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LIFE SUSTAINHUTS: SUSTAINABLE MOUNTAIN HUTS IN EUROPE

C3 Energy efficiency and new insulation materials

C3.3 Passive Actions Design Report

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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.

As the core of the project, innovative climate change adaptation technologies are going to be developed in 9 mountain huts distributed in four European countries. Ultimately the objective of the project is to demonstrate that concepts developed in SUSTAINHUTS can be replicated and transferred to other locations and applications.

This report presents the passive actions that have been assessed to improve the energy efficiency of some demo huts of the project from three points of view: demand side, energy consumption and energy loss avoidance. Regarding to the <u>energy demand</u>, some good practices rules are proposed, such us relocation of guests or more responsible use of hut appliances, pursuing to increase energy savings while maintaining or even improving the comfort in huts.

In terms of <u>energy consumption</u>, efficient devices were considered to be installed in different huts of the project. However it was found that there is a lack of high efficient appliances at industrial sized so no action on this matter will be done. The main action on this field will be the replacement of conventional light bulbs by LED lights.

Finally, concerning to <u>reduction of energy losses</u>, inputs from previous deliverables of this Action were used: 1) a State of Art (SOA) study on novel and recycled and insulation materials was accomplished, and 2) a complete Life Cycle Analysis (LCA) of materials shown in the SOA was also realized. As result, two innovative materials were chosen to improve the insulation of different huts of the project. One is made from recycled sheep wool (W4B insulator) and the other one is a thermal barrier paint (Imperlux paint).

Two huts located in Spain (Estós and Cap de Llauset) have been selected as demo sites to present W4B insulator good properties, while Bachimaña hut, also located in Spain, is where Imperlux thermal barrier paint will be applied. 6 different cases where these materials may be installed have been assessed, aiming at obtaining an estimation of expected benefits in terms of reduction of energy consumption.

By using W4B insulator is possible to achieve energy savings of up to 50%, demonstrating its great characteristics for sustainable buildings. On the other side, although simulations show that thermal paint is not interesting as thermal insulator, thanks to its great features avoiding water filtrations and moisture formation it’s of great interest for mountain huts.

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List of Key-Words and Abbreviations

BOM – Bill of materials.

ETH Zürich – Eidgenössische Technische Hochschule Zürich.

EU – European Union.

GA – Grant Agreement.

IEA – International Energy Agency.

ISO – International Organization for Standardization.

LCA – Life Cycle Analysis.

LED – Light-Emitting Diode.

PV – Photovoltaic.

SOA – State of Art.

UNE – Una Norma Española.

W4B – Wool4Build.

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 in relation with renewable energy and other eco-friendly technologies.

As the core of the project, innovative climate change adaptation technologies are going to be developed in 9 huts from four different countries, which will demonstrate that can be easily replicated and transferred to other places independently of the climate, latitude or country.

Namely, the aim of this report is to explain actions followed to increase the energy efficiency in some huts of the project. Those actions can be divided in three main pillars: one from the demand side, the other from the offer side and the last one regarding to the reduction of the energy losses.

Concerning the **energy demand**, the main goal is to decrease the energy demanded in the huts basically by using good practices in the energy management, while maintaining the same comfort level.

With regard to the **energy offer**, the intention is to decrease the consumption of energy through the use of devices with higher efficiency, and again maintaining the same comfort level.

Finally, in terms of **energy conservation (reduction of energy losses)**, two specific actions will be carried out in some SUSTAINHUTS. On the one hand, a new insulator material is going to be placed in some huts. In more detail, by following guidelines defined in the project proposal, this insulator will be implemented in huts for each altitude category. On the other hand, in Bachimaña hut thermal barrier paint will be applied.

Nevertheless, some changes with regard to the project purpose have been accomplished, specifically concerning the places where the insulator material is going to be installed. These changes are fully explained below in chapter 3.

All actions defined in this task will help to determine the work plan to achieve in the Task C4.1, in which transport plans to carry all materials required to accomplish those actions will be specified.

2 Actions

As it was mentioned in the GA of this project, one of the main goals of SUSTAINHUTS project is to increase the energy efficiency of demo huts, not only by decreasing the use of energy of a determined technology, but also by implementing innovative technologies which allow to maintain the same comfort level by reducing substantively the consumption. The objective of the project is to improve the energy efficiency of demo huts over a 20% (or even more).

In this chapter, a discussion of the different actions to do in each category (demand, consumption, and conservation) is presented.

2.1 Demand

Here, some recommendations, or good practices for improving the energy management have been worked out aiming at transmitting more rationality or austerity in the use of the energy. Hereafter some suggestions are described:

- **Relocation of guests**, aiming at reducing the use of energy in the heating system. The idea is to allocate guests in the minimum possible amount of rooms, keeping locked the rest of rooms of the hut.
- **Responsible use of household appliances**. These devices use a huge amount of energy so a responsible use can have a great impact in energy savings. Its use should be avoided when the amount of guests does not reach a certain threshold. Some ideas to achieve efficient management of these devices are shown below:
    - Washing dishes by hand instead of using the dishwasher when not completely full.
    - Waiting for using the washing machine until full of items.
    - Using fridges instead of freezer cabinets whenever possible due to its better efficiency. It’s remarkable that fridges consume over the 15% of the energy consumption of a building [1], so optimizing their amount and capacity may reduce significantly this energy use.
- **Informative posters**. The use of notice boards could be used to remind guests about the relevance of following good practices in the use of energy (for instance by turning off the lights if going out the room or reducing the use of hot water as much as possible).

2.2 Consumption

It is clear that one way of decreasing the energy consumption in the huts is through the use of efficient devices:

- **Low energy LED lights**. By replacing conventional lights bulbs by low energy LED lights an important decrease of energy consumption can be achieved, even up to 50%.
- **More efficient household appliances**. The acquisition of new efficient equipments will reduce significantly the energy needed during its operation. Information about the efficiency appears in the Directive 2010/30/UE of the European Parliament and of the Council [2].
- **Better exploitation of local resources**. During C1.1 action, better exploitation of the kind of energy available in the huts was assessed. Thus, new technologies proposed will take advantage of local resources, reducing the external energy dependency and, in consequence, increasing the sustainability of energy balances. Electrification of the thermal load in Bachimaña, the thermo chimney installed in Lizara or the new plant to capture rain water in Torino are examples of these actions that, considering the energy dependency, improve efficiency in huts.

During the searching done during this task different suppliers were contacted. The conclusion achieved was that currently there is a lack of high efficiency devices (A+++) for industrial household appliances, which is the type of devices used in the huts due to their capacity/size. For example, in case of industrial dishwasher, the usual method for reducing electrical consumption is through the replacement of the internal resistance by a hot water connection instead. This solution is hardly applicable for a mountain hut as it entails a high investment. Apart from that, it was found that A+++ devices are oriented to domestic households more than industrial sizes.

In addition to the technologies described in C1.1 reports, low energy LED lights will be installed in some huts aiming at achieving the targets of energy consumption. After analyzing huts requirements, a preliminary estimation of the amount of LED lights and locations where they can be placed has been carried out (*Table 1*). The final list is under consideration between the hut owner and the hut manager.

Hut	Number of LED lights
Estós	20
Lizara	15
Bachimaña	15

TABLE 1: NUMBER OF LED LIGHTS WILL BE INSTALLED IN SUSTAINHUTS

2.3 Insulation

Regarding actions aiming at improving the thermal insulation, two innovative materials are going to be used in different huts. These materials are an insulating material (Wool4Build) and thermal barrier paint (Imperlux Termic). Chapter 3 (Insulation actions) of this report develops in detail the specific cases where these materials are suitable for being installed and the methodology followed to estimate the expected benefits after installing them.

This action is in strong connection with the other task included in Action C.3 of the SUSTAINHUTS project. The starting point is the task C3.1, where a study of the state of art (SOA) of novel and recycled insulation materials was carried out, and also a complete Life Cycle Assessment (LCA) of materials presented in the SOA was accomplished. Thus, after comparing all materials recovered in this market review, a specific material was decided to be used in the project, named **"Wool4Build"** (W4B), presented in the LCA report.

These materials are described now in more detail.

2.3.1 Wool4Build insulator material (W4B)

W4B (*Figure 1*) 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 [3].

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, favouring the enhancement of the thermal comfort and the reduction of energy consumption, and also works as an efficient acoustic insulation. It´s 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 in *Table 2*. W4B is available in comfort and premium versions, which differ from each other in the thickness and density, to suit different construction requirements.

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 2: TECHNICAL DATA OF WOOL4BUILD INSULATOR

FIGURE 1: WOOL4BUILD INSULATOR

2.3.2 Imperlux Termic thermal barrier paint

Main function of this paint is avoiding water filtrations, but thanks to its innovative characteristics is also suitable for working as a thermal insulator.

This material will be 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 [4].

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.

FIGURE 2: IMPERLUX TERMIC THERMAL BARRIER PAINT

This material was not identified in the previous reports of Action C3 because it is not purely a thermal insulator material, and its application is suitable only to huts where water filtrations are a common problem.

3 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. As previously has been mentioned in Section *2.3*, two innovative insulator materials will be installed in 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.

Comparing to the Grant Agreement, some changes have been identified and are described below:

- For the demo hut at low altitude (<1.000 m), GA stated as demo place the Doftana Valley hut in Romania (800 m). However, in 2017 Transylvania University of Brasov (TUB), which is responsible for managing this hut, requested to drop out the Project.
- For this reason, Doftana Valley was replaced by Montfalcó hut (780 m), located in Spain, in the province of Huesca. During the assessment of this hut (Action A1) it was found that it is very well insulated as a consequence of a recent refurbishment so the hut did not require any action on this matter.
- At medium altitude, the GA indicated Lizara (1,650 m) as the demo-site. However, it has been found that this hut is not suitable for this kind of action, and it will be replaced by Estós (1,890 m).
- At high altitude the GA identified two demo-sites, Bachimaña (2,200 m) and Cap de Llauset (2,400 m). In this case some actions will be done in both huts.
- At extremely high altitude, Rifugio Torino (3,375 m) was selected in the GA. However between the proposal submission of this project and the positive response obtained, insulation of some parts of Torino were already done and therefore no action will be executed in Torino.

This chapter 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 to be analysed**: in this section each location where insulation may be installed is described in detail. Specifically, W4B insulator will be placed in Estós hut in three rooms of the top floor and in the north wall of the stairs, and also in the electrical room of Cap de Llauset hut. On the other hand, Imperlux thermal barrier paint will be applied to the internal walls of ground and first floors of Bachimaña hut.
- **Results**: a summary table of expected gains in terms of saving costs in each location where an insulator will be placed is shown.

3.1 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 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 mail 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 doesn´t 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.

3.2 Cases assessed

Down below, all cases where insulator materials will be placed are fully explained. In Estós hut the objective is to improve the insulation of stairs (Case 1) and of each room of the top floor (Cases 2, 3 and 4), by installing W4B insulator. In Cap de Llauset hut, W4B will be also used, in this case in the Electrical Room (Case 5), with the main goal of enhancing the insulation of this room due to the fact that batteries don´t work properly under cold weather conditions. Finally, in Bachimaña hut, thermal barrier paint will be applied in the ground and the first floor, specifically in all outside walls of these floors (Case 6). *Table 3* shows a resume of locations where thermal insulator will be enhanced and the main objective desired to reach. For each case it’s only shown the value obtained in terms of percentage of energy savings and the quantity of insulator material has to be acquired. The complete set of data used in simulation can be checked in the annex.

Case	Hut	Location	Insulator material	Objective
1	Estós	Stairwell (north wall)	Wool4Build	To improve its thermal insulation, to decrease energy costs.
2		Puerto de Oö room (outside walls and ceiling)		
3		Posets room (outside walls and ceiling)		
4		Chistau room (outside walls and ceiling)		
5	Cap de Llauset	Electrical room (outside wall)		To enlarge the lifetime of batteries
6	Bachimaña	Ground floor and first floor (internal walls)	Imperlux Termic	To avoid water filtrations, to improve its thermal insulation

TABLE 3: RESUME OF LOCATIONS WHERE THERMAL INSULATION WILL BE IMPROVED

3.2.1 Case 1: Estós Hut. North wall of the stairs

Here, the goal is to enhance the insulation of the stairs. Thus, W4B material will be place in the north wall of the stairs, i.e. the outside wall.

To maintain the desired indoor temperature and by following all assumptions previously defined, the energy consumption is given for three different situations: without insulation (current), after installing comfort version (comfort) and with premium version (premium). It has been done in every cases presented in this report.

By observing results obtained after performing calculations, that there will be a significant decrease in energy consumption needed to maintain desired conditions. Namely, calculations show that it would be possible this consumption in about **21%** by installing comfort version and **25%** premium version (*Table 4*).

Thermal improvement [%]		Number of W4B panels
Comfort	Premium	
21	25	14

TABLE 4: THERMAL IMPROVEMENT EXPECTED AND NUMBER OF W4B PANELS FOR CASE 1

3.2.2 Case 2: Estós Hut. Puerto de Oö room

In this second case, the installation of the W4B material aims at improving the insulation of one of the top rooms of the hut, named Puerto de Oö, by getting down the ceiling and enhancing the insulation of each outside wall.

Assumptions considered are the same than in the previous case, and also constructive materials and initial conditions. It's necessary to remark that now there will be heat transfer between the room and the outside through the ceiling and two walls.

Thus, the expected percentage of energy savings would be of **49%** and **56%** after installing W4B comfort and premium version respectively (*Table 5*):

Thermal improvement [%]		**Number of W4B panels**
Comfort	Premium	
49	56	50

TABLE 5: THERMAL IMPROVEMENT EXPECTED AND NUMBER OF W4B PANELS FOR CASE 2

3.2.3 Case 3: Estós Hut. Posets room

In this room, the procedure followed to obtain the expected gain after installing W4B insulator is the same than for Puerto de Oö room. For this room, it's considered only a heat transfer between the room and the outside, through the roof and one outside wall.

Thus, the expected percentage of energy savings would be of **38%** and **45%** after installing W4B comfort and premium version respectively (*Table 6*).

Thermal improvement [%]		**Number of W4B panels**
Comfort	Premium	
38	45	58

TABLE 6: THERMAL IMPROVEMENT EXPECTED AND NUMBER OF W4B PANELS FOR CASE 3

3.2.4 Case 4: Estós Hut. Chistau room

The method followed is the same than in the other two rooms, changing only room dimensions. As in Puerto de Oö room, heat transfer will be given among the room and the outside through the roof and two walls.

Thus, the expected percentage of energy savings would be of **46%** and **53%** after installing W4B comfort and premium version respectively (*Table 7*).

Thermal improvement [%]		**Number of W4B panels**
Comfort	Premium	
46	53	43

TABLE 7: THERMAL IMPROVEMENT EXPECTED AND NUMBER OF W4B PANELS FOR CASE 4

3.2.5 Case 5: Cap de Llauset Hut. Electrical room

In case of Cap de Llauset, W4B insulator will be placed in the ground floor, specifically in the north wall of the electrical room. In this room there is not a heating system, so the simulation has not been assessed. There are two diesel engines in the next room, and the heat generated by both engines increases indirectly the temperature of the electrical room.

The main reason of trying to enhance this room insulation with W4B insulator is to maintain batteries in better operating conditions (low temperatures are not good for them), so improving the insulation of the room where they are located may enlarge the lifetime of batteries. **8 W4B panels** will be installed in this location.

3.2.6 Case 6: Bachimaña Hut. Thermal barrier paint

In this study case, in Bachimaña hut thermal barrier paint is going to be applied. Moreover, it has decided to paint all the internal side of the outside walls of the ground and the first floor of the hut.

Regarding to construction characteristics of Bachimaña hut, in the document of the execution project a briefly summary of the composition of the wall is explained. These characteristics can be looked up in the annex of this report.

The improvement expected in Bachimaña hut after using Imperlux thermal barrier paint, following all assumptions previously defined, will be over a 0,25% (*Table 8*). This low value deals with the fact that, despite of this thermal paint has a good value of thermal conductivity (0,056 W/m*K), it's applied only with thickness of 700 microns; consequently it has not a high effect in the heat transfer global value. Even though, Imperlux thermal paint is also a good acoustic and water insulator and it avoids moisture condensation, so it's still interesting for SUSTAINHUTS project because the energy consumed for heating the hut will be lower (although very difficult to estimate)

Thermal improvement [%]	Number of paint cans
0,25	80

TABLE 8: THERMAL IMPROVEMENT EXPECTED AND NUMBER OF PAINT CANS FOR CASE 6

3.3 Results obtained

In order to summarize the improvement expected to be attach in each case, *Table 9* shows a compilation of the insulation expected results given by simulations.

Case of study	Hut	Insulated place	Insulation material	Thermal improvement [%]
Case 1	Estós	North wall of the stairs	W4B Comfort W4B Premium	21 25
Case 2		Puerto de Oö room	W4B Comfort W4B Premium	49 56
Case 3		Posets room	W4B Comfort W4B Premium	38 45
Case 4		Chistau room	W4B Comfort W4B Premium	46 53
Case 5	Cap de Llauset	Electrical room	W4B Comfort W4B Premium	- -
Case 6	Bachimaña	Ground floor and first floor	Thermal barrier paint	0,25

TABLE 9: EXPECTED THERMAL IMPROVEMENT IN EACH LOCATION

It's also necessary to remark that percentage of energy savings shown in each section doesn't refer to the whole hut, but only to the room being considered in the simulation.

As it has been explained in previous sections, disparity in results for each hut is due to different reasons. Firstly, each building has different constructive characteristics. On the other hand, although Imperlux Termic has a great value of thermal conductivity (0,056 W/m*K), it's applied with a small thickness. That's the reason of such a low value of expected thermal improvement. However, thanks to its great characteristics of avoiding water filtrations and moisture formation, it's still so interesting for SUSTAINHUTS project.

4 BILL OF MATERIALS LIST

In this section, a breakdown of all materials to be acquired to achieve objectives defined in the Grant Agreement for Task C3.2 (Passive actions design) is shown, aiming at defining future actions to be accomplished in Task C4.1. Namely, in that task transport plans to carry all materials required to accomplish those actions will be specified.

This Bill of Materials (BOM) list refers to: 1) LED lights bulbs will be acquired achieve goals of decreasing energy consumption defined in section 2.2, and 2) insulator materials defined in section 3.

By following supplier advices, hereafter all materials needed to accomplish a properly installation of all materials are mentioned. Specifically, to install W4B insulator it's necessary to acquire, besides the material itself, a coating material. In this case, panels made of drywall have been chosen. In case of thermal paint or LED lights, any additional material is needed.

Thus, in *Table 10* a list of materials is shown. Firstly, some explanations should be done for an appropriated understanding of data shown in this table:

- Both W4B insulator versions (comfort and premium) are sold in panels of 0,81 per square metre each one. That's why for both qualities the same number of panels is required. The difference lies in the thickness and the density.
- For Drywall panels and for LED lights, at the moment of preparing this report, it was not decided the supplier yet. By reviewing different suppliers, the prize of drywall panels is around 2,5 per square metre, and LED bulbs over 3 € per bulb.
- Thermal barrier paint is marketed by Arelux in cans of 4 litres each one.

Material	Supplier	Quantity	Unit cost (€)	Cost (€)
LED lights	Generic supplier	50 LED bulbs	3	150
W4B comfort	Inpelsa	175 panels	10,35 (€/m^2)	1.460
W4B premium			15 (€/m^2)	2.126
Drywall panels	Generic supplier	49 panels	2,5 (€/m2)	367
Thermal paint	Arelux	80 paint cans	41,8 (€/can)	3.344
TOTAL COST (€)			**5.321 € (W4B comfort)** **5.987 € (W4B premium)**	

TABLE 10: BOOM LIST OF INSULATOR MATERIALS

It's necessary to remark that this budget breakdown doesn't include labour cost or costs to carry out materials to each hut.

5 References

[1] Naturgy, “10 formas de ahorrar energía en el uso de electrodomésticos y gasodomésticos,” [Online]. [Accessed August 2018].

[2] E. U. “Directive 2010/30/UE,” [Online]. [Accessed 2018 April].

[3] G. Lederval, “http://www.wool4build.com/,” [Online]. [Accessed May 2018].

[4] Arelux, “https://arelux.com/pintura-termica/productos/,” [Online]. [Accessed May 2018].

ANNEX

This annex aims to complete the information given in the report in order to facilitate the understanding of followed methods.

Specifically, this annex shows more in detail simulations were carried out trying to obtain an idea of possible improvement to achieve after enhancing insulation of different parts of some SUSTAINHUTS. It is structure by huts, showing all data considered when performing calculations. As it has been previously commented, any simulation was carried out in Cap de Llauset hut.

ESTÓS

After carrying out an analysis of which locations where more appropriated to improve its insulation in Estós hut, it was decided to install W4B insulator in four places: in the north wall of the stairs (case 1) and in the three rooms of the top floor (cases 2, 3 and 4).

As it has been mentioned previously, to make calculations were necessaries some assumptions regarding to constructive techniques followed in Estós hut. The document of the technical memory of the building was not at hand at the moment of performing simulations, so constructive materials and their measures were supposed. *Figure 3* and *Figure 4* show drawings of estimated structures of walls and ceilings in Estós hut respectively.

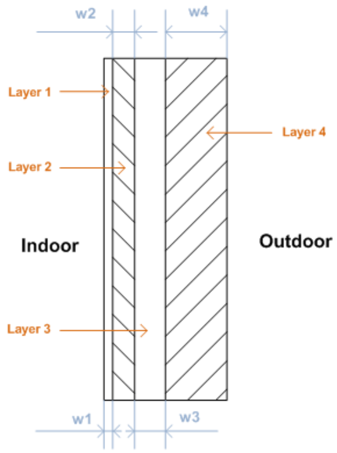

FIGURE 3: DRAWING OF THE OUTSIDE WALL OF ESTÓS HUT

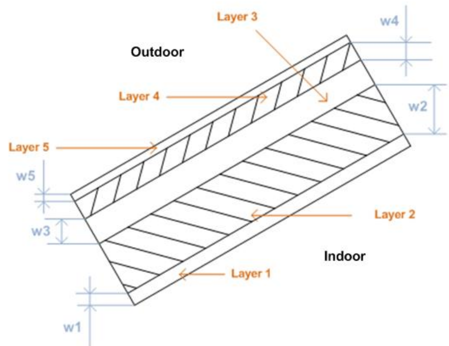

FIGURE 4: DRAWING OF THE CEILING OF ESTÓS HUT

Table 11 shows constructive materials and their thickness. These materials were chosen by following keeper's comments. Rest of data used in simulations for Estós hut appear in *Table 12*.

	Layer	Material	Thickness (m)
Wall	Layer 1	Plaster	0,02
	Layer 2	Hollow brick	0,05
	Layer 3	Internal air chamber	0,05
	Layer 4	Granitic rock and mortar	0,45
Ceiling	Layer 1	Plaster	0,02
	Layer 2	Concrete	0,4
	Layer 3	Internal air chamber	0,05
	Layer 4	Asphalt cloth	0,05
	Layer 5	Slate	0,05

TABLE 11: MATERIALS AND THICKNESS OF THE WALL AND THE CEILING FOR ESTÓS HUT

Variable	Description	Value
T_o	Outdoor temperature (ºC)	5
T_i	Indoor temperature (ºC)	15
$k_{p,1}$	Thermal conductivity of plaster (W/m*K)	0,3
$k_{p,2}$	Thermal conductivity of hollow brick (W/m*K)	0,49
$k_{p,4}$	Thermal conductivity of granitic rock and mortar (W/m*K)	2
$k_{t,1}$	Thermal conductivity of plaster (W/m*K)	0,3
$k_{t,2}$	Thermal conductivity of concrete (W/m*K)	1,5
$k_{t,4}$	Thermal conductivity of asphalt cloth (W/m*K)	0,16
$k_{t,5}$	Thermal conductivity of slate (W/m*K)	1,9
h_{cha}	Heat transfer coefficient of internal air chamber, horizontal surface (W/m^2*K)	5,56
h_{cha}	Heat transfer coefficient of internal air chamber, vertical surface (W/m^2*K)	6,25
$h_{ind,h}$	Heat transfer coefficient of indoor air, horizontal surface (W/m^2*K)	10,5
$h_{ind,v}$	Heat transfer coefficient of indoor air, vertical surface (W/m^2*K)	7,7
h_{out}	Heat transfer coefficient of outdoor air (W/m^2*K)	29,1

TABLE 12: VALUES OF DATA USED IN SIMULATIONS FOR ESTÓS HUT

In case 1, main objective is enhancing the thermal insulation of the stairwell, by installing W4B in its outside wall. *Figure 5*, *Figure 6*, *Figure 7* and *Figure 8* show drawings of stairs. In this case, it's considered a heat transfer through the ceiling and the outside wall.

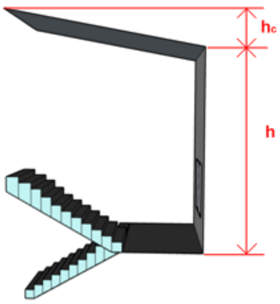

FIGURE 5: FRONT VIEW OF ESTÓS STAIRS

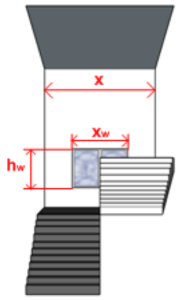

FIGURE 6: LATERAL VIEW OF ESTÓS STAIRS

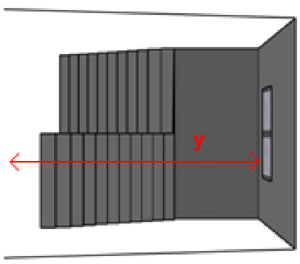

FIGURE 7: TOP VIEW OF ESTÓS STAIRS

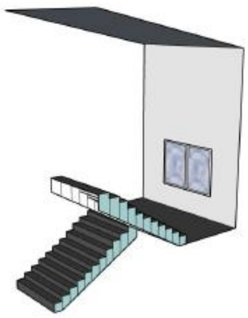

FIGURE 8: 3D VIEW OF ESTÓS STAIRS

Table 13 shows dimensions of the stairwell. Due to the lack of data, to obtain these measurements keepers of the hut were contacted.

h	Room high (m)	5,6
h_c	Ceiling high (m)	0,65
x; y	Dimensions of the room (m)	3,66; 2,17
x_w	Window depth (m)	1
h_w	Window high (m)	1

TABLE 13: DIMENSIONS OF THE STAIRWELL (CASE 1)

Results obtained from the simulation are shown in *Table 14*.

	Current	**Comfort**	**Premium**

Heat loss (W)	206,5	162,8	155,6
Thermal improvement [%]	-	21,1	24,6

TABLE 14: HEAT LOSS IN STAIRS IN CASE 1

Figure 9 shows a drawing of the three rooms where insulation will be enhanced in Estós hut. Namely, W4B insulator will be placed in three rooms of the top floor: Puerto de Oö room (case 2), Posets room (case 3) and Chistau room (case 4). In those rooms W4B will be installed in outside walls and in the ceiling.

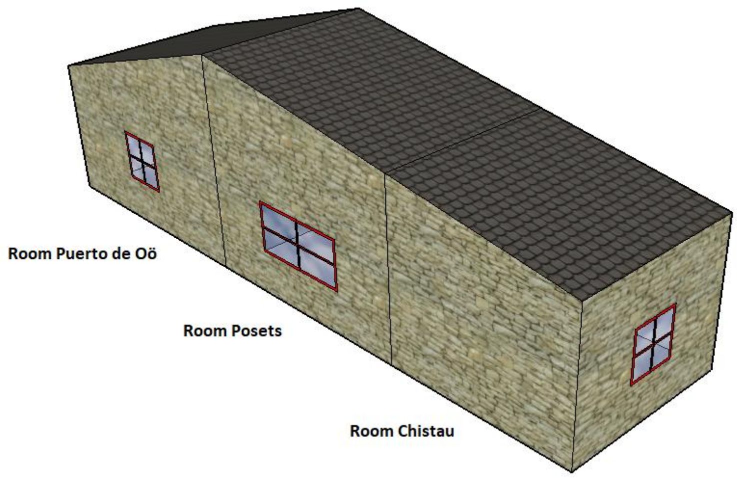

FIGURE 9: TOP FLOOR OF ESTÓS HUT

Figure 10, *Figure 11*, *Figure 12* and *Figure 13* show drawings of a room of the top floor of Estós hut. Namely, it represents Puerto de Oö room, but for the other two rooms these drawings have been also considered, changing only room dimensions.

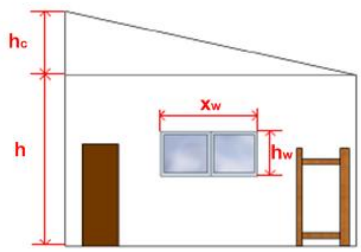

FIGURE 10: FRONT VIEW OF PUERTO DE OÖ ROOM

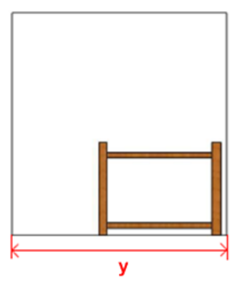

FIGURE 11: LATERAL VIEW OF PUERTO DE OÖ ROOM

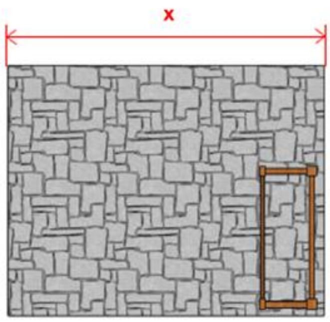

FIGURE 12: TOP VIEW OF PUERTO DE OÖ ROOM

FIGURE 13: 3D VIEW OF PUERTO DE OÖ ROOM

Dimensions of Puerto de Oö room (case 2) can be checked in *Table 15*:

Variable	Description	Value
h	Room high (m)	2,7
h_c	Ceiling high (m)	1
x; y	Dimensions of the room (m)	4,95; 3,59
x_w	Window depth (m)	1
h_w	Window high (m)	1

TABLE 15: PUERTO DE OÖ ROOM DIMENSIONS (CASE 2)

So, for this room of the top floor in Estós results shown by the simulation are shown in *Table 16*:

	Current	Comfort	Premium
Heat loss (W)	429,5	218	190
Thermal improvement [%]	-	49,2	55,8

TABLE 16: HEAT LOSS IN PUERTO DE OÖ ROOM

Dimensions of Posets room (case 3) are shown in *Table 17*:

Variable	Description	Value
h	Room high (m)	3,04
h_c	Ceiling high (m)	0,66
x; y	Dimensions of the room (m)	6,37; 4,6
x_w	Window depth (m)	2
h_w	Window high (m)	1

TABLE 17: POSETS ROOM DIMENSIONS (CASE 3)

So, for this room of the top floor in Estós results shown by the simulation are shown in *Table 18*:

	Current	Comfort	Premium
Heat loss (W)	495,7	305,2	270,5
Thermal improvement [%]	-	38,4	45,4

TABLE 18: HEAT LOSS IN POSETS ROOM

Finally, dimensions of Chistau room (case 4) are shown in *Table 19*:

Variable	Description	Value
h	Room high (m)	2,7
h_c	Ceiling high (m)	0,34
x; y	Dimensions of the room (m)	3,19; 4,6
x_w	Window depth (m)	1
h_w	Window high (m)	1

TABLE 19: CHISTAU ROOM DIMENSIONS (CASE 4)

So, for this room of the top floor in Estós results shown by the simulation are shown in *Table 20:*

	Current	Comfort	Premium
Heat loss (W)	363,1	196,9	172,4
Thermal improvement [%]	-	45,8	52,5

TABLE 20: HEAT LOSS IN CHISTAU ROOM

BACHIMAÑA

Figure 14 shows a drawing of supposed structure of outside walls in Bachimaña hut. Methodology to obtain the expected thermal improvement after enhancing the insulation with the thermal barrier paint is similar than this followed for Estós hut. Constructive materials and their thickness have been also assumed by following keeper's guidance.

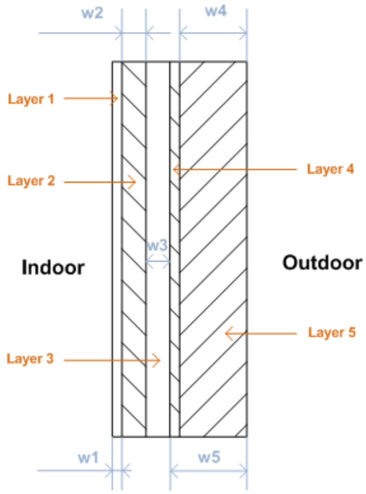

FIGURE 14: DRAWING OF THE OUTSIDE WALL OF BACHIMAÑA HUT

Materials and thickness are shown in *Table 21*, and specific values used to perform calculations can be checked in *Table 22.*

	Layer	Material	Thickness (m)
Wall	Layer 1	Plaster	0,02
	Layer 2	Concrete	0,25
	Layer 3	Internal air chamber	0,14
	Layer 4	Insulator	0,05
	Layer 5	Granitic rock and mortar	0,25

TABLE 21: MATERIALS AND THICKNESS OF THE WALL OF BACHIMAÑA HUT (CASE 6)

Variable	Description	Value
T_o	Outdoor temperature (ºC)	5
T_i	Indoor temperature (ºC)	15
$K_{p,1}$	Thermal conductivity of plaster (W/m*K)	0,3
$k_{p,2}$	Thermal conductivity of concrete (W/m*K)	0,25
$k_{p,4}$	Thermal conductivity of insulator (W/m*K)	0,03
$k_{p,5}$	Thermal conductivity of granitic rock and mortar (W/m*K)	2
h_{cha}	Heat transfer coefficient of internal air chamber, vertical surface (W/m^2*K)	6,25
$h_{ind,v}$	Heat transfer coefficient of indoor air, vertical surface (W/m^2*K)	7,7
h_{out}	Heat transfer coefficient of outdoor air (W/m^2*K)	29,1

TABLE 22: VALUES OF DATA USED IN SIMULATIONS FOR BACHIMAÑA HUT

Finally, results of simulation are shown in *Table 23*:

	Current	**Thermal paint**
Heat loss (W)	1795,4	1790,9
Thermal improvement [%]	-	0,25

TABLE 23: HEAT LOSS IN BACHIMAÑA HUT