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LIFE Project Number
LIFE19 CMM/ES/001327

Final Report
Covering the project activities from 01/06/2020 to 31/05/2025

Reporting Date
29/08/2025

LIFE PROJECT NAME or Acronym
ZEROENERGYMOD

Data Project

Project location:	Huesca (Spain)
Project start date:	<01/06/2020>
Project end date:	<31/05/2024> Extension date: <31/05/2025 >
Total budget:	1,178,265 €
EU contribution:	553,382 €
(%) of eligible costs:	55

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This table comprises an essential part of the report and should be filled in before submission

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Package completeness and correctness check	
Obligatory elements	✓ or N/A
Technical report	
The correct latest template for the type of project (e.g. traditional) has been followed and all sections have been filled in, in English <i>In electronic version only</i>	✓
Index of deliverables with short description annexed, in English <i>In electronic version only</i>	✓
<u>Mid-term report</u> : Deliverables due in the reporting period (from project start) annexed <u>Final report</u> : Deliverables not already submitted with the MTR annexed including the Layman's report and after-LIFE plan Deliverables in language(s) other than English include a summary in English <i>In electronic version only</i>	✓
Financial report	
The reporting period in the financial report (consolidated financial statement and financial statement of each Individual Beneficiary) is the same as in the technical report with the exception of any terminated beneficiary for which the end period should be the date of the termination.	✓
Consolidated Financial Statement with all 5 forms duly filled in and signed and dated <i>Electronically Q-signed or if paper submission signed and dated originals* and in electronic version (pdfs of signed sheets + full Excel file)</i>	✓
Financial Statement(s) of the Coordinating Beneficiary, of each Associated Beneficiary and of each affiliate (if involved), with all forms duly filled in (signed and dated). The Financial Statement(s) of Beneficiaries with affiliate(s) include the total cost of each affiliate in 1 line per cost category. <i>In electronic version (pdfs of signed sheets + full Excel files) + in the case of the Final report the overall summary forms of each beneficiary electronically Q-signed or if paper submission, signed and dated originals*</i>	✓
Amounts, names and other data (e.g. bank account) are correct and consistent with the Grant Agreement / across the different forms (e.g. figures from the individual statements are the same as those reported in the consolidated statement)	✓
Mid-term report (for all projects except IPs): the threshold for the second pre-financing payment has been reached	N/A
Beneficiary's certificate for Durable Goods included (if required, i.e. beneficiaries claiming 100% cost for durable goods) <i>Electronically Q-signed or if paper submission signed and dated originals* and in electronic version (pdfs of signed sheets)</i>	N/A
Certificate on financial statements (if required, i.e. for beneficiaries with EU contribution $\geq 750,000$ € in the budget) <i>Electronically Q-signed or if paper submission signed original and in electronic version (pdf)</i>	N/A
Other checks	
Additional information / clarifications and supporting documents requested in previous letters from the Agency (unless already submitted or not yet due) <i>In electronic version only</i>	✓
This table, page 2 of the Mid-term / Final report, is completed - each tick box is filled in <i>In electronic version only</i>	✓

**signature by a legal or statutory representative of the beneficiary / affiliate concerned*

1. Table of contents

1. Table of contents.....	3
2. Executive Summary (maximum 2 pages).....	5
3. Introduction (maximum 2 pages).....	7
4. Administrative part (maximum 1 page).....	9
5. Technical part (maximum 25 pages).....	10
5.1. Technical progress, per Action	10
5.2. Main deviations, problems and corrective actions implemented.....	28
5.3. Evaluation of Project Implementation	30
5.4. Analysis of benefits.....	34
6. Key Project-level Indicators	36

List of figures

Figure 1: Pre-assembly carried out at ARPA's facilities.....	11
Figure 2: ZEROENERGYMOD final design layout (integrating 3 PASSIVMOD modules + 1 ENERMOMOD module in a combined prototype with a common central space).....	13
Figure 3. Covers of the 3 guides developed.....	19

List of key-words and abbreviations

ATEX	Explosive Atmospheres
BZAP	Batallón de Zapadores (Sapper Battalion)
CAPEX	Capital Expenditures
CUDZ	Centro Universitario de la Defensa Zaragoza (Zaragoza University Defense Center)
DAP	Dissemination and Awareness Plan
DCF	Discounted Cash Flow
EF	Environmental Footprint
EHEC	European Hydrogen Energy Conference
EU	European Union
EUSEW	European Sustainable Energy Week
FHA	Fundación Hidrógeno Aragón (Aragon Hydrogen Foundation)
GA	Grant Agreement
GAs	General Assembly
GHG	Green House Gas
HVAC	Heating Ventilating Air Conditioning
IP	Intellectual Property
IPR	Intellectual Property Rights
KER	Key Exploitable Result
KOM	Kick-off Meeting
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
OPEX	Operating Expenses
PEM	Proton Exchange Membrane
PESTEL	Political, Economic, Social, Technological, Legal, and Environmental
PHI	Passive House Institute
PHPP	Passive House Planning Package
PV	Photovoltaic
nZEB	nearly Zero Energy Buildings
NGO	Non-Governmental Organization
SDG	Sustainable Development Goal
SIMENDEF	Official Messaging and Document Management System of the Spanish Ministry of Defence
S- TBD	To Be Determined
VAT	Value-Added Tax
WHEC	World Hydrogen Energy Conference
ZEM	ZeroEnergyMod

2. Executive Summary (maximum 2 pages)

The LIFE ZEROENERGYMOD project was conceived to demonstrate a new generation of nearly zero energy, mobile, habitable modules. Its core objective was to develop and validate a self-sufficient, transportable building solution, that complies with the Passivhaus standard and integrating photovoltaic and wind energy systems with a hybrid storage configuration composed of batteries and hydrogen-based seasonal storage. These modules, designed to be rapidly deployable and easily assembled, aim to address energy efficiency demands in remote or mobile contexts, with a special focus on military, civil or scientific applications.

This report presents the progress, milestones and deviations of the project from June 2020 to May 2025. In April 2024, an amendment was submitted to **extend the demonstration period phase by 12 months (until 31 May of 2025) to be able to collect representative data on performance of the modules in the demo and to implement some already identified improvements**. The request did not affect the budget, personnel allocation, or anticipated environmental impact of the project.

Under the coordination of Fundación Hidrógeno Aragón (FHa), the project partners ARPA EMC, CUDZ, and BHAUS executed specific responsibilities aligned with their respective expertise. FHa led the overall project management and dissemination, and was responsible for designing the ENERMOD energy module, assessing its performance, and conducting LCA, and environmental analyses. ARPA EMC played a central role in construction and commissioning of the modules, overall energy system integration, and setup of monitoring infrastructure. BHAUS designed the PASSIVMOD prototype, covering structural and material design, installations, and passive strategies, and they managed the Passivhaus certification process. CUDZ acted as a key liaison with users, obtaining necessary permits and providing input data for the PASSIVMOD design and implementation, as well as monitoring both thermal indoor environment and energy consumption in habitable modules.

The **main achievement** during the project period was the successful design and construction of the prototype, which in its first demonstration (Demo 1) delivered superior performance in terms of energy consumption, higher renewable energy generation, and avoided emissions than originally foreseen in the Grant Agreement.

The final environmental impact of the project can be considered satisfactory, despite not being demonstrated in all the locations originally foreseen. The war in Ukraine had a direct bearing on the project, since the second demo was scheduled at a Latvian NATO base near the Russian border, where there was a considerable risk that logistics could not be completed or the prototype could not be retrieved. Consequently, alternative sites were explored for testing under cold weather conditions while the first demonstration was already underway. Permits were even secured for installation at a mountain military school in the Spanish Pyrenees, though this option was ultimately dismissed as user availability during the demonstration period could not be guaranteed.

The **environmental impact achieved** by the project during the nearly three years of demonstration is reflected in the following figures:

- ✓ Total reduction in energy consumption per year: 3,228 kWh/m² (96% decrease compared to current solution)
- ✓ Total renewable energy production: 13,470 kWh
- ✓ Total amount of diesel consumption avoided: 135,180 litres

- ✓ Total CO₂ emissions avoided: 360 tonnes
- ✓ Total NO_x emissions avoided: 5,21 tonnes
- ✓ Indoor Air quality improvement: IDA1

The ENERMOD and PASSIVMOD modules, originally conceptualized as separate units, were reconfigured into an **integrated building solution to optimize performance** and usability. The final architecture has evolved from 2 habitable modules to a combined solution of 3 habitable modules, 1 energy module, an interior circulation area and a sanitary area, increasing the total living space and including the installations within the thermal envelope, with a view to facilitating maintenance of the installations and extending the useful life of the equipment.

Thanks to the project, there is now a **real solution for sustainable living in container-based buildings with high performance**, both in terms of thermal comfort and indoor air quality, as well as energy production and management, compared to the standard solution, which offers poorer indoor air conditions with higher fossil fuel consumption.

This design optimization required **innovative solutions** to integrate a hydrogen system into a PASSIVHAUS thermal envelope, which was a real challenge and yielded valuable lessons for similar projects. The results is a genuine innovation: **the ZEM project is the first modular and fully demountable building** of such a small size, constructed from shipping containers, to integrate built-in hydrogen facilities while also achieving Passivhaus certification. The pioneering combination paves the way for future installations to adopt and replicate such high-performance, sustainable solutions.

The implemented solution for **renewable energy production and hybrid energy storage complements the excellent low energy demand offered by the PASSIVHAUS system**. The hybridization of renewable sources with battery storage, which was already known, has been improved and strengthened with a more complex solution thanks to improved energy storage with hydrogen, which is something new and offers performance flexibility that reinforces its replication.

The **dissemination of the project** was done by means of a comprehensive 360° communication plan, to reach out to users through a range of channels: social networks, the web, newsletters, written press and digital media. Most of the targets in this area were successfully achieved.

Despite pandemic related delays and geopolitical disruptions, the **project achieved its core objectives**: demonstrating a replicable, fully autonomous, zero energy mobile module, validating key performance indicators; and laying the foundation for future applications in remote or critical environments.

3. Introduction (maximum 2 pages)

The LIFE ZEROENERGYMOD project supports the European Union's climate mitigation and adaptation strategies, particularly those outlined in the EU 2050 Roadmap for reducing greenhouse gas (GHG) emissions by 80 - 95% compared to 1990 levels. The project is also aligned with the EU Strategy on Adaptation to Climate Change, as it contributes to enhancing infrastructure resilience and energy autonomy in off-grid and climate vulnerable settings across Europe.

Modular infrastructure is extensively used in military operations, humanitarian assistance, and civil protection missions. These structures, typically deployed in remote or harsh environments, rely almost exclusively on fossil fuel-based generators, primarily diesel, to meet energy demands for electricity, heating, and hot water. This dependence poses several challenges: high logistical costs, increased operational risks, substantial carbon emissions, and strategic vulnerability stemming from reliance of the European Union's (EU's) reliance on imported fossil fuels, approximately 80% of which originate from geopolitically unstable regions.

Given these constraints, there is a clear need to develop and validate energy-efficient solutions for off-grid modular applications that are both environmentally sustainable and operationally robust.

The primary objective of the LIFE ZEROENERGYMOD project was to design, develop, and demonstrate a robust, transportable, zero energy mobile module that integrates advanced insulation (Passivhaus standard), renewable energy sources (solar and wind), and hybrid energy storage systems (short-term batteries and long-term hydrogen storage). The solution aimed to achieve autonomous operation, eliminate fossil fuel dependency, and enable rapid deployment in various geographical contexts.

The technical approach involves two core subsystems:

- **PASSIVMOD:** A habitable module meeting the stringent energy efficiency and comfort requirements of the Passivhaus standard, designed to ensure optimal thermal performance and indoor air quality.
- **ENERMOD:** An integrated energy generation and storage unit comprising photovoltaic panels, wind turbines, lithium-ion batteries, and a complete hydrogen cycle (electrolyser, hydrogen storage tanks, and a fuel cell), enabling year-round renewable energy supply.

During the design phase, the initial configuration of two separate modules was optimized into a single integrated unit (ZEM prototype), which improved compactness, operational efficiency, and ease of implementation.

The LIFE ZEROENERGYMOD solution was designed to provide substantial environmental and technical benefits, including:

- Reduction of energy demand in approximately 285 kWh/m² per year (a 75% decrease compared to current solution).
- Avoidance of 15 tons CO₂ and 0.33 tons NO_x emissions per year, based on an annual reduction in diesel use by approximately 5,700 litres per habitable module.

- Full energy autonomy through renewable production exceeding 4,000 kWh/year, verified through demonstration monitoring.
- Achievement of Passivhaus indoor air quality levels.
- Reduction in deployment time and operational complexity, enhancing applicability in remote or climate stressed environments.

The technical implementation of the project was structured around a series of interrelated actions.

- Action A1: Completion of baseline studies detailing the current state of modular energy solutions and permitting strategies for demonstration sites.
- Actions C1-C4: Design, construction, and integration of the PASSIVMOD and ENERMOD components.
- Action C5: modules transportation, implementation and demonstration.
- Action C6-C8: Life Cycle Assessment (LCA) and environmental analysis, development of flexible business model to support market replication, and guidelines to facilitate implementation of the solution, including compilation of lessons learned.
- Action D1 - D2: Monitoring of project impact, collecting real-time data on temperature, humidity, CO₂ concentration, energy production, and consumption.
- Action E1 - E2: Communication and dissemination of results.
- Action F1- F2: Project management and After LIFE communication and conservation plan.

Beyond its immediate demonstration goals, LIFE ZEROENERGYMOD is expected to contribute to several long-term outcomes:

- Support for EU climate action policy, through the validation of off-grid, zero emissions infrastructure that reduces the carbon footprint of military operations, peacekeeping deployments, humanitarian field missions, and other temporary facilities.
- Replicability and transferability, enabled through comprehensive technical documentation, personnel training, and engagement with international stakeholders.
- Market feasibility, supported by the development of a business model and LCA, targeting applications in defence, post-natural disaster reconstruction, refugee camps, humanitarian aid, and sustainable development contexts where resilient, low-emission modular infrastructure is needed.
- Alignment with the European Green Deal and Repower EU objectives, by demonstrating the practical integration of renewables and hydrogen technologies in sectors traditionally reliant on fossil fuels.

Although the demonstration planned in Latvia did not take place due to geopolitical and logistical restrictions, the prototype demonstration has remained in operation with active users continuously for almost three years. The granting of the requested 12-month extension allowed for the implementation of important improvements, including photovoltaic panel repositioning, hydrogen system automation, and disaggregated energy monitoring, helping to achieve the set objectives and further decrease the environmental impact.

LIFE ZEROENERGYMOD represents a high value demonstrative innovation in modular infrastructure, offering a technically feasible, scalable, and climate-resilient solution for autonomous energy operations across Europe and beyond.

4. Administrative part (maximum 1 page)

Organisation/co-ordination of the project

Ten General Assembly meetings were organised during the reporting period:

#	Code	Date	Type	Format/Location
1	M1	30 June 2020	KOM	online
2	M2	24 July 2020	Technical KOM	face-to-face, FHA facilities
3	M13	22 July 2021	Consortium meeting	face-to-face, ARPA facilities
4	M23	6 April 2022	Consortium meeting	face-to-face, CUDZ facilities
5	M32	18 January 2023	Consortium meeting	face-to-face, CUDZ facilities
6	M36	5 May 2023	Consortium meeting	face-to-face, CUDZ facilities
7	M47	4 April 2024	Consortium meeting	face-to-face, CUDZ facilities
8	M48	22 May 2024	Technical workshop	face-to-face, FHA facilities
9	M59	28 April 2025	Consortium meeting	online
10	M60	29 May 2025	Final event	face-to-face, COATZ facilities

All members attended and played an active role in these General Assembly meetings. As all partners speak the same language and their facilities are located close to each other, this facilitated smooth and agile communication, based on monthly follow-up meetings and reinforced with phone calls, emails, and regular visits.

As the contribution consisted of only four partners, each contribution was very specific and clearly defined. Project management and interactions did not reach a level of complexity that required the creation of Steering or Technical Committees. Instead, informal working groups were formed naturally, aligned with the actions in which each partner is involved.

Communication with EASME/CINEA and the Monitoring team

Communication with both EASME/CINEA and the Monitoring Team was continuous throughout the project. The Monitoring Team helped resolve the consortium's queries and reviewed the project's financial information, monitoring reports, and extension request before it was submitted to LIFE.

The Monitoring Team visited the project four times (2021, 2022, 2023 and 2025), with the LIFE Project Adviser accompanying the 2023 visit. An additional online follow-up meeting was held in 2024.

Amendments to the Grant Agreement

An amendment was requested on 26/05/2024 exclusively to extend the demonstration period at the current location by 12 months (until 31/05/2025). The aim was to implement changes to bring the performance of the modules closer to the proposed Key Performance Targets, to collect representative information on the technologies installed, and to analyse the effect of these changes on the solution. The request did not affect either the budget, personnel resources, or the expected environmental impact of the project.

5. Technical part (maximum 25 pages)

5.1. Technical progress, per Action

Reference assessment. Permits and authorization				Status:	Completed	
A.1	Start date	Foreseen:	1/06/20	End date	Foreseen:	30/05/25
		Actual:	1/06/20		Actual:	26/05/25

Action A.1 (June 2020 - March 2021), led by CUDZ, delivered a reference assessment (A1.1) on EU climate goals, energy standards, and defence infrastructure needs. It mapped best practices in nearly Zero Energy Buildings (nZEBs) and confirmed their suitability for modular defence applications, establishing the technical and regulatory foundation for the ZEROENERGYMOD prototype.

CUDZ also managed the permitting process with military and institutional stakeholders. The first demo site at San Jorge Base (Zaragoza) was approved in July 2021 and installed in early 2022. While a NATO deployment in Latvia was cancelled due to geopolitical tensions and a fallback site in Candanchú was discarded, efforts focused on enhancing results in Zaragoza. A planned Antarctic demonstration was postponed to the After-LIFE phase due to budget constraints. In total, more than 20 coordination meetings and SIMENDEF procedures were carried out to secure authorisations and ensure successful project implementation.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
A1.1 Report on current status of the technologies to affecting ZEROENERGYMOD	A1	30/03/2021	CUDZ	-	Finished
A1.2 Agreements of collaboration for demo-sites deployment	A1	26/05/2025	CUDZ	-	Finished

Name of the Milestone	Associated action	Achieved
Agreements signed with demosites	A1	26/05/2025

Deliverable A1.1 Report on the current status of technologies affecting ZEROENERGYMOD presents the current state-of-the-art in energy efficiency measures implemented in buildings across Europe, with the aim of curbing climate change. The study analyses both the global context and the specific context of the Armed Forces.

Outcome: The objective accomplished with 6-month delay

Deliverable A1.2 Agreements of collaboration for demo-sites deployment provides a breakdown of the steps taken to apply for and manage the demo permits, along the whole project period; however, additional permits for the Antarctica location will continue to be managed during the After-LIFE phase. *Outcome: The objective accomplished.*

Design and construction of ENERMOD				Status:	Completed	
C.1	Start date	Foreseen:	1/06/20	End date	Foreseen:	30/06/21
		Actual:	1/06/20		Actual:	13/04/23

TC1.1 Design and calculation of the equipment to be included in ENERMOD

In the C1.1 report (**C1.1 Executive project**), FHa described the methodology used to model several configurations for ENERMOD, considering mainly technical and economic criteria, analysing different configurations.

The final configuration consisted of 5 kWp of solar panels, 9.6 kWh of lithium-ion batteries, a 2.4 kW electrolyser, and a 2.5 kW fuel cell. For wind turbines, the assessment of total capacity of 6 kWp (two turbines of 3 kW); however, only one was purchased due to budget limitations, resulting in a final wind power capacity of 3 kW. Energy storage in the form of H₂ was initially set at 6 kg but was increased to 12 kg to improve the ability of the system to store renewable energy on a seasonal basis.

Outcome: The task was finished with a delay of 5 months. Objectives were achieved.

TC1.2 Purchases and supplies

Following the final design of the energy solution, ARPA procured the required equipment and materials in 2020 - 2021, despite some manufacturing challenges and delivery delays.

The purchasing process and delivery logistics for the fuel cell caused a 13-month delay. This delay was not considered critical, as testing and commissioning could not continue until the H₂ production system was operational and hydrogen had been stored in advance.

Outcome: The task was finished, with a delay of 13 months. Main objectives were achieved.

TC1.3 Assembly

This task followed the previous ones and was closely linked to Action C3, where the final distribution of the module was defined. Pre-assembly was carried out at ARPA's facilities under its engineering team's direction. PV modules and the wind turbine were excluded to avoid unnecessary foundation and connection costs, as these components are standard, commercially available, and guaranteed by suppliers.

Outcome: The task was finished, with a delay of 9 months. Main objectives were achieved.



Figure 1: Pre-assembly carried out at ARPA's facilities

TC1.4 Tests and pre-monitoring

Assembly and engineering teams verified all equipment and connections before disassembly, with separate checks for PV panels and the wind turbine. The first demo site was also inspected to confirm correct module operation. As the solution was built to Passivhaus standards, the milestone 'Satisfactory tests of ENERMOD' was tied to Action C3 'Certification of PASSIVMOD achieved'.

Reports C1.2 and C4.1 were prepared jointly to streamline verification and testing, ensuring a coherent response across both deliverables: C1.2 ('Final Report on ENERMOD') included tests and, covered the requirements of C4.1 ('Testing of ENERMOD and PASSIVMOD') as well. *Outcome: The task was finished, with a delay of 10 months. Main objectives were achieved.*

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C1.1 Executive project	C1	16/02/2021	ARPA	FHA	Finished
C1.2 Final report on ENERMOD including tests	C1	13/04/2023	ARPA	FHA	Finished

Name of the Milestone	Associated action	Achieved	Status
Design of ENERMOD finalised	C1	16/02/2021	Finished
Satisfactory tests of ENERMOD	C1	13/04/2023	Finished

C.2	Study of materials and suitable prefabricated building techniques of PASSIVMOD			Status:	Completed
	Start date	Foreseen: 1/06/20 Actual: 1/06/20	End date	Foreseen: 31/05/21 Actual: 01/05/21	

TC2.1 Processing of the thermal characterization data of the Bases and interviews

At project start, CUDZ used existing data from three Spanish Armed Forces bases on thermal comfort, energy use, and building conditions. This was processed to assess the current situation, identify main problems, and propose technical/design alternatives.

Outcome: The task was completed as scheduled.

TC2.2 Establishment of boundary conditions that will define the requirements that materials and construction types must meet.

Using information from subtask TC2.1., CUDZ established the requirements that ZEROENERGYMOD must meet regarding the PASSIVHAUS standard, NATO standards, and European building techniques. *Outcome: The task was completed as scheduled.*

TC2.3. Search for solutions and test their validity

Following TC2.2 requirements, CUDZ and BHAUS assessed suitable commercial materials, economic conditions, and construction processes. For Antarctic deployment, Arctic Polar Committee guidelines were applied, including stainless steel cladding and avoiding exterior polymers. *Outcome: The task was completed as scheduled.*

TC2.4. Development of the study implementing the defined technical solutions

After selecting materials and typologies, CUDZ, BHAUS, and ARPA integrated them into the PASSIVMOD design, detailing structure, joints, enclosures, assembly, and conducting preliminary energy and cost calculations. The outcomes fed into Action C3 and provided feedback for Action C2 to adjust materials or assessments if needed during construction.

Outcome: The task was completed as scheduled.

CUDZ, with the support of BHAUS, prepared a joint report including C2.1 and C2.2, compiling all information and research developed.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C2.1 Initial report of the technical solutions found	C2	25/09/2020	BHAUS	CUDZ	Finished
C2.2 Final report of the technical solutions for PASSIVMOD	C2	01/05/2021	BHAUS	CUDZ	Finished

Name of the Milestone	Associated action	Achieved	Status
Identification of the materials selected for PASSIVMOD	C2	01/05/2021	Finished

C.3	Study of materials and suitable prefabricated building techniques of PASSIVMOD			Status:	Completed
	Start date	Foreseen: 1/06/20 Actual: 1/06/20	End date	Foreseen: 31/06/22 Actual: 24/06/25*	
	<i>*Remark: Design and construction was completed in February 2022. Passivhaus certification was achieved in June 2025, after further tests at demo site 1 and certification application process.</i>				

TC3.1 Final design of the PASSIVMOD habitable module

BHAUS finalized the PASSIVMOD design, meeting all requirements in Action C2. The module, based on 20-foot containers, is modular and adaptable for accommodation, offices, communications, and housing. The initial plan of three modules (one ENERMOD + one PASSIVMOD) was revised to four (three habitable + one integrated energy module). Applying Passivhaus and ATEX standards to the energy module ensures operation above 0 °C, improving efficiency, durability, and maintenance under extreme conditions, and represents one of key technical challenges of the project.

Beyond the main configuration modification, the design incorporated key enhancements to improve habitability and reduce energy consumption: expanded and redistributed space with an inner patio for bathrooms and corridors, a separated entrance to limit heat losses, and provide protection against solar radiation and snow.

Outcome: Task completed, with an 18-month delay, mainly due to formal report elaboration. Main objectives were achieved; modules were built and transported to demo site 1.

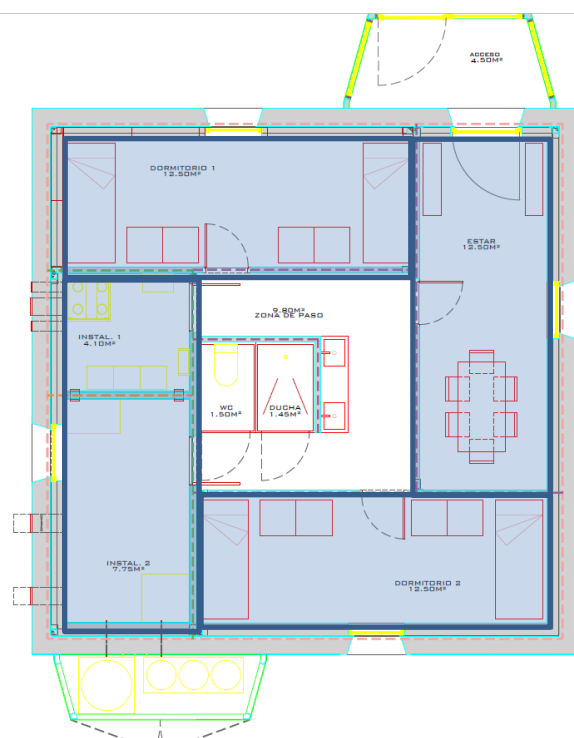


Figure 2: ZEROENERGYMOD final design layout (integrating 3 PASSIVMOD modules + 1 ENERMOD module in a combined prototype with a common central space).

TC3.2. Elaboration of executive project of the PASSIVMOD habitable module

The Executive Project includes details of the final configuration and all modifications implemented during the design and construction processes. This document was also useful

during the certification process with the Passivhaus Institute. BHAUS led this task, with the support from CUDZ and ARPA.

Outcome: The task completed, with a delay of 15 month, mainly due to report presentation. Main objectives were achieved as modules were constructed and transported to demo site 1.

TC3.3. Purchases and supplies

Once the final configuration of the habitable solution was defined in TC1.3, ARPA's purchasing department, supported by its engineering department and BHAUS, procured the necessary materials, mainly during 2020 and 2021. The procurement process was influenced by manufacturing challenges, resulting in longer lead times and requiring adjustments to the evolving definition and configuration of the solution.

Outcome: The task was finished, with a delay of 9 months. Main objectives were achieved.

TC3.4. Assembly

This task followed the previous ones and was closely linked to Action C2, where the energy solution was defined. Pre-assembly was carried out at ARPA's facilities, according to the drawings developed by BHAUS and ARPA's engineering team, and under their direction and supervision.

Outcome: The task was finished with a delay of 9 months. Objectives were achieved.

TC3.5. Test and pre-monitoring

As in TC1.4, the workshop and engineering teams tested the habitable modules, windows, and joints to confirm insulation and air tightness before dismantling. Since reassembly was required, their performance was checked again, and the workshop team later travelled to demonstration site 1 to verify proper operation on location.

Outcome: The task was finished at ARPA's facilities with a delay of 9 months, and it also was transported, re-built on demo site 1 and finally tested there. Objectives were achieved.

TC3.6. Passivhaus certification of the module

Certification of the ZEROENERGYMOD module was led by BHAUS, with support from CUDZ and ARPA. Although full Passivhaus certification was the initial goal, the innovative features of the module, container structure, ATEX hydrogen system, and Antarctic deployment, resulted in it being awarded the "PHI Low Energy Building" certificate by the Passivhaus Institut on 24 June 2025.

This certification confirms the high energy efficiency and comfort standards of ZEM. It required full PHPP documentation and independent verification by an accredited PHI certifier. Notably, ZEM is the first modular, demountable, and transportable building worldwide to achieve this distinction, marking a major milestone in sustainable off-grid construction.

Outcome: The task was finished with a delay of 3 months, due to delays on Passivhaus certification process. Objectives were achieved.

Name of the Deliverable	Ass. action	Completion date	Deliverable Leader	Support	Status
C3.1 Final design of PASSIVMOD	C3	01/06/2022	BHAUS	ARPA/CUDZ	Finished
C3.2 Executive project of PASSIVMOD	C3	10/06/2022	BHAUS	ARPA/CUDZ	Finished
C3.3 Report of the testing PASSIVMOD	C3	24/06/2025	BHAUS	ARPA/CUDZ	Finished

Name of the Milestone	Associated action	Achieved	Status
Executive Project of PASSIVMOD finalised	C3	10/06/2022	Finished
Certification of PASSIVMOD achieved	C3	24/06/2025	Finished

Integration and testing of ENERMOD and PASSIVMOD				Status:	Completed	
C.4	Start date	Foreseen:	1/06/21	End date	Foreseen:	31/06/22
		Actual:	1/01/22		Actual:	13/04/23

This action was originally planned to integrate and pre-assemble ENERMOD (Action C1) and PASSIVMOD (Action C3) prior to deployment at Demo Site 1, allowing technical issues to be resolved in a controlled environment. Following the decision to merge both into the same building, the activity was incorporated into the testing at ARPA's facilities and the commissioning at the demo site. To optimize reporting, deliverables C1.2 and C4.1 were consolidated into one comprehensive final report, providing a coherent and technically aligned record of testing and evidence.

Outcome: The task was finished with a delay of 10 month. Objectives were achieved.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C4.1 Report on the testing of ENERMOD and PASSIVMOD combined	C4	13/04/2023	ARPA	All	Finished

Name of the Milestone	Associated action	Achieved	Status
Combined system ZEROENERGYMOD ready to be deployed	C4	13/04/2023	Finished

Operation of demsites				Status:	Completed	
C.5	Start date	Foreseen:	1/10/21	End date	Foreseen:	31/05/25
		Actual:	1/03/22		Actual:	31/05/25

TC5.1. Work plan and modules transportation

This task focused on Demo site 1 and is documented in the report **C5.1 (Work plan and transportation to demo-site 1, Spain)**. It details the planning process, machinery and equipment needed for disassembly, preparation, packaging and labelling of parts, evaluation of transportation options, and preliminary work required at the demo site.

Outcome: The task was completed at demo site 1 with a 6-month delay. All objectives were achieved.

TC5.2. Modules implementation

This task, also developed for Demo site 1, is detailed in report **C5.2 (ZEROENERGYMOD deployment in demo site 1, Spain)**, which explains the installation and assembly of the module, PV panels, and micro-wind turbines. Measurement equipment is listed and further detailed in the deliverable D1.1 (ZEROENERGYMOD monitoring protocol report).

FHa, with support from CUDZ, prepared a merged report (**C5.1 + C5.2**) to present the entire process in a logical and coherent manner, without cross-references between separate reports.

Outcome: The task was completed at demo site 1 with a 6-month delay. All objectives were achieved.

TC5.3 Modules demonstration

The demonstration phase began on 22 July 2022, following a four-month logistical delay, with monitoring focused on Passivhaus requirements fulfilment, renewable generation, and hydrogen storage efficiency under seasonal conditions. A user training session promoted the best energy practices, while continuous monitoring of technical and habitability data supported system improvements and ensured replicability for future ZEROENERGYMOD deployments.

Outcome: Module demonstration began in July 2022 and remained operational until the end of the project (31 May, 2025). Demo site 1 was operational with a 4-month delay.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C5.1 Work plan and transportation to demo-site 1 (Spain)	C5	17/05/2022	FHA	ARPA/CUDZ	Finished
C5.2 ZEROENERGYMOD deployment in demo-site 1 (Spain)	C5	13/06/2022	FHA	ARPA/CUDZ	Finished
C5.3 Work plan and transportation to demo-site 2 (Latvia)	C5	-	FHA	ARPA/CUDZ	*
C5.4 ZEROENERGYMOD deployment in demo-site 2 (Latvia)	C5	-	FHA	ARPA/CUDZ	*

Name of the Milestone	Associated action	Achieved	Status
ZEROENERGYMOD deployed in demo-site 1 (Spain)	C5	13/06/2022	Finished
ZEROENERGYMOD deployed in demo-site 2(Latvia)	C5	-	*

**Deliverables C5.3 and C5.4 were cancelled following the suspension of the Latvian demo site due to Russia's invasion to Ukraine, not being able to reach the corresponding milestone. The prototype remained in Zaragoza for validation through technical testing. This revised approach was approved by CINEA in May 2022*

C.6	Life cycle assessment and environmental analysis				Status:	Completed
	Start date	Foreseen:	1/06/20	End date	Foreseen:	31/05/25
	Actual:	1/07/23		Actual:	25/04/25	

TC6.1 Materials technology implementation study

Task C6.1, led by FHa, carried out a comprehensive Life Cycle Assessment (LCA) of the PASSIVMOD and ENERMOD prototypes, building on previous design and testing deliverables (C2.2, C3.2, C1.2, C4.). Once C1, C2, C3 and C4 were completed, a detailed Life Cycle Inventory was developed, covering more than 15.5 tonnes of materials and components, including structural systems, renewable energy technologies, storage and generation units, and ancillary equipment. Using the EF 3.1 methodology and the MLC 2023.1 database within LCA for Experts v10.7, the analysis quantified environmental impacts and identified platinum, magnesium, cobalt, carbon fibre, and Nafion as the main hotspots, emphasizing the environmental trade-offs of integrating advanced low emission technologies.

Outcome: The task was completed with two years delay due to dependence on the completion of previous actions, which were not identified at the start of the project. All objectives were achieved.

TC6.2 Zero emissions solution case study

Task C6.2, led by FHa, delivered an ISO 14040 - 44 compliant LCA of the ZEM system, combining the material inventory from Task C6.1 with operational data from two months of prototype deployment (October - December 2024). Applying the EF 3.1 method, the study highlighted major environmental hotspots, carbon fibre in hydrogen tanks, platinum in the PEM electrolyser, and reliance on Spanish grid electricity, while confirming the minimal impact of photovoltaic and wind systems as core low-carbon energy solutions. The results provide a comprehensive environmental profile of ZEM, offering clear guidance for future improvements in material selection, energy efficiency, and system design, while establishing a replicable framework for ZEROENERGYMOD and contributing to standardized LIFE aligned environmental guidelines.

Outcome: The task was finished with a delay of one month. All objectives were achieved.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C6.1 Report on Materials technology implementation	C6	29/08/2023	FHa	ARPA/CUDZ	Finished
C6.2 LCA report of final ZEROPASSIVMOD solution	C6	25/04/2025	FHa	ARPA/CUDZ	Finished

Name of the Milestone	Associated action	Achieved	Status
LCA of potential materials to be used in PASSIVMOD	C6	29/08/2023	Finished
Final LCA report	C6	25/04/2025	Finished

Replicability and transferability of results					Status:	Completed
C.7	Start date	Foreseen:	1/06/22	End date	Foreseen:	31/12/24
		Actual:	1/05/22		Actual:	30/01/25

TC7.1. Business model for ZEROENERGYMOD

Task C7.1, completed in November 2022 by FHa using the CANVAS methodology, produced a business model for ZEROENERGYMOD commercialisation, defining stakeholder roles, value creation, risks, and viability. It proposed sales and rental pathways, with market opportunities in military, construction, mining, research, and public infrastructure sectors, providing a flexible roadmap aligned with EU decarbonisation objectives and LIFE goals.

Outcome: The task was completed as scheduled. All objectives were achieved

TC7.2: Assessment of international and EU target markets potential for wide implementation including the selection of potential customers for real business cases development

Between September and November 2023, FHa assessed commercial potential of ZEM in Europe and abroad, identifying defence, construction, extractive industries, and public services as key sectors (based on TC7.1). NATO operations were seen as the main European entry point, while Japan, South Korea, the U.S., and Canada were highlighted internationally. A sensitivity analysis confirmed long-term viability despite barriers such as costs, regulation, and technology maturity. The task also initiated investor outreach, preparing the ground for post-LIFE commercialisation.

Outcome: The task was completed with a two-month delay. All objectives were achieved

TC7.3: Analysis of specific reference business cases linked to real installations

Task C7.3, completed in January 2025 under coordination of FHa, developed reference business cases to assess the commercial viability of ZEROENERGYMOD, building on tasks C7.1 and C7.2. Two financial models, direct sales and rental, were evaluated for priority markets in defence and humanitarian operations. Using 20-year DCF analysis with real world CAPEX/OPEX, the sales model achieved breakeven with ~17% margins, while the rental model required ~47% margins to ensure sustainability. Both scenarios excluded subsidies, providing conservative benchmarks. The findings confirmed ZEROENERGYMOD's feasibility in demanding markets, identified Key Exploitable Results (KERs) such as the ENERMOD and PASSIVMOD modules, energy management system, and IP assets, and set the foundation for Task C7.4.

Outcome: The task was completed with one-month delay. All objectives were achieved

TC7.4: Exploitation strategy and IPR for project results and foreground

Task C7.4, executed by FHa and finalized in January 2025, consolidated the intellectual property strategy and outlined the commercial exploitation pathway of the project. Building on prior deliverables (C7.1, C7.2, C7.3), the report defined seven KERs, including the ENERGYMOD and PASSIVMOD modules, a renewable energy control system, analytical and dissemination tools, and monitoring methodologies, while specifying ownership and protection conditions. Industrial property rights for PASSIVMOD were allocated to CUDZ and BHAUS (with a patent pending for the thermal envelope solution), while ARPA was granted operating licenses for their use. The report also aligned these results with project objectives, proposing a structured exploitation roadmap supported by PESTEL analysis and a long-term monitoring plan to ensure market impact, replicability, and adaptability of the ZEM solution.

Outcome: The task was completed with a month delay. All the objectives were achieved

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C7.1 Business model for ZEROENERGYMOD	C7	30/11/2022	FHA	ARPA/CUDZ	Finished
C7.2 Market assessment at EU end international level	C7	13/11/2023	FHA	-	Finished
C7.3 Reference real business cases	C7	08/01/2025	FHA	-	Finished
C7.4 IPR and exploitable results report	C7	30/01/2025	FHA	ARPA/CUDZ	Finished

Name of the Milestone	Associated action	Achieved	Status
Business model for ZEROENERGYMOD in related areas	C7	30/11/2022	Finished
IPR and exploitable results report submitted	C7	30/01/2025	Finished

C.8	Guidelines and methodologies to achieve ZEROENERGYMOD			Status:	Completed
	Start date	Foreseen: 1/06/23 Actual: 27/01/25	End date	Foreseen: 31/05/25 Actual: 31/05/25	

TC8.1 Implementation of Passive Haus standards, renewable energies and hydrogen technologies to achieve ZEROENERGYMOD

Task C8.1 (2023 - 2025), led by CUDZ and FHa, produced three technical guides to support ZEROENERGYMOD transferability in off-grid sustainable construction. The guides address Passivhaus standards in habitable modules (C8.1), renewable and hydrogen integration in extreme environments (C8.2), and a full implementation framework combining ENERMOD and PASSIVMOD (C8.3).

Under Task C8.1, the three technical guides (C8.1, C8.2, C8.3) were published on the website of the project and disseminated to key stakeholders to support replication of the ZEROENERGYMOD solution. CUDZ targeted 32 stakeholders from defence, research, and industry, while FHa reached over 200 additional contacts through digital channels and key events. Distribution was mainly digital, with limited printed copies at key meetings, ensuring effective knowledge transfer across sectors. *Outcome: The task was completed as scheduled.*



Figure 3. Covers of the 3 guides developed

TC8.2 Compilation of lessons learnt and demonstration activities during the project

Led by CUDZ and FHa, technical and operational lessons were identified and reported, based on the full lifecycle of the ZEROENERGYMOD modules. Two deliverables were produced (C8.4 and C8.5). Both deliverables compile practical insights for replicating the system in remote and extreme environments. C8.5 also includes feedback of users collected after more than two years of operation. *Outcome: The task was completed as scheduled.*

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C8.1 Guide for Implementation of Passiv Haus standards in habitable modules	C8	27/01/2025	CUDZ	BHAUS	Finished
C8.2 Introduction guide to renewable energies and hydrogen technologies on extreme environments	C8	18/03/2025	CUDZ	FHA	Finished
C8.3 Guide for implementation ZEROENERGYMOD	C8	09/04/2025	CUDZ	FHA	Finished
C8.4 Lessons learnt on developing ENERMOD	C8	31/05/2025	CUDZ	All	Finished
C8.5 Lessons learnt on developing PASSIVMOD	C8	31/05/2025	CUDZ	All	Finished

Name of the Milestone	Associated action	Achieved	Status
5 guides launched	C8	31/05/2025	Finished

Monitoring of the impact of the project actions						Status:	Completed
D.1	Start date	Foreseen:	1/06/20	End date	Foreseen:		31/05/25
		Actual:	1/06/20		Actual:		31/05/25

Task D1.1 Selection of indicators and monitoring protocol development

The task involved selecting final impact indicators for monitoring, based on those initially defined in the project and expanded with new ones identified during the first six months.

To characterize the behaviour of the module, sensors and meters were installed during the assembly phase at the first demo site to monitor total electrical energy consumption and indoor air quality. CUDZ prepared the deliverable **D1.1 (ZEROENERGYMOD monitoring protocol report)**, which was issued with a 7-month delay as a result of setbacks in module design and construction. The report details the monitoring procedure and specifies the materials and methods to be used.

Outcome: The task completed with a 7-month delay. The objectives were accomplished.

Task D1.2 Continuous evaluation of indicators

From July 2022 to May 2025, the TD1.1 monitoring protocol was applied to track energy consumption, renewable generation, battery and hydrogen storage, and indoor thermal comfort (humidity, temperature, CO₂ concentration). Results are compiled in the D1.2 report.

PASSIVMOD confirmed compliance with European regulations and Passivhaus standards, ensuring comfort and indoor environmental quality, particularly in winter. However, heatwave analyses highlighted the need for improved summer performance through external shading and enhanced cooling system. ENERMOD monitoring provided nearly three-year assessment of photovoltaic, wind, battery storage, and hydrogen systems, structured in two operational phases.

During the monitoring period, ENERMOD produced 13,470 kWh of renewable energy. The hydrogen system was technically validated, with a round-trip efficiency of 12.8% covering hydrogen production, compression, and electricity generation via fuel cell. Despite some inefficiencies in renewable surplus management and subsystem integration, the system proved robust and adaptable. Corrective measures during the project extension, including enhanced monitoring, wind turbine optimization, and solar adjustments, allowed improving the overall system performance, even if a backup grid connection has remained necessary.

Integrating PASSIVMOD and ENERMOD within the same thermal envelope allowed increasing the shape factor of the building and decreasing the construction costs. On the other side, it negatively affected on the air tightness (since ATEX hydrogen room requires emergency exhausts holes in the facade) implying a major challenge for attaining Passivhaus certification. The D1.4 report delivers guidelines for standardized monitoring, defining key parameters and equipment to ensure replicable performance assessment of the ZEM solution in future settings.

Outcome: The task was completed as scheduled. The objectives were accomplished.

Name of the Deliverable	Ass. action	Completion date	Deliverable Leader	Support	Status
D1.1 ZEROENERGYMOD monitoring protocol report	D1	01/06/2022	CUDZ	FHA	Finished
D1.2 Zaragoza-Spain demonstration monitoring report	D1	30/06/2025	CUDZ	FHA	Finished
D1.3 Latvia demonstration monitoring report	D1	-	CUDZ	FHA	*
D1.4 Final demonstration monitoring guideline	D1	30/06/2024	CUDZ	FHA	*

Name of the Milestone	Associated action	Achieved	Status
Monitoring protocol development	D1	01/06/2022	Finished
Zaragoza-Spain demonstration monitoring completed	D1	30/06/2025	Finished
Latvia demonstration monitoring completed	D1	-	*
Final demonstration monitoring guideline submitted	D1	30/06/2024	Finished

* Deliverable D1.3 and associated milestone were cancelled following Latvian demo site suspension due to Russia's invasion of Ukraine. The prototype remained in Zaragoza for validation activities.

D.2	Monitoring of the impact of the project actions				Status:	Completed
	Start date	Foreseen:	1/06/23	End date	Foreseen:	31/05/25
		Actual:	1/06/23		Actual:	30/06/25

TD2.1 Socio-economic impact of the project

Led by FHa in the final year of the project, this activity required close coordination with actions C8, E1, and E2 to ensure consistency with the technical results and dissemination efforts. The assessment included a stakeholder perception survey preparation and the Social Life Cycle Assessment (S-LCA) methodology, following ISO 14040 standards of the ZEM prototype.

Outcome: Task completed as scheduled. The objective was accomplished.

TD2.2 S-LCA of ZEROENERGYMOD

FHa carried out a full Social LCA of the prototype under ISO 14040/44 standards using open LCA 1.11.0 and the PSILCA v3 database. Six impact categories were assessed: fair salary, working hours, gender wage gap, fatal accidents, economic contribution, and social responsibility. The analysis, based on a fully operational ZEM module (C6.1, C6.2), identified moderate risks in upstream sectors (plastics, metals, machinery, electronics, water supply), mainly related to wage fairness, gender inequality, and safety. In contrast, the system demonstrated high potential to foster economic development and responsible practices depending on geographic and supply chain context. Stakeholder surveys confirmed strong socioeconomic benefits of the project, notably in job creation, energy autonomy, and sustainable off-grid development. Full results are detailed in deliverable D2.2.

Outcome: The task was completed as scheduled. Objective accomplished.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
D2.1 Socio-economic impact report	D2	25/02/2025	FHA	All	Finished
D2.2 S-LCA ZEROENERGYMOD report	D2	30/06/2025	FHA	All	Finished

Name of the Milestone	Associated action	Achieved	Status
Socio-economic impact report submitted	D2	25/02/2025	Finished

E.1	Dissemination and awareness plan (DAP) development and update				Status:	Completed
	Start date	Foreseen:	1/06/20	End date	Foreseen:	31/05/25
		Actual:	1/06/20		Actual:	20/06/25

The Dissemination and Awareness Plan (DAP) guided project communication with four updates deliverables:

- **E1.1 - DAP** (Feb 2021) set objectives, target audiences, and channels. Completed with a 1-month delay.
- **E1.2 - The first updated DAP** maintained stakeholder engagement, reviewed the effectiveness of communication tools (website, materials, networks), and tracked 11 activities against the original targets. Completed with a 2-month delay.
- **E1.3 - The second updated DAP** reported strong media coverage, event participation, updated materials, new website content (1,470 visits), a project video, and demo site visits. Dissemination outputs included 13 articles, a scientific paper, and 2 events, with KPIs refined to ensure focused, high-impact communication.
- **E1.4 - The third updated DAP** (M38 - M48) highlighted participation in 8 major events (4,300+ attendees), Energy Globe Award nomination, 25 social posts, 8 news articles, 4 demo visits (85 visitors), 883 website sessions, and one scientific article.
- **E1.5 – Final updated DAP** (M48 - M60) covered the final dissemination activities, including project extension. ZEM was showcased at six major events, including WHEC 2024 and European Hydrogen Week (reaching over 6,800 participants), and at two EUSEW 2025 workshops (98 attendees). Additional outreach included two demo visits (72 visitors), 49 social media posts, 44 news articles, 1,061 website sessions, and the wide distribution of the final technical guides (C8.1 - C8.3). Main KPI targets were met, and the project concluded with a closing event in May 2025, ensuring strong visibility and lasting impact.

Outcome: The tasks were completed with a minor delay. Objectives were accomplished.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
E1.1 Dissemination and Awareness Plan	E1	06/02/2021	FHA	-	Finished
E1.2 First Updated of DAP	E1	04/03/2022	FHA	-	Finished
E1.3 Second Updated of DAP	E1	31/01/2023	FHA	-	Finished
E1.4 Third Updated of DAP	E1	13/01/2025	FHA	-	Finished
E1.5 Final Report about Dissemination and Communication Activities	E1	20/06/2025	FHA	-	Finished

Name of the Milestone	Associated action	Achieved	Status
Dissemination and Awareness Plan Elaborated	E1	06/02/2021	Finished
Final Report about Dissemination and Communication Activities Submitted	E1	20/06/2025	Finished

E.2	Specific activities for DAP execution				Status:	Completed
	Start date	Foreseen:	1/06/20	End date	Foreseen:	31/05/25
	Actual:	1/06/20		Actual:	30/06/25	

FHa led overall dissemination, media strategy, and events coordination. CUDZ focused on institutional relations, technical and scientific outreach, military stakeholder engagement, and organized visits to the demo site. ARPA and BHAUS provided technical communication support. As the project progressed and the DAP was improved and updated, dissemination activities were compiled in the following deliverables:

- **E2.2 - First Diffusion Activities Report_M1-M12:** focused on project international positioning, on establishing the communications tools

- **E2.3 - Second Diffusion Activities Report_M13-M24:** reported project dissemination through key events (conferences and demo presentation) and strategic communication with national media coverage and release of brochures and posters.
- **E2.4 - Third Diffusion Activities Report_M25-M36:** visits to the prototype were promoted, participation in international forums continued, and digital communication was reinforced with interactive visits to the module, the final project video, and participation in webinars.
- **E2.4 – Final Diffusion Activities Report:** The consortium successfully implemented communication actions, meeting or exceeding most dissemination KPIs. Only scientific publications (5 vs. 8) and guided visits (13 vs. 15) fell short, to be addressed in the After-LIFE Plan. Overall, E2.4 fulfilled its objectives, establishing the project as a European reference in sustainable off-grid modular energy systems (check E2.4 for details).

Outcome: Objectives were accomplished.

TE2.1 ZEROENERGYMOD website, logo, and image

The project website (www.lifezeroenergymod.eu), launched in January 2021 in Spanish and English, provided project updates, news, and technical downloads. By June 2025, it had recorded 3,208 visits, with engagement peaking in the final year. Users came from over 10 countries, led by Spain (1,635), the U.S. (691), China (202), and the Netherlands (172), highlighting its role as a key communication and international outreach tool.

Outcome: Objective accomplished.

TE2.2. Notice boards, press releases and publications

At the first demo site, three notice boards displaying the LIFE and ZEM logos were installed to present project objectives and technologies, serving as key communication tools during visits and workshops. Throughout the project, dissemination efforts comprised 81 press releases and five peer reviewed publications, coordinated by CUDZ with support from BHAUS. All articles are available in the ‘Downloads’ section of the project website.

Outcome: Objectives were accomplished.

TE2.3. ZEROENERGYMOD project presentation, mid-term and closing events

The LIFE ZEROENERGYMOD project organized 37 dissemination events, engaging more than 13,600 participants. Outreach expanded from local initiatives in 2020 - 2021 to international recognition at flagship events such as Hydrogen Week and EHEC in 2023 - 2024, with the final year dedicated to sharing results and securing the legacy of the project.

On 29 May 2025, the final event of the project presented key outcomes, launched three technical guides, and highlighted recent awards, while stakeholders discussed legacy, replication, and alignment with EU sustainability goals. The event drew 42 registered participants, 23 of whom attending in person. *Outcome: The objectives were accomplished.*

TE2.4. Dedicated workshops

During EU Sustainable Energy Week 2025, FHa and CUDZ held two virtual workshops. The first (4 March, English) on building decarbonisation gathered 45 participants, while the second (9 April, Spanish) on energy efficiency in temporary and isolated buildings engaged 53 participants. Both featured expert speakers, offered participation certificates, and are available as recordings on the YouTube channel of FHa for broader dissemination.

Outcome: The objectives were accomplished.

TE2.5. Specific activities linked to demo sites

The project conducted 13 guided visits (2021–2025) to its demonstration module at San Jorge Military Base, engaging 290 stakeholders from construction, energy, defence, research, and public administration. In March 2025, five military engineers were trained in module disassembly and reassembly to prepare for deployment in Antarctica. A dedicated video showcasing the module’s functionality was also published on the project website ([Link](#)). *Outcome: The objective was accomplished.*

TE2.6. Networking with other LIFE projects

A total of 17 networking activities (9 national and 8 international) were conducted through key hydrogen, energy, and defence events, strengthening project visibility and collaboration.

In the first year of the project, a networking action was carried out with Life SmartAgroMobility project (LIFE19 CCM-ES-001206). Workshop 1 included a speaker representing the LIFE [SUSTAINHUTS](#) project (LIFE15 CCA/ES/000058). Although it is not a LIFE project, the coordinator of the [nZEM](#) project also gave a presentation, thanks to the networking facilitated by the CINEA Project Advisor, who identified significant synergies with this regional project. More opportunities for future collaboration would be explored as part of the After-LIFE Plan, with support from CINEA and the monitoring team.

Outcome: Limited activity. To be enhanced in the After Life Plan phase.

Task E2.7 Specific partners’ activities to disseminate the project

ZEROENERGYMOD was widely promoted through partner networks, the project website (3,208 users from more than 30 countries), 106 social media posts, 20 publications, and 37 events reaching over 15,000 people (report E2.4). A Layman’s report developed in May 2025, prepared by FHa with partner input, summarizes key achievements in renewable energy, energy-efficient construction, and real time monitoring of the project, and it will be disseminated broadly through digital channels and public outreach by the consortium.

Outcome: The objectives were accomplished.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
E2.1 Project website	E2	24/02/2021	FHA	All	Finished
E2.2 First diffusion activities report	E2	11/08/2021	FHA	All	Finished
E2.3 Second diffusion activities report	E2	26/07/2022	FHA	All	Finished
E2.4 Third diffusion activities report	E2	31/10/2023	FHA	All	Finished
E2.4 Final diffusion activities report	E2	20/06/2025	FHA	All	Finished
E2.5 Notice boards report	E2	10/02/2025	FHA	All	Finished
E2.7 Layman's terms report	E2	31/07/2025	FHA	All	Finished

Name of the Milestone	Associated action	Achieved	Status
Layman's terms developed	E2	31/07/2025	Finished
Final diffusion activities report submitted	E2	20/06/2025	Finished

Project management by FHa				Status:	Completed	
F.1	Start date	Foreseen:	1/06/20	End date	Foreseen:	31/08/25
		Actual:	1/06/20		Actual:	31/08/25

FHa **coordinated the activities** defined in the work plan, continuously monitoring progress, addressing emerging issues, activating specific tasks when necessary, and facilitating effective interaction between the partners.

Annual General Assembly (GAs) meetings and follow-up meetings were held at least monthly, combining online and face-to-face meetings. During the last year of the project, the project meetings were held every two weeks to ensure effective coordination and timely progress.

The project consortium is composed of four partners, all based in the Aragon region of Spain, each bringing diverse experience and competences. This regional concentration benefited the project by facilitating communication, whether in person, by email, or through quick calls, and promoting a collaborative atmosphere that fosters long-term relationships and future cooperation among the partners.

Nevertheless, the consortium had to deal with some unforeseen circumstances:

- Staff turnovers at the coordinating partner (FHa), which required additional effort to ensure project progress was not affected.
- The impossibility of carrying out the planned demonstration at the NATO base in Latvia due to its proximity to the Russian border, following the invasion of Ukraine.
- The evaluation of alternative options for a cold-weather demonstration, ultimately ruling out Candanchú (Spanish Pyrenees) due to the impossibility of guaranteeing users in the module.
- The request for a 12-month extension in 2024 to implement changes that would improve module performance and bring it closer to the Key Performance Targets.

Out of 45 deliverable reports, were completed. The three deliverables associated with the Latvia demonstration (C5.3, C5.4, D1.3) were not prepared, nor was F1.5, since no beneficiary exceeded €325k in funding and therefore an external audit was therefore not required.

45 deliverable reports out of 49 have been completed. The three deliverables associated with the Latvia demonstration (C5.3, C5.4, D1.3) were not prepared, nor was F1.5, since no beneficiary exceeded €325k in funding and an external audit was therefore not required.

Name of the Deliverable	Associated action	Completion date	Deliverable Leader	Support	Status
C2.1 Initial report of the technical solutions found	C2	25/09/2020	BHAUS	CUDZ	Finished
A1.1 Report on current status of the technologies to affecting ZEROENERGYMOD	A1	30/03/2021	CUDZ	-	Finished
E1.1 Dissemination and Awareness Plan	E1	06/02/2021	FHA	-	Finished
C1.1 Executive project	C1	16/02/2021	ARPA	FHA	Finished
E2.1 Project website	E2	24/02/2021	FHA	All	Finished
C2.2 Final report of the technical solutions for PASSIVMOD	C2	01/05/2021	BHAUS	CUDZ	Finished
F1.1 Progress report	F1	14/07/2021	FHA	All	Finished
E2.2 First diffusion activities report	E2	11/08/2021	FHA	All	Finished
E1.2 First Updated of DAP	E1	04/03/2022	FHA	-	Finished
C3.1 Final design of PASSIVMOD	C3	01/06/2022	BHAUS	ARPA/CUDZ	Finished
C3.2 Executive project of PASSIVMOD	C3	10/06/2022	BHAUS	ARPA/CUDZ	Finished
C1.2 Final report on ENERMOD including tests	C1	13/04/2023	ARPA	FHA	Finished
C5.1 Work plan and transportation to demo-site 1 (spain)	C5	17/05/2022	FHA	ARPA/CUDZ	Finished
C4.1 Report on the testing of ENERMOD and PASSIVMOD combined	C4	13/04/2023	ARPA	All	Finished
C5.2 ZEROENERGYMOD deployment in demosite 1 (Spain)	C5	13/06/2022	FHA	ARPA/CUDZ	Finished
E2.3 Second diffusion activities report	E2	26/07/2022	FHA	All	Finished
F1.2 Mid-term report	F1	29/07/2022	FHA	All	Finished
D1.1 ZEROENERGYMOD monitoring protocol report	D1	01/06/2022	CUDZ	FHA	Finished
C5.3 Work plan and transportation to demo-site 2 (Latvia)	C5	-	FHA	ARPA/CUDZ	--

Name of the Deliverable	Associated	Completion	Deliverable		Status
	action	date	Leader	Support	
C7.1 Business model for ZEROENERGYMOD	C7	30/11/2022	FHA	ARPA/CUDZ	Finished
C3.3 Report of the testing of PASSIVMOD	C3	24/06/2025	BHAUS	ARPA/CUDZ	Finished
C5.4 ZEROENERGYMOD deployment in demo-site 2 (Latvia)	C5	-	FHA	ARPA/CUDZ	--
E1.3 Second Updated of DAP	E1	31/01/2023	FHA	-	Finished
A1.2 Agreements of collaboration for demo-sites deployment	A1	26/05/2025	CUDZ	-	Finished
E2.4 Third diffusion activities report	E2	31/10/2023	FHA	All	Finished
F1.3 Progress report	F1	31/07/2023	FHA	All	Finished
D1.2 Zaragoza-Spain demonstration monitoring report	D1	30/06/2025	CUDZ	FHA	Finished
C6.1 Report on Materials technology implementation	C6	29/08/2023	FHA	ARPA/CUDZ	Finished
C8.1 Guide for Implementation of Passiv Haus standars in habitable modules	C8	27/01/2025	CUDZ	BHAUS	Finished
C7.2 Market assessment at EU end international level	C7	13/11/2023	FHA	-	Finished
C8.2 Introduction guide to renewable energies and hydrogen technologies on extreme environments	C8	18/03/2025	CUDZ	FHA	Finished
D1.3 Latvia demonstration monitoring report	D1	-	CUDZ	FHA	--
E1.4 Third Updated of DAP	E1	13/01/2025	FHA	-	Finished
After-life plan	F2	31/07/2025	FHA	-	Finished
C6.2 LCA report of final ZEROPASSIVMOD solution	C6	25/04/2025	FHA	ARPA/CUDZ	Finished
C7.3 Reference real business cases	C7	08/01/2025	FHA	-	Finished
C7.4 IPR and exploitable results report	C7	30/01/2025	FHA	ARPA/CUDZ	Finished
C8.3 Guide for implementation ZEROENERGYMOD	C8	09/04/2025	CUDZ	FHA	Finished
C8.4 Lessons learnt on developing ENERMOD	C8	31/05/2025	CUDZ	All	Finished
C8.5 Lessons learnt on developing PASSIVMOD	C8	31/05/2025	CUDZ	All	Finished
D2.1 Socio-economic impact report	D2	25/02/2025	FHA	All	Finished
D2.2 S-LCA ZEROENERGYMOD report	D2	30/06/2025	FHA	All	Finished
E1.5 Final Report about Dissemination and Communication Activities	E1	20/06/2025	FHA	-	Finished
E2.5 Final diffusion activities report	E2	20/06/2025	FHA	All	Finished
E2.6 Notice boards report	E2	10/02/2025	FHA	All	Finished
E2.7 Layman's terms report	E2	31/07/2025	FHA	All	Finished
D1.5 Final demonstration monitoring guideline	D1	30/06/2025	CUDZ	FHA	Finished
F1.4 Final report	F1	31/08/2025	FHA	All	Finished
F1.5 Audit report	F1	-	FHA	All	-

The project has reached **23 out of 26 milestones**. The three milestones not achieved were those related to the Latvia demonstration and the submission of the F1.5 Audit report.

Name of the Milestone	Associated	Achieved	Status
	action		
Dissemination and Awareness Plan Elaborated	E1	06/02/2021	Finished
Design of ENERMOD finalised	C1	16/02/2021	Finished
Identification of the materials selected for PASSIVMOD	C2	01/05/2021	Finished
Executive Project of PASSIVMOD finalised	C3	10/06/2022	Finished
Combined system ZEROENERGYMOD ready to be deployed	C4	13/04/2023	Finished
ZEROENERGYMOD deployed in demo-site 1 (Spain)	C5	13/06/2022	Finished
Mid-term report submitted	F1	29/07/2022	Finished
Monitoring protocol development	D1	01/06/2022	Finished
Business model for ZEROENERGYMOD in related areas	C7	30/11/2022	Finished
Satisfactory tests of ENERMOD	C1	13/04/2023	Finished
Certification of PASSIVMOD achieved	C3	24/06/2025	Finished
ZEROENERGYMOD deployed in demo-site 2(Latvia)	C5	-	-
Agreements signed with demosites	A1	26/05/2025	Finished
Zaragoza-Spain demonstration monitoring completed	D1	30/06/2025	Finished
LCA of potential materials to be used in PASSIVMOD	C6	29/08/2023	Finished
Latvia demonstration monitoring completed	D1	-	-
Layman's terms developed	E2	31/07/2025	Finished

Name of the Milestone	Associated action	Achieved	Status
5 guides launched	C8	31/05/2025	Finished
Final LCA report	C6	25/04/2025	Finished
Final Report about Dissemination and Communication Activities St	E1	20/06/2025	Finished
Final diffusion activities report submitted	E2	20/06/2025	Finished
IPR and exploitable results report submitted	C7	30/01/2025	Finished
Socio-economic impact report submitted	D2	25/02/2025	Finished
Final demonstration monitoring guideline submitted	D1	30/06/2024	Finished
<i>Audit report submitted</i>	F1	-	-
Final report submitted	F1	31/08/2025	Finished

Overall, the project results demonstrate **strong achievement of the objectives**. Despite delays affecting most design and construction deliverables and challenges with hydrogen system autonomy and airtightness, the project ensured technical validation, environmental performance, and strong replicability for future deployments.

After LIFE communication and conservation plan				Status:	Completed	
F.2	Start date	Foreseen:	1/03/24	End date	Foreseen:	31/05/24
		Actual:	1/03/24		Actual:	31/07/25

The After-LIFE Communication and Conservation Plan (2025 - 2030), completed in July 2025, focuses on dissemination, replication, and commercialization. FHA will continue outreach through the project website, social media, and EU/national events. ARPA would drive market integration of ENERMOD for defence, healthcare, and industry; BHAUS would expand PASSIVMOD applications; and CUDZ will integrate results into research and military innovation. Moreover, CUDZ is currently working on three scientific publications and will continue to promote technical visits on the demonstration site while the prototype remains at the San Jorge Base in Zaragoza

A final field demonstration is planned at Spain's *Gabriel de Castilla* Base in Antarctica to validate the system performance under extreme conditions. Its execution depends on national budget allocations for logistics and completion of the new scientific module at Deception Island. Aligned with the EU Green Deal, Sustainable Development Goals (SDGs), and NATO standards, the plan ensures long-term impact, scalability, and policy relevance of the ZEROENERGYMOD solution.

Name of the Deliverable	Associated action	Actual completion date	Deliverable Leader	Support	Status
After-life plan	F2	31/07/2025	FHA	All	Finished

5.2. Main deviations, problems and corrective actions implemented

The main deviations/problems/corrective actions that emerged during the project period have been:

- 1. Action A.1.** The GA anticipated that **permits** for all demos would be obtained within the first four months of the project. In practice, however, the project had to align with the Spanish Army's application timelines, as it was **not feasible to obtain such permits years beforehand**.
Solution adopted: The duration of this task was extended to cover the full duration of the project. All required permits have been granted.
- 2. Module design and construction (C1 and C3):** These required more time than originally anticipated. As this was a prototype rather than a commercial building, the process revealed opportunities to improve materials, construction techniques, and habitability. This made it necessary to revise the designs and construction procedures for all potentially affected elements.
Solution adopted: The consortium agreed it was worthwhile to pursue a more robust technical and functional solution, while advancing part of the work under Action C4 to compensate for the delays.
- 3.** Due to these **optimizations and design improvements**, the original plan of two independent modules (2 Passivmod habitable containers + 1 Enermod container) was replaced with a combined module integrating both typologies into a single solution, together with an additional Passivmod habitable container. This joint construction increased the available living space. As a result, Actions C5 and D1 began later than expected, following delays in the design and construction of the combined and optimized ZEROENERGYMOD.
Solution adopted: Action C4 has been overlapped with actions C1 and C3, cushioning the delays carried over from the previous activities (6-12 months delay).
- 4. COVID pandemic** reduced face-to-face meetings and caused delays in design and construction activities due to restrictions. It also disrupted delivery schedules and limited the availability of certain equipment and materials, further slowing the construction process.
Solution adopted: Online meetings and phone calls have been encouraged. The consortium decided to implement the modules at the demo site as soon as FV system was ready (2022). Wind turbine adjustments and fuel cell delivery delay overlap demonstration period in 2023 (D1).
- 5. Invasion of Ukraine:** Owing to the instability and risks created by Russia's invasion of Ukraine and given the proximity of the second demo site (Latvia) to the conflict zone, the consortium proposed during the 2022 annual monitoring visit to cancel the demo in Latvia. In 2023, CINEA encouraged the search for an alternative demo site with a comparable cold climate. The consortium explored the option of the Candanchú Mountain Military School (Spanish Pyrenees, 1,550 m); a feasibility study was conducted and permits

obtained, but the site was ultimately discarded due to the absence of users during a representative period.

Solution adopted: Deliverables and milestones related to the Latvia demo site will not be carried out. The module will continue to be monitored at demo site 1 (Zaragoza) and deliverables will include a longer period.

6. **Delays in design and construction and implementation of all systems led to initial inconsistent data.** After analysing performance data from the first year of the demo with all subsystems operational (April 2023-April 2024), the consortium identified higher energy consumption than Passivhaus standards and concluded that the hydrogen system had not achieved the expected autonomy. To address these challenges, the consortium proposes a **12-month extension** on monitoring at the San Jorge site until May 2025. *Solution adopted: Extension request was approved, enabling key technical improvements to enhance system performance:*

- *Relocation of photovoltaic panels to reduce shading and maximize renewable output.*
- *Implementation of a new monitoring system, along with additional testing and performance data for the hydrogen system. Details are provided in D1.2.*
- *Review and breakdown of consumption, new airtightness tests, and installation of solar shading on the south-facing window to reduce cooling loads. Completion of the Passivhaus certification process. All details are documented in C3.3.*
- *From 31 March to 4 April 2025, the module was partially disassembled to provide military training and refine assembly procedures for Antarctic deployment. This activity led by ARPA and supported by Salamanca Battalion provided practical training for future Antarctic deployment, improved thermal sealing, and validated logistics and assembly procedures. Lessons learned and blower door test data are being incorporated into DC8.5.*

Other **minor deviations** that have affected the project are summarised below:

7. Action C6: Deadline of the milestone “LCA of potential materials linked to PASSIVMOD” was postponed from 2020 to 2023, as this task could not start until Action C2 was finished and the final set of materials selected.
8. **Merging of deliverables:** To achieve a more practical methodology and avoid cross-references, several deliverables were merged:

<i>C2.1 Initial report of the technical solutions found</i>	+	<i>C2.2 Final report of the technical solutions for PASSIVMOD</i>
<i>C5.1 Work plan and transportation to demo-site 1 (Spain)</i>	+	<i>C5.2 ZEROENERGYMOD deployment in demosite 1 (Spain)</i>
<i>C1.2 Final report on ENERMOD including tests</i>	+	<i>C4.1 Report on the testing of ENERMOD and PASSIVMOD combined</i>

5.3. Evaluation of Project Implementation

The methodology proposed in the GA was followed and proven valid for the purpose of the project. It consisted of the following stages:

- i. Study of materials and suitable prefabricated building techniques.
- ii. Design and development of the modules following Passivhaus standards.
- iii. Build module prototype at ARPA's facilities.
- iv. Assess the most suitable way of transport it to first demo site.
- v. Dismantle the prototype, transport and install it at first demo site.
- vi. Compile all designs and changes made and prepare design and construction deliverables.
- vii. Test technology and put it in service.
- viii. Prepare first site monitorization following a methodology suitable for each technology.
- ix. Monitor demo sites: collecting data, extracting information, and analysing results.
- x. Adjustments, improvements or changes to the prototype, based on the results evaluated.

Summary of the results per action

Action	Foreseen	Results achieved	Evaluation
A1 Reference assessment. Permits and authorization	Objectives: - establish the starting point of the study. - agreements of collaboration for demos.	DA1.1 Report on current status of technologies DA1.2 Agreements of collaboration for demo-sites deployment (draft). Permits obtained as needed, positive reception within Spanish Army, involvement with the project	IN LINE WITH EXPECTATIONS
C1 Design and construction of ENERMOD	Objectives: Develop designing, engineering, purchasing and construction of energy module.	Designed, purchased and built at ARPA's facilities. Disassembled, transported and assembled at the first demo: - Energy production: PV panels + wind turbine - Energy storage: batteries + H2 system	EXCEED EXPECTATIONS Improved equipment working conditions, ensuring temperatures above 0°C, and easier access for maintenance activities as the ENERMOD is integrated into the PASSIVMOD enclosure. A larger living space was created with the optimised design.
C2 Study of materials and suitable prefabricated building techniques of PASSIVMOD	Objectives: - Select the most suitable materials to meet project requirements. - Select the most appropriate construction typology.	Materials selected have low maintenance, safety conditions and low environmental impact Construction typology allows to build in a modular, prefabricated and transportable way, able to adapt to 20-foot container	IN LINE WITH EXPECTATIONS
C3 Design and construction of PASSIVMOD	Objectives: Define and build a prototype of PASSIVMOD module	- PASSIVMOD executive project finished. - PASSIVMOD module built and tested	IN LINE WITH EXPECTATIONS. Higher level of certification was

	that meets all requirements established in action C2.	- Passivhaus Certification	expected but not possible with the integration of the hydrogen system.
C4 Integration and testing of ENERMOD and PASSIVMOD	Objectives: Combine the two modules built and tested individually in previous actions.	- PASSIVMOD and ENERMOD were built at ARPA's facilities as a combined solution. - ZEM combined module tested for Passivhaus requirements.	EXCEED EXPECTATIONS, as ENERMOD meets Passivhaus requirements and ATEX security standards.
C5 Operation of demosites	Objectives: Implement and test the zero-emissions solution developed during the project under real conditions.	- ZEM deployed in demo-site 1 (Zaragoza, Spain). - No transportation and implementation for demo site 2 (Latvia demo cancelled). - Partial dismantling carried out at demo site 1.	BELOW EXPECTATIONS
C6 Life cycle assessment (LCA) and environmental analysis	Objectives: Determine the environmental impact of the materials and technologies.	- LCA study that shows environmental impacts of a product during its lifetime.	IN LINE WITH EXPECTATIONS
C7 Replicability and transferability of results	Objectives: Replicate and transfer results to other EU and international areas similar.	- Business model for ZEM. - Exploitation strategy and IPR for project results - No clear dates to transfer prototype to Antarctica	IN LINE WITH EXPECTATIONS
C8 Guidelines and methodologies to achieve ZEM	Objectives: - Compile lessons learnt - Achieve good transfer of technical project results.	- 3 technical guides which will explain the process, design, deployment and characteristics of the modules developed and disseminated. - 2 lessons learnt reports	IN LINE WITH EXPECTATIONS
D1 Monitoring of the impact of the project actions	Objectives: Monitor modules performing in demos and measure environmental impact.	- ZEM monitoring protocol report (D1.1) - A monitoring report per demo (D1.2). - Final demonstration monitoring guideline (D1.4).	IN LINE WITH EXPECTATIONS, project extension has served to keep on testing the prototype in Zaragoza, achieving system improvements and adjustments.
D2 Evaluation of socio-economic impact	Objectives: Analyse socio and social-economic impact of a ZEM solution.	- Socio-economic impact report (D2.1). - S-LCA ZEM report (D2.2).	IN LINE WITH EXPECTATIONS
E1 Dissemination and awareness plan (DAP) development and update	Objectives: Develop and update a detailed dissemination, communication and awareness plan.	- Dissemination and Awareness Plan (DAP) and updates. - Final Report about Dissemination and Communication Activities.	IN LINE WITH EXPECTATIONS,
E2 Specific activities for DAP execution	Objectives: Develop and track DAP activities	- Web and logo launched. - Notice boards, press releases and publications. - Project presentations, demo visits, workshops, networking.	IN LINE WITH EXPECTATIONS, project results dissemination boosted during project extension

F1 Project management by FHa	Objectives: Optimize the management of the project, with the adequate assignment of resources, monitoring and validation of the results obtained.	<ul style="list-style-type: none"> - Monitoring reports submitted on time and form. - Continuous Project management. - Fluent communication with CINEA and monitoring team. - Ensure partners are committed and well informed. . 	IN LINE WITH EXPECTATIONS
F2 After LIFE communication and conservation plan	Objectives: Implement a communication action plan for the post - project period.	Continuity of the actions, expanding and scaling up the technologies proposed in this project. Antarctica: TBD, after completion of the new scientific module under construction and the state budgets.	IN LINE WITH EXPECTATIONS in communication.

Next table shows the **main results achieved** with respect to what states the Grant Agreement:

Technical results	
2 portable and habitable modules (2 PASSIVMOD + 1 ENERMOD)	Achieved and exceeded , an easy transportation combined solution: 3 habitable modules and 1 energy module.
Passivhaus standards in habitable module	Achieved in habitable modules and also in energy module (Passivhaus certification obtained)
Renewable energy sources and hybrid energy storage system	Renewable energy sources achieved : photovoltaic and wind turbine are installed and operating. Energy storage solution achieved : batteries and hydrogen system installed and operational.
Environmental improvements	
Reduction of energy consumption of habitable module in 285 kWh/m ² and year (75% compared to current solution).	Achieved , energy reduction per habitable module has reached 3.228 kWh/m ² per year, achieving a 96% reduction compared to conventional solution (diesel generator).
Reduction of diesel consumption in 5700 litres per habitable module per year.	Fully achieved , as energy supply via diesel generators was avoided throughout the whole demonstration. Prototype's energy backup was power grid.
15 tons/year of CO ₂ avoided	Achieved and exceeded , with a reduction of more than 40 tons/year of CO ₂ avoided per habitable module, including equivalent emissions associated with consumption from Spanish electricity grid.
0.33 tons/year of NO _x avoided	Achieved and exceeded , achieving a reduction of more than 0.58 tons/year of NO _x avoided per habitable module.
Production of 4000 kWh/year from renewable resources.	Achieved , with an average annual production of 4,490 kWh from renewable sources.
Indoor Air Quality Level will be IDA2 or IDA1 in habitable modules	Achieved , with average values in the living modules between 350 and 500 ppm of CO ₂ , corresponding to IDA 1 air quality.
Dissemination activities & Replicability	
8 international events	11 international events, achieved
2 workshops	2 workshops done in the second half of the project, achieved
2 network events	17 network events, achieved

Final event	Achieved , final event on 29 May 2025
Dissemination plan	Achieved
5 specific technical guidelines	Achieved

Effectiveness of the dissemination activities

Analysing dissemination activities, their degree of implementation and their impact in greater detail, below is a table shows the measurement and evolution of the indicators established in the DAP and its updates:

DAP	Concept	Units	Target	Jul'22	Jul'23	Jul'24	Jul'25	Achieved
1	Website	Unit	1	1	1	1	1	Yes
2	Links Project Consortium	Unit	20*	4	9	9	20	Yes
3	Website Visits	Sessions	2000*	860	1470	2283	3208	Yes
4	Events & Demo sites	People Attend.	500/10*	23/2	58/6	218/9	290/13	Partially
5	Networking	Unit	15*	4	7	13	17	Yes
6	Social Networks	Unit	40*	13	41	66	104	Yes
7	Brochures, Press Kit	Unit	2	2	4	5	8	Yes
8	News/Articles	Publications	50*	9	33	51	80	Yes
9	Specialized News/Articles	Publications	8	3	3	5	5	Partially
10	Attendance at Fairs, Congresses and Events	Unit	1000* (reach.)	828	1178	6546	13644	Yes
			15* (attend)	15	20	29	37	Yes
11	Workshop	Units	2	0	0	0	2	Yes

It can be concluded that 10 of the 12 objectives have been met, and the other two have been partially met. Consortium considers that the implementation of dissemination activities has been satisfactory, having achieved strong momentum in the final year of the project, made possible by the granting of an extension.

There are no impacts so far in policy.

5.4. Analysis of benefits

The expected results of the project are divided into 3 groups: technical results, dissemination and replicability outcomes and environmental improvements. Within the **technical results**, 3 milestones have been achieved and exceeded, with the prototype operational at the demo site:

- **ZEM prototype designed and built.** Thanks to the project, there is now a real alternative for sustainable living with high performance, both in terms of thermal comfort and indoor air quality, as well as energy production and management, compared to the standard solution, which offers poorer living conditions with high fossil fuel consumption.

In addition, the solution proposed at the beginning of the project has been improved, creating a combined solution that added one habitable module and an interior circulation area and toilets, increasing the total living space of the proposal from 28 m² to 56,84 m².

- **Passivhaus certification achieved** in habitable modules and the energy module. Passivhaus certification accomplished for the ZEM prototype. This is a real innovation, as PASSIVHAUS requirements are not currently considered in the standard solution and have proven to be difficult to achieve. The ZEM project is a pioneer in this application, being the first building of such a small size to integrate hydrogen that has achieved Passivhaus certification, paving the way and encouraging future installations to adopt it.
- **Renewable energy production and hybrid energy storage system** installed and operational. A solution has been implemented that complements the excellent low energy demand offered by the PASSIVHAUS system. A hybridisation of renewable sources with battery storage, which was already known, has been improved and reinforced with a more complex solution thanks to improved energy storage with H₂, which is something new and offers a flexibility of performance that reinforces its replication.

Dissemination efforts initially focused on publicising the initiative and presenting the project and its objectives to stakeholders, with the aim of raising awareness and interest in the development and expected results, as well as future support for replication opportunities. During the second half of the project, and especially during the extension year, visits to the module have been promoted and materials have been produced that show the operational prototype and explain its day-to-day functioning. Key results include:

- Website: 3,208 visits from different countries; 106 social media posts.
- Notice boards: Three notice boards installed at the demo-site prototype, displaying LIFE and partner logos, with LIFE logo stickers on equipment.
- Fairs and congresses: Participation in 36 events related to sustainable energy, hydrogen technologies, sustainable building, and defence.
- Workshops: Two workshops organised.
- Awards: Two awards won - Best Building Applied Innovation Project at the II Aragón Building Ceremony (2021), and the Energy Globe Award Spain in the Air category (2024).

Environmental improvements: The results achieved by the project for various indicators over the project's entire demonstration experience and annualised to a typical year of operation, are given below. This table shows average and cumulative results for the prototype **during the entire demonstration phase** and for 5 parameters: reduction of energy consumption, amount of diesel saved compared to the baseline, avoided GHG emissions (CO₂ and NO_x), renewable energy production and Indoor Air Quality improvement. These

parameters were defined at the beginning of the project in addition to others set out in the Grant Agreement.

DESCRIPTION	unit	Conventional solution (habitable module - diesel based)	ZEM project (habitable module - annual average)
Energy consumption of the habitable module and year	kWh/m2	3.341,75	112,83
	%	--	3,38%
Diesel consumption per habitable module	litres/year	15.020	0,00
GHG emissions	tons of CO2/year	40,10	0,08
	tons of NOx/year	0,58	0,00
Renewable energy production	kWh/year	0,00	4.490
Indoor Air Quality	ppmCO2	2.000	350

KPI	unit	OBJECTIVE	Results achieved by ZEM (average habitable module)	Results achieved by ZEM project (3 habitable modules; 3 demo years)	Assesment
Reduction of energy consumption of the habitable module and year	kWh/m2	285,00	3.228,93	3.228,93	Achieved
	%	75%	96,62%	96,62%	Achieved
Reduction of diesel consumption per habitable module	litres/year	5.700	15.020	135.180	Achieved
GHG emissions avoided	tons of CO2/year	15,00	40,02	360,18	Achieved
	tons of NOx/year	0,33	0,58	5,21	Achieved
Renewable energy production	kWh/year	4.000	4.490	13.470	Achieved
Indoor Air Quality	ppmCO2	IDA2	IDA1	IDA1	Achieved
	ppmCO2	400	350	350	

Some considerations to note:

- A habitable module is a living space of 13.43 m2. ZEM prototype has 3 habitable modules and a common area for toilets and circulation, total living area of 56.84 m2.
- The average performance of a diesel generator considered is 30%.
- The emission ratios considered: 2.66 kg of CO₂¹ and 38.56548 g of NO_x per litre of diesel² and 260 gCO₂eq per kWh for consumption from the Spanish electricity grid³.
- Details of the average and cumulative values for consumption, renewable production and grid consumption can be found in deliverable D1.2.

Consortium has identified an indirect impact related to social benefits. BZAP members have become really interested and involved in project deployment. For them, being in contact with sustainable construction techniques and learning from new technologies implemented in the project has helped them to progress and stabilize their military career. In the Spanish Army, if a soldier, sailor or corporal has reached 45 years of age and has not achieved promotion or a permanent position within the Army, they are obliged to retire from the institution.

¹ <https://connectedfleet.michelin.com/es/blog/calcular-emisiones-de-co2/>

² <https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-1-energy-industries/view>

³ https://canviclimatic.gencat.cat/es/actua/factors_demissio_associats_a_lenergia/index.html

6. Key Project-level Indicators

The final actual values of the KPIs for ZEROENERGYMOD has been introduced in the online KPI database (<https://webgate.ec.europa.eu/eproposalWeb/kpi>).

The results presented in the report allow a comparison to be made with the environmental objectives stated in the Grant Agreement:

KPI	Unit	OBJECTIVE	Results achieved by ZEM (average habitable module)	Assessment
Reduction of energy consumption of the habitable module and year	kWh/m ²	285,00	3.228,93	Achieved
	%	75%	96,62%	Achieved
Reduction of diesel consumption per habitable module	litres/year	5.700	15.020	Achieved
GHG emissions avoided	tons of CO ₂ /year	15,00	40,02	Achieved
	tons of NO _x /year	0,33	0,58	Achieved
Renewable energy production	kWh/year	4.000	4.490	Achieved
Indoor Air Quality	ppmCO ₂	IDA2	IDA1	Achieved
	ppmCO ₂	400	350	