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LIFE SUSTAINHUTS: SUSTAINABLE MOUNTAIN HUTS IN EUROPE

C7.3 Final guideline: "Energy efficiency and advanced materials applied to mountain huts"

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Executive Summary

LIFE SustainHuts is a demonstrative project which aims to reduce the environmental impact of the energy use in mountain huts by implementing renewable energy-based solutions, efficiency strategies and hydrogen technologies for storing renewable energy.

The aim of this guide is to present the technologies finally installed in the huts and the process that was followed from the initial idea of improving the sustainability of these facilities to the technologies finally installed, with the ultimate goal of promoting their reproducibility to other huts and similar isolated facilities. The process starts with a meeting between the technicians of the partners, the mountain federations and clubs, and the mountain hut keepers in which the potential improvements in the mountain huts are discussed and commented. The process ends with the installation of all the technologies, their testing and demonstration, the training that may be required by the keepers, and the monitoring protocol in place.

After the evaluation of the improvements, **30 technologies were finally selected, including renewable production and efficiency, hydrogen storage, and thermal insulation.** This guide presents the technologies related to **efficiency improvement and thermal insulation**, which are those highlighted in the next table.

ID	Hut	Technology	Guide	Comments
#1	**Lizara**	**Advanced Automation**	**C7.3**	
#2	Lizara	PV	C7.2	
#3	**Lizara**	**Thermo-Chimney**	**C7.3**	
#4	**Bachimaña**	**Electrification**	**C7.3**	
#5	Bachimaña	Micro-wind		Cancelled
#6	**Bachimaña**	**Efficiency**	**C7.3**	
#7	Bachimaña	H2 Storage	C7.2	
#8	Estós	Hydro		Cancelled
#9	**Estós**	**Advanced Automation**	**C7.3**	
#10	Estós	PV	C7.2	
#11	Estós	Pellet Stove	C7.2	
#12	**Estós**	**Insulation**	**C7.3**	
#13	Llauset	PV	C7.2	
#14	Llauset	Pellet Stove	C7.2	
#15	**Llauset**	**Insulation**	**C7.3**	
#16	Kočbekov	PV		Destroyed by fire
#17	Pogačnikov	PV	C7.2	
#18	Pogačnikov	Micro-Wind	C7.2	
#19	Torino	PV	C7.2	
#20	**Torino**	**Water Plants**	**C7.3**	
#21	Torino	Insulation		Cancelled
#22	Montfalcó	PV	C7.2	
#23	**Montfalcó**	**Advanced Automation of**	**C7.3**	
#24	Góriz	PV	C7.2	
#25	Dent Parracheé	PV	C7.2	
#26	Dent Parracheé	Hydro	C7.2	
#27	Dent Parracheé	Wood Stove	C7.2	
#28	Dent Parracheé	Solar Thermal	C7.2	
#29	Valentina dom	PV	C7.2	
#30	Valentina dom	Micro-wind	C7.2	

This guide first presents the technologies implemented in the field of energy efficiency, describing the initial situation in each hut as well as the implemented solution. In another chapter, a study of the art that has been elaborated in the project in relation to new thermal insulation materials is presented. Finally, the insulation materials finally used are listed, as well as the application cases identified and implemented.

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1 Introduction

LIFE SustainHuts is a demonstrative project which aims to improve the sustainability of mountain huts located in natural habitats by implementing novel and original solutions related to renewable energy and other eco-friendly technologies.

This report presents the implementation strategy followed in the huts to install the energy effciency technologies selected. The methodology developed as follow:

1) **Initial visit to the huts and initial status identification**. Interviews to hut keepers to understand the problems and necessities linked to the huts.

2) **Selection of the technologies**. The technologies were mainly proposed by hut keepers and SUSTAINHUTS technicians due to their wide knowledge of the huts and other European huts which are built under sustainable criteria.

The chapters below report details on Energy efficiency technologies and the insulation applied to the huts.

2 Energy Efficiency technologies

A final list of 30 technologies was selected. The final list is formed of all actions proposed, including energy production, storage of energy by means of hydrogen, and insulation, and also some initially selected but finally not executed for various reasons.

26 actions have been installed with technologies of energy production (either electricity or heat) like PV, micro-wind, pellet stoves, wood stoves, solar thermal panels, hydro-turbine, and several efficiency actions like improvement of batteries charge, electrification, changes of batteries, thermo-chimney, and improvement in the water pumping and water treatment. Some innovative technologies like storage of renewable energy by mean of hydrogen, and novel insulation materials are also considered. Next table shows the main technologies installed in each hut (those described in this guide are highlighted)

ID	Hut	Technology	Guide	Comments
#1	**Lizara**	**Advanced Automation**	**C7.3**	
#2	Lizara	PV	C7.2	
#3	**Lizara**	**Thermo-Chimney**	**C7.3**	
#4	**Bachimaña**	**Electrification**	**C7.3**	
#5	Bachimaña	Micro-wind		Cancelled
#6	**Bachimaña**	**Efficiency**	**C7.3**	
#7	Bachimaña	H2 Storage	C7.2	
#8	Estós	Hydro		Cancelled
#9	**Estós**	**Advanced Automation**	**C7.3**	
#10	Estós	PV	C7.2	
#11	Estós	Pellet Stove	C7.2	
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#22	Montfalcó	PV	C7.2	
#23	**Montfalcó**	**Advanced Automation of**	**C7.3**	
#24	Góriz	PV	C7.2	
#25	Dent Parracheé	PV	C7.2	
#26	Dent Parracheé	Hydro	C7.2	
#27	Dent Parracheé	Wood Stove	C7.2	
#28	Dent Parracheé	Solar Thermal	C7.2	
#29	Valentina dom	PV	C7.2	
#30	Valentina dom	Micro-wind	C7.2	

TABLE 1. SUSTAINHUTS INSTALLATIONS IN STATE OF PLAY AT THE END

The section includes those actions under the category of "energy efficiency" (actions not directly involving RES, i.e. AAI-Advanced Atomation of Installation, electrification, thermo-chimney, water treatment) whilst "energy production" technologies (those directly linked to renewable energy sources such as PV, wind, hydro, biomass) are discussed and described in C7.2 "Implementation of renewable energies and hydrogen technologies to achieve SUSTAINHUTS" guideline.

2.1 Spanish huts

2.1.1 Lizara

Status before SustainHuts. Lizara electric system is not as efficient as a usual off-grid system due to different reasons. The most remarkable fact observed is that the control and change between batteries, PV system and gensets operation is not automated, causing an inefficient use of the batteries which reduces their lifetime. This control is done manually by the hut keepers and frequently deep discharges of batteries occurred damaging them. This situation is also conditioned by the fact that all the elements of the microgrid (batteries, PV panels and gensets) are located in a dedicated shelter around 100 meters apart from the main building, situation which hampers its physical access in winter, making difficult the manual switching between diesel generators and batteries.

It has been found also that the system is quite inefficient, caused by different ageing of PV arrays and the bad condition of some of them. The panels are arranged in series of several units, so the total power is directly limited by the operation of the worst. Based on information provided by the PV arrays installers during the interviews done, only between 10% and 20% of the potential energy expected is generated. It implies that the useful power is extremely lower than the installed power, datum which has been taken into account during the assessment.

All the previous mentioned facts cause the gensets to work more frequently than expected, increasing the amount of fuel consumed and the environmental impact of the Lizara hut.

2.1.1.1 Optimization and automation of the electrical system – AAI [#1]

Another measure proposed for the Lizara hut is the automation of the electrical system, consisting in ***the implementation of an automatic start of the diesel generators when the battery charge level reaches its recommended minimum***.

For this, the group start-up is controlled by means of a new inverter, Studer XTH 8000/48, installed together with its programming console that allows the batteries not to suffer deep discharges and the group starts when they need to be charged, which extends the life equipment useful.

2.1.1.2 Thermo chimney [#3]

The thermo-chimney replaced the existing open chimney. It contains a heat exchanger to heat water inside that recovers the heat generated by it. This hot water, through devices external to the fireplace, such as recirculation pumps, safety valves and other hydraulic elements, is recirculated to the boiler room where it supplements or replaces the function of the existing gas boilers. In this way, the heat that was previously wasted through the smoke evacuation duct is now recovered to heat the building through the previously existing heating circuit. This system increases the energy efficiency of the hut from 10% to 78%, thus reducing natural gas consumption and CO2 emissions.

This thermo-chimney is installed in the living room as a replacement for the previous one, an open fireplace manufactured with an ornamental rather than thermal purpose, for which precise data are not available. The power of the thermo-fireplace is 23 kW and its dimensions are 77x139x66 centimetres, approximately the same as the previous one.

In addition, together with the thermo-chimney, a series of materials necessary for its installation are included, such as recirculation pumps, non-return valves, drains, safety elements, insulating elements, etc. In addition, the complementary installation of an interrupted power supply system (UPS) is proposed as a safety element to avoid the interruption of the water recirculation operation and safety elements in the event of a power supply interruption and the presence of a flame in the fireplace.

Lizara hut's micro grids implementation was simulated via dedicate SOFTWARE: PV installation, AAi (Advanced Atomation of Installation) and the thermo-chimney. The simulation takes in account all the main inputs: solar resource, electric consumption profile, heat consumption, hot water consumption, chimney, efficiency and firewood consumption. ***Other variable considered in the methodology is the altitude in order to assess gensets efficiency. It has been supposed the reduction of their efficiency by 1% every 100 meters altitude when above 1000 meters.***
Each action has been assessed individually and their impact in the final improvement of the sustainability has been found. Also, the combined effect of all the actions was assessed, finding an increase of 42508 kWh per year generated from renewable sources, ***meaning that around 50% of the energy produced at the end in the hut comes from those resources.*** In relation to the CO2 emissions, a reduction of 15908 kg every year is calculated after the implementation of the improvements, which equals to more than 44% of the initial emissions.

2.1.2 Bachimaña

Status before SustainHuts. Bachimaña hut is a Spanish hut located in Spanish Pyrenees at 2200 meters. The electricity of this hut is generated using a 30 kW hydro turbine during about 9 months per year, when enough water is available. Furthermore, two diesel generators of 25 and 8 kW are installed in order to provide electricity when no water is available. A rack of 24 batteries with a capacity of 73.1 kWh (2 V and 1523 Ah every battery) is installed too. In relation to heat, a diesel boiler of between 73 and 178 kW is used.

The power produced in the hydro turbine makes unnecessary to implement any other renewable power source like PV.

2.1.2.1 Electrification [#4]

The electrification of the Bachimaña hut was identified as a possible improvement with wide potential for improvement, increasing the consumption of energy from renewable sources by 77%. This proposal takes into account that hydro turbine can supply all the energy demanded, so the substitution of the diesel heater by electric boilers is proposed in order to replace the use of the fossil fuel by electricity coming from a renewable resource.

The installation of an electric boiler that heats the necessary water both for direct consumption and for heating, together with three hot water accumulators with their own resistances.

The proposal aims to reduce this thermal dissipation and transfer the energy to the hut itself to heat the domestic hot water (DHW).

The proposed boiler consists of three 3.3 kW resistors that regulate the use of energy based on demand. Thus, this boiler allows working in three modes, with one, two or three heating elements in operation.

In addition to this, two 300-liter hot water accumulators are installed which, added to the existing one, add up to a total of three water accumulators with resistance of 2.5 kW each (7.5 kW) in total. The mission of these accumulators is to keep the water coming out of the heater in optimum temperature conditions and to provide it for use.

2.1.3 Estós

Status before SustainHuts. Estós hut is a Spanish hut located in the Aragonese Pyrenees at 1890 meters. Estós is the oldest hut belonged to the project and was initially the hut with worst conditions in its micro-grid, so an ambitious plan to improve its generation was applied.
The electricity in this hut is generated using a genset of 24.8 kW. In addition, 2.9 kWp of PV are present as well as a micro hydro turbine of 5 kW which provides electricity directly to some charges. 24 batteries with a capacity of 38.4 kWh (2V and 800 Ah every battery) are installed too. In relation to the heat, a diesel heater is installed in order to provide heat and hot water to the hut, although the hot water access is limited for the owners.

Regarding the ***electric system, it is not as efficient*** as it was expected at the beginning due to different reasons. The most remarkable fact identified is that the control and change between batteries, PV system and genset operation is not automated, causing an inefficient use of the batteries which reduces their lifetime. This control is done manually by the hut keepers and frequently deep discharges of batteries occurred, producing an accelerated damage and reducing their lifetime. Furthermore, the micro hydro turbine only provides energy to some small loads and, when there is an excess of energy, this is dissipated to the ambient, so the micro hydro turbine cannot charge the batteries when there is surplus of energy. On the other hand, the power of the genset is too high concerning the electric demand of the hut, working always at low power and generating electricity in a low efficiency operation point.

It has been found ***also that the PV system is very inefficient due to the different ages of the arrays and the bad conditions of some of them***. The panels are arranged in series of several units, so the total power is directly limited by the operation of the worst. Only among 10% and 20% of the potential energy expected is generated. It implies that the useful power achieved is much lower than the installed power, a fact that has been considered during the assessment.

Regarding ***the micro hydro turbine, it was installed many years ago and it works out of optimal condition because of a bad water collection system***.

All the previous mentioned conditions cause the genset to work more frequently than desired, increasing the amount of fuel consumed and the environmental impact of the Estós hut.

2.1.3.1 Optimization and automation of the electrical system - AAI [#9]

Another measure developed for the Estós hut is the automation of the electrical system, divided into two clearly differentiated actions:

- Implementation of an automatic switching between the diesel generator and the batteries.
- Enable charging of the batteries through the surplus energy of the turbine.

The manual switching of power supply between batteries or generator entails the deep discharge of the batteries, since the electric demand exceeds the capacity provided by the photovoltaic field and the storage capacity of the batteries. Once the batteries run out of energy, the genset is started manually to energize the building and is turned off again when the demand of energy decreases, without having charged the batteries to an acceptable level.

The automatization permits to monitor the state of charge of the batteries and automates the start-up of the group such that the strategy is based on the batteries' needs instead of the energy demand profile. This automation leads to an earlier start-up of the group with the aim of maintaining optimum health of the battery bank.

The installation is very old, so no electronic control is possible. The solution found was to install a switch for charging batteries or delivering energy directly to the hut. During the day, the "hut mode" is selected and the energy coming from the turbine is consumed in the hut. Before going to bed, the hut's energy demand is lower, so the "battery mode" is selected in order to charge the batteries with the electricity surplus generated by the turbine that would be wasted otherwise. It was not possible to develop a better control strategy, so two options were selected, at least, it is better than only one mode.

2.1.4 Llauset

Status before SustainHuts. Cap de Llauset hut is a Spanish hut located in Spanish Pyrenees at 2450 meters. The electricity in this hut is generated using two gensets of 12 and 36 kW. In addition, 4.0 kW of PV are present as well as 24 batteries with a capacity of 57.6 kWh (2V and 1200 Ah every battery). In relation to the heat, biomass stoves are in the hut in order to provide heat to the hut, whereas the hot water is provided using a diesel heater.

In Llauset no energy efficiency technologies are installed.

2.1.5 Montfalcó

Status before SustainHuts. Montfalcó hut is a Spanish hut located in the Spanish range of Sierra del Montsec, at 790 meters. The electricity in this hut is generated using a genset of 50 kW. In addition, 5.7 kWp of PV are installed as well as 24 batteries with a capacity of 109.5 kWh (2V and 2280 Ah every battery). The PV arrays present inefficiency.

One diesel heater is installed too in order to provide heat and hot water to the hut.

Furthermore, another genset of 12 kW is used only for pumping water from a natural spring to the water tank located in the hut. This diesel generator is located close to the natural spring, which is far away from the hut and about one hundred meters down in altitude, so the genset function is to pump the water demanded from the natural spring to the water tank, which is located in hut, where the water is consumed. This genset only works one hour per day approximately (when it is necessary to pump water), being turned off during the rest of the time.

2.1.5.1 Optimization and automation of the electrical system – AAI [#23]

Considering the inefficiency detected in the water pumping, this action is focused on facing this inefficiency issue following three ways:

- The replacement of the water diesel generator (12.0 kW) by an electric pump connected to the micro grid. The electric pump consumes less energy than the genset, increasing the efficiency of the water pumping. This action improves the energy efficiency in the hut by decreasing the energy necessary to pump water (an electric pump has a higher efficiency than the diesel generator, which is oversized for this function).
- The movement of the diesel generator (12.0 kW) from the natural spring to the hut, including its integration into the micro grid. This action reduces the amount of time that the large genset is in operation, while increases the operation time of the 12.0 kW genset, whose power is closed to the loads demanded (so it will work under better efficiency). Furthermore, the 12.0 kW genset allows energy supply when the load is low enough, avoiding the use of the 50.0 kW genset (oversized for providing the usual loads demanded in the hut).
- The elimination of the operation of the large diesel generator (usually forced to do it from 08:00 to 09:00), allowing the microgrid to work under better conditions and reducing the diesel consumption. The commutation system between gensets and batteries is automated ensuring the correct discharge of batteries. Even so, in order to control the electric system, hut keepers turn on the diesel generators from 08:00 to 09:00 every day to ensure that the batteries have enough energy during the rest of the day.

It is observed that the automation of the microgrid reduces the operating hours of the large diesel generator although it increases the hours worked by the small genset. Even so, the action will produce a total reduction of 2854 litres of diesel per year, which leads to a reduction of 6865 kg of CO2 annually.

2.2 Italian hut

2.2.1 Rifugio Torino

<u>Status before SustainHuts.</u> The Torino Hut (Rifugio Torino) is a high mountain refuge in The Alps in the northwestern Italy. Located near the border with France, it is about 15 km southwest of Mont Dolent, the tripoint with Switzerland. The refuge is in the Mont Blanc massif above the town of Courmayeur in the Aosta Valley. It can be most easily accessed from the Italian side by the Skyway Monte Bianco cable car from La Palud in Courmayeur, with a change at the Pavilion du Mont Fréty. It can also be reached from Chamonix via the Aiguille du Midi, either by cable car which crosses the massif, or by a long crossing of the Glacier du Gèant. The refuge lies nearly directly above the 11.6 km Mont Blanc Tunnel, which passes deep underground, and connects Courmayer to Chamonix.

The hut is the only in SustainHuts grid connected, the electrical system is powered by the Low Voltage 230V three-phase power supplier (connected to electrical grid, MT), with a delivery point near the beginning of the connecting staircase between Rifugio Vecchio and Nuovo. The Rifugio has a counter of 70kW. Rifugio Torino had in 2016 an electrical energy consumption of 96155 kWh/year.

The Rifugio Torino gets most of the heat from electricity with different devices (electric heater, electric fan, etc.). Other heat sources are:

- 2 diesel fans with a modulated output from 20-60 kW (located one in the drying room and one in the self-service room)
- 2 pellet stoves, located one in the room bar (room area 88 m2) and one in the lunchroom (room area 53 m2)

A big problem due also to the high hut's altitude is the water supply for culinary uses and for toilets.

2.2.1.1 Water recovery plants [#20]

Due to the hut location, it does not have any source of water supply sufficient to meet the demands of the refuge. The water supply problem has always existed, and drinking water was transported by cableway, and the water for such other services, was obtained from the glacier through a small cave, natural melting during the day. Only during the summer period is possible to take water from the glacier.

Often, the toilet facilities were out of order because of lack of water. But after the construction of the new cableway, called "SKYWAY", finished in June 2015, the number of tourists has increased exponentially. With the new cableway the flow of visitors has exceeded all expectations.

Two water plants are installed.

1. Water recovery through filtration. The water provision is critical due to the high altitude of the hut and it is strictly linked with high CO2 emissions due to the transport. It is an Energy Efficiency Action (EEA)
2. Water recovery via dissolution of snow and rain collection.

Figure below illustrates the status:

- *Before SustainHuts* with the water transported via pickup, cableway, helicopter and pumped via glacier only in summer.
- *During SustainHuts*, thanks to the new plants installed:
    - water recovered via dissolution of snow and rain and after that pumped for use,
    - water recovered from toilets and treated with a suitable plant, equipped with the most modern filtration systems and stored in special storage tanks, where, through insulated pipes and pumps, reported in places tanks at Torino Nuovo, and through a specific facility, conveyed in Restrooms.

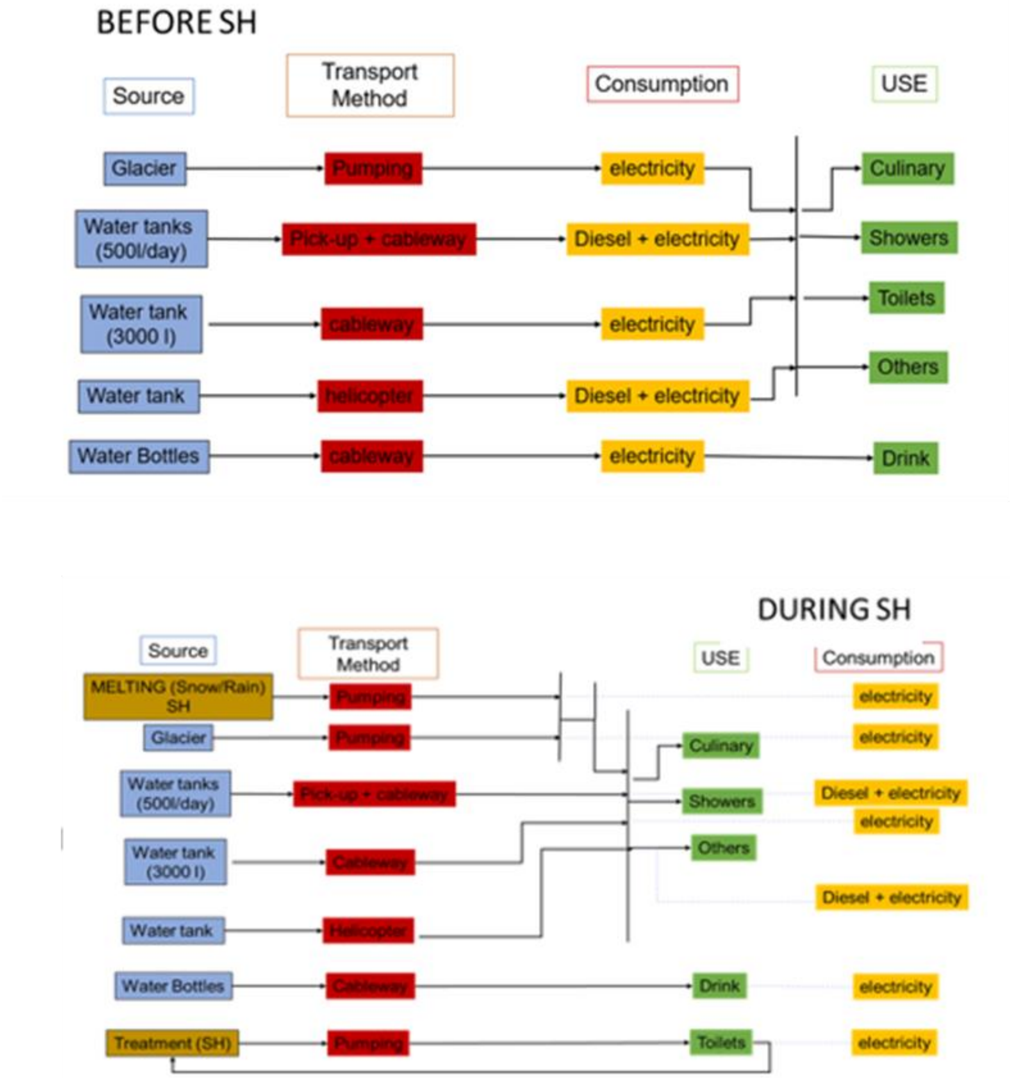

FIGURE 1. WATER TRANSPORTATION DIAGRAM TO TORINO HUT BEFORE SUSTAINHUTS (BEGINNING) AND DURING SUSTAINHUTS (END)

Comparing the actions proposed, it is concluded that each action has a different impact, but all of them improve the initial situation:

- PV installation entails a reduction of diesel consumed by the diesel fan. It will decrease diesel consumption by 267 kg (325 liters per year), avoiding the emission of 0,85 + 0,08 (related to the transport by cableway of diesel) tons of CO2 every year and 0,01 NOx/year.
- Water recovery plants (dissolution and filtration) lead to a reduction of about 9,4 tons of CO2 per year.

The Rifugio di Torino Hut situation is special because is connected to the grid, so the methodology implemented is not the same as the rest. The CO2 emissions have been calculated using the generation electric mix of Italy and the unit emissions of each technology. Therefore, knowing the electrical consumption of the hut, it has been possible to calculate the total amount of CO2 emissions. The avoided emissions foreseen are achieved in a great extent, but in this case the reduction is relatively low, only 14%, caused by the big amount of emissions of the hut at the beginning.

2.3 Slovenian huts

In Slovenia at the *state of the beginning* there were planned to include two mountain huts: Kocbekov dom na Korošici and Pogačnikov dom na Kriških podih. Unfortunately, Kocbekov dom was destroyed by a fire in autumn 2017 just after new equipment installation. After this incident, the new hut Dom Valentina Staniča was included and additionally financed.

2.3.1 Pogačnikov dom na Kriških podih

Status before SustainHuts. Pogačnikov dom is located in Triglav national park less than 4 km from Slovenia's highest mountain Triglav. It is seated at the altitude of 2050 m on the peak of Kriški podi and is surrounded by peaks of Bovški Gamsovec, Stenar, Razor and Pihavec. Like Kocbekov dom it is typically opened during summer season from June to September and is uninhabited during winter. The hut has a low flow of people and only opened during the summer. The idea was to install a hybrid system (solar and wind generation) with a storage system of batteries. It was evaluated that the combination between two technologies might provide the hut with a robust and reliable system for reducing a high amount of diesel fuel. Since the heat is already generated by the mixed wood, modifications in heat generation system were not foreseen.

In Pogačnikov dom no energy efficiency technologies are installed.

2.3.2 Dom Valentina Staniča pod Triglavom

Valentina Staniča hut was joined to the project after the Kocbekov hut destruction and after Pogačnikov installation, so the technologies to implement were easy to be chosen: the same than in Pogačnikov. The impact in Pogačnikov dom using a hybrid system was fantastic (and the good results of hybrid systems in isolated micro-grids are widely supported by bibliography), so the idea was to adapt and replicate the successful work done in Pogačnikov. Thus, a hybrid (PV-wind) supported with a batteries bank system has been installed in Valentina Stanica hut.

In Valentina Staniča no energy efficiency technologies are installed.

2.4 French hut

2.4.1 Dent Parrachée

Dent Parrachée is the last hut joined to the project, although no technologies have been financed by the project budget. The hut was refurbished in 2018, installed new renewable technologies in order to turn the hut into a more sustainable one. Considering it, no technologies are defined here, because the methodology (visit to the hut, hut keepers proposition, assessment of technologies, purchase, and installation) has not been applied in this hut, only the monitoring protocol affects it which is based on the comparison of this hut with Evettes, which a very similar hut without recent refurbishment. Even so, it is possible to declare that 4 renewable technologies have been installed in the hut: solar thermal panels, a hydro-turbine, a wood stove, and PV panels.

In Dent Parrachée no energy efficiency technologies are installed.

3 State of the art on novel and recycle insulated materials

3.1 Study background

Buildings are responsible for about 40% of the EU's total energy bill and 36% of Europe's CO_2 emissions, they use one third of the world's resources. Indeed, building thermal insulation have a significant effect on heating and cooling loads. As a result, reducing their energy consumption by improving buildings' energy efficiency is a key step in reducing their impact on the environment.

Thus, improving the thermal insulation of these huts is important to achieve these goals of energy efficiency. Furthermore, the high altitude and low temperature of this huts add one more difficulty to improve the energy efficiency.

In the study, all considered insulation materials of application in mountain huts at high altitude are described. Focus is given to novel and recycled insulation materials in order to complete and optimize the selection of the final materials used in the huts. Those novel and recycled materials have the advantage of being eco-friendly product with low environmental impact while maintaining a good thermal insulation.

3.1.1 Goals and targets

The main objective of this section is to ensure the choice of better materials that suit mountain huts characteristics. For each material considered, some characterization tables are delivered. Moreover, some technical capacities details, temperature ranges and coefficient are listed. The main goal is to provide a complete market review of novel and recycled insulation materials. Also, some widely used insulation materials are described. Furthermore, a complete market review will be done in order to complete and optimize the selection of the final materials used in huts.

3.2 Overview of the insulation materials under consideration

Insulation materials can be divided into five categories based on their composition: vegetable, mineral, animal, synthetic, and composite. This division facilitates the understanding of the structure and the material features. Indeed, an environmental impact assessment of the four life-cycle stages -procurement, production, use and scrapping- is made for six different materials- sheep's wool, hemp-kenaf, recycled polyester, recycled textile, mineral wools and expanded materials. It shows that recycled and natural materials have the lowest environmental impact.

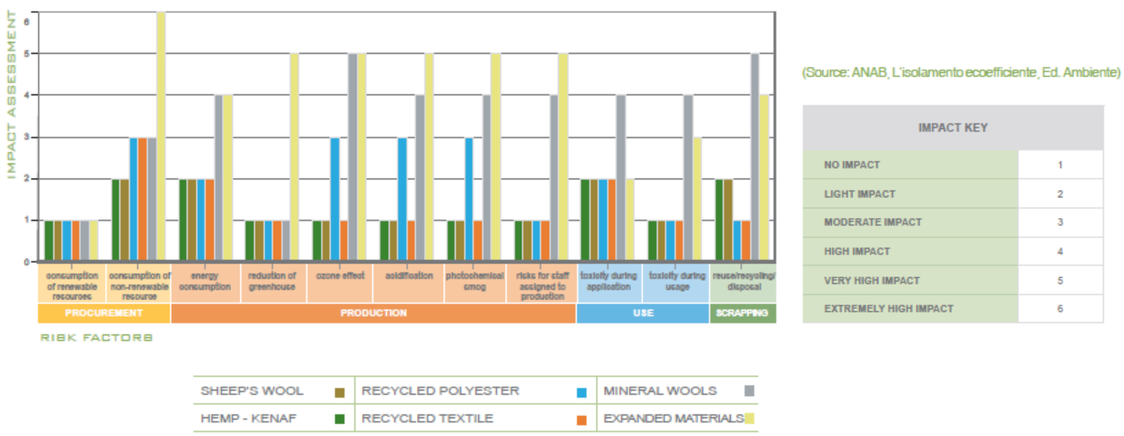

FIGURE 2. ENVIRONMENTAL IMPACT ASSESSMENT OF THE SELECTED INSULATION MATERIALS

This diagram compares six insulating materials through different stages of their life cycle. Indeed, for the procurement stage, two characteristics are compared: the consumption of renewable resources and the consumption of non-renewable resources. During the production stage, several risks factors- such as the energy consumption, the ozone effect or the risks for the staff- are higher for mineral wools and expanded materials. Then, the use of these materials presents two risk factors: the toxicity during the application and during the usage. Finally, the reutilization or disposal is evaluated for each material. Considering this LCA of these six materials, natural and recycled ones present a lowest environmental impact. Thus, this review will mainly focus on describing characteristics of **recycled** and **natural** insulation materials.

3.2.1 Vegetable origin

Insulation materials made from vegetable raw materials were one of the first used for this purpose. As a result, they need also to be considered since they present some environmental assets.

3.2.1.1 Hemp

Hemp cultivation has an extensive tradition in Europe and Italy. Also, it has many advantages such as excellent insulating properties in summer and in winter. It is stable in size and performance even in conditions of high humidity and its production chain is ecological. As a result, it is a privileged thermal insulation material. The insulation material is composed by 90% of hemp and 10% of polyester. Even if it is not made with recyclable materials, it is 100% recyclable. Its thermal conductivity is about 0.038 W/m K for a 50 kg/m^3 density.

CHEMICAL COMPOSITION	90% hemp - 10% polyester		
PARAMETER	**STANDARD**	**RESULT**	**DENSITY AND REFERENCE THICKNESS**
Thermal conductivity	UNI EN ISO 12667	λ= 0,038 W/mk λ= 0,040 W/mk	50 kg/m³ 30 kg/m³
Specific Heat	---	c= 1700 J/KgK	
Water vapour resistance factor	UNI EN 12086	μ = 1-2	
Recyclability	---	100%	

TABLE 2. HEMP INSULATION CHARACTERISTICS

3.2.1.2 Kenaf

Kenaf is cultivated for its fiber in several parts of the world such as India, Bangladesh, USA, Indonesia, and a small extent in Southeast Europe. This plant absorbs more carbon dioxide than any other plant-able species. It purifies the ground of toxic elements and produces a large quantity of oxygen for the soil. It has a good tolerance to drought and its cultivation does not require the use of herbicides and pesticides. Moreover, process scraps from fiber extraction can be reused as fodder and ecological fuel. To obtain NATURTHERM KE- the insulation material made from kenaf fiber and sold by Manifattura Maiano- the kenaf fibers, previously mixed with a low-melt fiber, are compacted by a mechanical and bonding process, without the use of any type of chemical additive. The intrinsic qualities of kenaf fibers make the materials immune to attacks by insects and rodents and give them excellent resistance to mold and putrefaction. The material is composed by 90% of kenaf and 10% of polyester. Its thermal conductivity is 0.030 W/m K for a 100 kg/m3 density. Moreover, it is applicable for a range of temperature between -40°C and + 110°C.

PARAMETER	STANDARD	RESULT	DENSITY AND REFERENCE THICKNESS
Thermal conductivity	UNI EN 12667	λ = 0.030 w/m K λ = 0.035 w/m K λ = 0.040 w/m K	100 kg/m^3 50 kg/m^3 30 kg/m^3
Specific Heat	---	c = 1700 J/kg K	
Water vapor resistance factor	UNI EN 12086	μ = 2.3	
Recyclability	---	100%	
Hygroscopic absorption	UNI EN 12571	u = 0.04	
Temperature of application	---	-40°C +110°C	

TABLE 3. KENAF INSULATION CHARACTERISTICS[1]

3.2.1.3 Wood pressed

Wood is a sustainable raw material. Its processing is not very energy intensive. To produce insulation boards, the raw materials used are wood chips. The company Siempelkamphas developed a Dry Process with a new bonding system. After the fibers are dried, they are blended with a special, fast curing Isocyanate resin. To apply this resin, a new method of spraying the fibers inside a tower was researched in depth, developed, and tested by the Siempelkamp Research and Development Department. Also new: after pre-pressing, the mat enters a calibration and curing step using Siempelkamp's unique pre-heating unit ContiTherm. Here the mat is heated rapidly by blowing a steam-air mixture through it. For the new concept, the ContiTherm was equipped with an extended calibration zone. The modified system allows for heating and curing even thickest mats of up to 300 mm. Finally, the endless board is cut by a diagonal saw to the required length.

[1] Natural and recycled fiber insulation, Manifattura Maiano, Italy

Wood-Fiber Insulation Board according to the Siempelkamp Dry Process					
Property/rigid boards			Density [kg/m³] / [lbs./cu.ft.]		
			110/6.9	140/8.7	200/12.5
Compression	EN 826	kPa	appr. 20	appr. 70	appr. 200
		p.s.i.	appr. 2.9	appr. 10.1	appr. 29.0
Thermal Conductivity nominal value	EN 13171	W/m*K	appr. 0.037	appr. 0.040	appr. 0.045
Fire behaviour [a]	EN 13501		Class E		

a) with fire retardant (depending on density)

TABLE 4. WOOD FIBER INSULATION CHARACTERISTICS[2]

3.2.1.4 Recycled Cellulose Fiber

Cellulose is among the oldest types of building insulation material. There are different types, from newspaper to cardboard. Modern cellulose insulation, made with recycled newspaper using grinding and dust removing machines and adding a fire retardant, began in the 1950s and came into general use in the US during the 1970s.

The Italian company EnerPaper had developed an innovative product -protected by an international pattern. The insulating Enerpaper material is unique by its shape: it has the form of spools. The trial directly foresees the realization in ribbons paper. The thickness is checked on. Then a superficial film of chemical additives is applied able to guarantee the following technical characteristics: anti-inflammation, anti-mold and anti-dust. The ribbons of papers confer a reduction of the costs of laying. 35% of reduction in energy consumption and a point not insignificant, particularly in the case of huts, this product allows a reduction of 70% in the transportation costs. It is made from 100% recycled fiber and the technology used provides a better insulation than competitive products while using less than half the material.

Density Kg/m³	Thermal conductivity W/ m K	Resistance to water vapor diffusion UNI EN 12086:2013	Fire resistance EN 13501-1:2009
23-35	0.036-0.037	3	B s1d0

TABLE 5. RECYCLED CELLULOSE FIBER INSULATION CHARACTERISTICS

3.2.2 Vegetable insulation materials list and data[3]

In this section, a non-exhaustive list of vegetable insulation materials is drawn up. The materials considered are listed and some characteristics are given. As these materials are used for their insulation proprieties it is interesting to compare their thermal conductivity, thickness, water vapor resistance factor and their fire resistance. The green cells represent the recyclable materials.

[2] Wood-fiber insulation board, Siempelkamp dry process

[3] MATERIALI ISOLANTI,NUOVE TENDENZE IN ARCHITETTURA, a cura di Elisabetta Carattin, Marco Franz, Sebastiano Luciano : Architetti, Dottorandi di ricerca in Tecnologie dell'architettura presso la Scuola di dottorato di ricerca dell'Università IUAV di Venezia

Material	Composition	Structure	Thermal conductivity W/m K	Density Kg/m³	Thickness mm	Water vapor resistance factor Kg/m s Pa	Fire Resistance
Jute fiber	Mixed compounds	Fibrous	0.05	100	2-5-10	1	
Flax fiber	Single material	Fibrous	0.04	30-60	2-10	1	B2
Corn fiber	Single material	Fibrous	0.0364	20-40	20-60	3.11	
Reed	Single material	Fibrous	0.056	190	2 or 5	1	E
Coconut fiber	Single material	Fibrous	0.043	85-125	10-50	1	B2
Pressed Wood	Single material	Fibrous	0.038	50	40-200	1-2	E
mineralized wood wool	Mixed compounds	Fibrous	0.065	400	25-50	5	B s1 d0
Kenaf and Hemp fiber	Mixed compounds	Fibrous	0.037	30-50	30	7	B2
Hemp Fiber	Mixed compounds	Fibrous	0.042	30-37	45-80-100	1-2	B2
Blonde cork	Single material	Fibrous	0.04	85-125	10-50	5/30	E
Cellulose fiber	Single material	Fibrous	0.039	22-56		1-2	B.s2.d0

TABLE 6. VEGETABLE INSULATION MATERIALS LIST AND DATA

3.2.3 Mineral origin

'Man-made mineral fibers' is a generic term that denotes fibrous inorganic substances made primarily from rock, clay, slag or glass. These fibers can be classified into three general groups: glass fibers (comprising glass wool and glass filament), rockwool and slag wool, and ceramic fibers. The overwhelming majority of glass fiber, rock wool and slag wool is produced for thermal and acoustic insulation applications. According to US Environmental Protection Agency, in 1980, approximately 80% of the glass wool produced for structural insulation was used in houses.

3.2.3.1 Expanded granular glass[4]

Foam glass is an insulation panel in expanded granular glass. It contains more than 66% of glass from recycled windscreen of cars, pipes of neon, glasses for windows and sand of quartz. The product is completely free of CFC, HCFC, HFC and of other harmful agents. It is particularly ecological, and its inorganic origin totally makes it incombustible. Besides, the material introduces a constant thermal conductibility value of 0.040 W/ m K. The structure of the material is constituted by millions of closed and hermetic cells in glass that assure an efficient resistance

[4] FOAMED GLASS – AN ALTERNATIVE LIGHTWEIGHT AND INSULATING MATERIAL, Roald Aabøe, Norwegian Public Roads Authorities, NPRA. Norway and Even Øiseth, SINTEF Civil and Environmental Engineering. Norway

to the vapor. The insulating Foam glass is impermeable to the water and pond to the vapor, it doesn't absorb damp, and it has good resistance to compression.

Technical Data	Density Kg /m3	Thermal conductivity W / m K	Compression resistance N/mm²	Specific heat	Thermal diffusion m² /s	Fire resista
	120	0.04	0.21-0.66	0.84	4.2 10^-7	Class 0

TABLE 7. EXPANDED GRANULAR GLASS INSULATION CHARACTERISTICS

3.2.3.2 Recycled glass fiber[5]

Glass fiber is made from molten glass, sometimes with 20 to 30% recycled content. The most common residential insulant. Usually applied as batts, pressed between studs. Most include a formaldehyde-based binder – exceptions are beginning to appear. Its thermal conductivity is quite good: 0.033- 0.04W / m K. Fiber glass is one of the most popular insulation materials and costs around 5-9 € per m².

3.2.3.3 Mineral insulation materials list and data

In this section, a non-exhaustive list of mineral insulation materials is drawn up. The materials considered are listed and some characteristics are given. As these materials are used for their insulation proprieties it is interesting to compare their thermal conductivity, thickness, water vapor resistance factor and their fire resistance.

Material	Composition	Structure	Thermal Conductivity W/m K	Density Kg/m³	Thickness mm	Water vapor resistance factor Kg/m s Pa	Fire Resistance
Expanded granular glass	Single material	Mineral-cellular	0.04	120	40-180		0
Glass wool	Mixed compounds	Fibrous	0.032		40-80	9	
Cellular glass	Single material	Alveolar-cellular	0.048	170	13-40	Infinite	0
expanded granular Clay	Single material	Alveolar-cellular	0.09	380			0
Natural cement	Mixed compounds	Mineral-cellular	0.085	400		6	Non-inflammable
Mineral Wool	Single material	Fibrous	0.037-0.04	40-180	15-250	1	A1
Expanded Perlite	Single material	Mineral-cellular	0.042-0.053	100	1-5	5-8	0
Pumice	Single material	Mineral-cellular	0.1	500-600	0-20	2-4	0
Recycled glass	Mixed compounds	Mineral-cellular	0.033-0.04	350	2-25		A1

TABLE 8. MINERAL INSULATION MATERIALS LIST AND DATA

[5] Building shell and thermal insulation, Energy Technology Systems Analysis Programme, IEA ETSAP - Technology Brief R01 – June 2012 - www.etsap.com

Animal origin

3.2.3.4 Sheep's wool

Sheep's wool, one of the most ancient insulating materials, long used in the most primitive constructions, is the ideal material to build according to bio-construction principles.

Thanks to its special micro-structure, sheep wool is therefore the ideal and natural alternative to mineral fibers used to provide thermal and acoustic insulation. Moreover, wool is a renewable and recyclable raw material that requires a very low energetic balance to transform it into an insulating panel. To manufacture it, sheared wool is used that is not suitable to be transformed into fabrics and yarns. The sheared wool is washed with natural soap and subjected to an anti-moth treatment, and is then carded and bonded at 180°, a process step that ensures the product is also fully sterilized.

CHEMICAL COMPOSITION	85% wool – 15% Polyester; also available in 100% pure wool version		
PARAMETER	**STANDARD**	**RESULT**	**DENSITY AND REFERENCE THICKNESS**
Thermal conductivity	UNI 7891	λ= 0,038 W/mk	20 kg/m³
Sound absorption	UNI EN ISO 11654	α_w= 0,80	20 kg/m³ 80 mm
Water vapor diffusion	UNI EN 12086	μ = 3,0	
Water vapor permeability	UNI EN 12086	δ = 0,23	
Specific heat	-	c= 1750 J/KgK	
Ecological and toxicological certificate	Certified product Oeko Tex standard 100	Class I RDP 1208054.0	
Recyclability	-	100%	
Temperature of application	-	- 40°C + 110°C	

TABLE 9. SHEEP'S WOOL INSULATION CHARACTERISTICS

3.2.3.5 Animal insulation materials list and data

In this section, a non-exhaustive list of animal insulation materials is drawn up. The materials considered are listed and some characteristics are given. As these materials are used for their insulation proprieties it is interesting to compare their thermal conductivity, thickness, water vapor resistance f actor and their fire resistance.

Material	Composition	Structure	Thermal Conductivity W/m K	Density Kg/m³	Thickness mm	Water vapor resistance factor Kg/m s Pa	Fire resistance
Sheep wool	Single material	Fibrous	0.037	17.9	30-240	1	B2
Animal Feather	Mixed compounds	Fibrous	0.04-0.042	25-35	40-110	6.537	

TABLE 10. ANIMAL INSULATION MATERIALS LIST AND DATA

3.2.4 Synthetic origin

3.2.4.1 Recycled polyester

With increasing global consumption and their natural resistance to degradation, plastic materials bring serious concerns. As a result, recycling part of them into insulation materials could be one solution among others to reduce their accumulation in the environment.

The insulation materials manufactured with polyester fibers obtained from recycled plastic bottles remains unaltered over time. Fully recyclable, it is a non-allergenic product that does not contain toxic substances that are harmful to man. It is composed by 100% of polyester. And 85% of the fiber is regenerated from PET. This insulation materials -produced by Manufattura Maiano- can be applied for a range of temperature between -40°C + 110°C. It's reaction to fire is classified B s2 d0, according to UNI EN13501-1. Another important parameter is its thermal conductivity which varies from 0.034W/m K to 0.048 W/m K depending on its density as it is shown in **¡Error! No se encuentra el origen de la referencia.**.

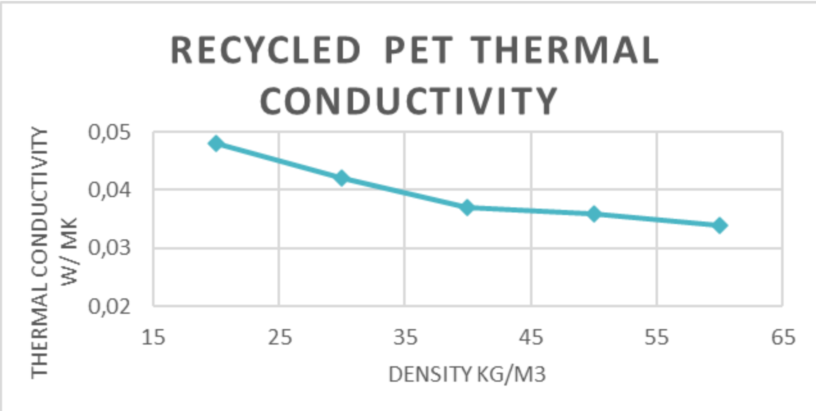

FIGURE 3. RECYCLED PET THERMAL CONDUCTIVITY IN DEPENDENCE OF ITS DENSITY

CHEMICAL COMPOSITION	100% polyester (85% of the fiber is regenerated from PET)		
PARAMETER	**STANDARD**	**RESULT**	**DENSITY AND REFERENCE THICKNESS**
Rating of sound absorption	UNI EN ISO 11654	α_w =0,65 α_w =0,75	50 kg/m³ 30 mm 30 kg/m³ 50 mm
Sound-insulation	UNI EN ISO 140-4	R'_w = 53 dB	Partition wall with metal framework and double plasterboard cladding, 12.5 and 15 mm, on both sides. Double slab of Sintherm FR 60.40 in cavity. (Various Certificates in place available on request)
Dynamic Stiffness	UNI EN 29052	S'_t =15 MN/m³ S'_t =1,8 MN/m³	100 kg/m³ 8 mm 50 kg/m³ 30 mm
Deformation under load 1 kPa	UNI EN 12431	3%	100 kg/m³ 8 mm
Thermal conductivity	UNI EN 12667	λ= 0,034 W/mk λ= 0,036 W/mk λ= 0,037 W/mk λ= 0,042 W/mk λ= 0,048 W/mk	60 kg/m³ 50 kg/m³ 40 kg/m³ 30 kg/m³ 20 kg/m³
Reaction to fire - Classification	UNI EN13501-1	B s2, d0	
	UNI 9177	CLASS 1	
Optical density of smoke and gas toxicity	ATS 1000.001-issue 4	limits satisfied	
Specific heat	---	c= 1200J/KgK	
Ecological and toxicological certificate	Certified product Oeko Tex standard 100	Class I RDP 1208054.O	
Recyclability	---	100%	
Temperature of application	---	- 40°C + 110°C	

TABLE 11. RECYCLED PET INSULATION CHARACTERISTICS

3.2.4.2 Synthetic insulation materials list and data

In this section, a non-exhaustive list of synthetic insulation materials is drawn up. The materials considered are listed and some characteristics are given. As these materials are used for their insulation proprieties it is interesting to compare their thermal conductivity, thickness, water vapor resistance factor and their fire resistance.

Material	Composition	Structure	Thermal Conductivity W/m K	Density Kg/m³	Thickness mm	Water vapor resistance factor Kg/m s Pa	Fire resistance
Expanded Polystyrene Foam	Single material	Alveolar-cellular	0.024	34	20-100	20	E
Aerogel	Single material	Mineral-cellular	0.018	5.6-6.2 lb/ft³	0.5-4.0		
Heat reflecting	Layered compounds	Alveolar-cellular	0.03		6.5	30769	
Expanded Polyethylene	Single material	Alveolar-cellular	0.04		40	>2000	
Polyester fiber	Single material	Alveolar-cellular	0.034	20	5	100.000	
Poly-propylene	Mixed compounds	Alveolar-cellular	0.03		10	>2000	E
Expanded Polystyrene	Single material	Alveolar-cellular	0.036	10	<60	80-250	E
Synthetic Expanded Polystyrene	Single material	Alveolar-cellular	0.035	10	10-500	80-100	E (B1)
Vacuum insulating panel	Layer compounds	Mineral-cellular	0.0053	180-210	10-40		B2

TABLE 12. SYNTHETIC INSULATION MATERIALS LIST AND DATA

3.2.5 Composite origin

3.2.5.1 Recycled textile fibers

The textile industry is one of the biggest consumers of natural resources. As a result, it is important to recycle textile in order to reduce its environmental impact. Manifattura Maiano transforms the fibers obtained from processing scraps from nearby industries in the textile district of Prato (Italy) and from recycled textile products that have reached the end of their life cycle into thermal and acoustic insulating panels. The manufacturing process is highly eco-friendly, because the raw materials, after having been sterilized at 180°C, are processed without the use of water, chemical products or binders. The product is 100% recyclable at the end of its life cycle.

Its thermal conductivity is about 0.0358 for 80 kg/m^3. And this material- composed by 25% of wool, 10% of cotton, 20% of polyester, 15% polypropylene and 30% of other textile fibers- is applicable for a range of temperature between -40°C and +110°C. Some parameters are described in the table below.

CHEMICAL COMPOSITION	25% wool, 10% cotton, 20% polyester, 15% polypropylene, 30% other textile fibers		
PARAMETER	**STANDARD**	**RESULT**	**DENSITY AND REFERENCE THICKNESS**
Thermal conductivity	UNI EN 12667	λ = 0,0358 W/mk λ = 0,0381 W/mk	80 kg/m³ 60 kg/m³
Acoustic-insulating Power	UNI EN ISO 140-4	R'_w = 52 dB	Brick wall, 12 cm thick, supporting wall on both sides made out of a double plasterboard cladding with 3 cm of Recycletherm 80.30. (Various Certificates for construction available on request)
Soundproofing coefficient	UNI EN ISO10534-2	α_n [500Hz] = 0,21	80 kg/m³ 30 mm
Deformation under load 1 kPa	UNI EN 12431	27%	80 kg/m³ 30 mm
Water vapor diffusion	UNI EN 12086	μ = 2,2	
Hygroscopic absorption	UNI EN 12571	u = 0,02	
Recyclability	---	100%	
Temperature of application	---	- 40°C + 11 0°C	

TABLE 13. RECYCLED TEXTILE FIBERS INSULATION CHARACTERISTICS

3.2.5.2 EPS and rubber layer

This panel for thermal and acoustic isolation of walls are realized with a plate of EPS joined on both sides with plates in rubber. Some rubbery materials are made from the recovery of tyres out of use. The central panel in EPS has a thickness of 40 mm and a density of 35 kg/m3. Graphite is added in order to decrease the thermal conductibility of the material.

Technical Data	Density Kg /m3	Thermal conductivity W / m K	Compression resistance kPa	Fire resistance
	35	0.04	220	Classe 1

TABLE 14. EPS & RUBBER LAYER INSULATION CHARACTERISTICS

3.2.5.3 Recycled rubber SBR and tarred paper

The panel composed of 90% of granules of recycled rubber glued to warm and closed among two supports of tarred paper. Its exceptional insulating ownerships do a product of high quality and advanced technology, to employ in the building sector. This material is chemically neutral.

Technical Data	Density Kg /m3	Thermal conductivity W / m K	Vapor diffusion resistance kg/ m s Pa	Fire resistance
	700	0.033	400	Classe 3

TABLE 15. RECYCLED RUBBER SBR AND TARRED PAPER

3.2.5.4 Natural fiber and polyester

This material is composed of mixed fibers coming from recycled fabrics and from reinforced polyester fibers, tied up through a process of thermal cohesion that exploits the different point of fusion of the two components. The material is composed of 50% of recycled fibers and 50% of polyester. It is mainly used as acoustic and thermal insulation, both under winter and summer conditions. Moreover, it is a nontoxic products and anti-dust. The product is easily cut with scissors and it doesn't release fibers. The process of formation of the panels and the rolls does not require the use of adhesive or other chemical or polluting products.

3.2.5.5 Composite insulation materials list and data

Material	Composition	Structure	Thermal Conductivity W/m K	Density Kg/m³	Thickness mm	Water vapor resistance factor Kg/m s Pa	Fire resistance
Coconut fiber coupled with panel of cork	Layered compounds	Fibrous	0.1	110-120		5-30	B2
EPS + Rubber layer	Layered compounds	Mineral-cellular	0.032	35	38	1	60-120
Recycled rubber SBR and tarred paper	Mixed compounds	Mineral-cellular	0.033	700	10-15-20-30-40	400	3
Cork granules and recycled rubber SBR	Mixed compounds	Mineral-cellular	0.033	300	10-15-20-30-40	400	3
Granules of recycled pneumatic rubber	Single material	Mineral-cellular	0.113	700			
Natural fiber and polyester	Matrix compounds	Fibrous	0.039	20-40	20-120	1.7-2.0	
EPS + bitumen membrane	Layered compounds	Mineral cellular	0.034-0.039		30-50		E
Polyester (diversified urban harvest)	Single material	Alveolar-cellular	0.034-0.04	10-40	10-145	3.2	1
Textile recycled fiber	Matrix compounds	Fibrous	0.036-0.038	20-40	7.6-12.7	1.7-2.0	1

TABLE 16. COMPOSITE INSULATION MATERIALS LIST AND DATA

3.2.6 Recycled materials comparison

In this section, the recycled insulation materials considered are compared as regards several characteristics such as their thermal conductivity, and their rate of embodied carbon. Through different comparisons, the point is to optimize the election of the final materials used on demo huts.

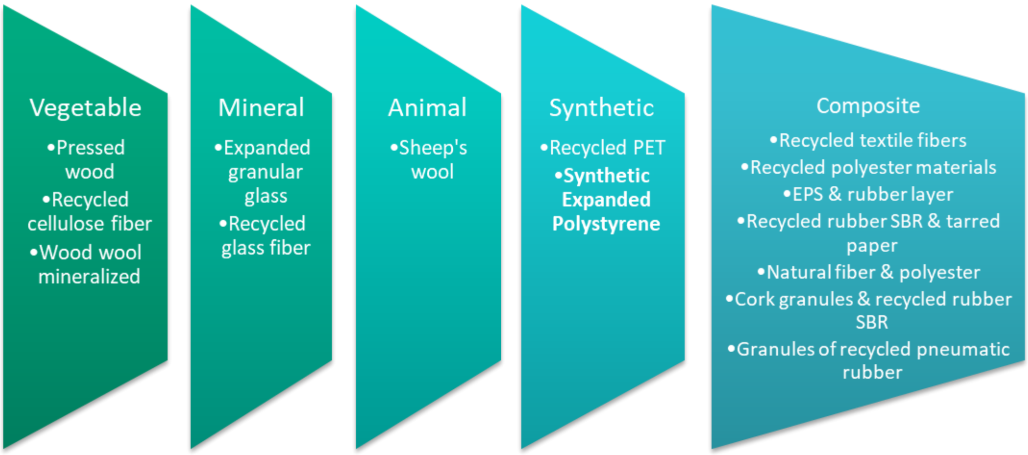

FIGURE 4. RECYCLED MATERIALS

3.2.7 Thermal conductivity comparison

Thermal conductivity is the physical property of a material to conduct heat. As a result, in the case of insulation material the lower is the thermal conductivity, the better the insulation material is. Indeed, the performance of the thermal insulation material is mainly determined by its thermal conductivity, which is dependent -among others- on the material's density.

Materials	Thermal conductivity W / m K
Pressed wood	0.04
Wood wool mineralized	0.065
Recycled Cellulose Fiber	0.036-0.037
Expanded Granular Glass	0.04
Recycled Glass Fiber	0.033-0.04
Sheep's wool	0.037
Synthetic Expanded Polystyrene	0.035
Recycled PET	0.034-0.048
Recycled textile fiber	0.035
Recycled polyester materials	0.034-0.04
EPS + rubber layer	0.032
SBR + tarred paper	0.033
Cork granules + recycled rubber SBR	0.033
Granules of recycled tyres rubber	0.113
Natural Fiber + polyester	0.039

TABLE 17. THERMAL CONDUCTIVITY COMPARISON

4 Insulation materials selected in SUSTAINHUTS

Regarding actions aiming at improving the thermal insulation, two innovative materials are considered.

4.1 Wool4Build insulator material (W4B)

W4B (Figure 5) is an insulating material made from recycled sheep´s wool, with high thermal and acoustic performance insulation. This insulator is marketed by Inpelsa, belonging to Lederval group, with its head-office in Canals (Valencia). W4B is the result of a European Union Project under the Eco-Innovation Programme, whose main goal is developing a thermal and acoustic recycled insulation material able to compete with actual insulators, not only economically, but also in technical terms[6].

W4B has a significant number of characteristics, which made it suitable for SUSTAINHUTS project. Thanks to the optimum properties of natural wool, W4B exhibits excellent conductivity values and heat resistance, favoring the enhancement of the thermal comfort and the reduction of energy consumption, and works as an efficient acoustic insulation. It is a completely recyclable insulator and the 85% of its raw material come from recycled materials. That leads to a considerable decrease in the energy used to manufacture it, making it an ideal product for sustainable buildings. Further, thanks to its specific treatment, W4B is fully protected against insects as Tineola Bissellielia, according to the ISO 3998 standard. Most relevant material characteristics are shown below. W4B is available in comfort and premium versions, which differ from each other in the thickness and density, to suit different construction requirements.

FIGURE 5. WOOL4BUILD INSULATOR

[6] G. Lederval, "http://www.wool4build.com/," [Online]. [Accessed May 2018].

Technical data	Comfort	Premium
Density	$20\ (kg/m^3)$	$30\ (kg/m^3)$
Thickness	40 (mm)	50 (mm)
Thermal conductivity	0,0362 $(W/m*k)$	0,0330 $(W/m*k)$
Insect resistance	1	1

TABLE 18. TECHNICAL DATA OF WOOL4BUILD INSULATOR

4.2 Imperlux Termic thermal barrier paint

Main function of this paint is to avoid water filtrations, but thanks to its innovative characteristics is also suitable for working as a thermal insulator. This material is used in Bachimaña hut. This hut is a stone-built building, and it has to be periodically treated with special products in order to avoid water filtrations. The main function of this paint is the avoidance of water filtrations inside the building, something undesirable not only for maintenance reasons of the walls and floors, but also because it affects negatively the heating efficiency of the building. But apart from humidity protection, this paint works also fine as thermal insulator, so it was decided to use it in the project.

This product is commercialized by Arelux (Zaragoza), and its insulating properties comes from the addition of ceramic microspheres which create an air chamber that breaks the thermal bridge and therefore improves the thermal insulation[7].

This paint has a thermal conductivity of 0,056 (W/m*K), according to the Standard UNE 92202:1989. The main properties are:

- The use of this thermal paint can decrease the total amount of energy use by up to 40 per cent.
- It avoids moisture condensation, main factor of mould formation.
- It's a 100 per cent ecological product and it´s free of solvent.
- It helps to reduce the outdoor noise, i.e. it works properly as an acoustic insulator.

[7] Arelux, "https://arelux.com/pintura-termica/productos/," [Online]. [Accessed May 2018]

FIGURE 6. IMPERLUX TERMIC THERMAL BARRIER PAINT

Ficha técnica

Densidad relativa a 23º	0.95-1.05Kg./.l
Coeficiente de conducción térmica (UNE 92202:1989)	λ = 0.056
Secado al tacto	1 hora
Secado total	12 horas
Diluyente	Agua
Espesor mínimo recomendado	700 micras

TABLE 19. IMPERLUX TERMIC THERMAL BARRIER PAINT DATASHEET

This material was not identified in the state-of-the-art assessment because it is not purely a thermal insulator material, and its application is suitable only to huts where water filtrations are a common problem.

5 Insulation actions

The aim of this section is to analyze which benefits in terms of energy savings could be achieved after improving the insulation of some huts of the project. Two huts located in Spain (Estós and Cap de Llauset) have been selected as demo sites to present Wool4Build insulator advantages, and Bachimaña hut, also located in Spain, to enhance its insulation with Imperlux thermal barrier paint.

This section is structured as follows:

- *Methodology*: a brief summary of the methodology used to perform calculations is given, aiming at providing an insight of the expected benefits of improving huts insulation with these innovative materials.
- *Cases of application*: in this section each location where insulation has been installed.
- *Results*: a summary table of expected gains in terms of saving costs in each location where an insulator will be placed is shown.

5.1 Methodology

In order to obtain a measure of the expected improvement to be accomplished after installing those materials, a specific simulation has been carried out. A static situation has been considered, by devising all data required to perform calculations. It has been done in each location where insulators will be placed.

First of all, there is a need to explain all assumptions that have been taking into account to perform calculations for the simulation:

1. The main assumption is to maintain a constant indoor temperature in the hut.
2. Each indoor room of the hut is at the same temperature. It means that there is not heat transfer between them. With regard to this assumption, there will be only heat transfer between the indoor and the outdoor through walls, the ceiling or the floor, depending on the room.
3. This procedure has been followed for each room where W4B insulator and thermal barrier paint will be placed, with the main goal of obtaining an idea of which benefits could be achieved with those innovative materials.
4. Results have been given as a percentage, which shows the energy savings of the insulation applied. For example, a result of 25% means that if before installing the insulation the fuel consumed for heating that room was (let's say) 100 litres, after improving the insulation the fuel consumption reduced down to 75 litres. That percentage does not refer to the whole hut, but only to the specific location where the insulator will be placed in each case without taking into account the rest of the building.

5.2 Cases assessed

The final application cases implemented are described below:

— In Bachimaña hut, innovative thermal barrier paint on the ground floor, in the inside walls of the living room was proposed.

— In Llauset hut, improvement of the thermal insulation of the electrical room where batteries are located.

— In Estós hut several actions: i) on the first floor, apart from the north wall of the stairs, the north wall of the entrance hall has been also insulated, ii) on the second floor, the final decision was to insulate the ceiling of all the rooms and the north wall of just one, the Puerto de Oö room.

5.2.1 Case 1: Bachimaña hut, thermal paint [#6]

In Bachimaña hut, an innovative thermal barrier paint (Imperlux Termic) has been used in the inside walls of the living room, located on the ground floor (Figure 7). Information on this material can be found in Annex 1 (main characteristics and CE certificate), where it can be observed that although the thermal insulation features are not very remarkable, the protection that it offers to those areas where moisture can appear are excellent. Therefore, there are expected some savings on energy used for heating due to the reduced levels of moisture in the rooms where this paint is applied.

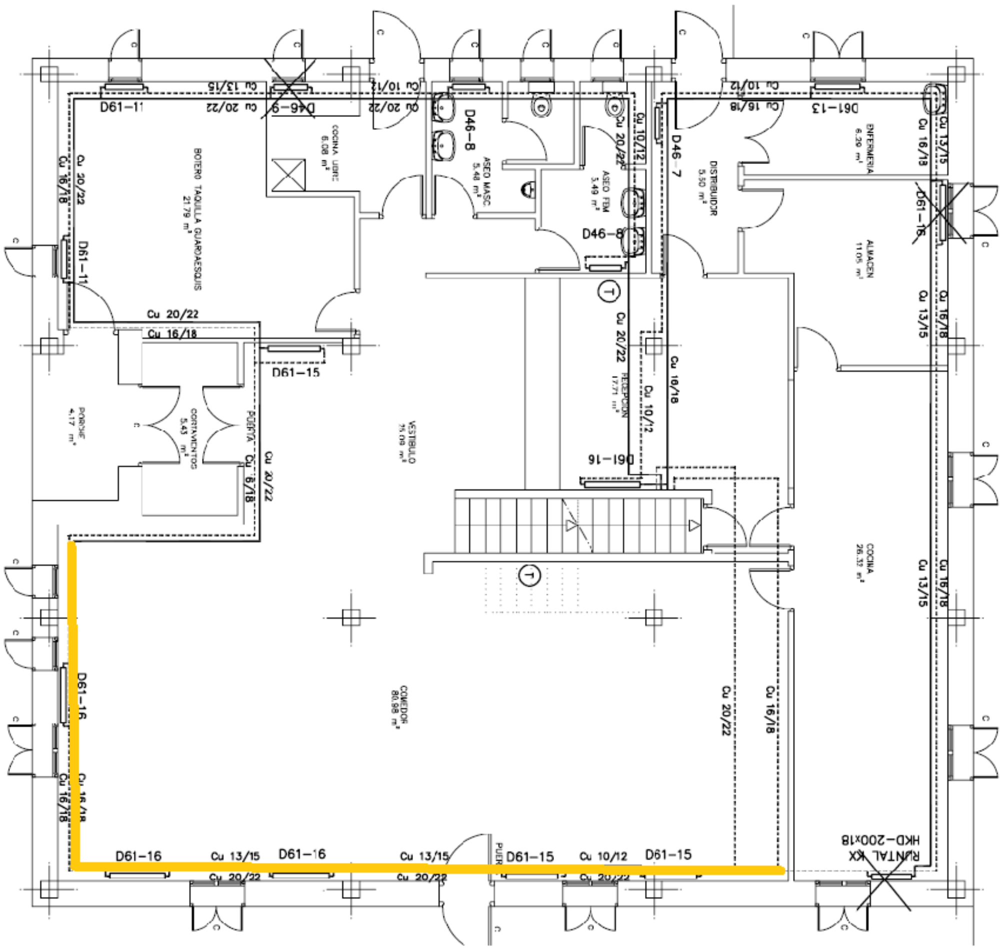

FIGURE 7. FIRST FLOOR OF BACHIMAÑA HUT

After the installation of this thermal barrier paint, hut keepers have noticed a significant reduction of moisture in the internal walls of the living room. As it is shown in Figure 8 (the wall covered by snow is the long section highlighted in Figure 7), in winter snow accumulates in some of the walls of the hut during long period of times, which leads to many problems of moisture. Thus, after applying thermal barrier paint, those problems have practically disappeared.

FIGURE 8. SOUTH WALL OF BACHIMAÑA HUT IN WINTER

5.2.2 Case 2: Llauset Hut. Thermal insulation of electrical room [#15]

The decision was to improve the thermal insulation of the electrical room (Figure 9). In this specific room there is not a heating system, and the main reason of trying to enhance its insulation was to maintain batteries in better operating conditions, aiming at enlarging their lifetime, as the lead-acid batteries **drop in capacity by about 20 percent in normal to freezing weather**, and down to about 50 percent in temperatures that reach about -30 ºC, which leads to an accelerated degradation and reduction of service life.

In Figure 10 is shown the place where W4B material is located. It was installed in the inside wall of the electrical room where the electrical devices (cabinets and inverters) are located. The installation consists of a 40 millimetres thick layer of W4B covered by a Pladur layer. Also, the opening of window that can be seen in Figure 9 (and also in Figure 10) on that wall was covered during the works in order to further improve the conditioning of the room.

FIGURE 9. LOCATION OF THE ELECTRICAL ROOM

FIGURE 10. W4B INSTALLATION IN THE ELECTRICAL ROOM OF LLAUSET HUT

W4B insulator was installed in Llauset hut in June 2020. After consulting the hut keepers, they have observed that the temperature in that room remains much more stable throughout the year, and significantly higher in winter than in the previous situation. The effect on the batteries' performance cannot be seen immediately, but it is sure that their durability will be longer than under previous conditions.

5.2.3 Case 3: Estós Hut. Insulation in several rooms [#12]

Regarding to the Estós hut the final decision was to improve the thermal insulation using W4B in north-facing walls, both on the bedroom floor and on the ground floor and on the stairs. The actions carried out are described in more detail below:

- Figure 11 shows the ground floor, and the area where W4B was installed is highlighted, which corresponds to the north wall of the stairs and the north wall of the entrance hall (see Figure 12).

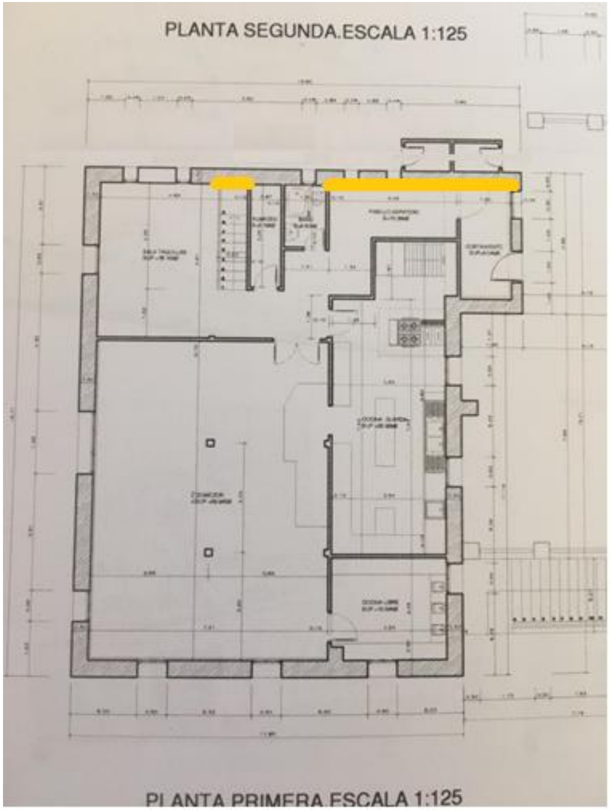

FIGURE 11. GROUND FLOOR OF ESTÓS HUT

FIGURE 12. ENTRANCE HALL OF ESTÓS HUT

— Regarding to the bedroom floor of the hut (Figure 13), finally the decision was to install W4B insulator in the roof of each room of this floor, and in the north wall of Puerto de Oö room (the coldest room).

FIGURE 13. SECOND FLOOR OF THE HUT

— Figure 14 shows the final aspect of one of the top rooms after installing W4B insulator in the roof (Puerto de Oö room), where is possible to notice that the ceiling has been getting down by adding a W4B layer covered with Pladur. This process has been repeated in each room of this floor.

FIGURE 14. ROOF OF ONE OF THE TOP ROOMS

6 Conclusions

Regarding the energy efficiency actions in **Spanish huts**, they have demonstrated an optimal good-for-value, as positive results are found with a very low investment. All the actions have been. All implemented actions have been carefully studied and planned in detail, being aware that they are not easy to implement.

Thus, some actions as the control of batteries or the replacement of water pumping in Montfalcó are successful actions, although great impact is difficult to achieve in buildings already in operation. As a general conclusion it can be said that energy efficiency improvement actions (like insulation, orientation, location, well micro-grid design, efficient facilities, etc) should be implemented when the installation is in the design phase as they are easier and cheaper to implement and therefore can achieve the desired reduction of the environmental impact.

Italian hut in the project is totally different from the others. The Rifugio di Torino Hut situation is special because is connected to the grid, so the methodology implemented is not the same as the rest. The CO2 emissions have been calculated using the generation electric mix of Italy and the unit emissions of each technology, so, knowing the electrical consumption of the hut, it has been possible to calculate the total amount of CO2 emissions in the hut (SOPB, CO2ton/year = 74,68; SOPB NOxton/year = 0,14).

Considering the considerable costs of water supply and the related emissions, the choice fell on a water recovery system through the creation of a roof + gutter system that would collect the largest amount of water possible. Naturally, the normal gutters positioned as usual, would not have withstood the snow discharges from the roof, therefore a greater number of retaining elements of the snowpack on the roof were installed, and of a particular type of gutter, with specific appropriately sized supports, and all positioned flush with the edge of the roof, to allow only the recovery of the dripping water, thus avoiding that the eaves are directly exposed to snow discharges, which, as in all other cases, could be damaged.

This apparently complex solution allowed the operator to avoid the transport of water by cableway, with considerable economic savings, which will repay the costs incurred in a short time.

For the same reason of the lack of water and in order to avoid using the roof water collected for kitchen tasks and bearing in mind the considerable amount of wastewater after the treatment (about 10-12,000 liters per day), a specific system for the recovery and filtration of the percolation water was created, with its respective storage tank and pump for sending the filtered water to the Torino Nuovo Refuge, located 90 meters above sea level. The water, at the Torino Nuovo Refuge, is appropriately stored in plastic tanks.

Slovenian huts developed and installed only Energy Production technologies.

Finally, **the table below summarises the main reasons** why a particular technology has been installed in a hut as well as other observations that are considered to be of interest in this respect.

ID	Hut	Country	SH Technology	Reason for implementation
#1	Lizara	Spain	Advanced Automation	Originally the system was manual, causing a bad operation and maintenance of batteries and management of the grid.
#3	Lizara	Spain	Thermo-Chimney	The original chimney was useful and pleasant for visitors. The idea, from FAM, was to take better advantage of this tool, turning it into a more efficient system.
#4	Bachimaña	Spain	Electrification	The obvious surplus of available renewable electricity indicated that the existing fossil-based heat generation system should be changed as soon as possible.
#6	Bachimaña	Spain	Efficiency	The hut keepers were noticing dampness on the inside of certain walls of the shelter. A solution was finally identified to eliminate this dampness and also to provide some thermal protection. FAM found the special paint and FHa assessed the impact, which was found to be positive.
#9	Estós	Spain	Advanced Automation	Originally the system was manual, causing a bad operation and maintenance of batteries and management of the grid.
#12	Estós	Spain	Insulation	The project partners asked the keepers about potential insulation improvement needs. They communicated the need to improve the protection of the walls of some rooms.This situation was analysed and its implementation was considered positive.
#15	Llauset	Spain	Insulation	The project partners asked the keepers about potential insulation improvement needs. They communicated the need to improve the thermal conditioning of the battery room due to the presence of humidity and in order to improve the lifetime of the batteries. This situation was analysed and its implementation was considered positive.
#20	Torino	Italy	Water Plants	The water supply was the first need of the hut manager based on several meetings with them. The project partners understood the problem and contacted with expert suppliers to identify the best solution. The role of the hut manager was therefore fundamental. The solution has proved to be satisfactory because the costs associated with water

				transport (previously done by several routes with a high cost and high related emissions) have been greatly reduced.
#23	Montfalcó	Spain	Advanced Automation	The water pumping was the first necessity demanded by keepers, which was confirmed with field visits to the hut. Different options to solve it were studied between FAM and FHa, finally deciding to change the equipment.

TABLE 20. TECHNOLOGY SELECTION JUSTIFICATION