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# LIFE SUSTAINHUTS: SUSTAINABLE MOUNTAIN HUTS IN EUROPE

## C7.4 Final guideline: "LIFE SUSTAINHUTS lessons learnt report"

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# Executive Summary

The SUSTAINHUTS project has implemented renewable energy production solutions, as well as different optimisation actions useful to improve the sustainability of these facilities and to promote sustainability in other shelters and similar facilities.

Throughout the different development phases of the project, a great deal of knowledge has been acquired based on the experiences that have occurred during the life cycle of the project. From the collection of information on the reference situation of the huts, through the evaluation and study of possible alternatives, to finally collecting materials, planning their installation, and carrying out the assembly, commissioning and operation of the technologies. From all these phases, a reflection and analysis of the factors that have affected the project, both positively and negatively, has been carried out.

This document presents all the knowledge acquired, classifying it in different categories and by country (Spain, Italy, France, Slovenia), and also presenting in a dedicated chapter the learning process in terms of obtaining permits and installation licences.

The following is a list of what can be considered as the main lessons learned in the broadest sense:

- For existing facilities, it is recommended to understand in detail the energy management done by the hut keepers, and customs and habits of the users.
- The most immediate actions should be aimed at assessing energy efficiency improvements (insulation, more efficient equipments, etc).
- Although there are no generic solutions, the most robust and economical recommendation is to hybridise PV and wind, with appropriate battery sizing.
- Hydrogen is an excellent means of seasonal renewable energy storage, suitable for installations where there is an excess of energy at certain times of the year, and a shortage at others.
- Difficult access (via helicopter) makes full life-cycle planning of the technologies a vital component to ensure successful installation and operation, both in terms of timing and economics. Installation must be carried out by competent personnel who are accustomed to this type of installation.
- A thorough analysis of the required permits and the environmental classification of the area where the shelter is located is essential for realistic planning of the sustainable actions.

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# 1 Lessons learnt from each hut

## 1.1 Spanish huts

The Spanish huts setting is made up by 6 demo facilities placed on Spanish Pyrenees and 1 in Sierra del Montsec:

- Lizara (1,540 m),
- Estós (1,890 m),
- Bachimaña (2,200 m),
- Cap de Llauset (2,450 m),
- Góriz (2,200 m),
- Montfalcó (800 m).

Here below are reported the major lessons learned relating to Spanish huts. These lessons will guide the possible replicability of technologies in other huts and will help huts owners in evaluating the best technology suitable for their hut.

### 1.1.1 General lessons

- There is a huge difference in the concept of "hut". Spanish huts can be dubbed as mountain "hotels" opened during all the year, with a very high energy consumption, and very complete offer of services, while on the other hand, Slovenian huts are small "shelters" with few beds and services only opened during the summer months. It is not possible to face the sustainability of this type of facilities without understanding the type of hut, the consumption, and the use of the energy. For example, considering Spanish huts, the complete elimination of their CO2 emissions is hardly possible, it is only possible to reduce their impact.

- The energy management of mountain huts is based on three pillars: robustness, cost, and sustainability. They are not always compatible, so robustness and cost will always be a priority. In this sense, the reduction in the cost of renewable energies will encourage their introduction in mountain hut applications, as is already the case of the photovoltaic energy.

- A deep knowledge on how the huts are operated from the energetic point of view is essential before carrying out actions on them, because many actions are highly dependent on the use made of the equipment, and therefore actions carried out without considering the habits of the people involved in the hut (keepers and hosted) are not always likely to be successful.

- To involve the guests in the energy management is essential. Consumption in huts can be very high if the energy is wasted, and this is usual if guests do not make good use of the energy. Therefore, to involve the guests themselves in the responsible energy use provides energy security for the huts.

### 1.1.2 About micro-grids

- Hybrid installations are more complete than the single-technology installations because they allow for generating in more diverse scenarios and are less dependent on a single generation source.
- The micro-grids of mountain huts, generally, show several areas for improvement, especially those that are older. Electrical improvement actions (automation, battery charging, load management, etc.) are possible once the hut has been built (corrective) but it is always better to consider them since the design phase.
- Currently, huts are not possible to be designed without a diesel back-up system, because these ultimately ensure the energy supply. It would be possible to conceive another back-up system based on biodiesel or hydrogen, although these systems are not sufficiently mature to be used nowadays. Therefore, the conception of a Spanish hut (of the type studied) being completely sustainable, renewable, and self-sufficient, is currently improbable to achieve.
- Photovoltaic technology is robust and economical, making it the most interesting technology to be introduced in mountain huts. On the other hand, if available, it is advisable to hybridise with hydro or wind (e.g., Slovenian huts), which will reduce generation costs.
- Storage systems are crucial and needed to be introduced with renewable energies due to the decoupling between generation and consumption. Batteries are the most affordable elements, although their energy storage is limited to a few hours. Other storage systems are potentially optimal for mountain huts (e.g., hydrogen storage), although the maturity of disruptive technologies is limited, and their cost is still high.
- The simplicity of microgrids is another factor to be considered. Simple and robust but complete systems (based, for example, on non-electric stoves with recirculation, hybridisation with single-phase batteries, etc.) are the most recommended options to have a robust system.
- Most Spanish huts have some devices with three-phase consumption due to the industrial appliances needed (dishwashers, coffee machines, fume extractors, etc.). This type of technology makes it more difficult to be compatible with simple micro-grids, with renewable energy systems and batteries, so it would be interesting to avoid them whenever possible (although the price of equivalent single-phase appliances is higher). Their operation implies the use of the diesel generator during the time they are working so, although it is not particularly problematic, generators also charge the batteries, and, on sunny mornings with the dishwasher used, the batteries are fully charged earlier, and the solar installation is under-utilised.

### 1.1.3 About efficiency

- The most renewable kWh is that one which is neither generated nor consumed. Therefore, to implement energy efficiency measures in huts is the most effective action to reduce emissions. These energy efficiency actions should consider the design, the orientation, location, and thermal insulation of huts.

### 1.1.4 Hydrogen as a means to store energy

- Hydrogen is an excellent means of storing renewable energy on a seasonal basis. For short cycle storage (days), a much more optimal solution is battery storage, but when large amounts of energy are to be stored, and its use is several weeks or even months later, the particularities of hydrogen make it a solution to be considered.

- A hydrogen-based system is essentially made up of 3 components: the electrolyser for energy production, the fuel cell to re-electrify the hydrogen, and a storage medium, usually in pressurised tanks. The sizing of each of these elements depends greatly on the particularities of the work case, such as the availability of excess renewable energy, the electricity demand profile, available space, and budget, among others.

- In the SUSTAINHUTS project the main elements have been prototypes, which has led to long delivery times, partly also because the manufacturing has been outside Europe. It is therefore recommended to take into account that delivery times, especially for the electrolyser and the fuel cell, can be a minimum of 3 to 5 months. In any case, in the 5 years that have elapsed since the project began, there are already commercial solutions for this type of system.

- In the design of the hydrogen system installed at Bachimaña, the simplicity of the process has been prioritised, so that the intervention of the guards is kept to a minimum, both in operation and maintenance.

- The design of the electrolyser had a robust protective insulation due to the very low temperature conditions that occur in winter. During commissioning, it was found that this insulation was oversized and had to be reduced in some subsystems in order to achieve optimum management of the electrolyser operating temperature.

- It is very important to bear in mind that all the elements had to be transported by helicopter with the weight restrictions that this entails. This was taken into account in the design and selection of equipment, and especially applied to storage, as a lighter than standard storage bottle material had to be selected (composite instead of steel).

- Due to the difficulty of working in remote facilities such as mountain huts, tests were carried out under controlled conditions at the FHa's facilities to check the correct operation of the electrolyser and the fuel cell. Despite this, several problems arose during the start-up of this equipment in the refuge that delayed its commissioning.

- The commissioning of a hydrogen system is complex as it is a chain process. First hydrogen has to be produced, then stored for a period of time, and finally re-electrified. This means that it takes quite some time, in the order of several weeks or even months, to successfully complete a full cycle.

- It is essential for a successful installation to carefully plan the transport, civil works and other work required for the installation of all the components and their interconnection.
- The weather has had an enormous impact on the implementation and start-up times. On the one hand, during periods when there is snow, no progress can be made, and on the other hand, when it rains, it is very difficult for inexperienced people to access the shelter.
- Finally, the hydrogen installation in Bachimaña allows the storage of 4 kg of hydrogen, enough for demonstration actions. However, this storage can be easily scaled up to larger quantities.

## 1.2 French huts

2 demo huts placed on French Alps. Only one with a demo. Des Evettes is not included as "sustain hut" in the project, it is only the reference for Dent Parrachée, but not a hut included in the project.

Here below are reported the major lessons learned relating to French refuges. These lessons will guide the possible replicability of technologies in other huts and will help shelter owners in evaluating the best technology suitable for their hut.

### 1.2.1 General lessons

The Dent Parrachée hut has been entirely refurbished from 2016 to 2018. As every technical system, renewable energy systems require lots of settings adjustments and commissioning in order to make them work with the best efficiency. This is not specific to mountain isolated sites, but extreme conditions and high altitude greatly complicate technical interventions.

We also learnt that a whole refurbishment for both energy systems and building insulation can positively decrease fossil fuel consumption (lower energy demand thanks to insulation, see D1.5 report) and increase hikers' comfort.

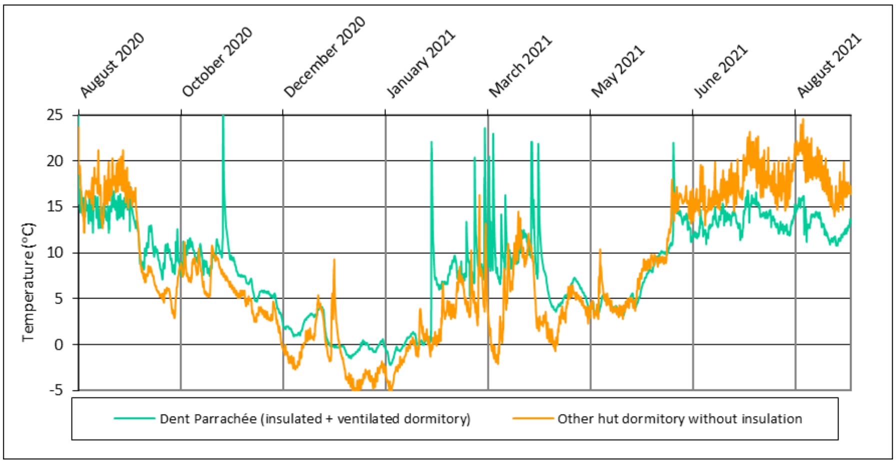


**FIGURE 1. TEMPERATURE PROFILE THROUGHOUT A YEAR OF TWO ROOMS: ONE INSULATED AND ONE WITHOUT INSULATION**

For instance, with temperature monitoring inside a dormitory, we notice that:

- Dent Parrachée insulation adds +5°C in the dormitory during winter even without heating (unkept period).
- Mechanical ventilation of the Dent Parrachée dormitories lowers temperature by -5°C during summer occupation.

### 1.2.2 About micro-grids

- **Solar arrays implantation**. Solar inclination could be quite different between summer and winter seasons. Main electric needs occur with the highest frequentation during summer; therefore, we intend to optimize solar arrays implantation for summer sunshine. But during winter, batteries still require a float charging current and we have to take this into account when designing a solar arrays installation. We also have to deal with snow falls which can cover solar panels. Thus, it can be a good practice to implement few solar panels dedicated to the winter sunshine, installed almost vertically to avoid snow cover (see Figure 2).
  This partial cover of solar panels by snow falls or shadows can also generate failures because of cells' overheating, for instance.

  It is also possible to install solar panels on a tiltable mount in order to adapt panels angle according to the season, as it have been done for the Dent Parrachée hut (see Figure 4).

FIGURE 2. VERTICAL PV PANELS INSTALLATION

Hereafter, other examples of solar panels optimized installation are shown.

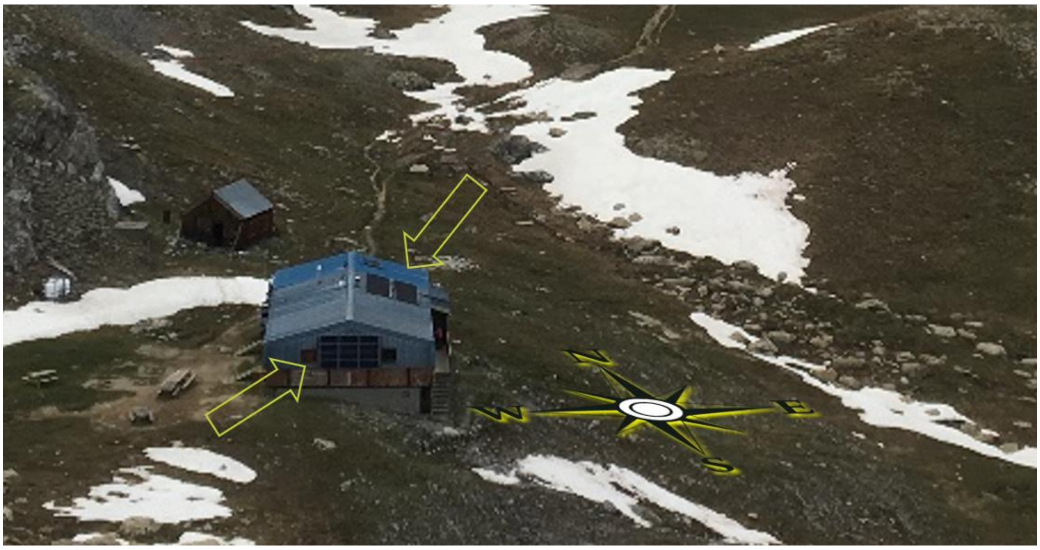


FIGURE 3. TWO SOLAR ARRAYS WITH DIFFERENT ORIENTATIONS FOR WINTER AND SUMMER SUNSHINE (VERTICAL ARRAY AVOID SNOW FALLS)


FIGURE 4. PREVENTING SNOW COVER OVER SOLAR PANELS (© COURTESY OF INES)

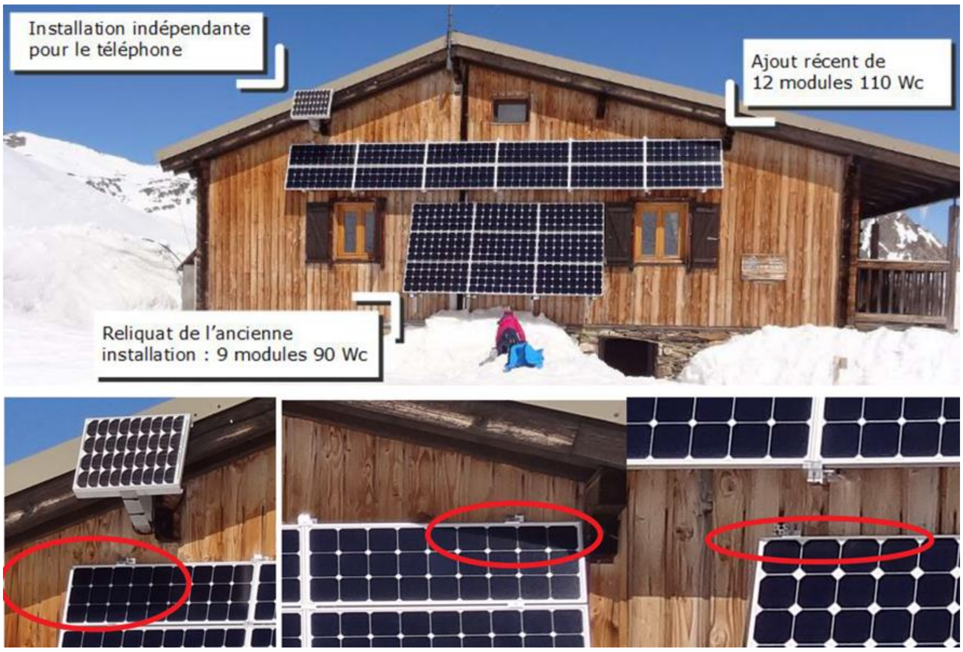


FIGURE 5. SHADOWS WHICH CAN CAUSE OVERHEAT CELL FAILURES (© COURTESY OF INES)

- **Thermal solar discharge**. As we've installed several thermal solar arrays producing hot water for showers and/or heating, we've learnt that a solar discharge system must be provided to prevent overheating dissipating excess heat. A good approach is to discharge it in a buffering hot water tank, which is then able to heat sanitary hot water or water radiators.

### 1.2.3 About efficiency

- **Water pipes draining**. Before winter season, the hut keeper has to drain all the water pipes of the hut to prevent leaks following freezing temperatures. The key point for this is to design the simplest pipe system with many drain valves and without any low sections where water could remain.
- **Hydro turbine**. We've learnt that even small hydro turbines are able to provide lots of electricity, but they can be quite difficult to adjust for fine setting. Settings also depend on the water stream which can change over time. Hydro turbines also require a discharge system when all the produced electricity cannot be used or stored.
- For the Dent Parrachée hut, the excess of electricity generated by the hydro turbine goes in an electric resistor inside the main hot water tank.

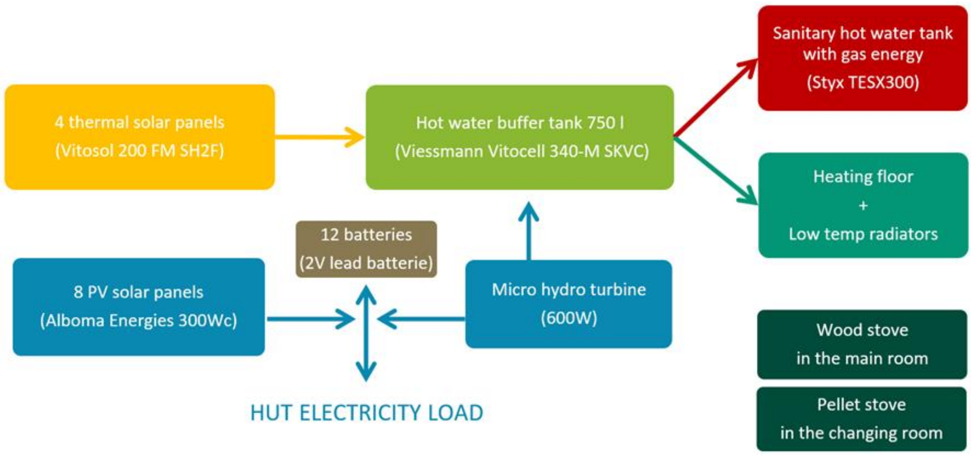


FIGURE 6. DENT PARRACHÉE HEAT AND HOT WATER PRODUCTION DIAGRAM


**FIGURE 7. DENT PARRACHÉE HYDRO TURBINE (600W)**

- **Insultation and moisture management**. Best insulation is usually exterior insulation to avoid thermal bridges: construction walls remain on the warm side and moisture condensation is not a problem (see Figure 8).

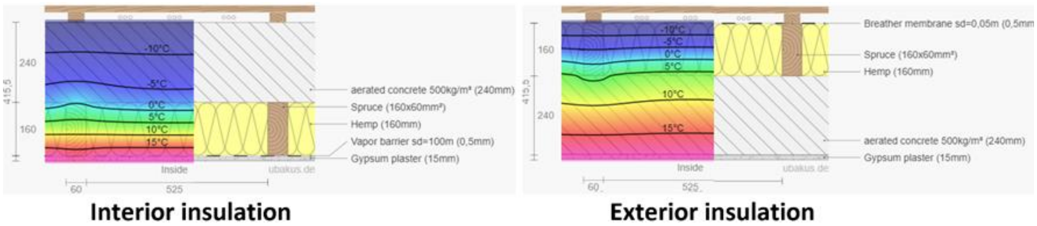


**FIGURE 8. WALL TEMPERATURE COMPARISON BETWEEN INTERIOR AND EXTERIOR INSULATION (OUTSIDE ON THE TOP, INSIDE ON THE BOTTOM)**

With interior insulation or wood walls, moisture condensation can become an issue: in these cases, construction walls and wood walls remain on the cold side of the insulation. Therefore, the water vapor coming from inside the hut through the insulation meets the cold surface of the walls, then condensates inside the wall causing long-term pathologies. If the plan is to refurbish a hut to add interior insulation, some precautions must be taken like vapor barrier membrane or perspirant "breathing" walls.

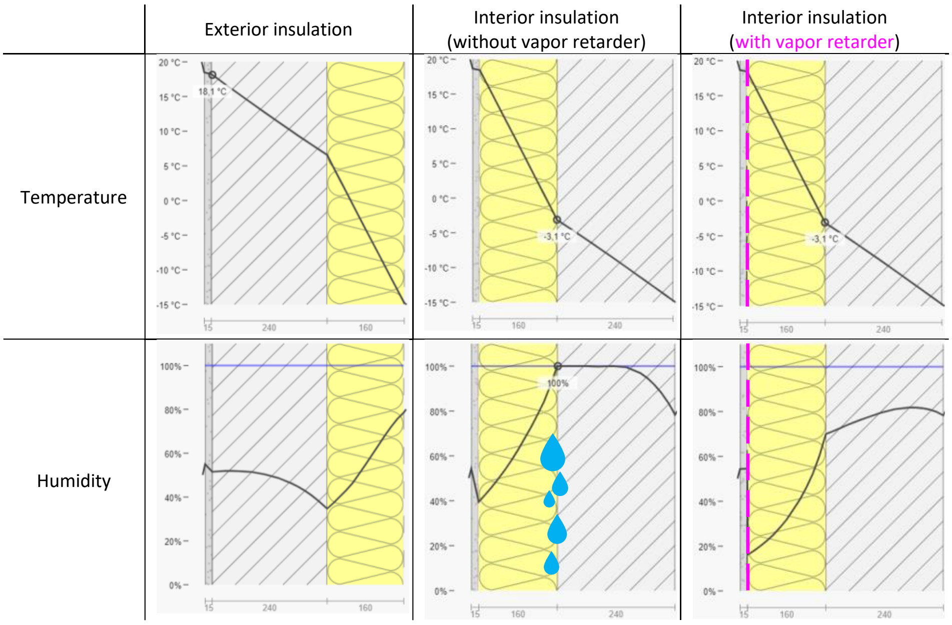


**FIGURE 9. TEMPERATURE AND HUMIDITY PROFILES IN THREE INSULATION CONFIGURATIONS**

- Bonus trick: free fridge! Dent Parrachée's keeper has found a low-tech solution to refrigerate a small room in the hut basement where he keeps vegetables and cheeses: he uses cold water from outside running through a heatsink cooler system and places behind it some small CPU computer fans to blow cool air into the room (see Figure 10).


**FIGURE 10. LOW-TECH FRIDGE TO KEEP FRESH CHEESES AND VEGETABLES (© P. BOLDO & F. BUISSON)**

## 1.3 Italian hut

### 1.3.1 General lessons

- Torino hut is totally different from the rest of the huts of the project. It is opened throughout all the year, and it can be considered an accommodation facility with many comforts compared to other huts on the Italian territory.
- It is a widely visited refuge and not only by connoisseurs of the mountain sector. Just think that in pre-COVID years, visitors amounted to around 6000-7000 per year. They are mostly tourists who go up to visit the peak of Mont Blanc/Monte Bianco. Therefore, there are many visits concentrated in the opening hours of the cableway.
- Torino hut is grid-connected, so the high consumption is totally covered by the connection to the cableway power supply. For that reason, achieving net zero emissions is not possible. It would be different for other shelters which are totally grid-independent, and much can be done by introducing new renewable sources.
- Other Italian huts are more similar to the Slovenian ones: small "shelters" with few beds and services only opened during summer months. It is not possible to solve the sustainability of this type of facilities without understanding the type of hut, the consumption, and the use of the energy.
- Due to the high altitude, the choice of robust materials and the location of the installations is fundamental, also linked to the choice of suitable companies with the ability to work for long periods at high altitudes. These two factors can be considered even more important than the equipment investment costs themselves. PV panels installation is an example because they are installed in the façade of the hut.
- The choice of installing a water recovery system, which becomes especially fundamental in high altitude areas, proved to be a winner. The identification of this action was the result of talking with the manager of the shelter, understanding their more pressing problems, and identifying the correct solution with expert suppliers.
- The role of the refuge manager was, therefore, fundamental. During the subsequent visits to the installation, it then emerged that all the costs associated with the transport of water (previously transported by several routes with a high cost and high related emissions) have been greatly reduced. Thus, the refuge became self-sufficient, in terms of water, thanks to the water of the glaciers and thanks to the water recovered.
- It is important to understand how the shelter works in terms of energy and logistics before deciding on the actions to be taken, as the outcome will be highly dependent on the use of the equipment that produces or consumes energy. Actions that are carried out without considering the habits and customs of both visitors and hut's managers are likely to be unsatisfactory in terms of achieving a more sustainable facility.

### 1.3.2 About micro-grids

- To know how the huts work and how they are connected is the key on the technology identification stage: part of the Torino hut is used as a winter shelter, always open and without custody for the winter months. It needs to have an energy "reserve" for heating the dormitory rooms, the drying room clothing and the storage for boots and materials. The choice and sizing of photovoltaic panels with a power of a few kW (4kW) was carried on in order to power the dormitory rooms.
- To involve the guests in the energy management/micro grids, analysis is essential.

### 1.3.3 About efficiency

- Italian huts always bear improvement and optimization in mind, in particular a hut like Turin, which is in the spotlight due to the type of visitors.
- The recovery of water had a positive effect on the shelter. This type of systems is especially suitable for the Turin hut given that the large turnout and, therefore, the associated water consumption.
- The system for dissolving snow and rainwater recovery is particularly simple, as it consists in a series of plastic pipes that collect and convey all the water in a series of underground metal tanks.

## 1.4 Slovenian huts

The Slovenian huts consist of 3 demo huts:

- Pogačnikov dom (2050 m),
- Valentina Stanica dom (2332 m)
- and Kocbekov dom (1808 m), which was destroyed by an accidental fire.

Here below are reported the major lessons learned relating to Slovenian refuges. These lessons will guide the possible replicability of technologies in other shelters and will help shelter owners in evaluating the best technology suitable for their hut.

### 1.4.1 General lessons

During SUSTAINHUTS, it was identified that the following stages are key for implementation and upgrading of energy distribution systems in Slovenian mountain huts: (i) data collection process determining the energy consumption, basic load profiles and dynamics of energy consumption; (ii) modelling of possible energy system topology according to available renewable energy sources; (iii) basic design of the energy system that is online with financial frameworks and spatial planning and legislation; (iv) test period of equipment with accurate measurements of energy generated by different components; (v) optimization procedure in control system where possible.

When the aim is to perform a new installation, some points must be regarded:

- I**mportant stakeholders must be connected**: hut's owners (mountaineering clubs), mountaineering association (PZS), knowledge institutes (Faculty) and contractors to find optimal solution regarding experiences, available technologies, onsite limitations (transport, winter temperatures, high winds, renewable energy sources availability, etc.), investment and legislation.

- **Insurance** of the installed energy system must be done prior to installation procedure or parallel to installation procedure. In the case of Kocbek hut, the damage just few days after caused the project serious financial damage.
- In the case of a new mountain hut, there is a strong interest in installing the new energy system and a **weather station** should be mounted onsite to get realistic renewable energy sources availability. With this approach it is easier to design the peak power of the energy system and the required energy storage capacity.
- All mountain huts have relatively good internet connection, so data **acquisition system** for monitoring the energy generation and consumption could be visible online.
- Mountain huts are isolated energy systems that must be carefully designed to **avoid overloads of the system** at any time.
- An energy system has to be designed in a way that **allows an easy operation for the hut's caretaker**.

### 1.4.2 About microgrids

- When collecting the data regarding energy consumption of the hut, the visit of the hut and discussion with hut's caretaker is crucial when no data acquisition is available. With that we can obtain **good approximation of energy consumption** within the year and during the day. Electricity load profile is crucial in planning of the energy system power and the size of electricity storage.
- Mountain huts in high mountains in Slovenian Alps are **open just for 3-5 months in the year**, so the energy system for heat and electricity distribution must be designed in the manner to be able to be **in hibernation mode during the winter** without to be damaged.
- Energy consumption of Slovenian mountain huts is **relatively small** since they are opened just in the summer, and they do not need massive heat generation during the wintertime. Nevertheless, there is always **the room for improvements**, new insulations, optimization of energy system, the change of energy carriers, etc.
- Mountain huts in Slovenia are **not big huts**. Usually, huts have **heat generated mainly with mixed biomass** and **electricity with diesel** or gasoline gen-sets. In some cases, **small PV systems** are already installed, but not big enough to cover electricity demand of the hut.
- In Slovenian mountain huts PV system can be designed **to fulfill all electricity demand** and with that we **exclude the gen-sets totally**. It is good to let gen-sets as a backup system if needed in the case of emergency.
- The most useful technology for electricity generation in Slovenian mountain huts **is photovoltaic technology**, if possible, with combination with **wind turbines** where

constant wind is available. Wind turbines are good solution, but we have **to be sure if wind is not too gusty** to damage the turbine blades and rotor (case of Pogačnik hut).

- **Electricity storage** in Slovenian mountain huts should be **battery** stack that could be stored during the wintertime without damage. Hydrogen as a storage of excess renewable energy sources electricity is not suitable because of 6-8 months of no-operation.

### 1.4.3 About environmental impacts

- **Environmental impacts** in Slovenian mountain huts are relatively low compared with huts in other countries. Most impacts come from diesel and gasoline gen-sets for electricity generation that could be removed with good PV and wind electricity generation system. In this case, the only environmental impacts come from natural gas for cooking (if used in mountain huts), hot water and refrigerators (if run on natural gas).

- **Environmental impacts** come also from **heat generation** when using mixed logs. When mixed logs are combusted in old systems, the combustion process is far from optimal. So, there is room for improvement especially through the upgrading of combustion control systems in heat generation technologies.

- **Transport** in the Slovenian huts is an issue, because in most high mountain's huts it is done by the helicopter, which is expensive, has high environmental impacts and the weight carrying capacity is limited.

# 2 Lessons learnt from the technologies’ transport and installation

The transport plan is strictly connected to the hut altitude, typology of accessibility and climatic conditions. It is necessary for each hut to distinguish the different stages of transport: Inspection phase, Procurement’s material phase, Installation phase, Execution phase.

For each of them is necessary an accurate forecast of the climatic condition and to plan the implementation and opening period of the shelter. Moreover, it is necessary in the expense plan to foresee the expenses related to transport which can be by helicopter, cableway, pickup. During the installation phase, it is required to assess whether the health conditions of the workers allow them to stay at high altitudes. As regards the works at the Torino Refuge (3,840 m) only a few companies are specialized to carry out this type of work at high altitude and with adverse weather conditions.

Transport to mountain huts is critical since most of them can only be accessed on foot or by helicopter. This requires an exhaustive organization of the facilities so that they can only be carried out once all the material is prepared and ready. This tends to delay installation times.

The installation of technologies is only possible in a window of months a year, especially in summer, due to difficult access and external work conditions during winter, when the organization is more complex.

Other considerations:

- **Climatological estimation**: transport by helicopter can be done the whole year. But for the installation of equipment is determined to the no-snow condition and to the opening season of the hut. For helicopter transport is crucial that there is no foggy/cloudy weather. This can influence to the execution of the transport, while it can happen, that transport cannot be done one week or even more.
- **Economic criteria**: transport represents a high cost, mainly is using the helicopter.
- **Sustainability criteria**: The criterion of sustainability and low environmental impact, which is embedded within the SustainHuts project, has been essential during the development of the transport plan. As there is no other possibility as helicopter transport plan foresees the minimum number of helicopter flights to transport needed material.

# 3 Lessons learnt from the use of technologies implemented: impact of extreme conditions and high altitudes.

- The impact of extreme conditions is evident in mountain huts. One of the highest impacts is the difficult access to the huts during a remarkable part of the year, which makes the installation and the repair actions extremely difficult. This must be taken into account before proposing new actions in the huts.
- Extreme weather has an impact on photovoltaic production because it reduces its production in winter due to snow and episodes of temporary clouds. In addition, the orography of the terrain can produce shadows in certain parts of the day.
- Effect of cold in the battery's durability. Prolonged exposure to cold temperatures also has a big impact on battery performance and safety. When temperatures drop, the internal resistance of the battery is increased. This means that it requires more effort by the battery to charge, in turn lowering the capacity. The reduced capacity has to be taken into account when sizing the system batteries.
- Strong gusts where huts are located: wind turbines are not easy to install, for example in Bachimaña, it was observed that vertical axis wind turbines were not suitable because they fell down and got damaged due to the high winds.

# 4 Lessons learnt from the permitting/licences for the installation

The partners in charge of the implementation of the technologies, based on their previous experience in this field, have revised and identified the procedures to follow in each country to obtain the corresponding authorizations. The main lessons learnt in this scope are the following.

- The permits to install technologies, modify parts of the installations, or refurbish are sim
- In Spanish huts, not was not necessary to request any specific authorisation to implement the technologies foreseen regarding RES installation (PV and batteries), insulation of parts of the huts, automation actions, or more efficient equipments.
- The case of hydrogen is special. Regarding hydrogen systems there is no in force any specific European or national order which regulates the construction or operation of these systems, so any permit is based on the main aspects affected by the implied process, like PED (Pressurised Equipment Directive), ATEX Directive and Risk Control of major accidents, storage of a flammable substance, and Fire Protection Codes. These regulations are country and even region specific, so dedicated analysis has to be done in the location where H2 system is to be installed. Regarding the specific case of the Spanish hut where H2 is installed, and due to the size of the system (lower than 10 kW) the permit needed was requested based on the civil works to be done in the hut, although a technical memory describing the above-mentioned aspects was submitted to the Town Council.
- It is recommended to establish a fluent contact between the entity managing the hut the Regional Administration on these matters.
- Spanish regulation is quite restrictive regarding the installation of wind turbines in Natural Parks, whatever the power. Also, hydro turbines installation has its own protocol, long and difficult. Both technologies have not been required in the Spanish huts.
- In Italy, CAI had to obtain the corresponding authorisation for the PV installation. Regarding Energy Efficiency Actions, one requires a special action, the establishment of an agreement with the entity proprietary of the soil where it is installed. Water recovered via snow dissolution: this is an intervention inside the CAI private property, that does not create any environmental impact and landscape, so it was not necessary to require special permissions. Wastewater recovery: spaces are not in CAI private property; so it was necessary to include an agreement with "Società Funivie del Monte Bianco".
- In Slovenia, approval to install equipment (PV and wind) has to be given by the National Institute for Nature Protection.
- In France, the installation of solar arrays (thermal or photovoltaic) requires an authorization form the Municipality because it may affect exterior appearance of the

building. In general, modifications which take place inside a building without modifying exterior appearance does not require a Municipality authorization. For instance, internal insulation can be done without permit. But an exterior insulation which will change exterior wall aspect, requires a permit. For water turbine the authorization process has been simpler than general case because the power station took place on a water drain deviation which has been previously authorized for human water consumption. The only authorization needed was from the Vanoise National Park because the hut is inside this natural protected area.

- At the beginning of the project Romania was one of the participating countries and an analysis of the required permits for two types of technologies, photovoltaic and hydro was also carried out. The conclusions of the study are as follows:
  - For the PV plants there is a law issued by the ANRE (National Agency for Regulations in the Energy domain) which is stating that for under 500 kW there are no approvals required,
  - In the case of Micro Hydro Power Plant, there are a lot of documents to be fulfilled and to be approved by different authorities, no matter of the installed power. The procedure is as follows:
    1. Official Extract from the Land Funduary Registry.
    2. Meeting with the Territorial administration of the zone where the hut is situated to establish what kind of documentation is required. If the hut is not situated in an urban area, only a Building Authorization is required.
    3. Elaboration of documentation to be issuer to Local Authority. It has to be signed by an authorized architect/civil engineer
    4. Request of approvals from the following authorities: Environmental Agency, Romanian agency for the internal water resources (Rivers), Water Management Agency.
    5. Once the dossier fulfilled, Local Authority has to issue the final approval.

# 5 Lessons learnt regarding the major criticalities identified: materials degradation, freezing of the materials, availability of sun only in certain periods

- The main criticality in a mountain hut is the need for robustness in its microgrid. This implies to bet for sustainable solutions that can be easily introduced in the grid and that can be managed by the guards of the huts, so the electronic control of the equipment must be simple and reliable.
- Difficult access to mountain huts implies that all the sustainable actions entail greater energy independence in order to reduce external dependence on fuels.
- The correct functioning of the microgrids is critical in the operation of the huts, increasing their autonomy whenever possible. In the Spanish huts studied, to increase autonomy guarantees longer equipment lifespan and better conditions of managing and maintaining.
- Effect of cold in the durability of batteries. Prolonged exposure to cold temperatures also has a big impact on battery performance and safety. When temperatures drop, the internal resistance of the battery is increased. This means that it requires more effort by the battery to charge, in turn lowering the capacity. The reduced capacity has to be taken into account when sizing the system batteries.

# 6 Lessons learnt from LCA

- **The scope** used in the case of mountain huts operational phase is from **gate to gate**. In other words that means just operational phase of mountain huts. The best way to make environmental profile evaluation in mountain huts is to compare emissions or impact indicators **before and after energy system upgrade**. So, in the state of play at the beginning (SOPB) and in the state of play at the end (SOPE).

- To be able to combine technical, economical, and environmental results the timeframe used in LCA modelling should be **1 year of mountain huts operation**.

- The main data for LCA is the **consumption of energy carriers** for one year: diesel, gasoline, Liquefied petroleum gas, natural gas, wood, pellets. If mountain huts are connected to the grid, also **electricity consumption** is very important and crucial in environmental profile calculation. Cumulative values have to be obtained for one year operation. In addition, the transport of energy carriers has to be included since it is done primary with trucks, vans, rope ways or helicopter that all used fossil fuels and causes additional environmental impacts.

- In the first step, **basic inventory analysis for mountain huts** should be done based on the data from the operation of mountain huts within one year. Energy carriers and technologies used in mountain huts have to be identified for electricity generation, heat generation and transport used.

- In generic databases, technologies in mountain huts have to be linked with **the most appropriate process** in GaBi professional and Ecoinvent databases that will be used for LCA modelling. If possible, process picked from generic database has to meet the size of the technology, the operational characteristics, and also geographical location. For example: for photovoltaic system PV mounted on the slanted roof should be used; for Spanish huts geographical data should be picked with ES; in the case of Refugio Torino Italian electricity mix should be used and not EU 28 mix; for diesel generic dataset for the size below 20 kWe is used since there is not a lot of datasets for gen-sets available.

- Life cycle impact assessment should be done **using environmental impact indicators** (as carbon footprint, acidification, eutrophication, human toxicity, etc.in addition to target emissions defined in the project ($CO_2$, $SO_X$, $NO_X$, particles) because environmental impact indicators give us more precise information regarding environmental profile of the technology. They also enable us to see the impacts globally, regionally, and locally and in all areas caused by technology (water, soil, and air).

- LCA methodology could be used also in the case of **system optimization** to show environmental impacts reduction or increase when making technological changes. This is crucial in the cases in which technological optimization needs huge investments, so environmental benefits and emission reduction could motivate the governments, investors and/or caretakers to invest in modification despite large financial investment.

# 7 General conclusions

In conclusion what merged by the SUSTAINHUTS executions is:

- The biggest possible improvement regarding sustainability in mountain huts is the introduction of the lessons learned in SUSTAINHUTS during the design stage of the huts. Thanks to measures like energy sizing, energy efficiency, robustness, orientation, provisioning and others, the huts can become much more sustainable and robust, but reducing a large part of the costs of a future refurbishment as well.
- In all the huts already built, the least invasive reforms that improve sustainability are: introduction of photovoltaic technology, introduction of biomass stoves, improvement of the insulation of windows and doors, the improvement in the electrical control of the microgrid, and improvement in the habits and customs of the huts management.
- Consumption of the energy and use of the hut is not the same. So preliminary design is needed starting from the energy consumption and also involving the hut manager.
- The sizing of the technologies installed depends a lot on the duration of opening periods and number of visitors.
- During SUSTAINHUTS project, different actions are identified for each hut, but not all actions are suitable for all the huts.
- 26 actions have been conducted with 9 technologies: PV, thermo-chimney, micro-wind, hydro-turbines, hydrogen storage, pellet stoves, solar thermal panels, wood stoves, water treatment, water recovery plant, and efficiency actions as improvement of batteries charge, electrification, changes of batteries, and improvement in the water pumping. The most part of them can be replicated in other huts.
- The sizing of the renewable energy sources also depends on whether the hut is old or new.
- Solar panels efficiency is different between summer/winter. This affects the sizing.
- Insulation wood can lead to moisture problems, since water vapor condensates on the wood.
- It is easier to implement insulation in a new hut.