention does not change visual aspect of the building.

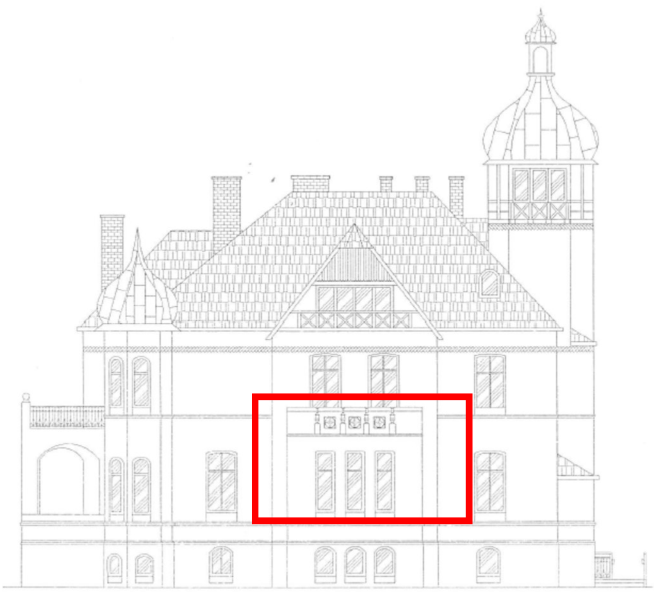

Figure 20: Polish Museum - Side elevation

Existing windows are old box windows with double sash opening to the inside, filled with a single glass. As whole window construction is deteriorated and needs renovation, frame and sash will be repaired by sealing, painting, changing gasket and performing all necessary works required for its proper functioning assessed after evaluation of the particular frames on site.

Old single glass will be replaced with EENSULATE VIG of thickness 12,2mm (6+0.2+6mm) and weight 30kg/m2, by dismantling the window sash.

Window sash will be removed carefully in order to perform renovation works, it will be sealed and painted, hardware will be renew and new gaskets will be attached then single glass will be replaced by VIG. The same sash will be installed in renewed, existing frame. During this intervention, the window opening will be protected against damaging and weather conditions. Thanks to the thorough assessment of necessary works on site the time of intervention will be reduced to minimum.

Figure 21: Polish Museum - Internal view of the windows

Figure 22: Polish Museum - Window view with old roller shutter boxes.

Additional as originally windows were equipped with old roller shutters no longer used, existing coffers will be filled with insulating foam developed by project partner, in order to minimize thermal bridges.

3.2.2.3 Replacement strategy

Amount of glass to be replaced is minimised in order to be able to cover area to be retrofitted. It is adjusted to the available quantity of VIGs manufactured in the EENSULATE project. Alternative is to install reduced part of the VIGs in part of the windows and standard single glass in the other part in order to have comparison of performance and monitor the process of replacing the glass in historical buildings without damaging of existing windows and possibility of adapting the solution to this demanding type of construction giving the possibility of reducing time and scope of intervention (during renovation and installation process).

3.2.3 Monitoring design for validation phase

Also Demo 2 – Polish Museum will be monitored to estimate relative glass transmittance performances, therefore two glass systems will be monitored: the one that includes the EENSULATE system (dashed red line in Figure 23) and the traditional one (solid yellow line in the same figure). In addition, in the Dzierżoniowie Museum, the thermal comfort will be monitored. To this aim the following quantities will be measured:

- room mean radiant temperature
- relative humidity
- velocity of the air in the room

Figure 23: Polish Museum front and zoom on the window to be monitored

3.2.3.1 Dzierżoniów Museum system architecture

The figure below illustrates the plan of the museum first floor and the set-up of the sensors that will be installed to monitor the glass transmittance and the room comfort. The measurement chain is identical to that described in the section related to Demo 1 (Polish Primary School) with the addition of the following three sensors necessary for estimating comfort:

- a globe-thermometer measuring the mean radiant temperature
- a thermo-hygrometer measuring the relative humidity
- an anemometer measuring the air velocity

The acquisition system is similar to the one described for the Demo 1 in Section 3.1.3.1 except for the addition of a further NI DAQ board, the NI-9219 able to acquire signals produced by thermal resistance sensors, as the ones exploited by the globe thermometer. Table 2 details the sensors to be installed and Figure 25 sketches the connections between the sensors and the acquisition system.

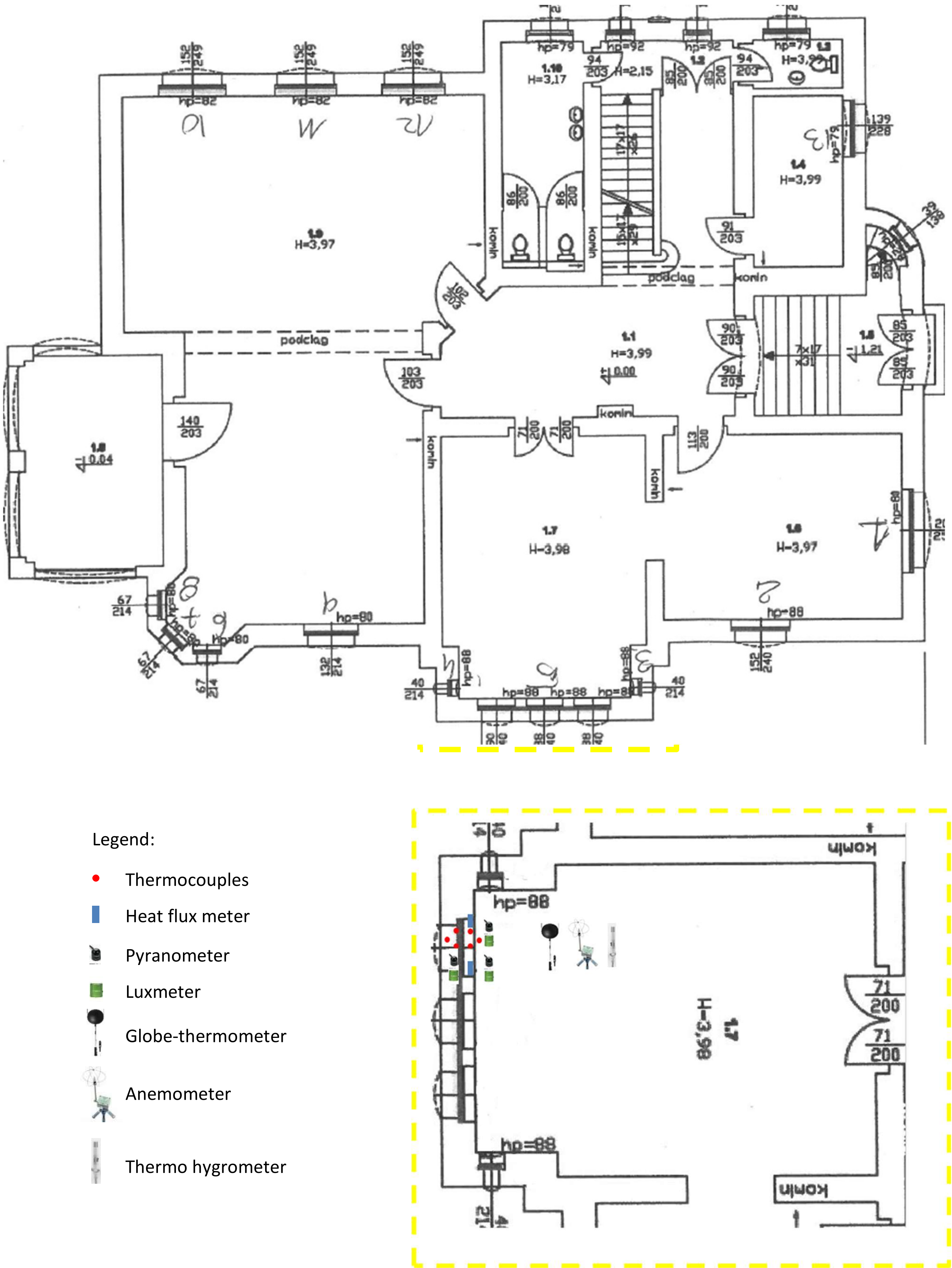

Figure 24: Set-up of the glass transmittance monitoring sensors and comfort instrumentation – Demo 2

Table 2: Sensors list and acquisition/control system components - Demo 2

N°	Sensors	Measurement unit
Thermal transmittance measurement		
12	T type Thermocouples	°C
2	Heat Flux meter Hukseflux HFP-01	W/m^2
Visual and infrared radiation measurement		
3	Pyranometer SP-110-SS, Apogee output 0-250mV	W/m^2
3	Luxmeter SE-100-SS, Apogee output 0-200mV	klux
Indoor Comfort		
1	Globe-thermometer Delta Ohm TP 875.1	°C
1	Anemometer Delta Ohm HD4V3TS4	m/s
1	Thermo hygrometer EE08	RH% - °C
N°	**Acquisition/control system**	
1	NI cDAQ-9185 CompactDAQ Chassis (4-Slot Ethernet)	
1	NI 9213 Spring, 16-ch TC, 24-bit, 75 S/s AI module	
1	NI 9207 Spring, 16-Ch voltage/current, 24-bit, 500 S/s AI module	
1	NI 9219 4-CH universal module, 24-bit, 100 S/s	
1	Desktop Computer Intel NUC NUC8i5BEK SSD M.2 480GB -RAM Crucial 16GB DDR4-2400 SODIMM	
1	Industrial Router InRouter600 S-Series 4G, 4 Ethernet slots	

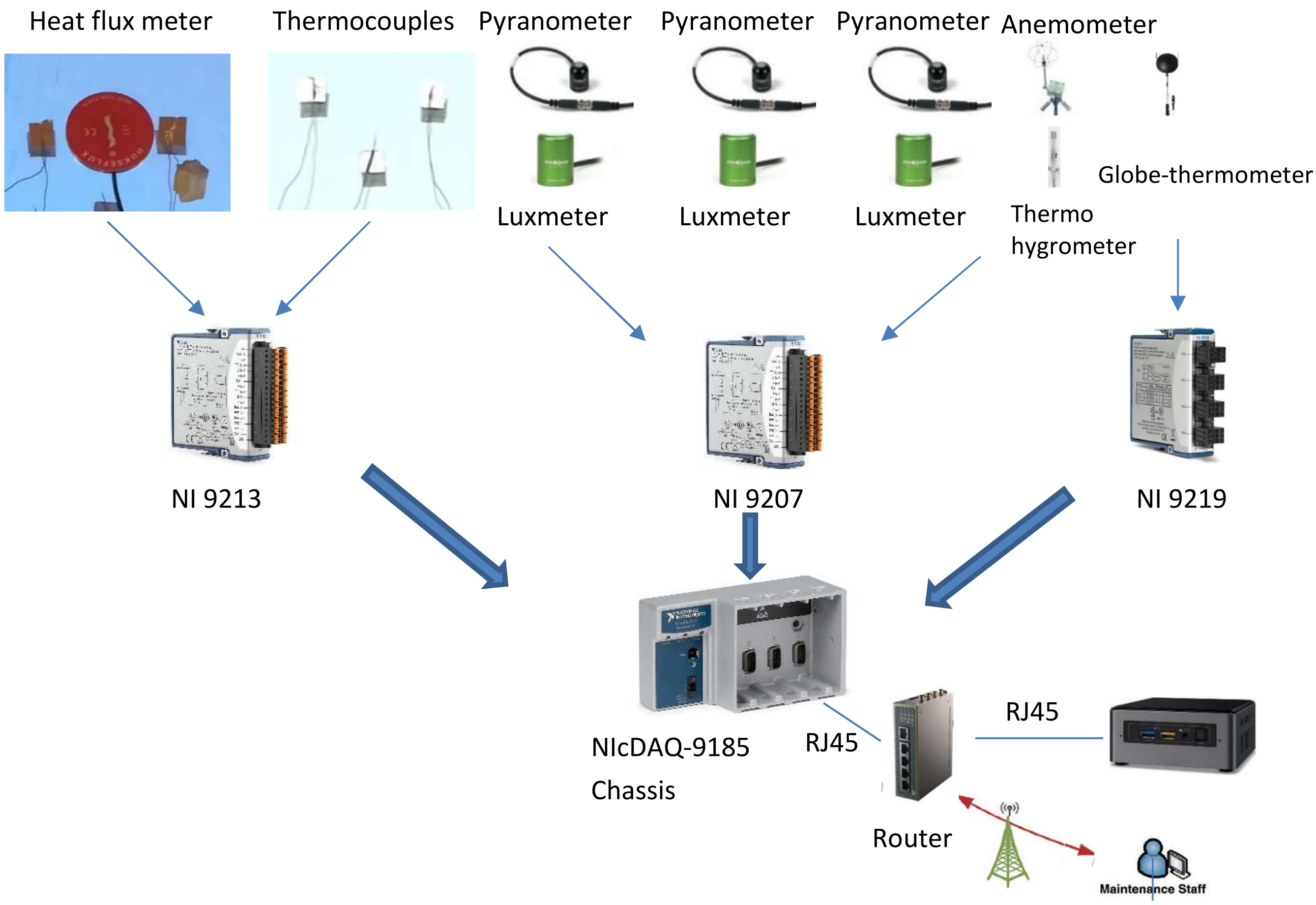

Figure 25: Connections scheme – Demo 2

3.3 Demo 3 – San Giovanni Public Library

3.3.1 Overview

San Giovanni Public Library located in Pesaro (Italy) is the third demo building object of EENSULATE retrofitting. Hosted by the ancient monastery of the Frati Minori Osservanti, once annexed to the church of San Giovanni Battista and planned by the Della Rovere family's architect Girolamo Genga, the library San Giovanni is an example where the historical and contemporary architecture elements coexist. The historical building has been object of a full renovation in 2000 and many contemporary elements have been introduced. However, the technological progress in the last twenty years can push in the adoption of new solution as the EENSULATE ones.

Figure 26: San Giovanni Public Library: main entrance

Figure 27: San Giovanni Public Library: internal view

3.3.2 Design for EENSULATE retrofitting

3.3.2.1 Boundary conditions: Architectural and normative requirements

San Giovanni Public Library is a complex building owned by Pesaro Municipality, protected by the regimentation of Architectural Superintendence. Therefore, the possible intervention for the application of EENSULATE solutions have been evaluated to compel with the existing architectural configuration of the building and decrease the approval process needed and without certainness of success. For this reason, the demo has been considered not suitable to validate the retrofitting through the EENSULATE module. Nevertheless, different options were possible and have been evaluated:

- **Façade in the rear entrance –** curtain wall façade with wooden frame and Double Glazed Unit (DGU). The retrofitting of this façade would have maintained the existing wooden frame, but the existing DGU would have replaced with VIG; in the correspondence of spandrel part, the EENSULATE foam could have been tested. However, the intervention on this façade was excluded due to the huge amount of VIGs to be manufactured.

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Figure 28 San Giovanni Public Library: Façade in the rear entrance.

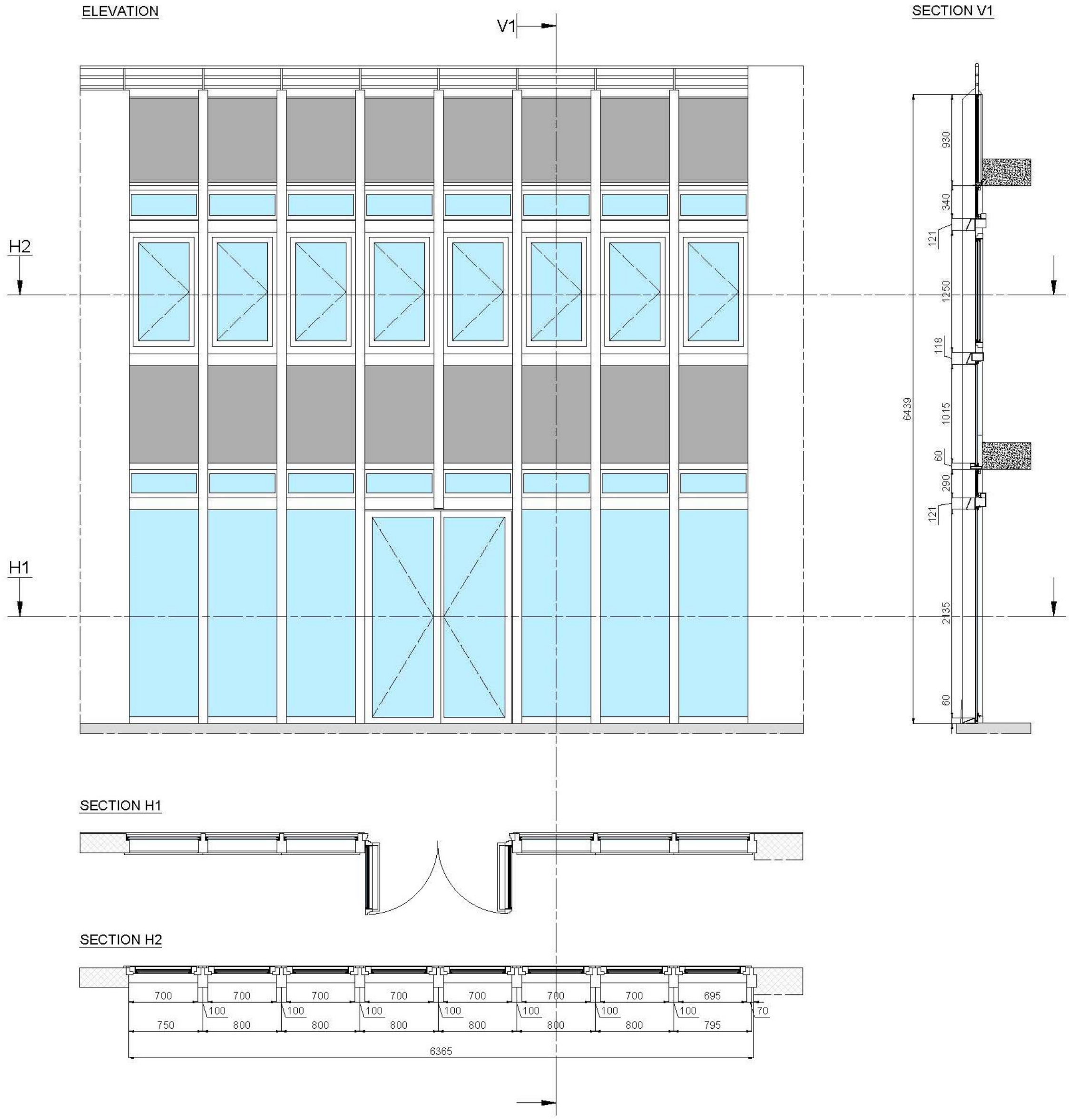


Figure 29 - San Giovanni Public Library: survey of façade in the rear entrance conducted during evaluation phase (plant, section, elevation)

- **Lateral window –** the window is 1,7 m x 3,4 m with a steel frame and a DGU (at this moment broken). The intervention on this window would have replaced the existing DGU with the VIG but creating a partition of the glass due to VIG maximum dimension (2,5 m) using at this purpose the aluminium frame as defined in the EENSULATE project. This scenario could not have been accepted by the Municipality of Pesaro without the approval (uncertain) of Architectural Superintendence and for this reason the lateral window has been excluded.

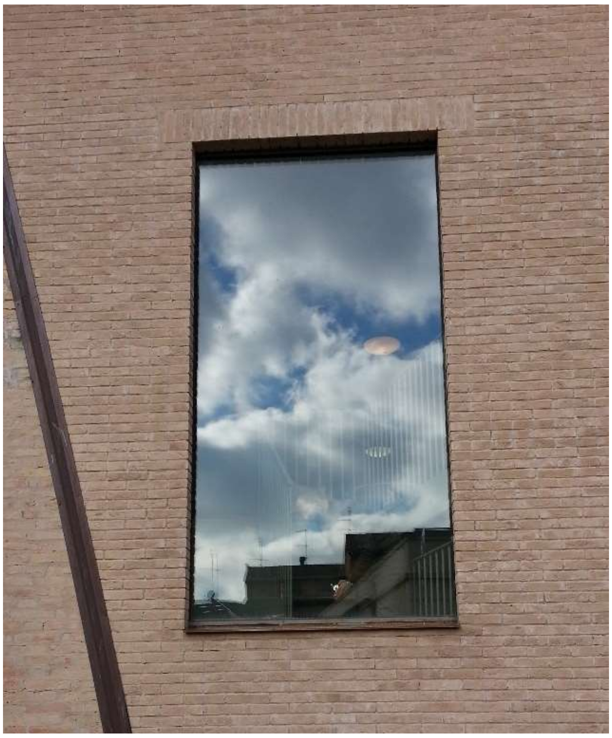


Figure 30 - San Giovanni Public Library: lateral window

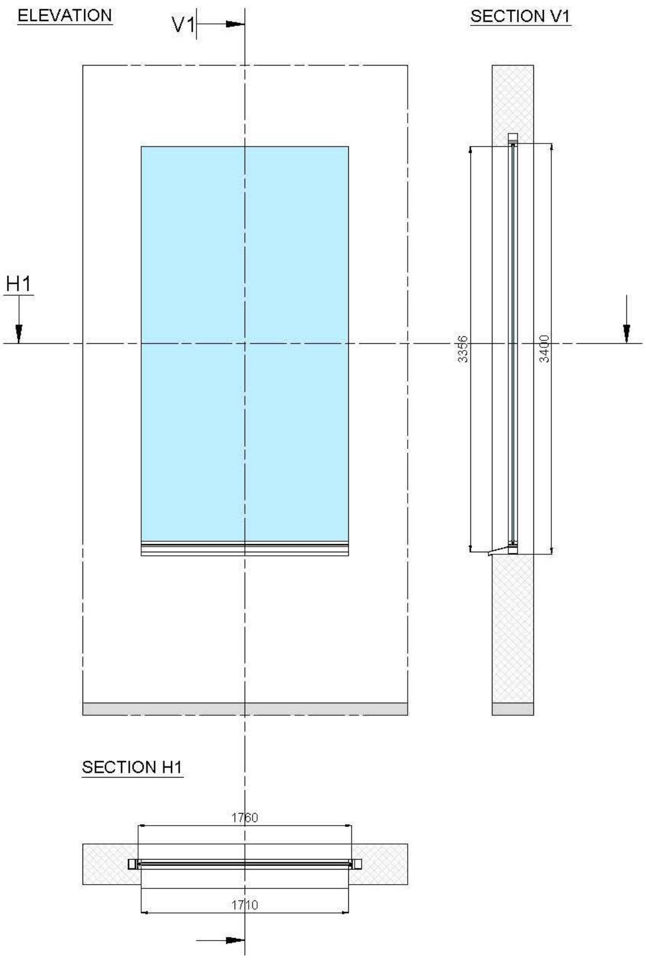


Figure 31 - San Giovanni Public Library: lateral window survey

- **Door-window –** along the main corridor of the Library, there is a long interior with door-windows with wooden frame and DGU. In this case the retrofitting will include the EENSULATE VIG utilization replacing the existing DGU. Not affecting the aesthetic of the building, this EENSULATE VIG application is the one object of retrofitting in this demo.

Figure 32 - San Giovanni Public Library: door-window

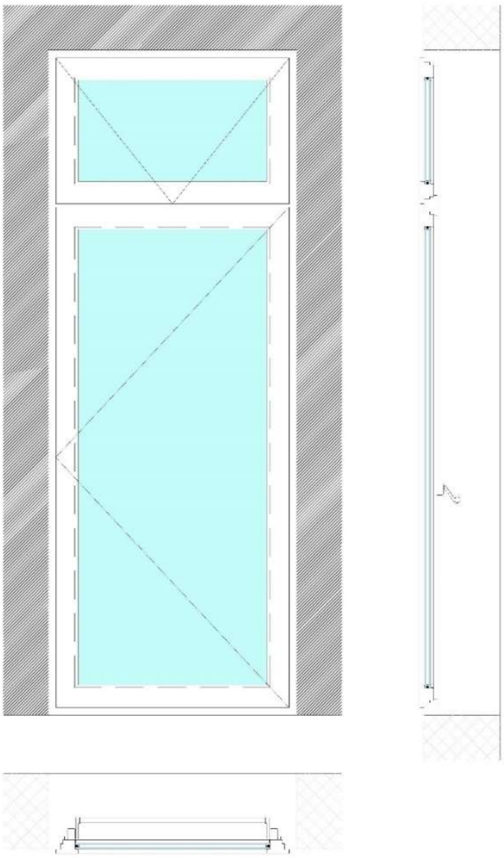


Figure 33 - San Giovanni Public Library: DGU door window technical drawing

3.3.2.2 Retrofitting design

The retrofitting of the door-window plans to preserve the overall window frame and replace only the DGU (28 mm) with the VIG (18 mm). The intervention will be conducted removing the internal aluminium frame which restrains the DGU, cleaning the area from the existing sealant, placing the VIG, sealing the edge to create air and water tightness performance and repositioning the aluminium restrain in their initial position.

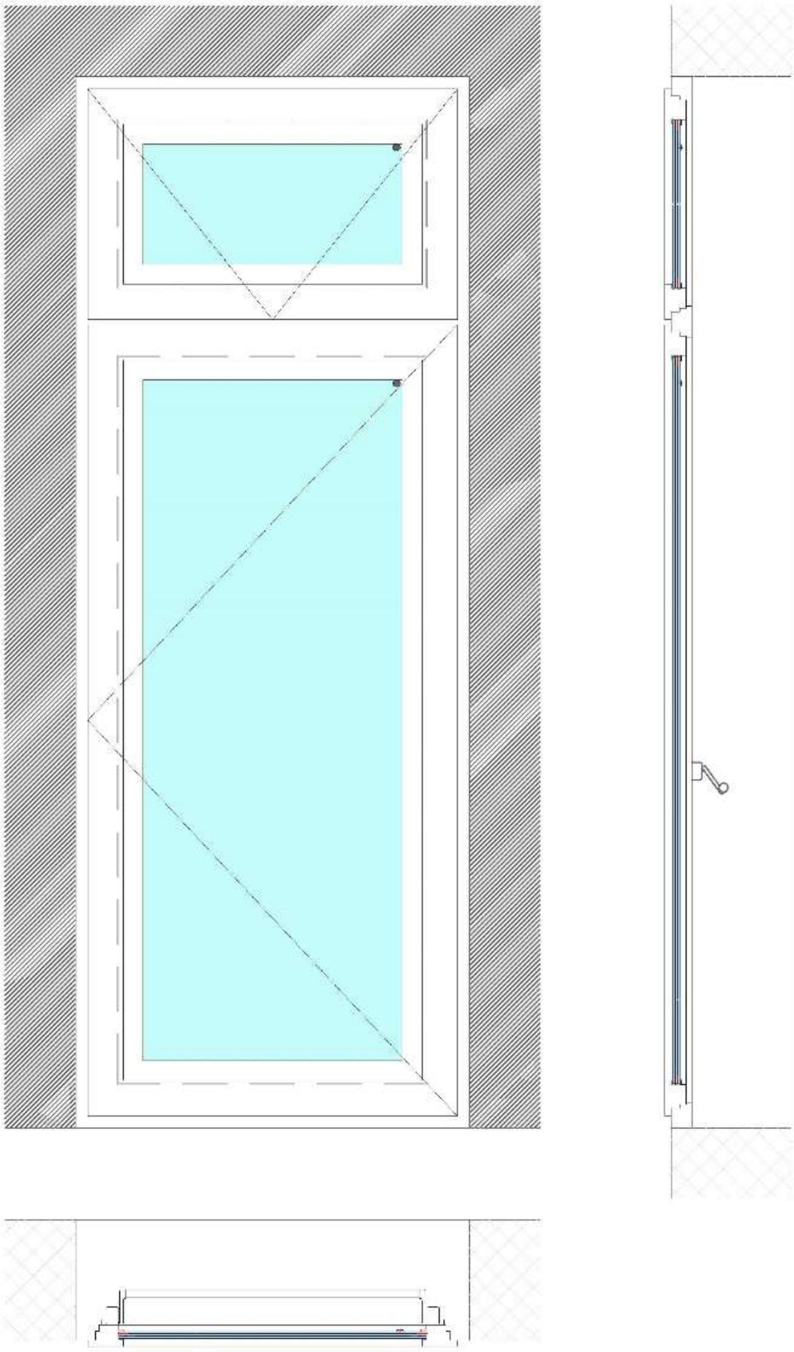


Figure 34 - San Giovanni Public Library: VIG door window technical drawing

3.3.2.3 Replacement strategy

In case of VIG failure , the replacement with the already installed DGU is the best option.

3.3.3 Monitoring design for validation phase

Demo 3 (San Giovanni Public Library) will be monitored in terms of glass transmittance and room comfort as for Demo 2 (Polish Museum). In addition, in this historical building, the wall transmittance is measured as well by means of a heat flux meter and thermocouples installed on the internal and external surface of the wall itself. The same quantities as for Demo 2 will be measured with the same sensors with an exception: the comfort will be monitored by a unique system which is the Comfort Eye patented by UNIVPM.

The monitoring has been started in Demo 3 since October 2019 for assessing the transmittance of the glass currently installed and the indoor comfort. The data registered will be used for monitoring the glass performances and room conditions in the as-is configuration and for assessing the improvement that will be obtained with the replacement of the window with the EENSULATE system.

Figure 35: San Giovanni library and window chosen for monitoring

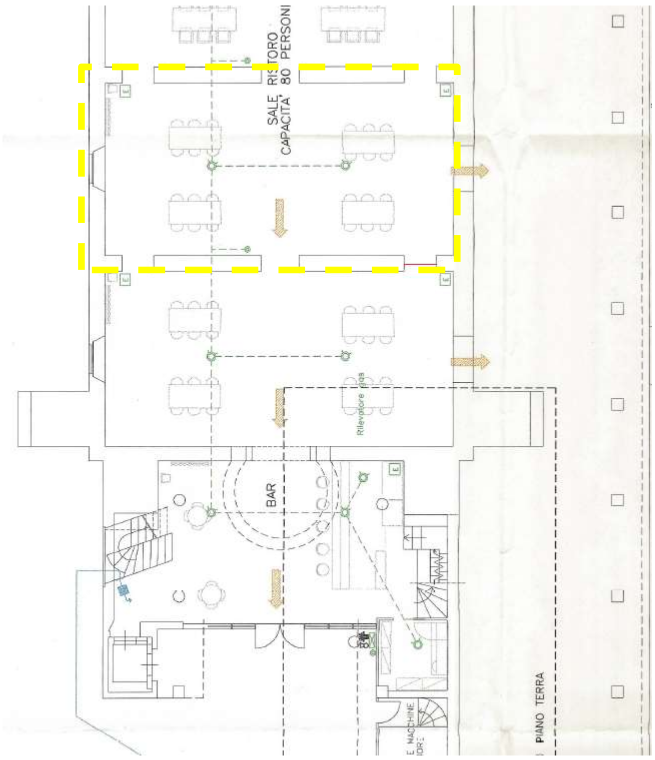
3.3.3.1 San Giovanni Public Library monitoring system architecture

Figure 36 evidences in yellow the room chosen for monitoring and sketches the sensors installation plan.

The sensors employed in Demo 3 are listed in

Table 3: for the indoor comfort assessment the Comfort Eye is used instead of the globe-thermometer and thermo hygrometer.

The acquisition system is a Keysight 34972A hosting a 20 Channel Multiplexer (Keysight 34901A module) for voltage and current acquisition. Like for Demo 1 and 2, the control system includes a mini PC and a router for communication with external and remote devices.



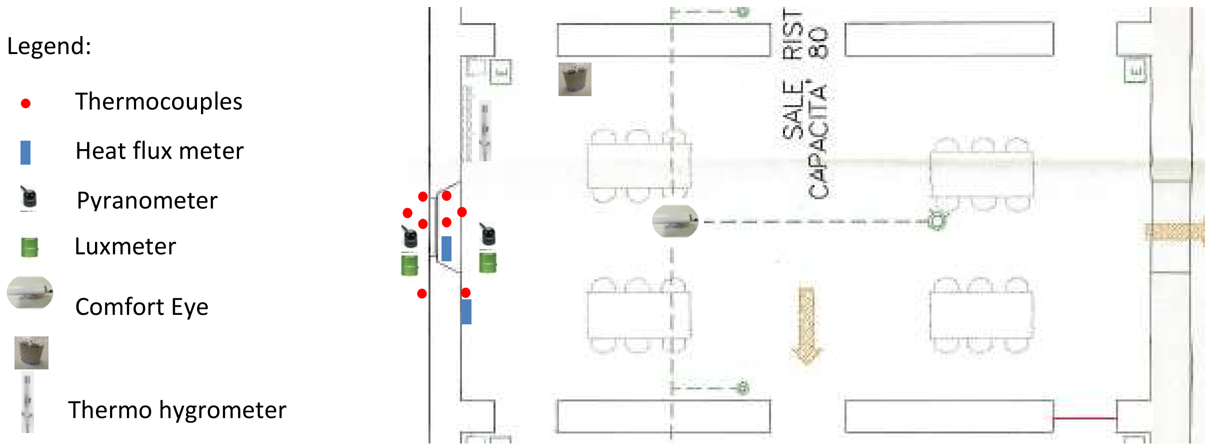


Figure 36: Set-up of the glass transmittance monitoring sensors and comfort instrumentation – Demo 3

Table 3: Sensors list and acquisition/control system components - Demo 3

N°	Sensors	Measurement unit
Thermal transmittance measurement		
8	T type Thermocouples	°C
2	Heat Flux meter Hukseflux HFP-01	W/m^2
Visual and infrared radiation measurement		
2	Pyranometer SP-110-SS, Apogee output 0-250mV	W/m^2
2	Luxmeter SE-100-SS, Apogee output 0-200mV	klux
Indoor Comfort		
1	Comfort Eye	°C – RH%
1	Thermo hygrometer HD 9008TR2 Delta Ohm	RH% - °C
N°	**Acquisition/control system**	
1	Keysight 34972A, 3-slot mainframe with USB and LAN, 22-bit, scanning up to 250 channels per second	
1	Keysight 34901A 20-Channel Armature Multiplexer Module, 60 ch/s scanning	
1	Desktop Computer Intel NUC NUC8i3BEK SSD M.2 480GB -RAM Crucial 16GB DDR4-2400 SODIMM	
1	Router TP-Link TL-WR841N 2.4 GHz 300 Mbit/s	

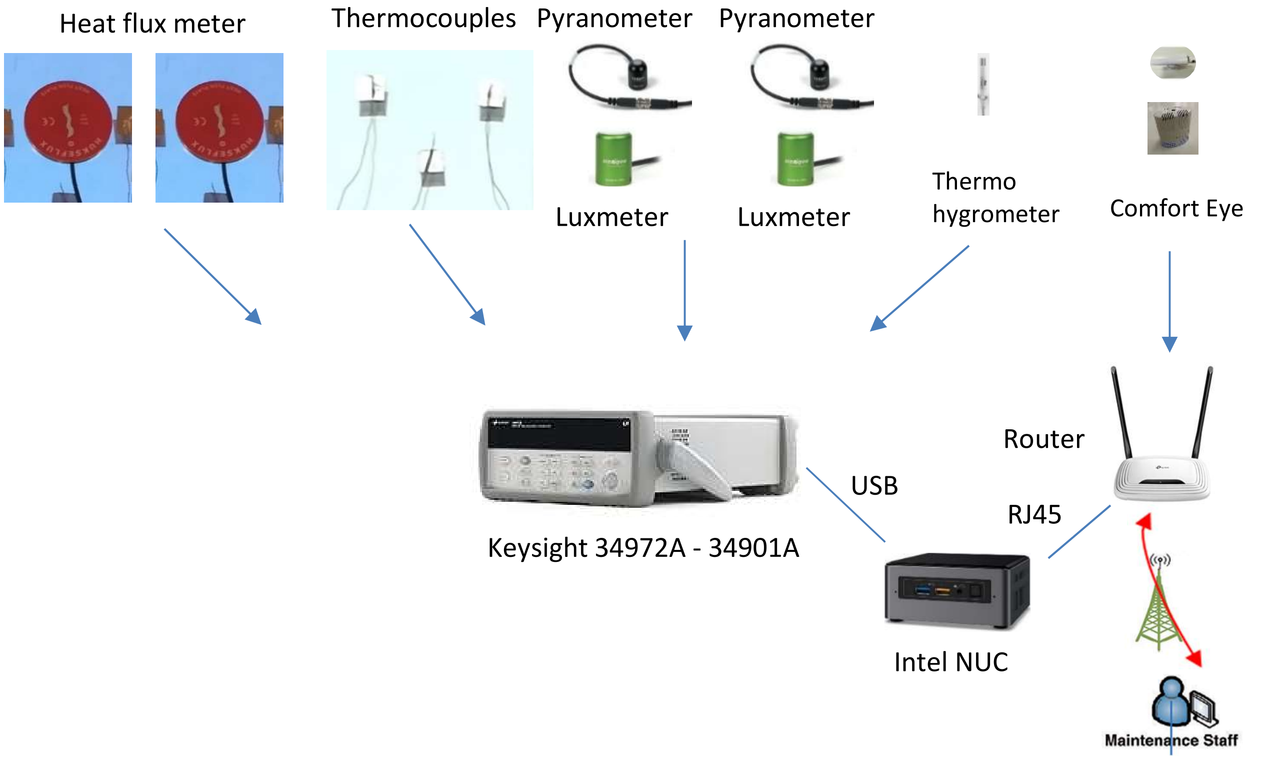


Figure 37: Connections scheme – Demo 3

3.4 Demo 4 - Focchi Headquarters

3.4.1 Overview

Built in 2005 on design by MCA (Mario Cucinella Architect), the office building of the Focchi Group Headquarters has the purpose to host executive, administrative and design services together in a single settlement with the manufacturing plant. This project is the extension of the existing building with a single transparent volume. Constructed on two levels: ground floor and first floor, the building is designed as two open volumes which communicate visually with the outside.

In 2017, the edifice has been object of a replacement of its glazing surface from DGU to TGU with a relevant improvement of energy performance of the building.

Figure 38: Focchi Headquarter's office building.

3.4.2 Design for EENSULATE retrofitting

3.4.2.1 Boundary conditions: Architectural and normative requirements

To test and validate the EENSULATE solutions, the Focchi Headquarter (office building and factory) offered the opportunity for different EENSULATE solutions validation:

- **Focchi Office –** the office building has full glass surface with TGU for a total of 2.000 sqm. The retrofitting will have included the replacement of the TGU with the VIG. Due to the huge amount of VIG to be manufactured, this full intervention would have been out of manufacturing possibility within the project.
- **Entrance "Officine Focchi" –** the factory building has full glass surface with DGU for a total of 50 sqm. The retrofitting will have included the replacement of the DGU with the VIG. Due to the large dimension of VIG to be manufactured (2,0 m x 2,5 m), this intervention is out of VIG manufacturing and dimension expected in the project (1,5 m x 2,5 m).
- **Conference room –** the conference room has full glass surface with DGU for a total of 95 sqm. The retrofitting will have included the replacement of the DGU with the VIG. This façade has been discarded due to the amount of VIG to be manufactured and within the contingency plan to achieve the EENSULATE project expected outputs.
- **Testing Lab –** the Testing Lab could change the existing façade with other façade solution. In this case, the EENSULATE module would have been installed and its performances testes. This solution has been discarded because did not compel with the need to have a "living environment" to test the EENSULATE solutions.

Figure 39: Focchi Headquarter's "Officine Focchi" entrance

Figure 40: Focchi Headquarter's conference Room

Figure 41: Focchi Headquarter's Testing Lab

- **Factory's windows** – one of the facilities in Focchi Headquarters has some windows with TGU installed. In this case, the retrofitting strategy would have replaced the existing glass with EENSULATE VIG. The solution was not considered relevant for the project purpose and to validate large scale VIG.
- **Meeting Room –** inside the office building, the meeting room has the possibility to replace the TGU with VIG testing a retrofitting with EENSULATE VIG in a full scale (1,5 m x 2,0 m), but in a small space

and having a living environment to support the validation. This solution has been considered the one to be selected among Focchi alternatives and it has been object of retrofitting design.

Figure 42: Focchi Headquarter’s facility

Figure 43: Focchi Headquarter’s meeting room in Focchi Office

3.4.2.2 Retrofitting design

The retrofitting design has been defined on the base of EENSULATE module system design presented in D4.1 "Detailed design of the EENSULATE envelope System". Indeed, the Focchi headquarter façade is a mixed system with stick and unitized solutions, and the conclusion of EENSULATE module design have been used to direct this retrofitting. The existing TGU can be replaced with EENSULATE VIG without changing the existing profiles but including the internal curved elements part of EENSULATE module and useful to mitigate isotherm due to VIG's sealant thermal bridge.

For safety reason, the EENSULATE module was designed with a mechanical restraint and not with structural silicon to reduce the safety risk in the installation of a not already validated glass; for this reason also in Focchi meeting room retrofitting design a mechanical restrain has been applied. However, the Focchi office has structural silicon solution to fix the TGU. The choice has been to design the EENSULATE VIG also in structural silicon configuration. This solution would have been validated in further steps to test mechanical behaviour of VIG. In the meantime, of this mechanical testing phase, Focchi had defined an exclusion zone in the internal courtyard where the meeting room is exposed, preventing any access and the consequent risk in case of failure of VIG with structural silicon.

In the next pages, the retrofitting drawings for both mechanical restraint as well as for structural silicon are presented.

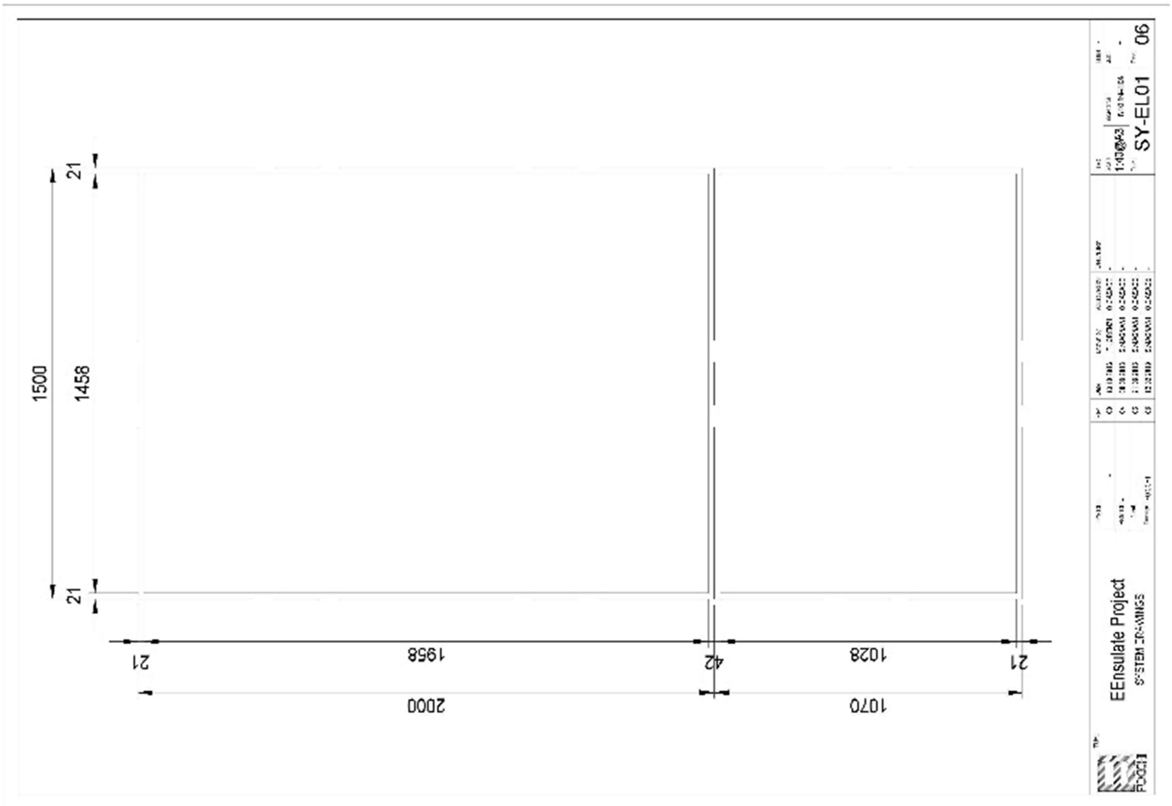


Figure 44: Unit elevation with mechanical restrain – Demo 4

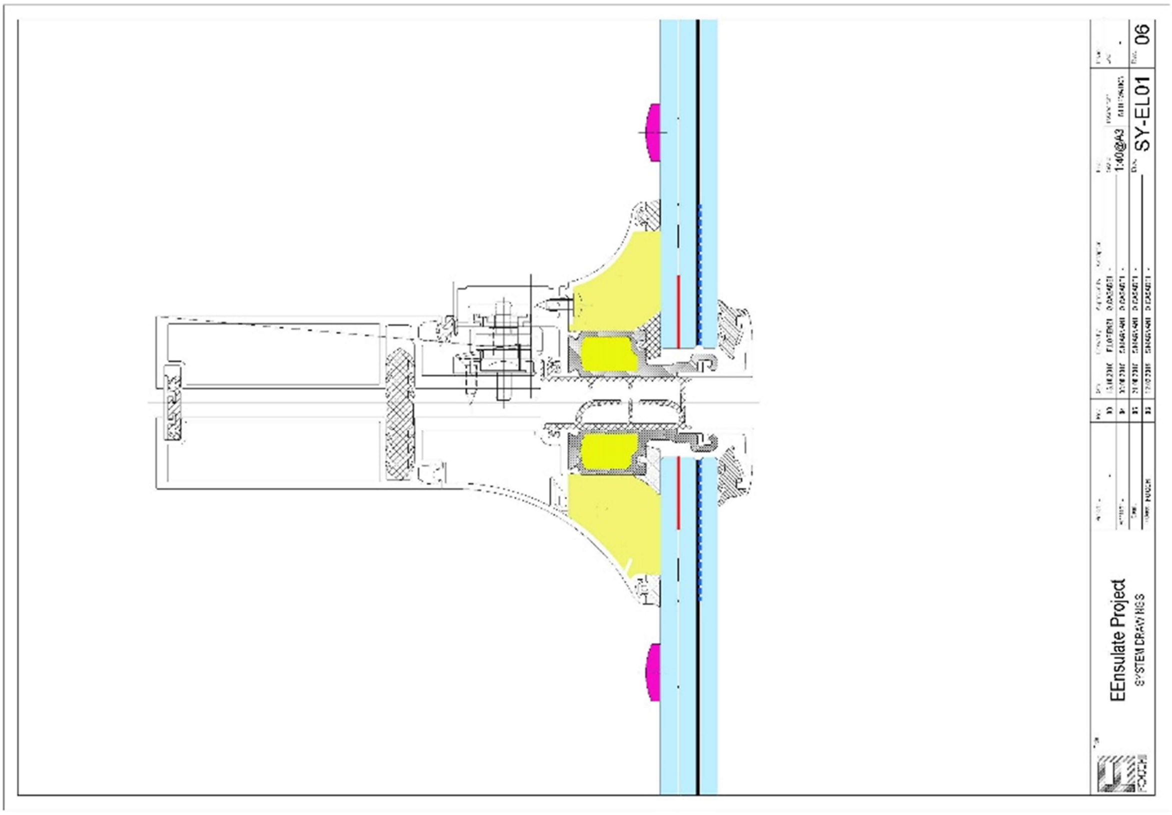


Figure 45: Vertical section of unit elevation with mechanical restrain – Demo 4

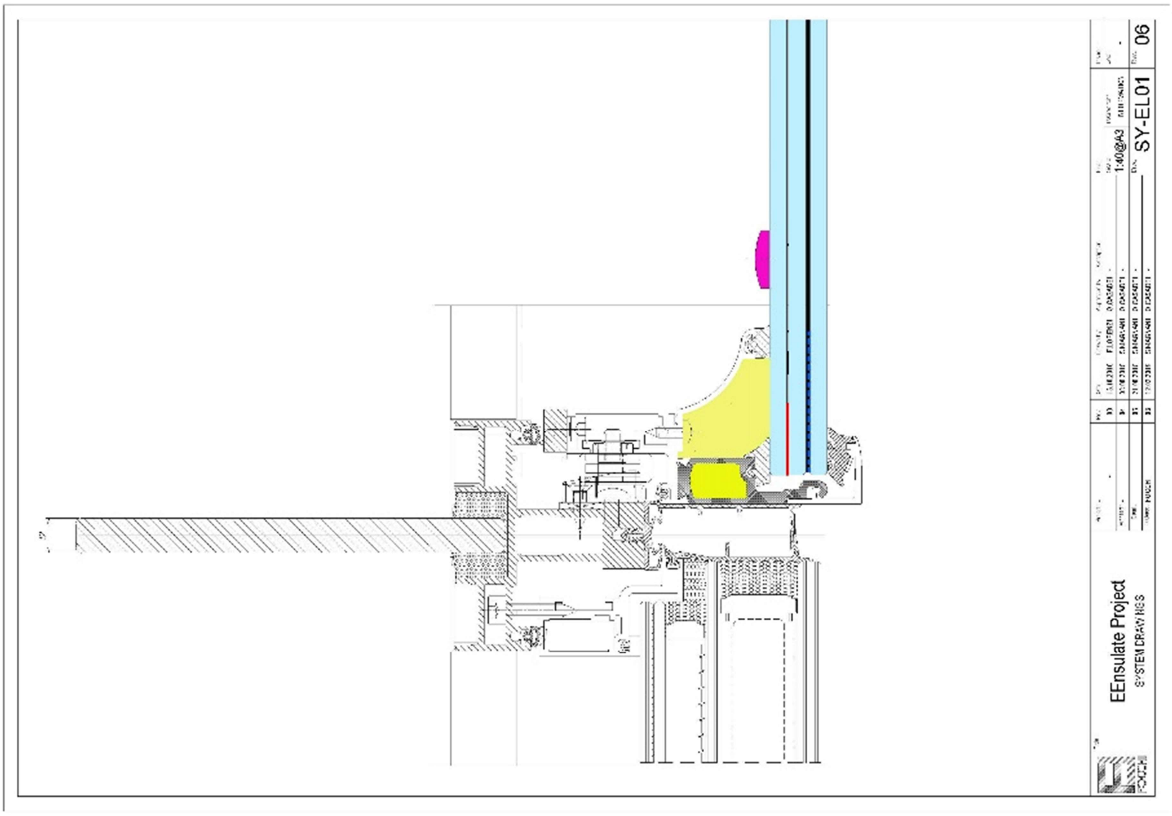


Figure 46: Horizontal section between unit elevation with mechanical restrain and exiting – Demo 4

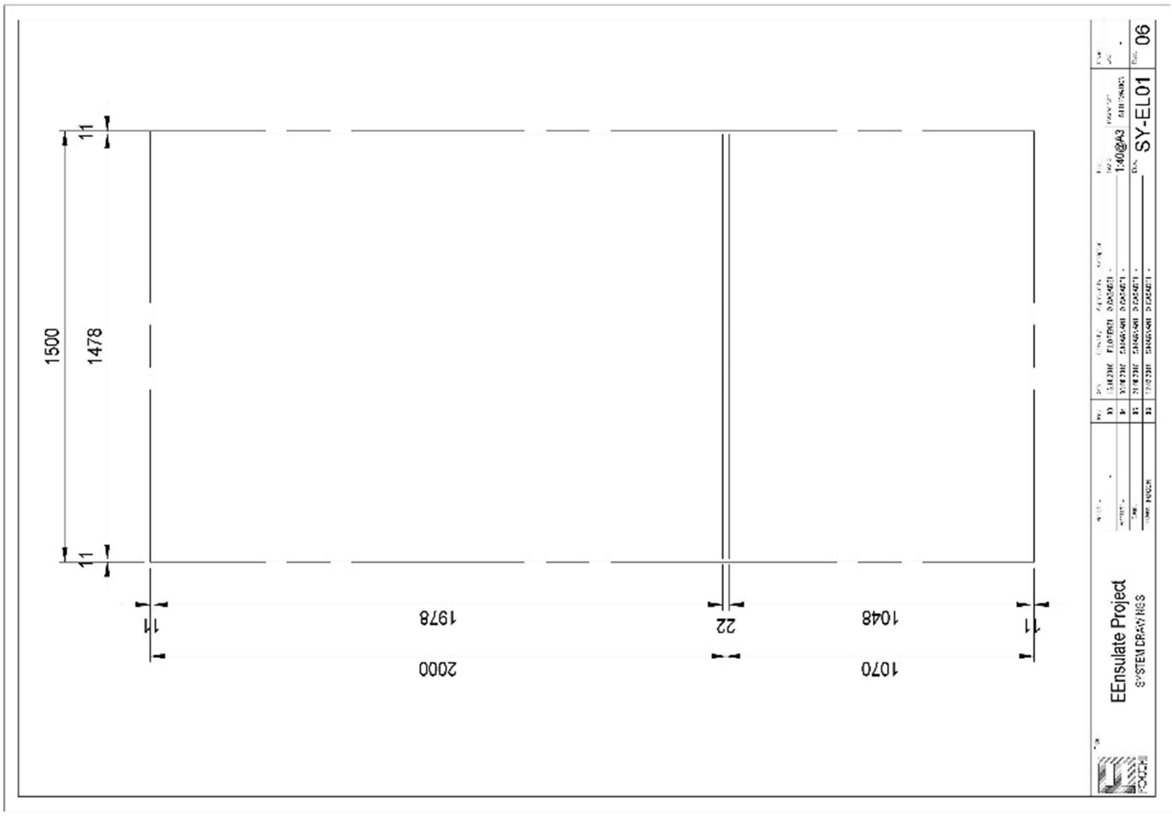


Figure 47: Unit elevation with structural silicon- Demo 4

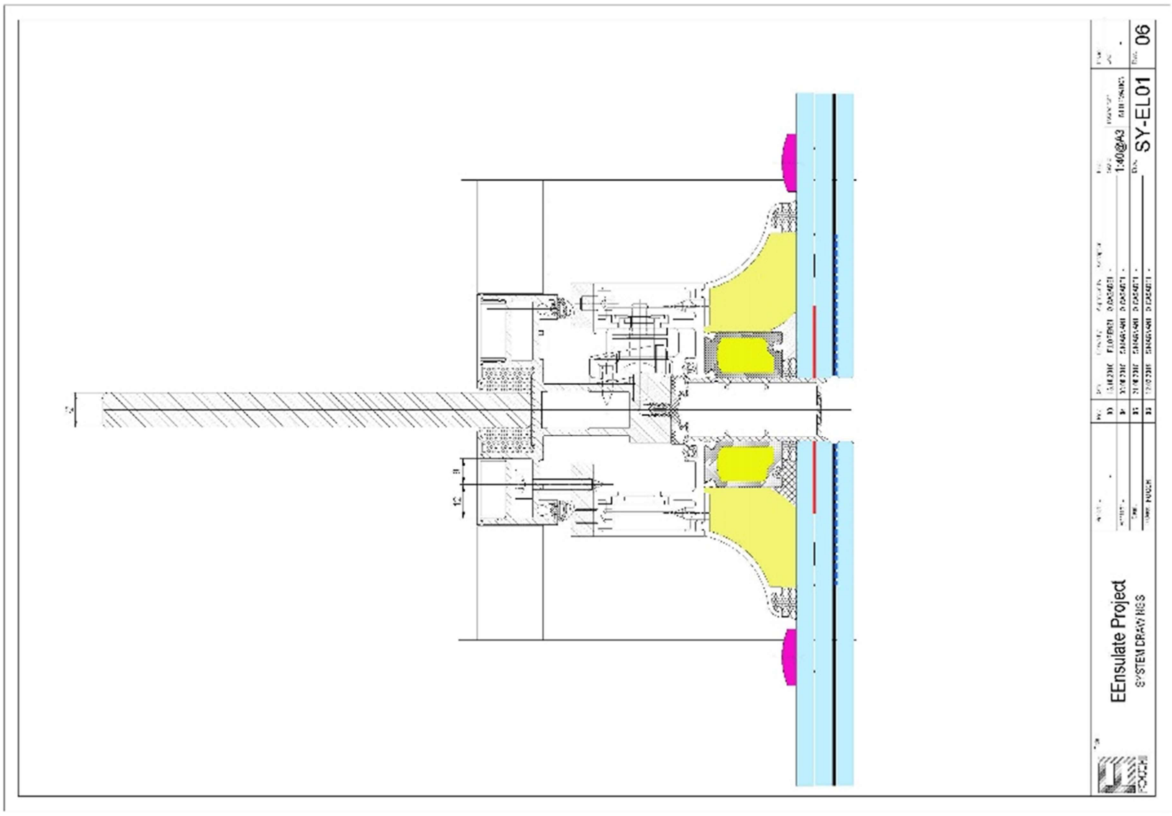


Figure 48: Horizontal section of unit with mechanical restrain – Demo 4

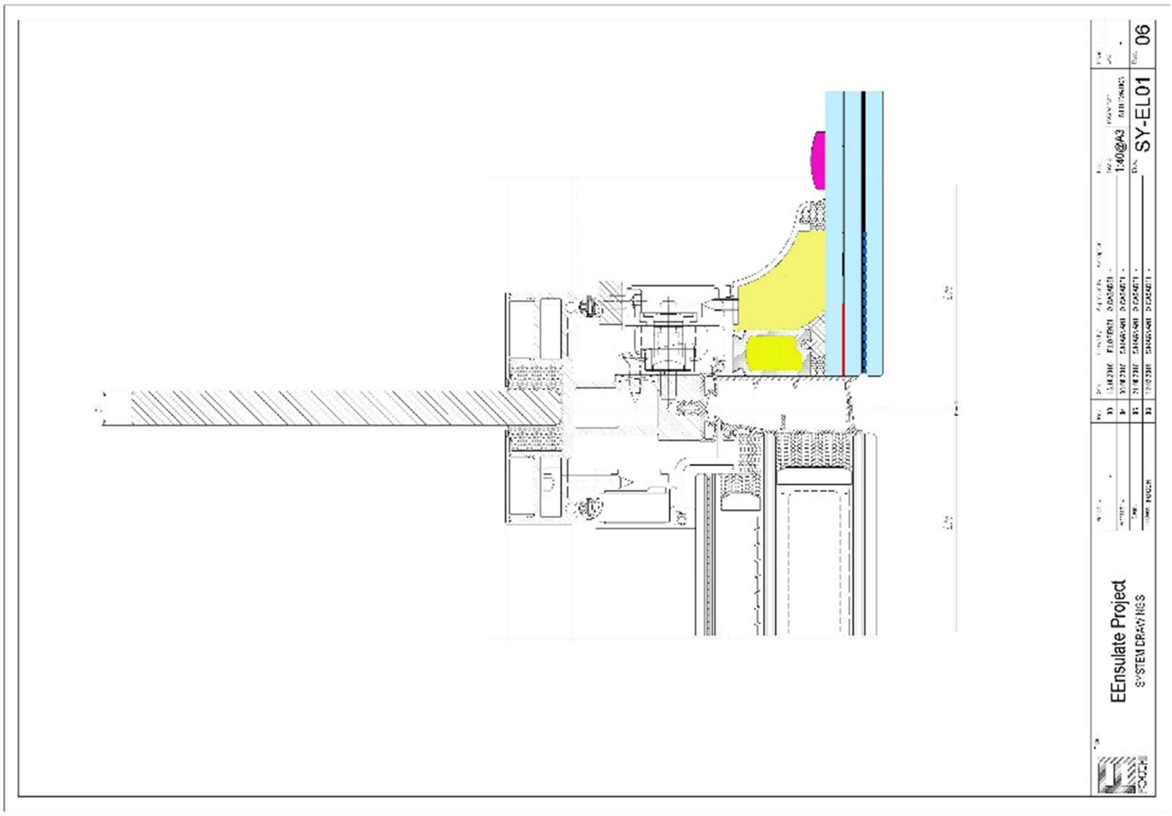


Figure 49: Horizontal section between unit elevation with structural silicon and existing unit - Demo 4

3.4.2.3 Replacement strategy

In case of failure of EENSULATE VIG, the replacement strategy plans to remove the VIG and the new curved profiles and reposition the TGU already existing.

3.4.3 Monitoring design for validation phase

Demo 4 can be monitored in terms of glass transmittance and indoor comfort as Demo 2; the glass chosen for the monitoring is marked in yellow in Figure 50. As for Demo 3, the sensors were installed in Demo 4 and data are available since May 2019.

Figure 50: Focchi Headquarters meeting room monitored

3.4.3.1 Focchi Headquarters monitoring system architecture

The instrumentation installation plan is sketched in Figure 51 while the list of sensors and acquisition modules and their connections are reported in Table 4 and Figure 52.

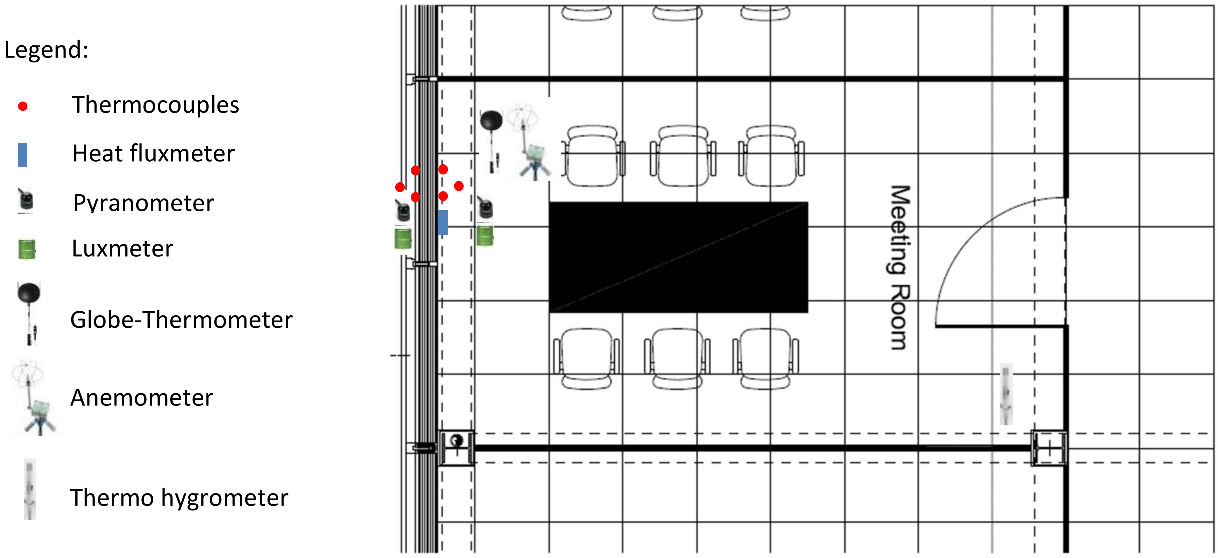


Figure 51: Set-up of the glass transmittance monitoring sensors and comfort instrumentation – Demo 4

Table 4: Sensors list and acquisition/control system components - Demo 4

N°	Sensors	Measurement unit
Thermal transmittance measurement		
6	T type Thermocouples	°C
1	Heat Flux meter Hukseflux HFP-01	W/m^2
Visual and infrared radiation measurement		
1	Pyranometer SP-110-SS, Apogee output 0-250mV	W/m^2
1	Luxmeter SE-100-SS, Apogee output 0-200mV	klux
1	Luxmeter Thermokon Li65	klux
Indoor Comfort		
1	Globe-Thermometer Delta Ohm TP 875.1	°C – RH%
1	Thermo hygrometer Setecna Modbus MB-T	RH% - °C
1	Anemometer Delta Ohm HD4V3TS4	m/s
N°	**Acquisition/control system**	
1	cDAQ-9174 CompactDAQ Chassis (4-Slot)	
1	NI 9213 Spring, 16-ch TC, 24-bit, 75 S/s AI module	
1	NI 9219 4-CH universal module, 24 bit, 100 S/s	
1	Desktop Computer Intel NUC NUC8i3BEK SSD M.2 480GB -RAM Crucial 16GB DDR4-2400 SODIMM	

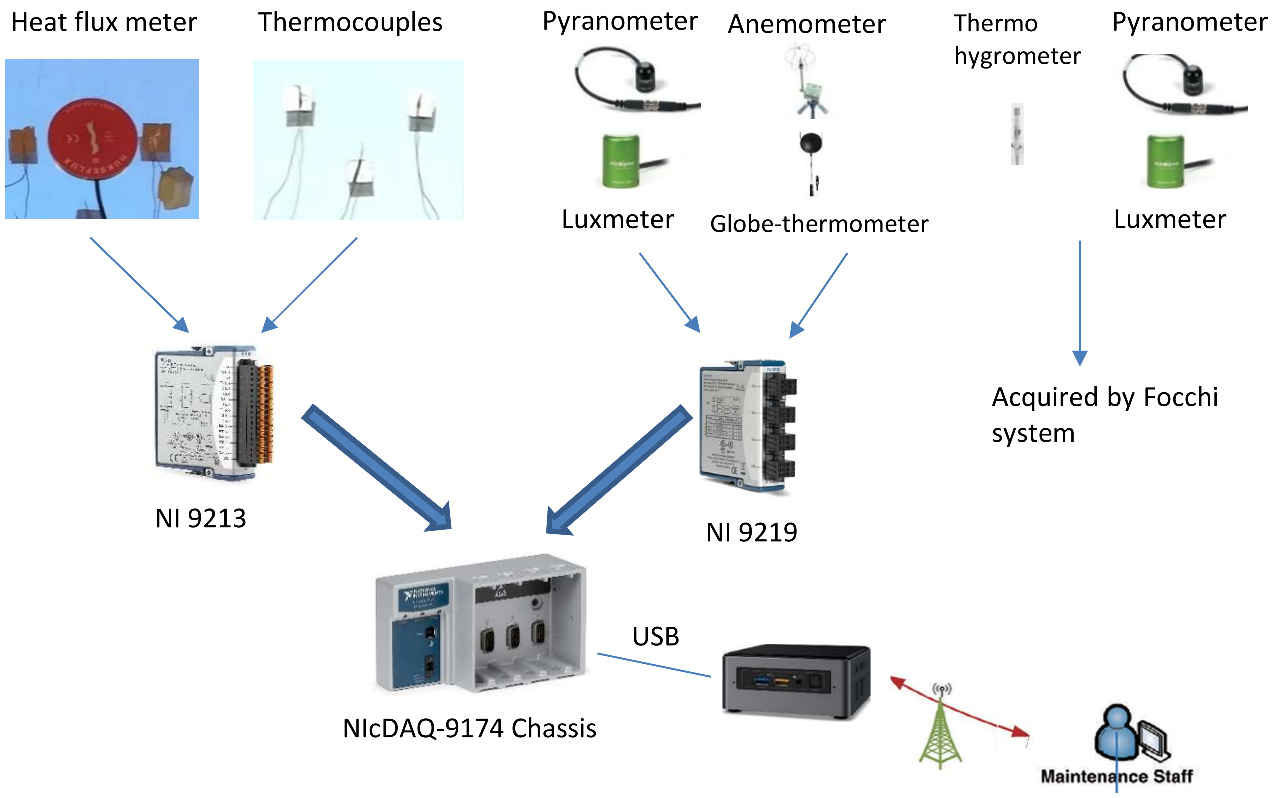


Figure 52: Connections scheme – Demo 4

4 Conclusions

The design of EENSULATE solutions for retrofitting scenarios here presented, demonstrates the wide applicability of EENSULATE components in different building object of retrofitting, proving their scalability and applicability. Some application guidelines can be defined supporting the retrofitting market with EENSULATE components, as summarised below:

- **Retrofitting of Curtain Wall Façade:**
    1. ***Façade replacement –*** EENSULATE module is a solution which seems to be applicable for the replacement of existing Curtain Wall Façade (Demo 1). Indeed, the EENSULATE module is a lightweight solution able to not improve the weight on the load bearing structure of the building but able to increase the energy performance. The profile color of the EENSULATE module can be customized to meet specific architectural needs.
    2. ***Existing glass replacement –*** EENSULATE VIG is a solution which is applicable for the replacement of other glazed elements in Curtain Wall Façade (Demo 4). The adoption of the EENSULATE VIG is possible with minor changes in Curtain Wall system and with the adoption of a curved profile to mitigate thermal bridge. Moving from TGU and VIG (Demo 4) and *viceversa* (Demo 1 replacement strategy) guarantee the application of EENSULATE VIG.
- **Retrofitting of Windows**
    1. ***Historical window –*** EENSULATE VIG is a solution which seems applicable for the replacement of historical glass with improvement of energy transmittance without affecting the overall configuration of the window.
    2. ***Contemporary window –*** EENSULATE VIG is a solution which seems applicable for the replacement of DGU/TGU in existing window with improvement of energy transmittance without affecting the overall configuration of the window.

The next EENSULATE steps will move from retrofitting design to the validation of Demo1 – Polish Primary School, Demo2 – Polish Museum and Demo 3 – San Giovanni Public Library in the real environment.

5 Annex 1 Monitoring system and acquisition protocol design

Since the beginning of the project UNIVPM has worked on the design of the monitoring system in order to define:

- the parameters to be monitored
- the sensors to be installed
- the acquisition system to be employed.

To this aim a preliminary measurement chain was set-up and installed in the Focchi mock-up illustrated in Figure 52, by employing sensors available at UNIVPM laboratory and Focchi facility. The list of the sensors is reported in

Table 5. Two glazed systems and a wall of the mock-up were instrumented with thermocouples and heat flux meters to measure the thermal transmittance. The radiation energy entering the room was measured via four pyranometers, one placed outdoor close to the first glazed system and two placed indoor close to both the glazed systems and one placed in the middle of the room. The visible radiance was measured by a luxmeter located in the center of the room. The indoor comfort was assessed by calculating the quantitative indicator called PMV (Predicted Mean Vote) derived from the measurement of mean radiant temperature, relative humidity and air velocity at two nodes in the room. The monitoring of two zones inside the room had the objective of verifying if comfort inhomogeneity occurred. The room was therefore ideally divided into a lower and an upper zone. The mean radiant temperature, relative humidity and air velocity in the two zones were measured by two globe-thermometers, two thermo hygrometers and two anemometers. To monitor energy consumption, the power absorbed by the HVAC system installed in the mock-up was measured. The sensors, acquisition and control components list and installation scheme are detailed in Table 5 and Figure 54.

Figure 53: Focchi mock-up demo

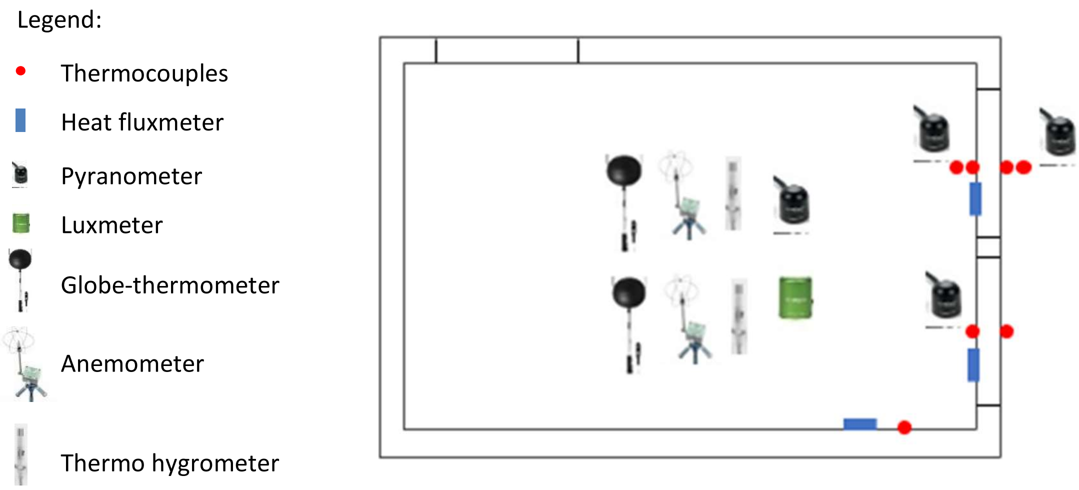


Figure 54: Set-up of the glass transmittance monitoring sensors and comfort instrumentation – Focchi mock-up demo

Table 5: Sensors list and acquisition/control system components - Focchi mock-up demo

N°	Sensors	Measurement unit
Thermal transmittance measurement		
7	T type Thermocouples	°C
3	Heat Flux meter Hukseflux HFP-01	W/m^2
Visual and infrared radiation measurement		
4	Pyranometer LP PYRA 03 AV Delta Ohm	W/m^2
1	Luxmeter LP PHOT 03BLAV Delta Ohm	klux
Indoor Comfort		
2	Globe-Thermometer DELTAOHM TP 875.1	°C – RH%
2	Thermo hygrometer HD 9008TR2 DeltaOhm	RH% - °C
2	Anemometer Delta Ohm HD4V3TS4	m/s
Energy consumption		
1	Power meter FEMTO ECT RJ45 D6	W
N°	**Acquisition/control system**	
1	Keysight 34972A, 3-slot mainframe with USB and LAN, 22-bit, scanning up to 250 channels per second	
1	Keysight 34901A 20-Channel Armature Multiplexer Module, 60 ch/s scanning	
	LabJack T7 PRO	

1	Portable Computer Sony Vaio

A preview of the data recorded in the week from 8th to 15th January 2018 is reported in Figure 55, Figure 56 and Figure 57.

Figure 55 shows the trend of:

- temperature measured on the first glazed system surfaces indoor (Tg1 in) and outdoor (Tg1 out) in the top plot
- temperature measured on the second glazed system surfaces indoor (Tg2 in) and outdoor (Tg2 out) in the middle plot
- indoor air temperature measured in the middle of the room (Tair room), close to the wall (Tw in) and close to the first glazed system (Tair in) and the outdoor air temperature measured close to the first glazed system (Tair out) in the bottom plot.

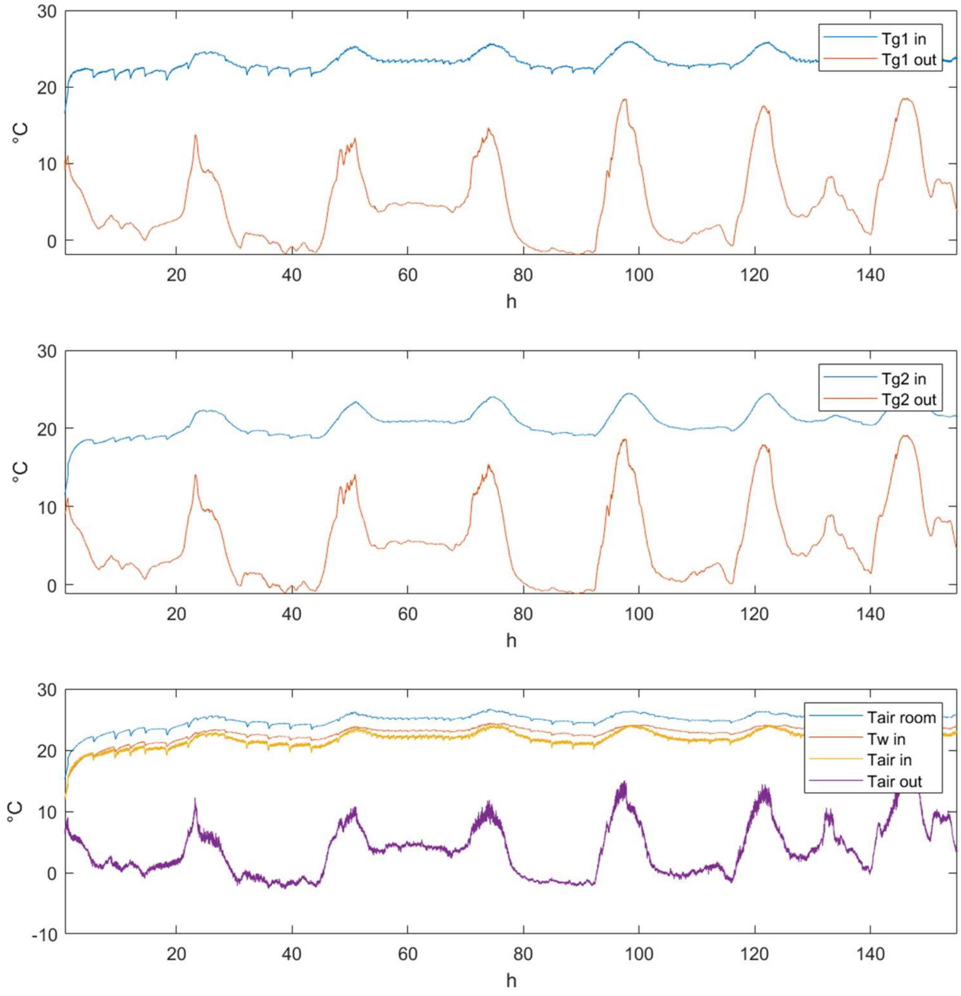


Figure 55 Raw temperature data – week 8-15th January 2018

Figure 56 shows the trend of:

- heat flux through the glasses (HF1 for the first glazed system and HF2 for the second one) in the first plot
- solar irradiance entering the room measured in the middle of the room (SI room) and close to the two glazed systems (SI1 and SI2) in the second plot
- visible irradiance measured in the middle of the room (Lux room) in the third plot
- relative humidity measured in the middle of the room in the fourth plot

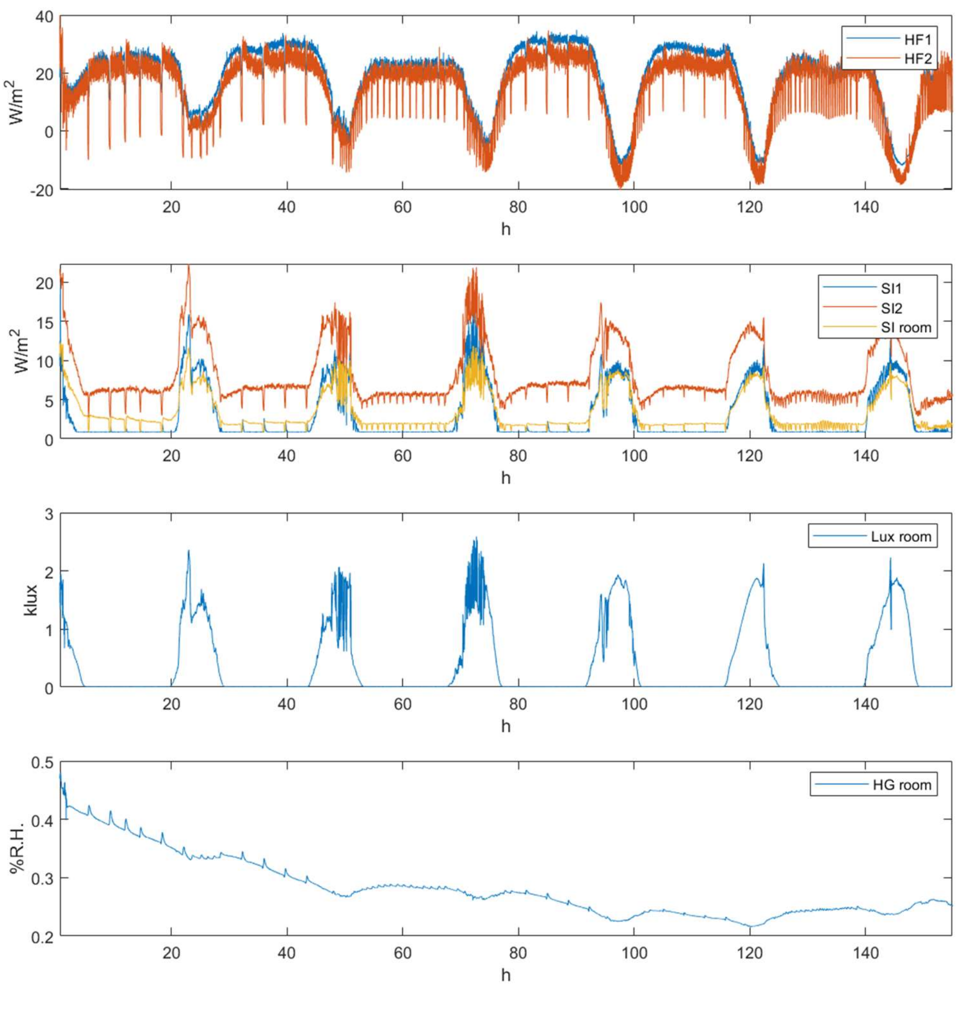


Figure 56 Raw data in terms of heat flux through the glass, solar irradiance entering the room, visible irradiance and relative humidity – week 8-15th January 2018

Figure 57 shows the trend of:

- heat flux through the wall (HFw in) in the first plot
- solar irradiance measured outdoor (SI out) in the middle plot
- active power absorbed by the HVAC system in the bottom plot

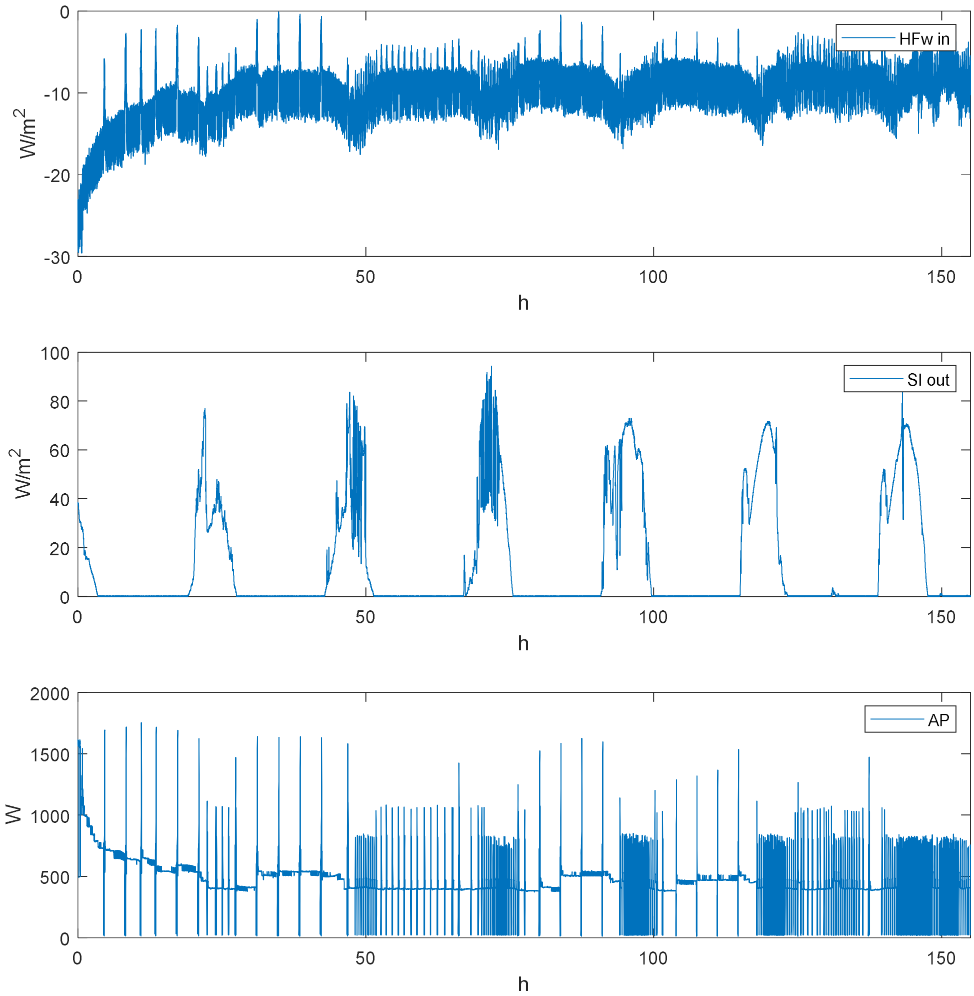


Figure 57 Raw data in terms of heat flux through the wall, outdoor solar irradiance and active power absorbed by the HVAC system – week 8-15th January 2018

The thermal comfort level perceived inside the room and specifically in the two zones monitored was estimated using the PMV that is a function of the indoor air temperature, the mean radiant temperature, the air velocity, the water vapor partial pressure obtained from the relative humidity measurement, the clothing insulation, and the metabolic rate. The last two parameters were set to 0.7 and 1.2 respectively. In fact, 1.2 is the metabolic rate for a typical sedentary activity (office, dwelling, school, …) and 0.7 the clothing insulation associated to a person wearing a business suit. The PMVs calculated for the two zones (PMV inf and PMV sup) are plotted in Figure 58, together with the recommended limits (-0.5<PMV<+0.5) defining the comfort zone.

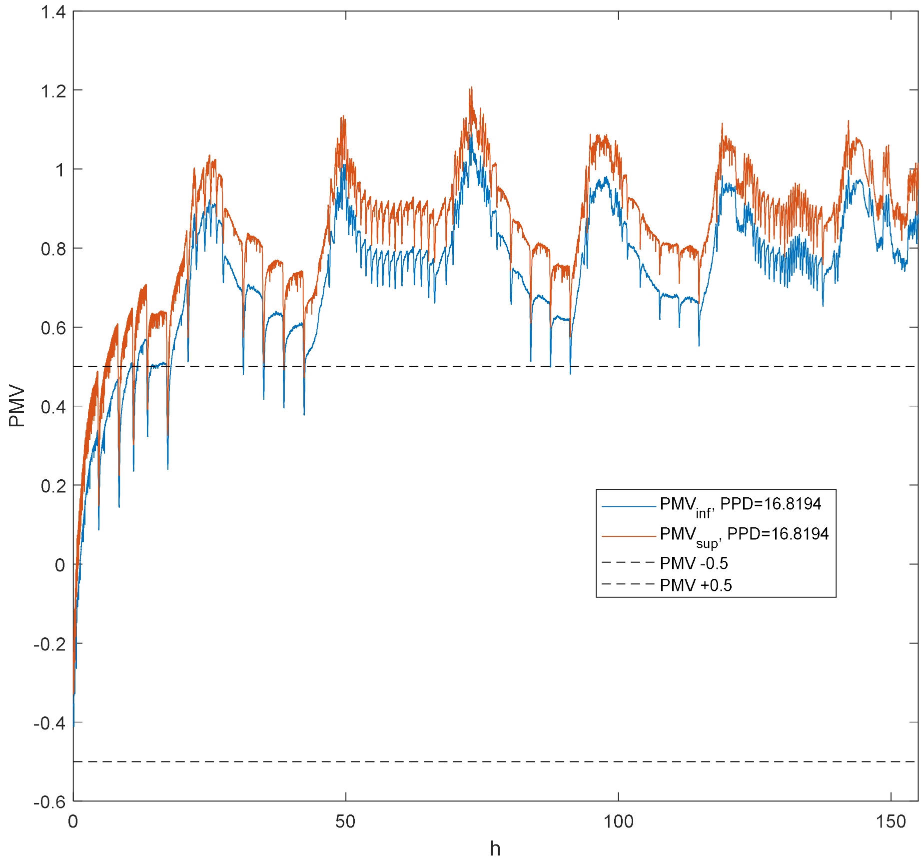


Figure 58 PMV measured in the rooms (upper and lower zone) and comfort limits (dashed line)