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Deliverable

ENVELOPE MATERIAL SYSTEM WITH LOW IMPACT FOR ZERO ENERGY RENOVATION AND CONSTRUCTION

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Deliverable description	*Test design and experimental techniques for these kinds of products, including a description will be described in this report. This cover results from the simulations run in task 5.2, linked with virtual tools usually used in the construction sector (for industry and customers) with complete scenarios (meteo, energy grid...).*

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Glossary

CEA	Commissariat à l'énergie atomique et aux énergies alternatives (project partner)
DTI	Dansk Teknologisk Institut (project partner)
SINTEF	Stiftelsen for industriell og teknisk forskning (project partner)
USTUTT	University of Stuttgart (project partner)

1. Executive summary

1.1 *Description of the Deliverable content and objectives*

This deliverable provides practical guidelines for the design and execution of experimental tests applied to novel bio-based and recycled insulation materials developed within the EASI ZERo project.
The primary objective of this document is to support researchers, laboratories and industry partners in planning and conducting a reliable experimental campaign for innovative products of this type. The deliverable covers key aspects of test design and interpretation of results, presenting relevant parameters in accordance with standards.
The guidelines are grounded in the experimental work carried out within EASI ZERo at multiple partner facilities, both in controlled laboratory environment and outdoor test facilities. Results and lessons learned, including practical difficulties encountered and solutions adapted, are synthesised into transferable recommendations applicable beyond the project context, supporting the broader adoption of low-carbon bio-based insulation products in the construction sector.
This deliverable is closely linked to D4.2, where detailed description of the wall-assembly and experimental facility are provided, and D5.3 and D5.4 where are described respectively the work conducted with simulation tools and the deeper description of the data acquired and the results obtained in terms of key indicators.

1.2 *Scope of the deliverable*

This deliverable addresses the experimental characterisation of novel bio-based and recycled building envelope materials developed within the EASI ZERo project, with a focus on thermal performance testing at material and wall assembly level. It covers both laboratory and outdoor testing campaigns conducted across partner institutes and provides guidelines applicable to this category of innovative products.

The scope includes:

- the design of test campaigns for new insulation products, from the definition of boundary conditions to the selection of measurement protocols and instrumentation;
- the characterisation of thermal performance, including U-value/R-value calculation in accordance with EN/ISO standards (EN 12667:2001, ISO 9869-1:2014);
- the connection between experimental results and simulation models;
- lessons learned from the testing activities carried out within EASI ZERo, including practical constraints related to the development timeline of novel products and the requirements of outdoor long-duration measurements.

Experimental results from the testing campaigns are reported separately in D5.4 and are not included in this document.
This deliverable does not cover the detailed description of wall assemblies, which is addressed in D4.2. It is likewise not intended as a comprehensive review of simulation activities and simulation results within the project.
The guidelines presented here are intended to be transferable beyond the EASI ZERo context, serving as a reference for researchers and industry partners working with similar innovative insulation products in future projects or standardisation efforts.

1.3 *Relation with other deliverables*

This deliverable is part of Work Package 5 - Performance evaluation in test environments. It should be read in conjunction with other related outputs of the EASI ZERo project, in particular:

- D4.2 “Prototypes and wall combination proof of concept”: provides the detailed description of the wall assemblies tested within the project. Readers are referred to D4.2 for specifications on material layering and other characteristics of the tested wall assemblies.
- D5.3 “Numerical code for simulations”: provides the numerical codes for the simulations, information on the parameters used, input and output of the numerical models.
- D5.4 “Experimental data” extensively reporting the results of the measurement campaigns carried out within WP5 together with a description of the walls, sensors and boundary conditions applied.

1.4 *Document structure*

The document is organised into three main parts. Section 2 constitutes the technical core of the report and is divided into six subsections. Section 2.1 provides a brief overview of the products and wall assemblies tested within the project. Section 2.2 describes the experimental facilities involved in the campaigns. Section 2.3 presents the test design guidelines, covering the criteria for facility and test selection, the definition of boundary conditions, and the approach to test duration. Section 2.4 describes the specific experimental setup adopted at each of the four facilities, including instrumentation and data acquisition. Section 2.5 addresses the calculation of thermal transmittance and thermal resistance. Section 2.6 describes how the experimental data feed into the simulation and modelling activities of Task 5.2.
Section 3 presents the lessons learned from the experimental campaigns, organised thematically across four areas: project and timeline planning, facility selection and preparation, boundary conditions and test design, and sensor placement and instrumentation. Section 3.5 discusses the transferability of these lessons to future projects and standardisation efforts.

1.5 *Deviation from objective, corrective actions*

All the measurements were conducted according to the plan prepared within WP5.

The description of this deliverable as stated in the Grant Agreement does not fully reflect the activities and outputs associated with it. The work carried out under this document consists of the description of the guideline and transferable lessons learned for testing novel material such as those developed in EASIZERo. The results of the experimental campaigns are reported in D5.4. These results were intended to be used, and were indeed used, to validate the numerical model carried out in T5.2 and reported in D5.3, since the inclusion of new materials in the numerical simulation required a validation against experimental results. This connection may not be clearly conveyed in the original deliverable description. The discrepancy is likely attributable to a misalignment between different versions of the documents during the preparation phase and does not affect the substance or relevance of the work carried out, which remains fully consistent with the overall objective of WP5.

1.6 *Dissemination activities*

Dissemination activities were conducted in the framework of the associated task, specifically task 5.2, in which the dataset acquired was used to validate the numerical models developed and which was disseminated in 1 conference paper (published) and one journal paper accepted with minor review. The dataset is also used in a conference paper associated with task 5.3, which was recently presented at a conference and will be published in the conference proceedings.

2. Technical content

2.1 *Products and assemblies under testing*

The experimental campaigns carried out within EASI ZERo involved the whole range of novel products developed by the industrial partners of the consortium

The products were tested as part of complete wall assemblies, whose composition and layer configurations are described in detail in D4.2. The present deliverable does not reproduce those descriptions, and the reader is referred to D4.2 for full specifications of the assemblies tested at each facility.

2.2 *Experimental facilities*

The four experimental facilities used within EASI ZERo are operated by research partners distributed across different European climate zones. The facilities include two outdoor test cells, the Passys cells facility at CEA (France) and the ZEB Test Cell at SINTEF (Norway), and two laboratory-based facilities operating under controlled conditions: the EOTA wall test facility at USTUTT (Germany) and the climate simulator at DTI (Denmark). Figures 1-4 show a synopsis of the facilities.

Detailed descriptions of the facilities, including their technical specifications and instrumentation infrastructure, are reported in D4.2. The present deliverable focuses on the experimental setup adopted at each facility for the specific campaigns carried out within the project, as described in Section 2.4.

A recap of the main characteristics of each facility is reported in Table 1.

Facility	Partner	Type	Location	Climate
PASSYS Test cells	CEA	Outdoor	Chambery, France	Temperate continental/alpine (Cfb)
ZEB Test Cell	SINTEF	Outdoor	Trondheim, Norway	Cold humid (Dfc)
EOTA wall test facility	USTUTT	Laboratory	Stuttgart, Germany	-
Climate simulator	DTI	Laboratory	Copenhagen, Denmark	-

Table 1: the four facilities used



Figure 1 The PASSYS cell facility at CEA



Figure 2 The ZEB Test Cell facility at SINTEF



Figure 3 The EOTA wall test facility at USTUTT



Figure 4 The climate simulator at DTI

2.3 *Test design guidelines*

This section provides guidelines for the design of experimental campaigns aimed at characterising the thermal performance of novel insulation products, developed in the EASI ZERo project. The guidelines cover the main decisions that need to be made before and during a test campaign: the selection of the appropriate test setup, the definition of boundary conditions, the determination of test duration, and the placement of sensors. Where relevant, practical difficulties encountered

during the project are highlighted, as these constitute useful reference points for researchers and industry partners planning similar campaigns in the future.

2.3.1 Criteria considered for test selection

The assignment of products to test facilities was guided by three main considerations. The first was the nature of the test required and the type of infrastructure available within the consortium. The allocation of assemblies to research facilities was therefore driven by this distinction, with logistical considerations, such as the proximity between the industrial partner producing the material and the research facility hosting the test, also playing a role in facilitating the delivery and mounting of novel assemblies still under development at the time of testing. Beyond logistical aspects, the choice of test type was also driven by the specific properties and sensitivities of each product: different materials respond differently to environmental variables, and the selected test setup needed to be capable of capturing the phenomena most relevant to the product's performance and intended use.
The second consideration was the compatibility between the product and the test facility itself. In some cases, structural or dimensional constraints of the facility imposed additional limitations on which products could be tested.
The third consideration was the climatic relevance of the facility location with respect to the target market of the product. Where possible, products were tested in a climate representative of the conditions in which they are intended to be used to obtain performance data under realistic boundary conditions. As a result, different products were distributed across facilities located in different European climate zones.
The test walls were also defined with reference to the Use Cases involved in WP6. To represent retrofitting actions, the wall tested at CEA (France) had a similar structure to that of initial Use Case 2[4], while the wall tested in SINTEF (Norway) was comparable to the walls of the upper floor of Use Case 3.
In some cases, when feasible, the same product was tested in more than one facility, allowing for cross-comparison of results obtained under different climatic and experimental conditions.

2.3.2 Boundary conditions

The definition of boundary conditions is a critical aspect of test design, as it directly affects the quality and reliability of the thermal performance measurements. In the project, we used two outdoor facilities and two laboratory-based facilities.

Concerning the CEA Passys cells, the test walls are exposed to outdoor climate on one side, and indoor environment on the other side. The cells are on rotating platforms, so the tested walls could be oriented alternatively to the South and North direction, allowing for testing the façades in various

[4] The Use Case that served of example has in between been changed as described in amendments

solicitations. A weather station records the most relevant parameters on the test site. The interior climate was either heated or cooled at a constant set-point or let free floating.

At the SINTEF ZEB Test Cell in Trondheim, the external boundary conditions were determined by the outdoor climate and required no specific control measures. The climate conditions were registered by a weather station mounted on the roof of the facility. An additional pyranometer registered the solar radiation impinging on the façade. The indoor conditions were fixed and controlled in temperature. The relative humidity of the indoor environment was kept as stable as possible; however, the removal of excess humidity was not possible through the control system. The indoor setpoints are reported in Section 2.4.2. The test setup is shown in Figure 7 and Figure 8.

At the USTUTT EOTA test facility, located at the University campus complex in Stuttgart, Germany, the test setup is located inside a closed building structure. Therefore, conditions around the test rig were only indirectly influenced by outside weather conditions, with the inside of the hall heating up significantly during summer, when the test procedure was performed. To account for and measure those fluctuations over time, sensors were installed on the inside and outside of the test chamber, measuring hygrothermal conditions on the surfaces as well as air temperatures close to the test rig, with sensor positions mirroring each other on the respective sides of the wall. This was especially necessary for U-value determinations, since the difference in temperatures between inside the chamber (Te) and outside the chamber on the hall side (Ti) directly influences the calculation of U-values. The test chamber itself is connected to a climate conditioning aggregate capable of reaching temperatures above 70°C and below -20°C, as well as applying artificial rain at a known rate (1.5 l/m²min) to the inside surfaces. For a more detailed overview of the experimental setup, see chapter **Erreur ! Source du renvoi introuvable.**.

The DTI climate simulator is situated in the basement of the DTI facilities in Aarhus. It consists of a half-open climate chamber, where the open side can be closed by a test wall. The inside climate conditions inside the chamber can be programmed, in terms of temperature and relative humidity, from -20°C to 40 °C, and RH from 10 % to 95%, including the ability to apply a water spray.
The outside of the test wall is exposed to the indoor conditions of the facility basement, which can be affected by the outdoor weather. To minimize this effect and create a stable humid “indoor” climate, a tent was constructed with humidifiers set to a fixed humidity of 60%RH. Furthermore, the temperature and humidity were recorded with sensors on both sides of the test wall (climate chamber and basement side).

2.3.3 Test duration

The approach to test duration differed significantly between outdoor and laboratory facilities, reflecting the different nature of the boundary conditions and the measurement objectives in each case.

For outdoor facilities, the primary objective was to capture the thermal behaviour of the wall assembly across a full range of seasonal conditions. This requires exposure to the natural variation of the outdoor climate over an extended period. For this reason, the campaigns at the SINTEF ZEB Test Cell and the CEA Passys facility were designed to run for the longest duration feasible within the project timeline and the actual availability of the facilities.

For laboratory facilities, test duration was primarily determined by the specific test protocol adopted at each facility, rather than by seasonal or climatic considerations. Since boundary conditions are controlled on both sides of the assembly, stable and repeatable measurement conditions can be achieved within shorter and more predictable timeframes. The specific durations adopted at USTUTT and DTI are reported in Sections 2.4.3 and 2.4.4 respectively.

A constraint affecting test duration in both cases, and particularly for outdoor campaigns, is the sequential nature of the workflow when working with novel products under development. Materials need to be produced by the industrial partners, shipped to the test facilities, and wall assemblies need to be mounted and stabilised before measurements can begin. This process reduces the time available for the actual measurement campaign within the project duration. This aspect is further discussed among the lessons learned.

The specific phases and durations of each experimental campaign are reported in the respective facility sections (2.4.1–2.4.4).

2.4 *Experimental setup and facilities*

The experimental campaigns were carried out across four facilities at four different institutes. Two of these are outdoor facilities exposing the test assemblies to real climate conditions, the PASSYS Cell at CEA (France) and the ZEB Test Cell at SINTEF (Norway). The other two, the EOTA wall test facility at USTUTT (Germany) and the climate simulator at DTI (Denmark), are laboratory facilities operating under controlled conditions.

The measurements were conducted independently at each facility, reflecting the specific products and assembly configuration requirements. In some cases, some products are part of more than one assembly. The following subsections describe the specific experimental setup adopted at each facility, including instrumentation, data infrastructure, and measurement protocol.

2.4.1 Experimental setup in Passys cells



Figure 5 PASSYS cell: internal view of the unrefurbished wall during the construction phase



Figure 6 PASSYS cell: internal view of the refurbished wall during the construction phase

Two test cells were used simultaneously, with the same orientation, in order to compare a base wall and a retrofitted wall. The experimental set-up consists, for each test cell, of a test wall under investigation, installed as one external wall of a climate chamber (cfr Figure 5 and Figure 6). The other walls are highly insulated. The climate chamber can be conditioned so that the test wall is subjected on one side to controlled temperature, and on the other side to outdoor climate. The Passys cells can be rotated so that the test wall can face any orientation.

The base wall consists of a typical French construction, with exterior coating, hollow concrete blocks, small polystyrene insulation and gypsum board. It serves as a reference. The retrofitted wall has the same structure, where, in addition the EasiZero developed Bio-PUR sprayed foam was applied on the interior side. Then a gypsum board is added for aesthetic purposes.

Both walls comprise a window equipped with a blind box. In the retrofitted wall, the window is the EasiZero Bio-PUR frame, and the blind bow is a wooden blind box. At the end of the campaign, a PCM-wooden blind box was added to the base wall.

The measurement campaign ran from January 2025 to January 2026, including heating, cooling and free-floating scenarios. The blinds were also alternatively closed or open.

Sensors were placed in the test cell as well as on and within the test walls, including thermocouples and heat fluxmeters.

More details are given in D5.4 datasets on wall construction, sensor positioning and scenarios.

2.4.2 Experimental setup in SINTEF ZEB Test Cell

The experimental campaign was designed to characterise the behaviour of a timber-frame external wall under controlled indoor conditions, both in its original non-refurbished configuration and following an interior insulation upgrade. The primary objectives were threefold: to assess the effect of the refurbishment on the moisture and heat transfer across the wall assembly; to generate a comprehensive pre/post dataset enabling a direct comparison of wall performance under equivalent boundary conditions; and to contribute high-quality in-situ measurement data to a

European database of monitored building envelopes, to be used by project partners for the validation of hygrothermal simulation models.

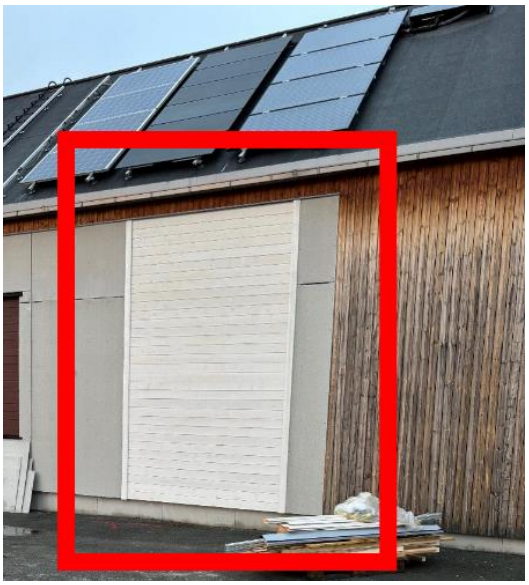


Figure 7 The test facade at the ZEB Test cell: external view



Figure 8 The test facade at the ZEB Test Cell: internal view during the construction phase

The ZEB Test Cell Laboratory is an outdoor experimental facility located at the NTNU Gløshaugen campus in Trondheim, Norway (63.42° N, 10.40° E). The site is representative of a cold Scandinavian climate (Köppen class Dfb), characterised by extended cold winters with outdoor temperatures regularly falling below −10°C, moderate summer temperatures, and persistently high relative humidity levels throughout the year.

The facility consists of two identical, fully independent test cells, each with one surface of the cell envelope exposed to real outdoor boundary conditions through a south-facing façade, while the remaining five surfaces are surrounded by a thermally guarded volume. The indoor air conditions of both the test cells and the guarded volumes can be independently controlled. The primary purpose of the facility is to test building envelope components, including insulation materials, cladding systems, and façade solutions, under realistic climatic conditions.

The wall assembly tested was built making use of the innovative wood fibre insulation product developed by Hunton Fiber in the framework of the project. Further information on the wall assembly prototype is reported in deliverable D4.2.

	Period	Wall configuration	Indoor setpoint
Phase 1	01/01 – 31/05	Non-refurbished	20°C / 40% RH
Phase 2	03/04 – 17/05	Refurbished	20°C / 40% RH
Phase 3	19/05 – 20/10	Refurbished	20°C / floating RH

Table 2 Experimental phase in the campaign at SINTEF facility

The campaign was structured in three consecutive phases, spanning from January to October 2025, to capture both winter and warm-season conditions. In Phase 1 (January–March 2025), the wall was monitored in its original non-refurbished configuration (Figure 7 and Figure 8), with the indoor environment maintained at a setpoint of 20°C and 40% relative humidity. This phase provided the baseline hygrothermal performance of the assembly under cold winter conditions. The refurbishment, consisting of the addition of a 50 mm interior insulation layer between the gypsum board and the existing vapour retarder, was carried out in early April 2025 during a brief interruption of the measurements. Phase 2 (April–May 2025) resumed monitoring of the refurbished wall under the same indoor setpoint of 20°C and 40% RH, allowing a direct comparison with Phase 1 under similar seasonal conditions. Phase 3 (May–October 2025) maintained the refurbished configuration but raised the indoor setpoint to 30°C [2].

Sensors were deployed at the interfaces between the main functional layers of the wall (gypsum board, vapour retarder, insulation, and wind barrier) at three heights (0.2 m, 1.225 m, and 2.25 m above floor level) to account for potential vertical gradients. Temperature (type T thermocouples), relative humidity (capacitive sensors), and heat flux (heat flux plates) were measured simultaneously at each monitoring point, providing a spatially always resolved picture of the hygrothermal state of the assembly. Outdoor boundary conditions were recorded by a weather station mounted on the roof of the facility.

2.4.3 Experimental setup in USTUTT EOTA wall test facility

The experimental setup for the hygrothermal testing of the materials developed within the scope of EZ0 was planned and executed at the materials testing facility (MPA) on campus at the University of Stuttgart, Germany (USTUTT) in accordance with EN 16383. This standardized test is designed to evaluate the hygrothermal performance of insulation materials by exposing them to harsh, artificial climatic conditions over time within realistic wall assemblies, documenting damages or changes in material behaviour throughout the testing regime.

The setup consists of two opposing wall sections (4.00m wide, 2.10m high), each consisting of two sections with one reference wall assembly and one experimental wall assembly. Wall 1 contained PCM-filled bricks, with wall 2 containing mineral-wool-filled bricks for reference. The hollow bricks of wall 3 were coated with the EZ0 aerogel insulation render, while the bricks on wall 4 were coated with a reference insulation render by the same manufacturer (see Figure 9). For further details on the wall assemblies, see D4.2.

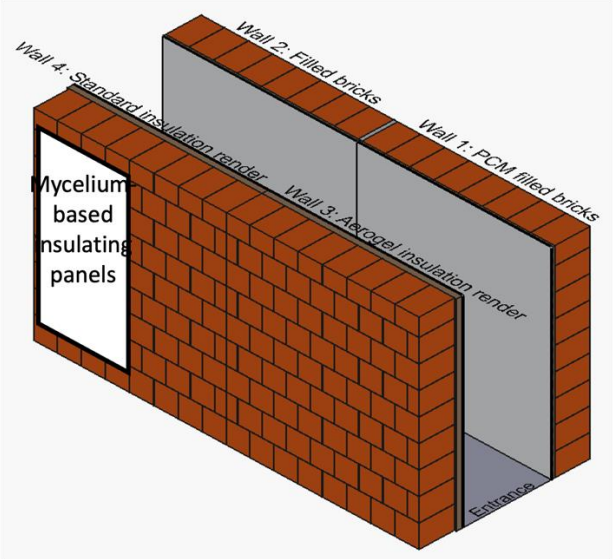


Figure 9 Description of the experimental layout at the EOTA test wall facility

Those wall assemblies were planned and built in a state-of-the-art manner, representing walls that could be built on an actual construction site. Onto those walls, a ceiling element was set, as well as a back and front wall segment, the latter of which contained a door for simple access during the test. This created an enclosed chamber with the two opposing walls having all relevant layers applied on the inside surface. Inside this chamber, diverse climate conditions (heat, cold, rain, frost-thaw-events) were induced artificially in regular cycles with conditioning periods in between over a duration of over two months.

Due to the experiment being conducted during the summer, higher temperatures within the hall containing the test rig were prevalent. However, due to measurements of the air conditions, this challenge was manageable, only resulting in a higher energy demand by the climate conditioning aggregate regulating climate conditions within the chamber during cooling periods. The chamber-sided surfaces were regularly investigated with a black-light torchlight to search for visible cracks and other damage.

Hygrothermal conditions throughout the wall assemblies (heat flux through the walls, air conditions inside and outside, conditions below and above render layers, as well as hygrothermal conditions on the surfaces on the inside and outside) were constantly monitored by a wide range of sensors. Data was collected and saved by multiple data logger devices in regular time steps between 10 seconds and 5 minutes, depending on the sensor type. Sensor malfunction was a rare but still occurring problem, resulting in a slightly reduced dataset as the test progressed. In addition to hygrothermal parameters, horizontal deformation on the surface of the wall assemblies was monitored by a total of eight fibre-optic deformation sensors. A frequent challenge with these sensors was the detachment of anchor plates from the surface due to high strain stress and the harsh climatic conditions they were exposed to. This resulted in a reduced dataset in this regard as well.

2.4.4 Experimental setup in DTI climate simulator

The DTI climate simulator test setup is a half-open climate chamber designed for weathering testing of a complete building envelope, with a focus on durability under stress from accelerated weathering cycles. For the EASI ZERo project, the test focused on the dynamic hygrothermal properties of the EASI ZERo products. The open side of the climate chamber was closed with the EASI ZERo wall element, consisting of a wood-based construction. The EASI ZERo products included were wood fibre insulation from Hunton and mycelium acoustic panels from SQIM. The wall did not include a dedicated moisture barrier membrane, but only an OSB-type board towards the inside. Towards the outside, the wall was protected by a treated solid wood façade with a ventilated cavity against a wind board from Hunton.



Figure 10 The DTI climate simulator during the measurement phase

At each interface, a sensor recording temperature and relative humidity was installed. The sensor setup was a custom-build setup acquisition system, based on Arduino. Data was recorded every 6 seconds.

The experimental conditions were a seasonal campaign, running at a fixed temperature and RH, using the average conditions for a Danish season. First summer (16.1 °C, 70% RH), then Autumn (9.5 °C, 85% RH), and finally winter (7.3 °C, 76% RH). The first two seasons were run for 1 month, at which point all parameters were stable. Unfortunately, the climate chamber had a major malfunction early in the winter campaign, so stable conditions were not reached.

2.5 *Calculation Methods*

The thermal transmittance (U-value) and thermal resistance (R-value) of the wall assemblies were determined from the experimental data following the procedures defined in ISO 9869-1:2014 [1]. The average method described in the standard was applied.

Prior to the calculation, a selection of valid measurement periods was performed.

The average method calculates the U-value by dividing the mean heat flux density over the selected period by the mean indoor-outdoor temperature difference.

Both the U-value and the R-value were calculated for each assembly. The experimentally determined values were subsequently compared with the theoretical thermal transmittance. This comparison provides an indication of the consistency between the designed and measured thermal performance of the assembly and serves as input for the validation of simulation models within the project, as described in Section 2.6.
All calculations were performed using in-house tools developed specifically for this purpose.

2.6 *Contribution to the simulations (T5.2)*

The experimental campaigns described in this deliverable provide the primary data input for the simulation and modelling activities carried out within Task 5.2 of the EASI ZERo project, which is led by SINTEF. The connection between experimental measurements and simulations follows a one-directional flow: raw measurement data collected at the test facilities are transferred to the simulation teams.
The simulation work focuses exclusively on the thermal performance of the wall assemblies.
The simulation tools used within T5.2 are EnergyPlus and IDA ICE, both of which are widely used in the building energy modelling community. The experimental measurements and associated boundary condition data serve as a reference against which the outputs of these models are validated. The objective of the task in the project framework is to provide a validated numerical model of the novel products developed in EASIZERo.
A more detailed description of the simulation process, including the modelling assumptions, validation methodology, and results, is provided in the deliverable D5.3.

3. Conclusions

This section synthesises the practical experience gained during the experimental campaigns carried out within EASI ZERo, with the aim of providing transferable guidance for researchers and industry partners planning similar testing activities in future projects. The lessons learned are organised thematically, covering project planning, facility selection, test design, and instrumentation.

3.1 *Project and timeline planning*

One of the most significant challenges encountered in the project was to fit the development time and the long test time in the project duration. Novel insulation products need to be produced by the industrial partners in the necessary amount, usually as prototypes, given they are not yet engineered for mass production. Once ready, they need to be shipped to the test facility, and the wall assemblies need to be mounted and prepared before measurements can begin. In the experience of EASI ZERo, this sequential process required on the order of several months, significantly reducing the time available for the measurement campaign itself within the project timeline.

This constraint is particularly critical for outdoor facilities, where long measurement periods are required to capture the thermal behaviour of the assembly across different seasons. It is therefore strongly recommended that the planning of experimental campaigns begins as early as possible in the project, and that sufficient buffer time is allocated between the expected completion of product development and the planned start of measurements. Underestimating this lead time is one of the most common sources of pressure on experimental timelines in projects involving novel products.

3.2 *Facility selection and preparation*

The selection of the appropriate allocation of each product to the most suitable test facility should be made carefully and as early as possible in the project. Beyond the criteria discussed in Section 2.3.1, several practical aspects of the facility should be verified before the assignment is finalised.
Facility availability is an important and sometimes overlooked factor. Test facilities may be occupied by other campaigns in certain periods of the year or may not be available at all in certain years. However, it should be noted that facility availability is only a relevant constraint if the products are ready to be tested. If the product development is delayed, securing early facility slots may not translate into earlier measurements.
The humidity control capabilities of the facility should also be verified in advance when testing hygroscopic bio-based materials whose moisture behaviour may be of interest. If active humidity control is not available or is limited, this should be considered in the test design and the interpretation of results. A longer transition time when a change in the setpoint happens should be taken into account.
Finally, structural and dimensional constraints of the facility, including the maximum assembly size and weight, and the available number of data acquisition channels, should be checked against the planned instrumentation layout before the test design is finalised.

3.3 *Boundary conditions and test design*

When the focus is on insulation potential, and especially for outdoor facilities, maintaining a sufficient indoor-outdoor temperature difference is a key challenge during the warm season. It is recommended to consider raising the indoor setpoint temperature above standard comfort conditions during summer periods in order to ensure that the ΔT across the assembly remains above the 5 K threshold recommended by ISO 9869-1:2014 and that the heat flux signal is within a range suitable for reliable analysis. It is to be noted that, in summer, it is also possible to determine the R-value of walls in cooling conditions, provided that the temperature difference is high enough and, more importantly, that the heat flux does not change sign. The methods can give appropriate results, requiring a longer duration (10 to 15 days). This work is under publication in NSB 2026 conference. This can more easily be achieved on a South-oriented wall but requires the use of

surface temperature rather than exterior air temperature, thus giving the R-value and not the U-value.

The selection of valid measurement periods from the raw data is an essential step in the data analysis process and should be planned from the outset rather than treated as an afterthought. Not all data collected during a campaign will meet the quality criteria required for U-value calculation. In particular, it is necessary to pre-heat (or pre-cool) the wall before actually starting the U-value determination. Indeed, the calculation converges to realistic results only when quasi-steady state (or dynamic steady state) is reached.

For outdoor campaigns, designing the test to span multiple seasons is strongly recommended, as it allows characterisation of the assembly under a wider range of boundary conditions and increases the probability of capturing sufficient stable measurement periods.

3.4 *Sensor placement and instrumentation*

The number of available data acquisition channels is a practical constraint that should be assessed early in the instrumentation planning phase. When the number of channels is limited, a compromise between spatial coverage and measurement redundancy may be necessary. In such cases, priority should be given based on the specific objectives of the campaign and the properties of the assembly under test. Sensor adhesion to specific products should be assessed in advance, and sufficient space must be available for the installation of sensors embedded within the wall. Except for thermocouples, other sensors (e.g. relative humidity and heat flux sensors) require dedicated cavities within the wall structure. Creating such space, particularly in brittle materials, can be challenging and may lead to damage in the material. It is strongly recommended to include the producers in this phase of the experimental design.

For heat flux measurements on the wall surface, some sensors might be more affected than others by convection movements and give a highly fluctuating signal. It might be preferable to use in surface heat fluxmeters with a sufficient thermal mass (such as 5mm thick sensors). On the contrary, between layers, a thinner sensor will disturb less.

Ensuring contact of surface sensors is a key point during the installation of such sensors. In the large-scale artificial weathering test performed at USTUTT, diminishing sensor adhesion of heat flux plates on brick wall surfaces was a recurring problem that needed to be dealt with. Also, Fibreoptic sensors installed on plaster surfaces within the chamber repeatedly detached themselves, as the mounting plates of said sensors ripped off the plaster they were glued to under high stress. One heat flux plate installed on a reference wall meant to be a redundancy delivered impossible results, possibly due to radiating heat from the nearby climatic aggregate. The placement of sensors in such proximity needs to be carefully evaluated. Additionally, testing each sensor in advance for functionality and precision is highly advised to reduce the number of redundancies. Sensors exposed to especially wet conditions should be sealed carefully, however malfunction is still probable and should be considered during the planning phase to implement additional devices in such positions.

3.5 *Lesson learned and transferability*

Although the lessons documented in this section are grounded in the specific experience of the EASI ZERo project, they are intended to be applicable beyond its context. The challenges encountered, from timeline management to facility selection, boundary condition control and instrumentation, are not unique to the products or facilities involved but reflect structural features common to any project combining the development of novel building materials with large-scale experimental validation. The recommendations presented here are therefore offered as a practical reference for researchers and industry partners approaching similar testing activities in future projects or standardisation efforts, independently of the specific material, facility, or climatic context involved.
A recommendation for future projects is the careful assessment of options for the adhesion/installation of sensors to various surfaces. A recurring problem in more than one experimental facility was the detachment of sensors, such as heat flux measurement plates, from the surface they were meant to adhere to, even though a heavy-duty two-sided tape was used for installation. This could be mitigated during the measurement process through daily search for small detachment sites at the outer edges of sensor plates and careful reattachment, which is time-consuming, or choosing another adhesion option in the first place. The same can be said about fibreoptic sensor mounting plates, which tend to detach from the wall as climatic conditions in the test chamber put the strains and glue under significant stress. For future projects, the usage of plugs and screws will be prioritized over two-component glues, if possible. Additionally, the influence of outside airborne transmissive heat from machines, in the case of USTUTT, a powerful climatic aggregate next to the test chamber, needs to be reduced, if possible. A simple solution would be a layer of insulating material between the machine and the test chamber to partially reduce heat radiation and transmission.

4. References

[1] ISO 9869-1:2014. Thermal insulation — Building elements — In-situ measurement of thermal resistance and thermal transmittance — Part 1: Heat flow meter method. International Organization for Standardization, Geneva.

[2] Meng, X. et al. (2024). Influences of Average Temperature Difference and Measurement Period on Estimation of In Situ Thermal Transmittance of Building Exterior Walls Using the Average Method of ISO 9869-1. Energies, 17(5), 1177. https://doi.org/10.3390/en17051177