AWeS0Me

Agricultural WastE as Sustainable 0 km building MatErial

DELIVERABLE D.T2.3.1

PROTOTYPES

Project number: ITALME-419

Work package: T2 Pilot action

Partner responsible for the deliverable: Politecnico di Bari

Dissemination level: PU - Public

Activity A.T2.3. This activity will deal with the development and deployment of the four prototypes system in pilot public buildings including the purchase of the equipment (thematic equipment) necessary to perform hygrothermal and physical properties. The prototypes, also realized by self-building technique, will be installed in public buildings in order to assess the effective energy saving produced by the use of a passive strategy as a bio-based building component. Monitoring tools, ideally connected to public electronic displays, will also contribute to show the practical short-term and long-term advantages related to the use of the proposed materials in buildings. Presentation events, one for each region, will be organized to promote and show the potential advantages of the involved technologies and use of sustainable materials in buildings.

Deliverable D.T2.3.1. Prototypes.
One prototype in each territory will be built in public buildings. The prototypes will be monitored by means of sensors and suitable equipment.

Status: Final

Date: 28/02/2023

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1. Introduction

The international energy outlook predicted that the global energy consumption will grow up to 42% by the end of 2050 due to several factors as the increase in building constructions and the fast growth of global population. A brief analysis of world population statistics highlights a steady increase in the human population, rising from 6.8 billion in 2009 to 7.7 billion in 2019 and an estimated 9.7 billion by 2050.

On one hand, the population increase directly indicates that health and mortality rates are improving over time, thereby leading to population growth. On the contrary, rising population levels also imply an increase in pressure levels exerted on available social amenities such as housing. As the demand for housing increases exponentially, this further strains the construction industry as well as the production of conventional materials such as cement, steel, aluminum and wood, among others. It was found that the production of the conventional construction materials such as cement also utilizes significant thermal and electrical energy amount and, as a result, translates into higher building costs. Furthermore, the conventional building industry is responsible for increasing the energy demand due to the huge consumption of non-renewable resources.

It can be also considered that the plastic materials provoke 4.5% of global GHG emissions significantly contributing to the pollution of ocean and seas. The catastrophic scenario of the raise of the Earth's average surface temperature of about 5°C by the end of 2100 is closer than expected.

On the flip side, emerging research has shown that the reuse of agricultural waste and by-products in the development of construction materials, either in part or wholly, is a viable and tentative solution to tackle the environmental identified challenges. A growing literature can be observed lately about the use of organic components and natural fibres for the production of insulating panels, mortars, plasters and bricks.

As previously discussed in the deliverable D.T2.4.1, several researchers developed sustainable insulators with different vegetable fibers and components as jute, flax, hemp and straw focusing on mechanical and physical properties and highlighting the analogy existing between the experimental materials and the traditional ones currently available on the market. Other research works showed the results of thermal characterization and life cycle analysis of building insulation panels made with cork scraps, end-life granulated tires, rice husk and coffee chaff.

Nonetheless, current researchers have shown that the re-use of agricultural waste as new raw matter for sustainable building materials try to solve the environmental issue concerning the disposal of the waste in landfills with the consequent burning practice.

In this framework the aim of the Activity A.T2.3 was to demonstrate the possibility to use the agro-waste for the energy refurbishment by the development of one prototype in each country involved in the project. Each study case was finally realized in public buildings in order to show the results of the realization to public institutions, private enterprises, instruction institutions.

Promotional events, local workshops were organized and held in each country involving local authorities, universities, research centers, private enterprises, schools.

Different techniques (filling, mortar, blocks), mounting conditions were performed in each country, proving several possible applications of the agro-waste and demonstrating the suitability for high efficiency building components. Measurement equipment for thermal behaviour monitoring were used, also during pilot-action presentation, in each sides to show in real-time the potential enhancement and advantages achieved when using the sustainable agro-waste based materials.

2. Theoretical background

The thermal performance of a building envelope is one of the most important parameters for calculating the energy demand of a building because it is directly affected by the external environment. Accurately measuring the U-value of a building envelope is important. The U-value is defined by ISO 7345 as "the steady-state heat flow divided by the area of a system and the temperature difference between the surroundings on each side." The U-value is obtained by measuring the heat flow through a building element while ensuring that the temperatures on both sides of the element are in the steady-state condition.

Expressed in W/m²·K, the U-value depends on the thermal resistance of each of the elements that make up the surface (the percentage in which a building element is opposed to the passage of heat), and this, in particular, obeys the thickness of each layer and its thermal conductivity (ability to conduct the heat of each material).

The U-value expresses the building's level of thermal insulation in relation to the percentage of energy that passes through it; if the resulting number is low, a well-isolated wall is achieved and, on the contrary, a high value alerts of a thermally deficient wall assembly.

The general formula for calculating the U-Value is:

$$U = \frac{1}{R_t}$$

where:

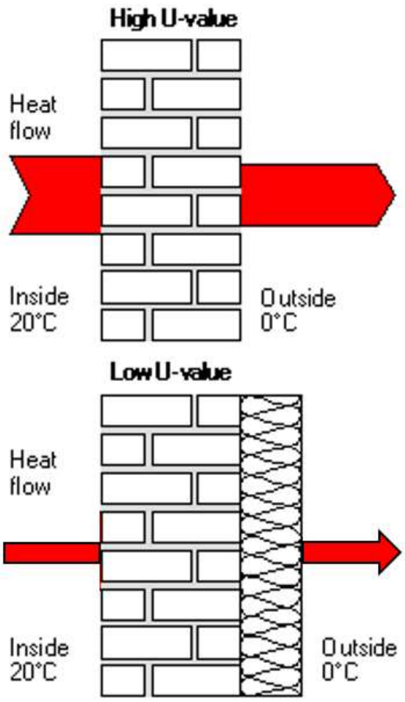
- U = Thermal Transmittance ($W/m^2 \cdot K$)
- R_t = Total Thermal Resistance ($m^2 \cdot K/W$) of the wall assembly consisted of different layers with different thermal resistance (R) obtained according to:

$$R_t = R_{si} + R_{s1} + R_2 + \cdots + R_{se}$$

$$R_i = \frac{s_i}{\lambda_i}$$

- s_i = thickness of the single layer (m)
- λ_i =thermal conductivity of the single layer (W/(mK))
- R_{si} =internal surface resistance (m^2K/W)
- R_{se} =external surface resistance (m^2K/W)

In order to improve the energy performance of an existing building, different strategies can be considered, as the renovation of the active components (i.e. low consumption energy systems) or enhancement of passive components as the building envelope. In order to improve this latter one it is necessary the substitution or the addition to the existing wall of and an external or internal layer of thermal insulator (i.e. panel, plaster, bricks). As consequence, the thermal transmittance will be reduced, assuring also an energy saving of the building itself due to the reduction in winter of heat flux leakage and in summer of the heat flux absorption.



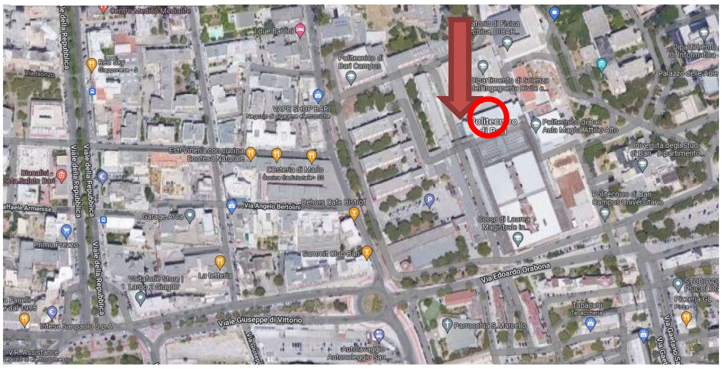
Thermal transmittance (U-value) of an existing wall before (above) and after (below) the thermal insulator addition.

3. Pilot action at Politecnico di Bari

3.1 Context and materials

Two different prototypes were built in Politecnico di Bari, in a public room (INFO POINT), addressed to give information about the university life to the students.

a)



b)

c)

Figure 1 Politecnico di Bari (a), territorial framework (b), Pilot Action, InfoPoint Politecnico di Bari (c)

It was chosen the wall with north exposition. The assembly wall consists of 25 cm fired bricks with two layers of internal and external cement-gypsum plaster of 1.5 cm thickness.

In order to compare the effect of the agro-waste materials use, the wall in question was divided into three different sections: the first one was left as it was, the second one was covered by straw-lime prefabricated blocks, provided by Presspaglia company and the third section was covered by a straw-lime plaster of 10 cm thickness, casted-in-situ, provided by Terrabuilding design company, using a wooden reinforcing as filling control.

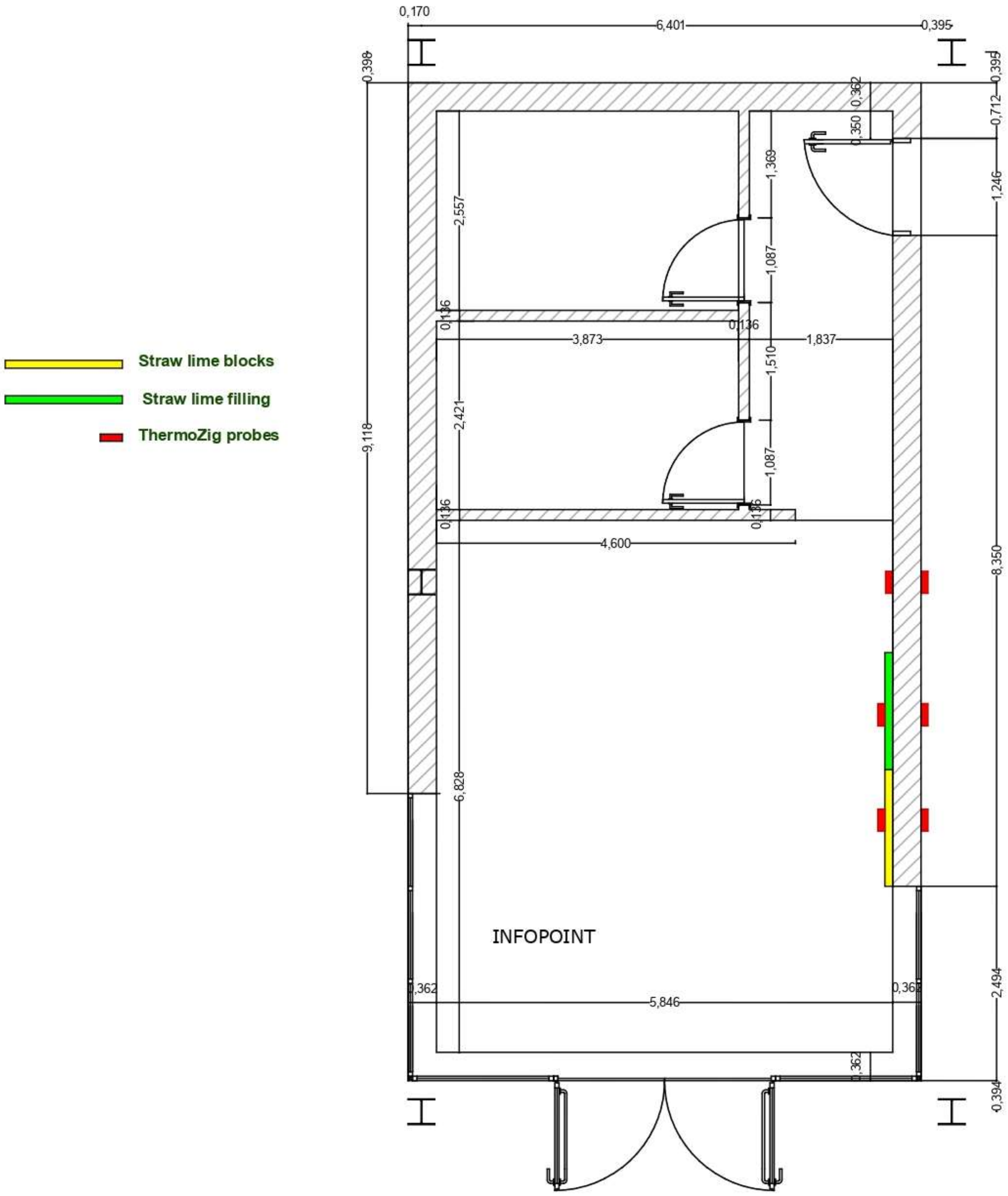


Fig.2 Layout of the test room and monitoring probes position.

Fig. 3 Assessed wall, from left to right: 1) reference wall, 2) wall covered by lime-straw mix, 3) wall with lime plaster blocks.

The first treatment (by Terrabuilding design), directly made on-site, was developed by preparing the wall with wooden supporting elements and compacting in different layers a wet mixture of straw and lime mortar.
Main physical properties of the final wall are:

- ✓ Thickness 10 cm
- ✓ Thermal conductivity 0.07 W/mK (referred to loose material)
- ✓ Density 426 kg/m^3

After the filling, the wall was left to dry for 15 days; then it was applied a lime-straw plaster of 1.00 cm.

a) b) c) d)

Fig. 4 Lime-straw mix wall manufacturing process: a) filling with straw-lime mix, b) layers's compaction, c) detail of layer compaction, d) final covering with lime-straw plaster.

The prefabricated blocks (developed by PressPaglia) are industrially developed by a mix of straw and

hydraulic lime with a final size of 50 cm x 50 cm and a thickness of 10 cm. The blocks were created in such a way that they fit together.
Main physical properties are:

- ✓ Thickness 10 cm
- ✓ Thermal conductivity 0.0823 W/mK
- ✓ Density 554 kg/m^3.

After pasting the blocks by a lime mortar of 1.00 cm, they were set on the wall an left to dry for one week. Then, the new layer was covered by a lime plaster and shaving in order to make the wall ready for final painting.

b)

a) c)

Fig.5 Wall with lime plaster blocks, manufacturing process: a) block preparation with lime mortar, b) block fixing on the wall, c) covering with final lime based mortar.

3.2 Monitoring

In order to monitor both the walls and comparing them with the reference wall, since the beginning of the creation of the prototypes, there were used two different systems: infrared camera and flux meters to check curing evolution and the final thermal performances of the prototypes.
From the direct measurement of U-values, thermal conductivity of the added layers was estimated.

Fig. 6 Monitoring systems of the prototypes (from left to right: infrared thermal camera, thermal flux meter).

The thermal transmittance measurement was carried out according to the standard ISO 9869 by using a Bluetooth Low Energy wireless sensor network (Thermozig BLE system, figure 7). The thermal conductance of each wall was computed by the moving averaged means of the in situ measurements (figure 7).

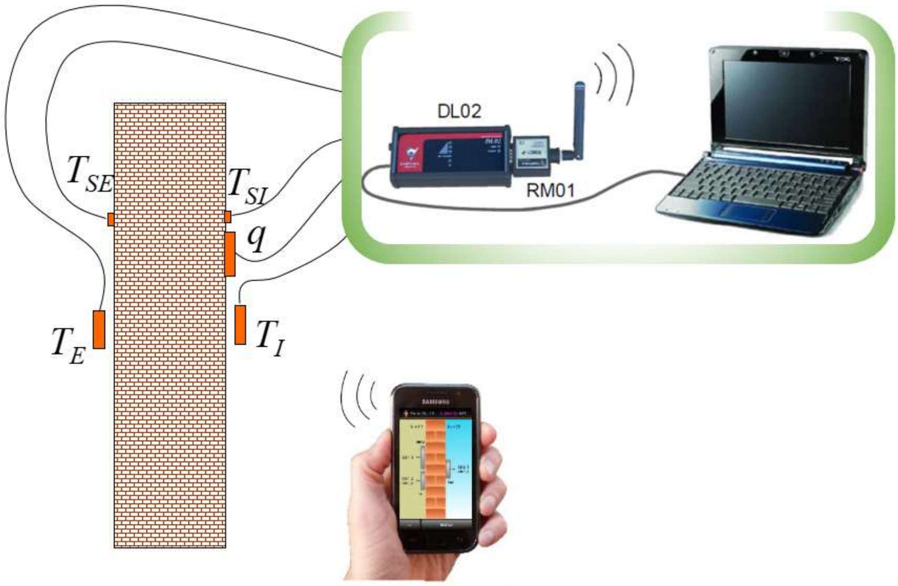


Fig. 7 Thermal transmittance in situ measurement.

The graphs in figure 8 show the temperature range in terms of difference between the indoor and outdoor temperature. It can be observed that the addition of the innovative materials on the reference wall causes a significant reduction of this value. Furthermore, the graph in figure 7 highlights that the thermal transmittance of the sustainable wall with the straw-lime blocks is reduced of about 20%, while the presence straw-lime filling decreased of approximately 35%.

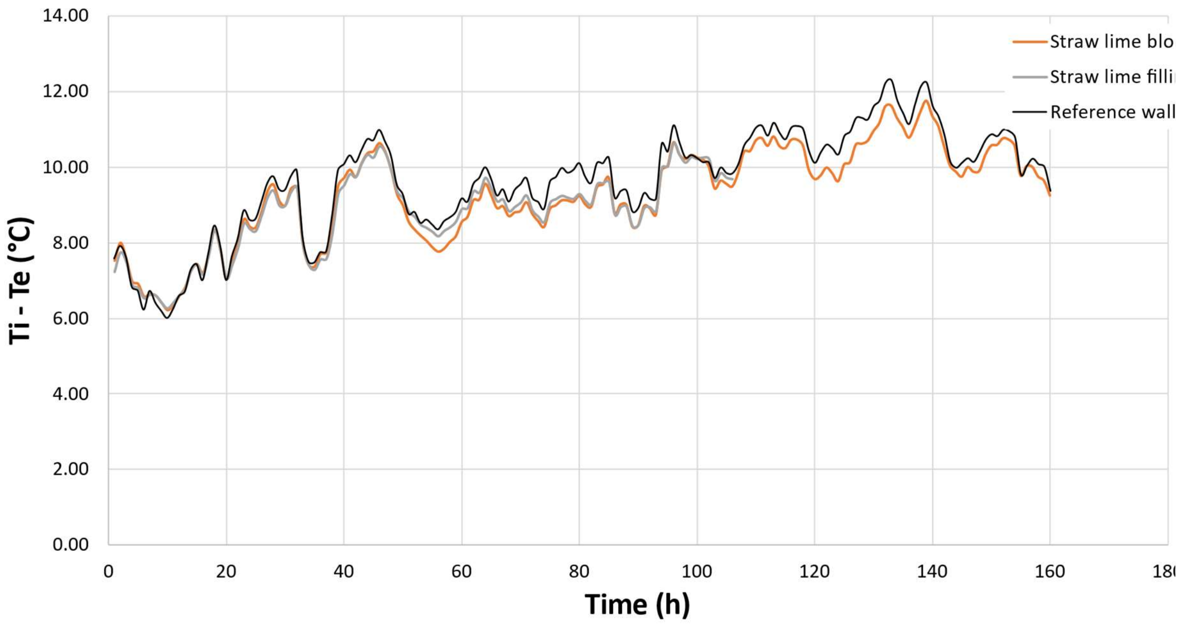


Fig. 8 Indoor and outdoor variation of temperature.

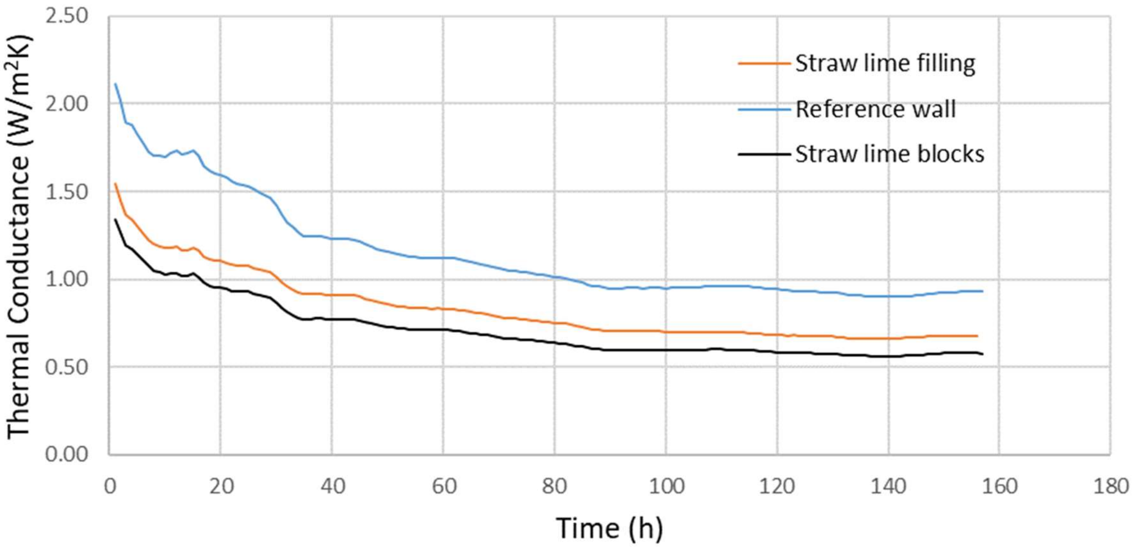


Fig. 9 Trend of the measured thermal conductance for the three walls.

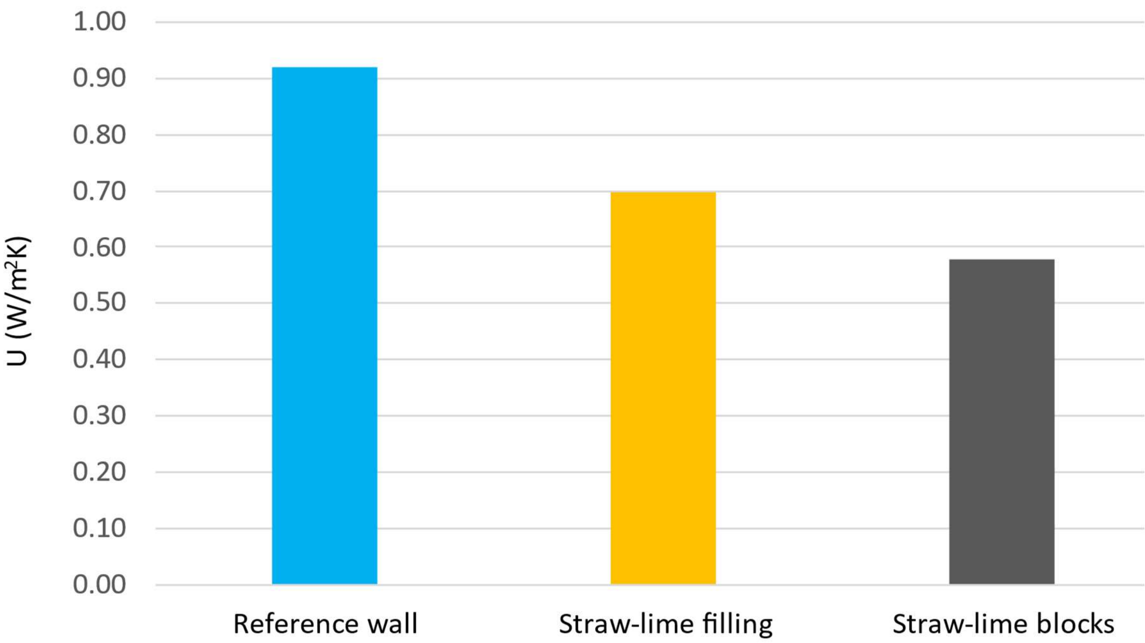


Fig. 10 Thermal transmittance evaluation

3.3 Dissemination activities

The Pilot Action was presented during a regional event held on November 7 2022, in which the major stakeholders were invited. Open Labs were held for secondary schools during the following days, involving more than 100 students.

Fig.11 Workshop November 7 2022

Fig. 12 Open days November 8-9 2022 with the involvement of the schools.

Fig.13 Open days November 8-9 2022 with the involvement of the schools.

Fig.14 Workshop poster.

4. Pilot action at GAL Molise verso il 2000

4.1 Context and materials

The prototype was developed in Campobasso, in the Conference Room of the public building where the premises of GAL are located. It was chosen a wall adjacent to outside. The manufacture of the prototype was performed involving some experts, building workers, teachers according to the self-building practice.

a) b)

Fig.1 – Pilot action, Gal Molise verso il 2000 (a), Territorial framework (b)

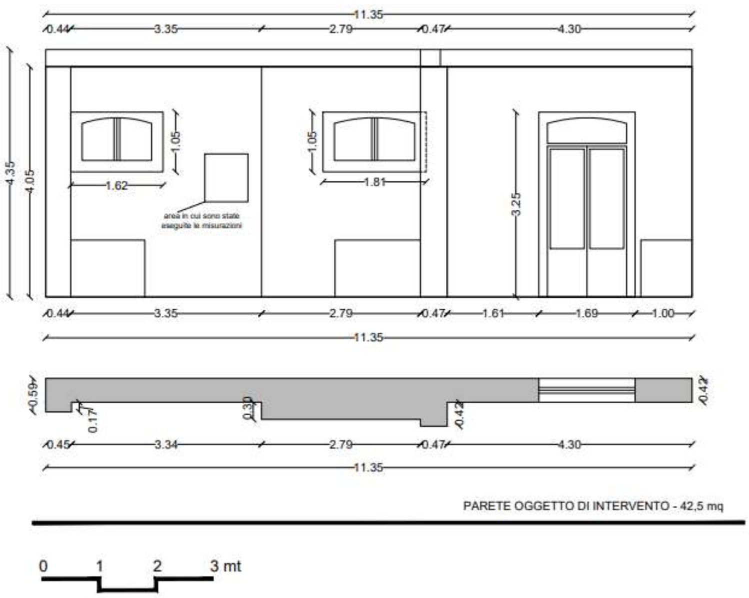


Fig.2 Building details of the prototype

Fig.3 Preliminary phase: breaking existent plaster

Fig.4 Fired bricks wall after preliminary phase: wooden framework application.

The prototype-wall was realized by the Terrabuilding Design company, using a filling of lime straw (Fig. 5). Firstly, the plasterboard layer was moved from the existent wall up to find the underlying fired bricks original wall. Once the support was cleaned, a first layer of hydraulic lime-based was applied in order to make the wall rougher as well as to regularize its roughness and prepare the best adhesion of insulating material based on straw and lime. A plinth was also been provided with two rows of solid bricks in order to create a detachment from the non-insulated pavement.
At the same time, the wooden slats (two rows of 5 cm with 1 m interest) were mounted as a support for the formwork for filling the insulating material, fixed with simple dowels on the existing masonry.
Then, the filling of lime straw was poured from the bottom to up, pressing it in following layers, disarming the wooden table and repeating the procedure for the next step.

Fig.5 Lime straw mix filling.

During the workshop days (Fig. 6-7), professionals, companies, students, teachers were involved in the manual activities in order to demonstrate the simplicity of technology and the absolute absence of risks
in the application of the totally natural material, without the use of synthetic additives also harmful for health.

Fig.6 Prototype preparation during the workshop

After drying, the wall was covered by a clay plaster with the addition of straw fibers. Then, before applying the last painting layer, it was left to dry again (fig. 7).

Fig.7 Curing of prototype.

Fig.8 Finishing layer application by a mud plaster with straw aggregates.

4.2 Monitoring

In order to monitor the indoor environmental conditions, Microclimatic Thermal Station HD32.3TC was used, measuring temperature, relative humidity, air velocity before and after the realization of experimental wall.
From the direct measurement of U-values, by flux meters, before and after the energy requalification, thermal conductivity of the added layers was estimated, assessing how the energy requalification has enhanced the indoor comfort conditions.

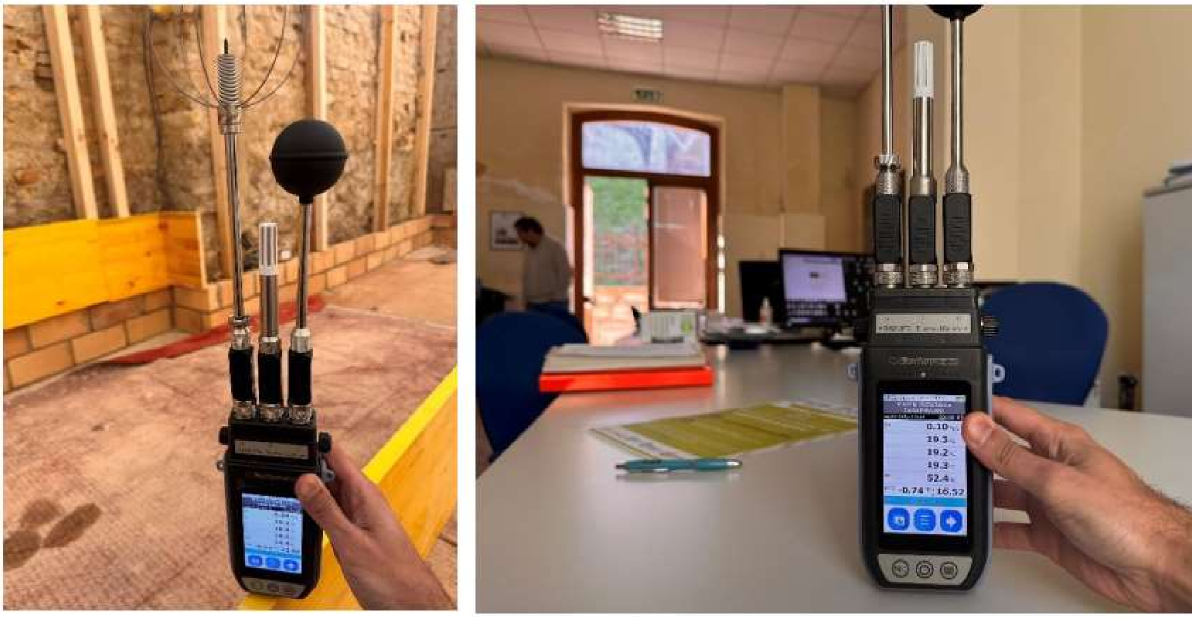


Fig.9 Monitroing equipment before and after the protypes development
(Microclimatic station HD32.3TC)

Before the requalification, the wall was monitored by the thermal flux meter (Fig.10) in order to assess the thermal transmittance U that was estimated to be 2.76 W/m^{2}K.
The monitoring with the infrared thermal camera allows to show the "critical points” of the examined wall, highlighting the temperature profile and, thus, the thermal bridges presence. The thermograms in figure 11 show demonstrate that any thermal insulation exists.
After removing plaster (fig.12), the thermograms show the presence of water vapour condensation. Later there were put wooden formworks for the filling of straw and lime pressed periodically. The wall was completed by the clayey plaster.
In the following weeks, continuous monitoring was carried out, in order to support the progressive drying phases of the wall and the formation of any adverse phenomena.
The straw lime layer (fig 13) demonstrates a uniform temperature profile of the prototype wall, even though the wall drying takes about three months. As a matter of fact, considering the presence of vegetable components as straw, times for complete drying was longer than a conventional insulator. As consequence, the data collected in the monitoring phase have sometimes been altered by the strong presence of persistent residual water in the mixture of the material itself.

Fig. 10 Thermal flux meter for the thermal transmittance estimation before (above) and after (below) the protypes development.

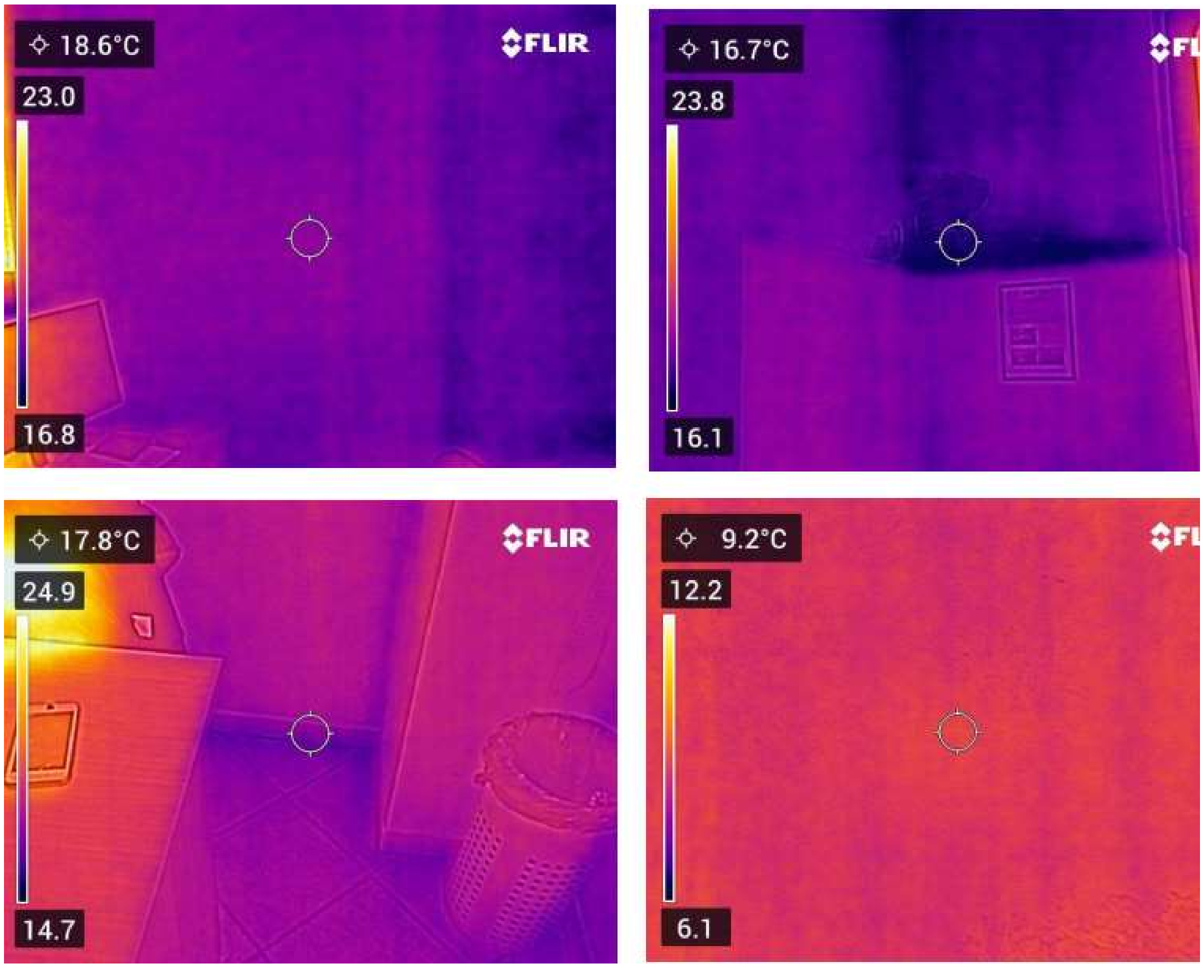


Fig. 11 Thermograms before the requalification.

The construction of the wall during the winter season (external temperatures not exceeding 5 degrees for several weeks) did not help the curing process of the lime-straw mixture, which was greatly slowed down. The final layer of clayey plaster was even more critical due to the greater presence of water and progresses began to be appreciated after about 6 weeks. The most appreciable results of the monitoring were obtained after about 120 days from the completion of the plasters, finally being able to assess a significant improvement of the thermal transmittance value.

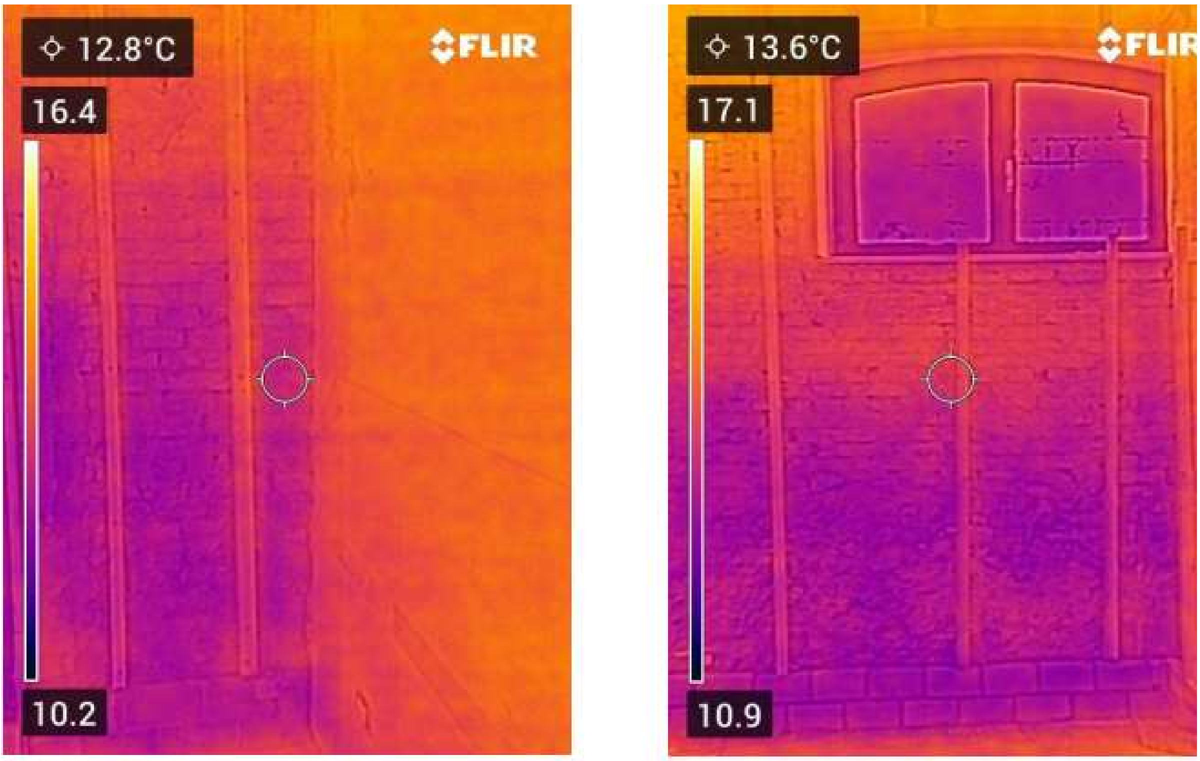


Fig. 12 Thermograms after plaster removing.

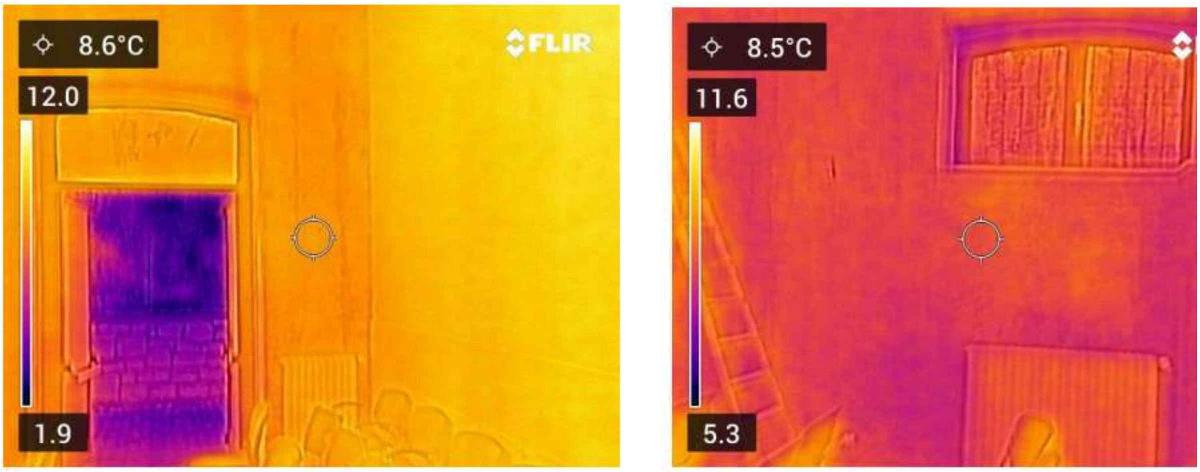


Fig. 13 Thermograms after requalification.

The final transmittance measured was finally measured by thermal flux meter; it was estimated a value of 1.06 W/m^{2}K, appreciating a significant reduction over 61% comparing to the initial phase.
A further in-depth analysis can be performed in the specific report in Appendix 1.

Fig. 14 Therrmal flux meter for thermal transmittance evaluation.

4.3 Dissemination activities

The self-building workshop, opened to building professionals, construction companies, as well as agricultural operators, was developed on November 3,4,5 2022 and had the aim to provide theoretical and practical knowledge on the use of materials recovered from agricultural waste, such as straw, to make CE-certified and 100% natural thermal external coating.
In a second phase of the workshop, organized on November 17 and 18, 2022, plastering has been performed. Having completed the straw drying phase, therefore, workshop participants were able to prepare the unfired lime plaster and ensure its installation directly on the straw and lime substrate.

Fig.15 Workshop activites by the involvment of the local community.

AWeS0Me

Agricultural WastE as Sustainable 0 km building MatErial

"Self-building Workshop with agricultural waste materials"

1st phase: 03-04-05 November 2022

2nd phase: 17 – 18 November 2022

Agenda

Gal Molise Verso il 2000
Conference Room "GAL Molise Verso il 2000"
Viale Monsignor Secondo Bologna, 15, Campobasso (Italy)

THURSDAY 3rd November 2022

14.30: The project *AWeS0Me*
Mrs. Clea Zurlo, Communication Manager Project Partner GAL Molise Verso il 2000

14.40: Preliminary operations - Illustration
Preparation of the intervention area, dismantling of the installations, cleaning of the existing wall, hydraulic lime rendering, skirting and preparation of spacer strips.
Mr. Mario Ferrarelli (Terrabuildingdesign)

15:00 Measurement of parameters before starting the work
Determination of the parameters/coefficients of the wall in the current state with the support of the thermal camera with temperature and relative humidity probes and of the environmental data with the support of the microclimatic station.
Mr. Alessandro Fioralba, Architect – External Expert project AWeS0Me
Mr. Giovanni Plescia, Agronomist - External Expert project AWeS0Me

15:30 Pre-Training for the participating companies
Organisation of the work phases with explanation of the work steps, indication of the materials and tools to be used, training and control for the safe execution of operations.
Mr. Mario Ferrarelli (Terrabuildingdesign)

16:00 Self-building work phases
Fastening of battens, guide rafters and anchoring of wooden formwork. Filling the formwork with straw and stripping. Repositioning of the panel for the next intervention area.
Mr. Mario Ferrarelli (Terrabuildingdesign)

18:00 Closure of the works

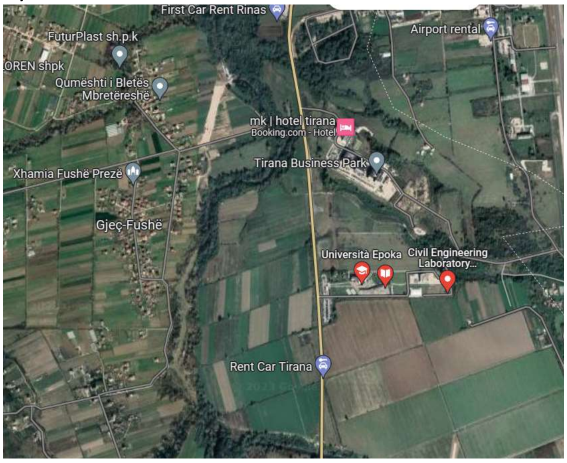
Fig. 16 – Workshop flyer

5. Pilot action in Tirana

5.1 Context and materials

The prototype was built in one of the rooms of the Construction Material Laboratory in Epoka University, treated with insulating panels made with rice straw provided by the Italian company RiceHouse.

a)



b)

c)

Fig. 1: a) Epoka University, b) territorial framework, c) Pilot Action

a) b)

Fig.2 Details of Pilot Action Laboratory

The room was totally covered by insulating panels (RH50) with a density of 50kg/m^3, thermal conductivity of 0.045 W/mK, specific heat capacity of 1790 J/kgK.

Each panel has an area of 120 x 60 cm and a thickness of 50 mm and consists of a mixture of rice straw (92%) joined together with 8% of polyester thermofusible fibers in order to achieve a semi-rigid insulating materials.

The panels were applied both on the vertical partitions and superior horizontal slab. Then, they were covered by a plasterboard layer and painted.

Fig.3 Details of the ricestraw panels.

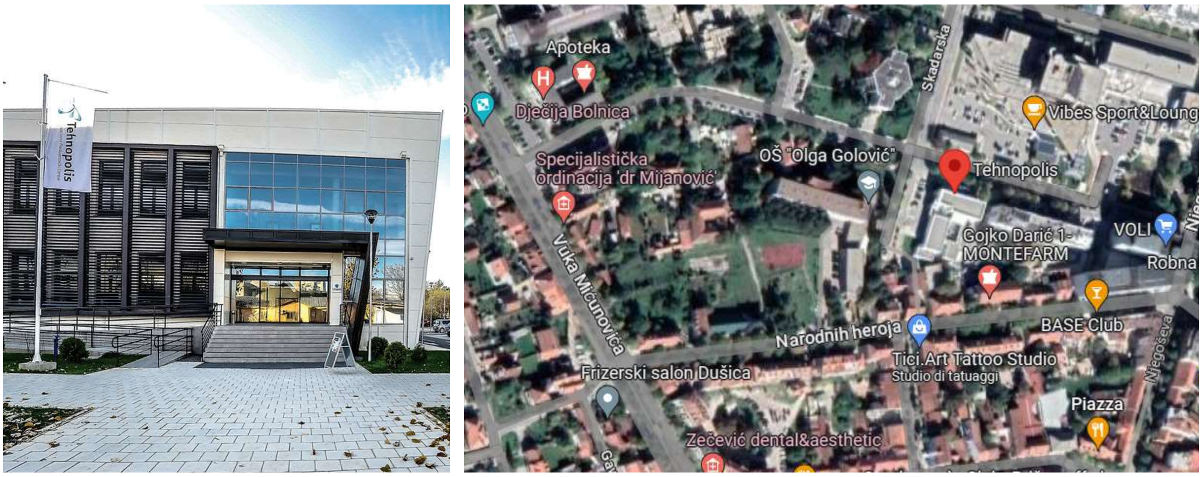
5.2 Dissemination activities

The self-building workshop, opened to building professionals, construction companies, as well as agricultural operators and schools was developed on December 22 2022 with the aim to show to the local community the suitability of the vegetable fibers to be used in sustainable building component for efficient buildings.

6. Pilot action at Tehnopolis

6.1 Context and materials

Innovation and Entrepreneurship Centre Tehnopolis implemented pilot action in Niksic within the Laboratory for industrial design TechLab Tehnopolis.



a) b)

Fig.1 Centre Tehnopolis (a), territorial framework (b).

The implementation of the pilot action included the construction of two walls: an internal partition and an external wall. The prototypes were realized by prefabricated panels with dimensions of 1220 mm x 2440 mm and a thickness of 10 mm, manufactured with a steel framework and plywood faces. They were filled by dried straw bales made with different agricultural by-products (baled soybean, wheat and hemp straw, and corn sorghum), which were previously treated with crushed hydrated lime. After the construction of the walls, the panels were plastered and painted.
It was assumed that the baled straw has λ=0,05 W/(mK) and a density of 80 kg/m^3.

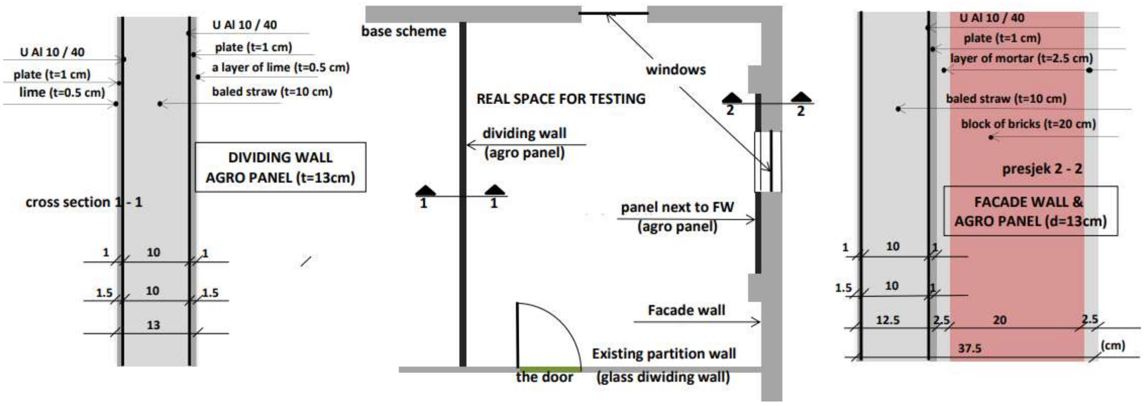


Fig.2 Layout of the test room and wall assembly details

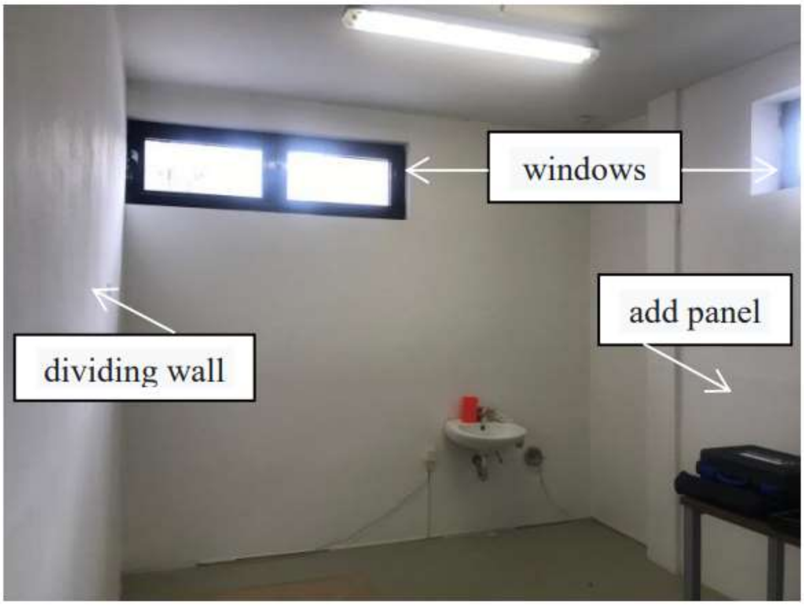


Fig.3 Test room details

Fig.4 Wooden-steel panel framework (internal partition).

Fig. 5 Straw bale filling (internal partition)

a)

b)

c)

Fig.6 Prototype manifacturing (outer wall): a) steel-wooden framework, b) filling with straw bale, c) plaster covering.

6.2 Monitoring

The measurement of the thermal characteristics of the real partition walls was carried out using the ThermoZig Ble - OPTIVELOX apparatus.

The measurement was made at two positions on the facade wall (one at the place of the coated wall, and the other at the place of the existing wall), as well as at one position of the partition wall.

The measuring probes were placed approximately at chest height from the floor level (Figure 7).

All measurements were made at environmental conditions (real values of temperature and humidity of the environment). The readings are set with a step of 15 minutes (900 sec) lasting about 24 hours. In total, therefore, 4 measurements were carried out , i.e. two each on the facade and partition wall.

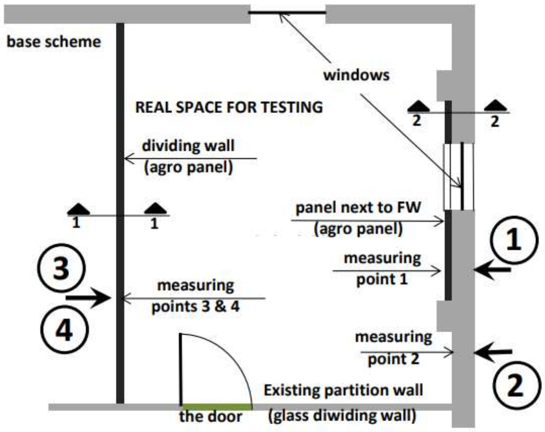


Fig. 7 Location of the measuring points (probes).

The estimation of U-value allows to achieve these results:

OUTER WALL: U = 0.348 W/m^{2}K
INTERNAL WALL: U= 0.443 W/m^{2}K

It was possible to deduce that an increasing of thermal resistance of about 5 times occurs if comparing to the initial case.

The in-situ monitoring must be critically analysed in view of the large number of influential parameters and the applied method. The method for testing requires very careful analysis of the boundary conditions as the temperature and reasonable processing of the obtained test results. Nevertheless, measurements made on the pilot project in question, which includes a partition made of agro-panels, show a significant contribution to the energy improvement of the bio-based panels.
A further in-depth analysis can be performed in the specific report in Appendix 2.

6.3 Dissemination activities

In order to promote the pilot action among stakeholders, Innovation and Entrepreneurship Centre Tehnopolis organized a promotional event within its premises on February 27th. There were shown the first results achieved and the building techniques adopted for the internal and external façade (fig-8-9-10).

Fig.8 Workshop of February 27th 2023

Fig.9 Workshop of February 27th 2023, showing the prototype details.

Fig.10 Workshop of February 27th 2023, showing the prototype details.

Naziv i akronim projekta

Agricultural WastE as Sustainable 0 km building MatErial – AweS0Me

Upotreba poljoprivrednog otpada za proizvodnju održivog građevinskog materijala visoke energetske efikasnosti

27.12.2022.

Inovaciono preduzetnički centar Tehnopolis
Radoja Dakića bb, 81400 Nikšić, Crna Gora

AGENDA

10:15 – 10:30	Registracija učesnika
10:30 – 10:45	**Prezentacija projekta AWeS0Me** Marijana Jovović Saradnica menadžera za upravljanje projektima, IPC Tehnopolis
10:45 – 11:15	**Zakonska regulativa u sistemu energetske efikasnosti u Crnoj Gori** dr Nataša Kopitović Vuković Saradnik u nastavi Građevinski fakultet, Univerzitet Crne Gore
11:15 – 12:00	**Upotreba poljoprivrednog otpada za proizvodnju održivog građevinskog materijala visoke energetske efikasnosti** dr Radomir Zejak Redovni profesor Građevinski fakultet, Univerzitet Crne Gore
12:00 – 12:15	Kafe pauza
12:15 – 12:45	**Primjeri dobrih praksi** dr Radomir Zejak Redovni profesor Građevinski fakultet, Univerzitet Crne Gore
12:45 – 13:00	Diskusija
13:00 – 13:30	Ručak

Fig.11 Workshop poster

7. Conclusions

The building of the prototypes in each partner country allows to demonstrate that a real application of the aro-waste materials is possible and suitable to improve the energy efficiency of existent and new buildings. The involvement of local community, by the workshops, was useful to point out the importance of re-use and re-cycle of waste for obtaining innovative sustainable building components. Overall, the results achieved by the monitoring in-situ demonstrate that the presence of bio-based components extend sometimes the curing time. Furthermore the applied method for testing thermal transmittance in–situ requires very careful analysis and reasonable processing of the obtained test results, due to restrictive boundary conditions as the temperature difference that it must be greater than 10°C.

In conclusion, it is possible to assert that the presence of the agro-waste panels can represent a challenge and an added value to the energy improvement of the buildings, even if the building operation conditions and the curing time of these materials are significantly different from the traditional materials.

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